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Deforestation and Cattle Ranching in the Brazilian Amazon: External Capital and Household Processes

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Summary. — This paper decomposes recent deforestation in four study areas in the Brazilian Amazon into components associated with large ranches and small producers. It then assesses in an inferential framework small producer deforestation with respect to the proximate causes of their farming systems, and the household drivers of their farming system choices. It is shown that, for areas with substantial in-migration of small producers, forest clearance at the household level is mainly attributable to the availability of hired labor, and not to household labor force or the physical capital at their disposal. The paper conducts the inferential analysis of small producer deforestation using measures of forest clearance taken from satellite image classification and directly from field surveys. A substantial discrepancy in the measures is identified, which has implications for household level research on land cover change.

1. INTRODUCTION

Pasture creation and cattle ranches have been identified as major factors in tropical deforestation in Latin America (e.g., Downing, Hecht, Pearson & Downing, 1992; Kaimowitz, 1996). The role of cattle ranching in Brazil has been particularly notable. Spurred by government incentive programs in Pará and Mato Grosso and by rural credit in Rondônia, herd sizes have grown dramatically in the Brazilian Amazon. Even with waning corporate interest

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in ranching activity in the north region of Brazil, small-scale enterprises continue to show strong interest in cattle, and conversion of tropical forest to pasture is pronounced among small producers no less than among large operators. During 1987–95, the northern[1] herd grew 21.6%, from 8,668,000 to 10,538,000, which represents nearly 10% of the national total (Faminow, 1997a). Evidently, transportation cost advantages over the south of Brazil have favored regional herd expansion, given dramatic urban growth in such cites as Belém and Manaus (Faminow 1997b, 1998).

The rationality of cattle ranching in Amazonia is a subject of great controversy. Many argue that pasture formation represents an inherently unsustainable tropical land use given low soil fertility and the unwanted abundance of invasive weeds and woody species that reduce the grazing quality of pastures (e.g., Browder, 1988; Hecht, Norgaard & Possio, 1988). Such constraints are said to reduce the long-run viability of ranching. In addition, the presence of numerous invasive and sometimes toxic plant species necessitates repeated burning to control them, and thereby results in the release of greenhouse gases. Despite frequent ecological criticisms, cattle ranching remains an economically attractive system widely implemented by small producers and heavily capitalized interests alike, which presumably reflects its economic rationality (Faminow, 1998).

This paper does not explicate the economic rationality of ranching or explain its advance into Amazonia in terms of the allocative mechanism of a regional land use system, driven by urban growth. Instead, we want to discuss ranching in a land cover change framework to provide an explanation of tropical deforestation that is both structural and behavioral. We take as given that economic considerations influence farming system choices, and that current market conditions for beef production provide adequate incentives for pasture formation and herd creation. This does not, however, invalidate legitimate concerns for the environmental consequences of tropical ranching. The primary goal of this paper is to explicate the link between cattle ranching and tropical deforestation, and to provide an empirical account of this linkage. To this end, we (a) disaggregate ranching activities into wealth-based social formations, and we (b) address the internal dynamics of herd building among small producers. The analysis provides a resolution of Amazonian deforestation into demographic and structural factors for the settlement frontier associated with opening of the Transamazon Highway in eastern Amazonia. (cf. studies by Moran, 1981; Smith, 1982; Fearnside, 1986a on the first decade of settlement in the area).

A secondary goal of this paper is to demonstrate a methodology linking remotely sensed data to household surveys. In particular, the analysis of small producers is based on an integration of satellite imagery and survey work undertaken in the summer of 1993 along the Transamazon Highway between Altamira and Uruará. The survey was conducted by three teams involving personnel from the Brazilian Agropastoral Research Center (EMBRAPA/CPATU), the Amazonian Development Agency (SUDAM), the Michigan State University, and The International Institute of Tropical Forestry (IITF). Data collection occurred over a one-month period during the dry season, and elicited farming system, economic, and demographic information from 132 small producers in the region. This field information was then used in conjunction with the satellite data in a statistical assessment of deforestation processes at the household level.

The paper is organized as follows. Section 2 discusses the link between deforestation and cattle ranching, and considers land use decisions leading to herd formation. Here, we focus on both the market and production side of cattle ranching, and attempt to uncover the main economic forces that have driven pasture expansion in the Brazilian Amazon, at the level of individual farming units. Section 3 gives an empirical account of pasture formation in the State of Pará, Brazil. We first disaggregate actual measures of deforestation into components associated with large ranches and small producers. Then, we focus on the land use processes of small producers in the region with an inferential analysis of proximate causation and household drivers of landcover change. Section 4 discusses the results pointing out the significant role of hired labor capacity in explaining the absolute amount of deforestation, while Section 5 concludes the paper. Small producers in this paper are identified as individuals who received land grants upon arrival in Amazonia of between 50–100 hectares. The rancher category consists of larger holdings in excess of 1,000 hectares. Land abundance in Amazonia enables possession of sizeable properties with modest economic resources.

2. THE ECONOMIES OF TROPICAL RANCHING

Links between cattle ranching and tropical deforestation have been exhaustively discussed and will not be considered here (Hecht, 1985; Eden, McGregor & Vieira, 1990; Downing et al., 1992; Kaimowitz, 1996). When a land-extensive system such as ranching replaces closed forest, deforestation is the necessary outcome. In adopting such systems, farmers assess the economic environment in light of their own capabilities, resources, and objectives, and make land-use decisions requiring the extensive clearance of trees to make way for pasture grasses and the herbivores they support. Although cultural factors and resource constraints affect farming decisions, we resist using the term *class* in the cattle ranching context. Nevertheless, characteristics of pasture-based systems, such as diversity in crop selection and capital intensity, are related to the economic resources commanded by the actors. We therefore refer to *fazendeiros*, or large landowners as those with properties in excess of 1,000 hectares (cf. Fearnside, 1993), and *small producers*, whose properties are typically confined to the original dimensions of their INCRA land grant of 50–100 hectares.[2] In drawing such a distinction, it must be kept in mind that the economic value of land is a direct function of distance from markets. On the Transamazon Highway, small producers with 100 hectares are much poorer than a landowner with a hundred hectares on the outskirts of Belém. Of course, small producers typically own their land, which distinguishes them from the 11 million landless peasants in Brazil (Thiesenhusen & Melmed-Sanjak, 1990). By definition, however, the deforestation impacts of the landless must be zero, excepting those who have squatted on federal and private lands. In any event, the amount of deforestation attributable to *posseiros* is probably small compared to that of the landless working as wage laborers and sharecroppers on properties of small and large producers alike. In the 1993 sample, the vast majority of the small producers (102) had remained on their original land grant and not expanded their holdings after an average of 15 years in residence. In a similar survey undertaken in Uruará in the summer of 1996, 199 of 261 properties possessed just one *lote*, a 100 hectare land grant.

Disaggregation by size-class introduces complexity into descriptions of land cover phenomena, as is appropriate in the case of cattle ranching and deforestation. While profit maximization may be the global incentive driving agricultural behavior in this regard, its articulation varies dramatically as a function of income, economic resources, and cultural setting. Of key importance is the recognition of the delayed nature of economic rewards that stem from ranching. Average slaughter age of cattle in Amazonia is four years (Fearnside, 1986a), and investments are necessary in building corrals and fences for herd management. By way of contrast, crops such as rice, corn, and beans yield annual returns. Although ranching may generate high income with sufficient herd size, resource constraints, lack of information, and risk aversion can inhibit adoption.[3] Such constraints and behavioral responses are clearly linked to both the wealth position and the cultural background of the household or economic entity.

The adoption of cattle-based systems may be explained by the provision of government subsidies, land-tenure policies that promote forest clearance, the land-extensive nature of beef production, policies discouraging forest management, low costs of production, and favorable market conditions (Kaimowitz, 1996). Indeed, any one or several of these factors may be present simultaneously, influencing the decisions of farmers. The present discussion, however, focuses mainly on the purely economic aspect of adoption in the pursuit of profits. In particular, profits are determined by the *prices* received for products and the *costs* incurred in their production.

For the case of cattle, much attention in this regard has focused on the price situation, and the claim is often made that growing demand for beef has stimulated pasture formation. In fact, the price of beef in world markets fell in real terms during the 1970s and 1980s (Kaimowitz, 1996). Be this as it may, the price of greatest interest to producers is the one they get, and regional data for northern Brazil suggest improving relative prices at farm level. Table 1 gives trends in relative producer prices for an important set of cash crops, namely rice, corn, and beans, and the perennials, cocoa and black pepper. These prices decrease relative to beef or remain constant for all crops presented and for both time periods. Price decreases are significant in the first time period for rice and cocoa, and significant in the second period for pepper. Price dynamics appear stationary for corn and beans in both periods. Clearly, market

Table 1. *Relative price dynamics — kg per kg 10-year average*[a]

	1976–1988[b]	1989–1994[c]
Rice	−0.01	−1.93[d]
Corn	–	–
Beans	–	–
Cocoa	−2.76	–
Black pepper	–	−10.45

[a] Relative price (relative to price of beef, in denominator) regressed against time, measured in months, using data from EMATER-PARA producer price series. Value in panels is slope coefficient multiplied by 120, to give 10-year change in relative price. Thus, the entry for cocoa indicates that, given the relative price change occurring during 1976–98, one would receive 2.76 kg less cocoa at the end of a 10-year period than in the beginning, in price determined exchanges for beef. Numerical entries only for statistically significant results; lack of entry indicates no trend in relative prices.

[b] Regressions performed on current crop price divided by current price for boi *gordo para corte*.

[c] Regressions performed on current crop price divided by current price for *bovino para corte.*

[d] Based on marginally significant trend; $\alpha = 0.075$, one-tailed probability.

forces have been propitious for pasture creation in northern Brazil. Regional price trends probably reflect the growing urban markets for beef in such cities as Belém and Manaus.

The cost side of the profit equation also seems to have provided incentives for herd expansions. If marginal cost remains constant or decreases with production levels, then there is no bound to the size of herd when the price of beef is greater than unit costs. Given that production varies in direct proportion to the amount of active pasture, ranchers possess incentives to continue accumulating land and expand production. Scale effects on profits have been demonstrated by Mattos and Uhl (1994) who show that for rearing and fattening operations, profits per hectare climb from $19.00 for 280 head on 554 hectares to $34.00 per hectare for 2,312 head on 3,500 hectares. For strictly rearing operations, the calculated values are $6.00 and $20.00 respectively (See also Arima and Uhl, 1996).

Among those who can afford to accumulate land, namely *fazendeiros*, profit maximization would seem to entrain a dynamic process of property aggregation due to scale economies of production, as has been observed in developed countries showing increasing returns to scale (Hayami and Kawgoe, 1989). Indeed, for the State of Pará, land concentration is correlated with herd sizes. At the level of the municipio, herdsize and the *absolute* quantity of land in properties greater than 10,000 hectares shows a correlation coefficient of 0.35 for 1990; the coefficient is 0.20 for the *percentage* of municipio land in large properties.

At some degree of accumulation, the externalities associated with social discord introduce limits to further expansion in the Brazilian case. As of 1990, 79 properties covering 8869 km^2 of land had been declared areas available for appropriation for the purpose of land reform. An additional 60 properties comprising 11,399 km^2 had been declared of social interest in this regard (IDESP, 1992, pp. 6–14). Furthermore, 15 *fazendeiros* were killed in land disputes in the State of Pará over 1980–89, as were 148 *peões,* low-skill *fazenda* laborers (Barata, 1995). Such violence is inconsistent with rural outmigration to urban labor-markets due to increasing wages, so the pattern of land distribution in Amazonia does not reflect an outcome of labor scarcity due to a migration process (cf. Kislev & Peterson, 1982). In the aggregate, the pattern of land ownership in Amazonia has tended to deconcentrate, as indicated by the decadal trend in the Gini coefficient (Schneider, 1995). Nevertheless, the size of holdings overall tends to show an increase over time at the frontier (Hecht, 1982; McCracken, Brondizio, Nelson, Moran & Siqueira, 1998), and it appears the inequitable distribution of land observed elsewhere in Brazil is being replicated in the north (Ozorio de Almeida, 1992).

Small producers may not be able to benefit substantially from scale economy effects given the cost of land accumulation, the importance of food production to household subsistence, and the degree of risk associated with agriculture in frontier areas, all of which promote diversified farming systems (Walker et al., 1997). Nevertheless, ranching is an important activity even among lower income producers, and may generate up to 29% of farm revenues, depending on the degree of household dependence on annuals production for subsistence (see also McCracken et al., 1998).[4] The net revenue associated with ranching within individual properties is likely to be substantially higher, given low labor inputs (Arima and Uhl, 1996).

Although economic conditions play the predominant role in the diffusion of cattle ranching throughout both the Brazilian Amazon and other parts of the New World tropics, cultural and institutional factors are also important. The successful development of a cattle ranch enables one to "*señorear*," become a great *señor*, and in Central America the "*cultura del potrero*," or the culture of the pasture, has often been upheld and supported by national governments (Joly, 1989). Pasture creation is consistent with the frontier "ethic," an important cultural attitude that views the claiming and preparation of land as an heroic act that imposes civilization on a "passive and unproductive" environment (Jones, 1989). Indeed, ranching has played an important developmental role since the earliest times of new world colonization, and land granting for the creation of pastures (for both beef and sheep) began in New Spain (i.e. Mexico) in the 16th century (Sluyter, 1997). Nor can it be forgotten that ranching has long been favored by legislative and macroeconomic policies in Latin America. During the opening of the Brazilian Amazon by means of development highways, well over three-quarters of the projects receiving fiscal incentives and tax holidays were cattle ranches (Kleinpenning, 1975; Moran, 1981). Cattle ranching has often provided a secure haven for capital, particularly during inflationary episodes.

3. DEFORESTATION: PROXIMATE CAUSES AND HOUSEHOLD PROCESS

Land cover change occurs as land managers respond to driving forces both internal and external to land management units, such as farming households. These responses lead to altered, land management systems, the proximate causes of land cover change (Turner, Meyer & Skole, 1994). The present paper adapts elements of this framework to assess that part of deforestation in the Brazilian Amazon mainly attributable to cattle ranching. To this end, we consider two issues, namely the relative amounts of deforestation accounted for by large producers on the one hand, and by small producers on the other; and the deforestation processes of small producers. By addressing the first issue, we resolve if incompletely the extent of land cover change attributable to large and small operators. This disaggregation provides relative deforestation magnitudes attributable to exogenous capital (*fazendas*)[5] and to in-migration interacting with endogenous household responses of small producers. By addressing the second issue, we disaggregate the cause–cover relationship into proximate causes on the one hand, and internal household processes on the other, an important component of the driving forces affecting small producers. We take as given the existence of a favorable external environment, based on the analysis of price trends for beef. Our analysis excludes an assessment of the driving forces affecting the behavior of large *fazenda* owners, although it depicts the land cover consequences of their actions.

(a) *Fazendeiro and small producer components of landcover change*

Fearnside (1993) has estimated that 70% of Amazonian deforestation is attributable to "ranching" operations. (See Faminow, 1998, pp. 119–120 for a discussion.) Evidently, this represents an upper bound to the estimates that have been made. Yokomizo (1989) reports that subsidized ranching projects account for 21% of the deforestation in Mato Grosso, but only 7.5% in Pará, while Reis and Margulis (1991) attribute little deforestation to ranching. On the other hand, Homma et al. (1994) suggest that ranching activities of small producers and *fazendeiros* together account for possibly 50% of forest clearance basin-wide. Faminow (1998) concludes that, since at least half of this area is likely to have been cleared by small producers, large-scale interests account for no more than 25% of the overall loss.

Table 2 presents data for four areas in the State of Pará showing extent of deforestation attributable to large-scale ranching interests.[6] Santana do Araguaia is a municipio in the extreme southeastern corner of the state, gateway to the so-called, *South of Pará*. Tucumã is north several hundred kilometers, roughly between Santana do Araguaia and the third largest city in Pará, Marabá. Altamira and Uruará are both sites on the Transamazon Highway somewhat distant from Marabá, in the central part of the state. Altamira is a town of colonial origins on the Xingu River, and Uruará is a new settlement about 200 km to the west.

Table 2 shows that deforestation attributable to large landholdings may range up to 100% for even large areas, as indicated for a subregion within the municipio, Santana do Araguaia. The 100% figure is calculated on the basis of an 80×50 km rectangle imposed on Thematic Mapper (TM) scene 224/066. This region covers a number of large ranching initiatives originally undertaken by SUDAM, including the projects Piquiá, ARPA, AGROVASA, Capri,

Table 2. *Percentage of deforestation attributable to Fazendeiros: TM-based estimates*

Region	Percentage	Date/Scene
Santana do Araguaia[a]	100	20 August 1986 TM scene 224/066
Tucumã/Ourilandia do Norte[b]	12	9 June 1994 TM scene 224/065A
Transamazon/Altamira[c]	8	18 September 1992 TM scene 226/062D
Transamazon/Uruará[d]	24	12 September 1992 TM scene 226/063A

[a] Deforestation numbers taken from SUDAM for development projects Piquiá, ARPA, AGROVASA, Capri, Companhia do Vale do Rio Cristalino, Fazenda Riachuelo, Fazendo Santa Marina, Pecuaria Santa Lucia, and Quixada Fazenda Bovina do Pará.

[b] Data developed by visual inspection for region north of PA-279; TM scene 224/065A, bands 3,4, and 5. Land south of highway is not assessed due to confused settlement geometry. Eight large clearings visible in analysis area.

[c] Eight aggregations are perceptible on TM sheets (226/062D) for band 4 and for band 5, viewed independently. Small producer deforestation taken as 60% along the highway axis, in lots extending 2 km north and south, and as a triangle along the crossroads, 5 km at the base near the highway axis (100% deforestation) and 13 km deep.

[d] Data developed by visual inspection of band four, TM scene 226/063A, for deforested land north of highway; southern portion presents interpretative difficulty. Six integrated clearings containing in excess of 16 *lotes* identified. Seventeen crossroads analyzed for small producer deforestation by measuring length of road and average width of cleared land. Deforestation along the Transamazon axis is assumed to be 60% of a strip 2 km wide, on the north side of the highway, along an extension 85 km long.

Companhia do Vale do Rio Cristalino, Fazenda Riachuelo, Fazendo Santa Marina, Pecuaria Santa Lucia, and Quixada Fazenda Bovina do Pará.

In settlement areas designated for small producers, the proportion falls considerably. For Tucumã, Table 2 shows that large producers account for 12% of the deforestation. This number is arrived at by estimating the amount of deforested land contained in eight large clearings in excess of 1,000 hectares each. Small producer deforestation is estimated as roughly 50% of the land in a semi-circle of radius of 25 km, centered on Tucumã, and a 30 km strip, 2 km wide, oriented in a direction northwest from the development area. Similar results obtain for colonization sites on the Transamazon Highway. Along a stretch starting 20 km west of Altamira and ending about 65 km further out, which includes 26 crossroads to the north and south of the main highway, only 8% of observed clearance is accounted for by eight sizeable forest openings (larger than eight lots).[7] Small producer deforestation is taken as 60% along the highway axis, in lots extending 2 km north and south, and as a triangle along the crossroads, 5 km at the base near the highway axis (100% deforestation) and 13 km deep. The amount of large producer deforestation climbs to the west in Uruará, where six integrated clearings containing in excess of 16 *lotes* can be observed on the north side of the highway; these account for 24% of deforestation in a strip to the north of the highway, starting 10 km west of Uruará, and running 75 km to the east toward Altamira.[8]

Clearly, there is much variation in the relative magnitudes of deforestation as a function of settlement history, development intervention, and stage of frontier evolution. The subregion studied in Santana do Araguia is notable as an area containing a concentration of SUDAM-sponsored development projects, while the other sites have been colonization targets for small producers. In the aggregate, an unweighted average of the four figures provides an estimate of 36% attributable to large producers, or *fazendeiros*. By implication, an upper bound to small producer impacts is 64%.[9] For areas of heavy in-migration, the large producer component may be on the order of about 20%. It is important to contextualize these estimates given the dynamic nature of the processes involved and their spatial manifestations; in particular, they reflect the relative proportions observable in the South of Pará and along the Transamazon Highway for the early 1990s. Small producers have been very active in forest clearance recently, and may have considerably increased their share of deforestation in relation to large landholders (Mourão, 1997).

Despite the *ad hoc* nature of the estimates in Table 2, they are in broad agreement with the findings of Fearnside (1993). Although Fearnside (1993) claims that about 70% of deforestation in 1990 and 1991 is attributable to "ranchers," the size class of holdings used in his estimates is all properties greater than 100 hectares. Fearnside's (1993) numbers show that for holdings larger than 1,000 hectares, about 33% of the deforestation in 1990, and 26% in 1991 is attributable to the largest class of landowners.

(b) *Small producers and deforestation*

Small producer deforestation is addressed by disaggregating the so-called cause-cover relationship. We begin by considering proximate causes associated with the actual land-use systems in place. Then, having assessed the land-use system of import (i.e., cattle ranching), we consider its formation in terms of household drivers, by reference to household production theory. The analysis is based on the 1993 survey activity that collected information on 132 small producers, taken to constitute the *full* sample. To facilitate sample selection during the field surveys, maps produced from 1991 Thematic Mapper (TM) imagery (path 224, row 61) were used in the field. A subset of the full sample was subsequently located on the maps, thereby composing a *restricted* sample of 32 properties, which include 40 physical properties given multiple holdings of properties by individual owners. In the following analysis, sample *one* refers to this restricted sample, and sample *two* is the full sample. Sample *two* includes the properties of sample *one*, and all data are identical except for deforestation measures.

In sample *two*, deforestation amount is taken from self-reported instances of forest clearance that were elicited in the survey questionnaire. For sample *one*, the deforestation magnitude was obtained by observing the amount of disturbance on each property in 1991, as indicated through unsupervised classification using Imagine software. This was accomplished as follows. Individual properties were identified on the TM image by visual inspection, and defined using vector overlays to construct rectangles consistent with the INCRA colonization scheme (see also McCracken, Brondizio, Nelson, Moran & Siqueira, forthcoming).[10] Given the relatively planar surface of the region, the colonization geometry proved relatively consistent and discernible. Unsupervised classification was then performed over the whole image using bands 2, 3, 4, and 5, and each property was partitioned into forest cover and cleared land categories. No attempt was made to resolve forest cover into secondary regrowth classes, or cleared land into agricultural activities and pasture (Moran, Eduardo, Mausel & Wu, 1994). The two classes so derived were compared to the visual imagery to ensure gross-level correspondence. Given the purpose and design of the field activity, ground-truth points were not obtained for subsequent accuracy assessments, although the land covers identified are in broad agreement with the field maps. For the statistical analyses, the amount of cleared land was calculated for each property using the appropriate boundary overlay. Figure 1 plots measured deforestation against the self-reported values, including estimates of initial pasture, for the 32 properties given on the TM scene. If these values were identical, we would expect to observe a slope of one. In fact, the slope is steeper (1.6), indicating a substantial amount of underreporting by the respondents.

Property centroids in sample *one* were also geo-referenced to UTM zone 22. This enabled assessment of spatial autocorrelation diagnostics for sample *one* properties, appropriate for agricultural activities given technological diffusion processes (Casetti & Semple, 1969). To accomplish this, we constructed three spatial weights matrices based on neighbors found within specified distances of each property (Cliff & Ord, 1973; Haining, 1990). In that we had no *a priori* grounds for selecting a distance, we defined neighborhoods with distance radii of 7,000, 20,000, and 40,000 meters. For each distance radii, we created a binary contiguity matrix, taking properties within the specified distance as *contiguous* (IE *neighbors*), and those outside, as noncontiguous. The binary weights were then row-normalized, and the resulting matrix used in defining the appropriate spatial autocorrelation diagnostic (Anselin, 1988, 1995). The greatest distance between two properties was 62,318 meters, while the average distance was 21,752. Most of the properties themselves were physically noncontiguous.

(i) *Proximate causes of deforestation among small producers*

The proximate causes of deforestation comprise the land use systems actually implemented by farmers, in this case small producers. Given stocking densities and average herd sizes in the region, the pre-eminent role of cattle ranching as a land-clearing impetus is evident *a priori*, and needs little elaboration. Nevertheless, a

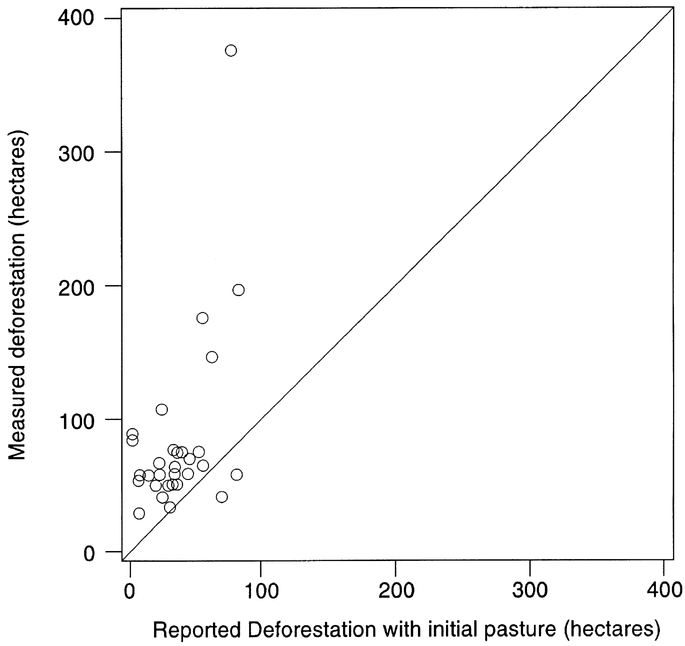

Figure 1. *Measured versus reported deforestation.*

"proximate cause" framework can be implemented for assessment purposes. This is accomplished with an additive land cover model in which the degree of land clearance is explained in terms of disaggregated farm component measures. In particular, let X_d be the extent of deforestation (measured in absolute terms, hectares). Then X_d is simply an additive function of the products of crop measures and associated land use intensities, or

$$X_d = b_o + b_i X_i + \cdots b_n X_n, \qquad (1)$$

where X_i is a measure (e.g., output) associated with crop i, and b_i is land-use intensity associated with the crop. The intercept term, b_o, may be regarded as a residual capturing deforestation not attributable to agricultural activity. This equation is static in nature and does not reflect farm evolution or the temporal relationship between crop types. In particular, annual crop production often gives way to pasture creation once crops are harvested, although small producers appear to maintain areas of relatively permanent shifting cultivation. The dynamic nature of herd formation is addressed in the sequel.

Table 3 presents ordinary least squares (OLS) estimation results for the two samples, taking as independent variables the main crops found on the properties in the region; occupation time is used as an independent variable to control for any autonomous trends in forest clearance. Both regressions show strong responses for herd size. Coefficients are positive and highly significant. *Cattle* is the only significant variable in the restricted sample of 32 properties, and the most significant variable in the full sample of 132 properties. The coefficient values for cattle enable calculation of land productivity measures associated with ranching; these are 29 kg-beef/ha and 142 kg-beef/ha for samples one and two, respectively.[11] Comparison with annual crops indicates order of magnitude differences in the productivity of land for beef, and by implication in the relative land requirements of ranching and annuals production. Rice productivity for the sample of 132 properties is 1284 kg/ha (Walker et al., 1997), and 983 kg/ha in a sample of 261 small producers in Uruará (in 1996).

Although insignificant in both models, the intercept term is positive and large for the restricted sample, suggesting that other factors beyond cropping decisions account for the amount of land cleared in the settlement process. This is consistent with the observation that deforestation facilitates land possession. The results of statistical estimation give a

Table 3. *Additive land cover model. OLS results for main crop components. Dependent variable: deforestation*

	Sample one		Sample two		
	$n = 32$[a]		$n = 132$[b]		
	b Value	Significance	*b* Value	Significance	Mean[c]
Intercept	36.13	0.3867	−0.87	0.8808	
Cattle	1.34	0.0009	0.28	0.0001	33[d]
Rice production[e]	−0.0017	0.7228	0.0005	0.1822	4062
Bean production[e]	−0.0026	0.9195	0.0058	0.0702	372
Corn production[e]	−0.0025	0.6465	0.0001	0.8449	2087
Number of cocoa trees	−0.0002	0.7208	0.0002	0.1902	10353
Number of pepper plants	−0.0038	0.5375	0.0010	0.3986	1371
Number of coffee plants	0.0002	0.9524	0.0006	0.6159	827
Farm occupation time[f]	0.9583	0.6526	1.27	0.0006	14

[a] The independent variable is a measure of deforestation calculated using TM imagery for individual properties, using four bands in unsupervised classification. Sample size is restricted due to satellite coverage. Farming system components taken from questionnaire responses derived from survey administered to 132 small producers in the summer of 1993. Mean value of deforestation for restricted sample: 77 hectares. Adjusted $R^2 = 0.22$ $F = 2.08$ (0.0808); parenthetic value is significance of *F*-statistic.

[b] The independent variable is a measure of deforestation derived from self-reported acts of land clearance for individual properties. Sample size indicates number of small producers interviewed in summer of 1993. Mean value reported: 34 hectares. Adjusted $R^2 = 0.38$, $F = 9.78$ (0.0001); parenthetic value is significance of *F*-statistic.

[c] Mean values based on full sample.

[d] The cattle variable includes those belonging to the property owner (mean = 29) and to others (mean = 4).

[e] Production is farm total in year preceding interview, given in kilograms.

[f] Period of residency on farm, in years.

measure of how much land may be cleared to achieve this nonproductive end.

(ii) *Household drivers of proximate causation*

Drivers of proximate causation may be addressed by reference to household production theory, in which economic factors compose a production function yielding an output—in this case, cattle (Singh, Squire & Strauss, 1986; Ellis, 1993). Herd expansion (i.e., size) is determined by the growth of the primary production factor, land, given the land extensive nature of ranching, the rudimentary forms of capital equipment observed in settlement frontiers, and the low labor requirements per unit of production.[12] Thus,

$$Y = f_y(A, t), \tag{2}$$

where Y is a measure of cattle production (herd size), A is land area (or extent of deforestation), and t is a time factor indicating a possible autonomous trend in stocking.

In the household economy, land functions simultaneously as an investment and as a food source during initial phases of farm establishment, since it may be used in the production of annuals for family subsistence prior to conversion to pasture grasses (Eden et al., 1990; Scatena et al., 1996; Walker & Homma, 1996). Dynamic land cover processes occurring on the Transamazon Highway are consistent with this pattern of change. Homma (1976) observed an average herd size of 1.4 animals among 96 small producers in the region in 1975. Reported pasture clearance was 6.41 hectares, not much larger than the land used in the production of rice, 2.54 hectares. In the same region, average herd size is now 33 animals ($n = 132$) and reported pasture clearance is 37 hectares,[13] substantially greater than the land devoted to annual crop production, 4.07 hectares. Although the farming systems are highly diversified (Walker et al., 1997), pasture represents the main component of forest clearance, as has been reported for the South of Pará by the Centro Agro-Ambiental do Tocantins (1992).

Taking land as a factor "produced" for the purposes of a ranching investment, the amount of deforestation is given as a function of household endowments of labor (family and hired) and capital, and the willingness of the household to undertake such investments:

$$A = f_a(K, L, F), \tag{3}$$

where A is as before (land area), K is available capital, L is available labor, and F is a family life cycle variable indicating household propensity to investment activity (Walker & Homma, 1996). Eqns. (2) and (3) constitute a recursive system, in which case they may be estimated independently.

Tables 4 and 5 present results for eqn. (2) for samples one ($n = 32$) and two ($n = 132$). In both samples, land is strongly explanatory of herd-size observed on the properties. Variables are highly significant in both models, and the value of R^2 reaches 41% in the sample of 32, where occupation time also emerges as a significant variable. The slope coefficient in this sample is consistent with the low stocking densities observed among small producers (Fearnside, 1986a), although the intercept term is large. This probably indicates nonlinearity in the functional relationship between deforestation and herd size, since the results from the additive model also show a positive intercept.[14] The negativity of the coefficient for occupation time, significant in the restricted sample ($n = 32$), reveals a process of herd reductions in the face of rising relative prices. Evidently, stocking densities are reduced on the order of two animals per year. Given the low levels of technology generally employed by small producers in the region, such stock reductions probably reflect declining pasture productivity due to loss of fertility and weed invasions. Pasture degradation has been widely observed throughout the Amazon, and much land abandoned to secondary succession was originally in pasture.

Eqn. (3) involves variables that present measurement issues, namely capital and labor. We take family wealth, as measured by possession of durable goods, as a proxy for capital. Tables 6 and 7 describe the wealth classes implemented in the regressions as an index variable, and gives values observed in the sample for initial and current periods, as well as wealth class transitions. Labor is specified in two different ways, as an aggregate variable combining household workers and hired hands, and in disaggregated form with household labor and hired workers broken out separately. Although the system comprising eqns. (2) and (3) is presented in static terms, eqn. (3) is dynamic in nature, and mutual interdependence (i.e., *simultaneity*) exists between deforestation and the production factors, capital and labor. Clearly, initial period factor levels are exogenous to deforestation outcomes following arrival on the farm property. Factor increments, however, may depend on land clearance and

Table 4. *Cattle and deforestation: the production function. OLS results Sample one*[a]

	b Value	Significance
Model 1: Adjusted $R^2 = 0.34$, $F = 16.99$ (0.0003)[b]		
Intercept	6.83	0.3865
Deforested land	0.31	0.0003
Model 2: Adjusted $R^2 = 0.41$, $F = 11.89$ (0.0002)[b]		
Intercept	35.89	0.0258
Deforested land	0.29	0.0004
Time	−1.74	0.0385

[a] Deforestation variable (mean = 77 hectares) for restricted sample derived from TM imagery using four bands in unsupervised classification. Deforestation mean: 77 hectares;
[b] The parenthetic value is significance of the F-statistic.

Table 5. *Cattle and deforestation: the production function. OLS results Sample two*[a]

	b Value	Significance
Model 1: Adjusted $R^2 = 0.31$, $F = 46.34$ (0.0001)[b]		
Intercept	2.44	0.6737
Deforested land	0.78	0.0001
Model 2: Adjusted $R^2 = 0.30$, $F = 23.00$ (0.0001)[b]		
Intercept	4.46	0.6262
Deforested land	0.79	0.0001
Time	−0.16	0.7749

[a] Deforestation variable (mean = 34 ha) for full sample constructed from self-reported acts of deforestation.
[b] The parenthetic value is significance of the F-statistic.

Table 6. *Wealth classes for beginning and current periods: distribution of small producers*[a]

Class	Beginning period		Currently	
	Frequency	Percentage	Frequency	Percentage
1	68	55.7	11	8.9
2	26	21.3	56	45.5
3	27	22.1	52	42.3
4	1	0.8	4	3.3

[a] Wealth classes are defined as follows. Class 1 refers to households that do not possess charcoal or wood stove, gas lamp, car, generator, refrigerator, or television; class 2 is differentiated from class 1 through ownership of charcoal or wood stove, or a gas lamp. Class 3 possesses at least one durable good: a car, generator, refrigerator, or a television; class 4 includes households that possess all four.

Table 7. *Class transitions from beginning period*[a]

Transition	Frequency	Percentage
−2	1	0.8
−1	9	7.5
0	39	32.5
1	43	35.8
2	28	23.3

[a] The transition measure is the difference between current and beginning wealth classes. Theoretically, the maximum absolute value is 3; however, the empirical maximum is 2.

resulting economic activity. The ability to hire labor could depend on the income associated with economic success, which is likely to be linked to growth of the land factor. Increases in the family labor force may or may not be affected by deforestation outcomes, a circumstance that depends on the degree to which households connect fertility decisions to their economic conditions in such an environment.

Table 8 presents results for three forms of eqn. (3); specifications differ by the simultaneity assumption and the specification of labor. Models 1 and 2 both implement disaggregated labor variables that distinguish between use of hired labor and increments to the family workforce, but wealth increment is endogenous in Model 1.[15] Model 3 aggregates family and hired labor. All estimations are for the restricted sample with TM-based deforestation measures. Models 1 and 2 perform well with high R^2, although two-stage least squares shows only a marginal increment from 0.64 to 0.65.[16] Explanation falls off appreciably in Model 3 with the disaggregated labor variables; here, R^2 is 0.24. Evidently, the labor factor is more important than capital in explaining the degree of deforestation. Although initial family workforce appears important in Model 3, it does not perform in Models 1 and 2 where hired labor is taken as an independent variable. Moreover, the increment in family labor is more significant than initial endowment in Model 3. None of the capital/wealth variables show significance in the models.[17]

The family life cycle variable is taken as age of household head (Jones, Dale, Beauchamp, Pedlowski & O'Neill, 1995). Here, a squared term is introduced to allow for a weakening of family interests and efforts in land creation beyond some point of maximum concentration. Although the results are uniformly insignificant, coefficient magnitudes in every case are consistent with the life-cycle hypothesis that there exists an age maximizing the extent of cleared land. For Models 2 and 3, this age is in

Table 8. *Spatial effects assessment: Lagrange multiplier statistics*[a]

	7000 m[b]	20000 m	40000 m
Additive model	0.01/0.16[c]	0.03/0.02	0.61/0.81
Eqn. (1)	(0.91) (0.69)	(0.87) (0.88)	(0.43) (0.36)
Production function	0.64/0.33	1.28/2.07	0.51/0.86
Eqn. (2) (Model 2)	(42) (0.56)	(0.25) (0.15)	(0.48) (0.35)
Land creation	0.62/2.06	0.10/1.03	0.73/1.49
Eqn. (3)	(0.43) (0.15)	(0.75) (0.30)	(0.39) (0.22)

[a] Lagrange multipliers calculated on basis of errors from OLS regression, for the three models indicated.

[b] The entries, 7000, 20000, and 40000 m refer to the length of the radii in meters used to identify "neighbors," necessary in implementing a contiguity matrix for assessing spatial effects.

[c] Left value is for error multiplier, and right value, for lag multiplier. Significance levels reported in parentheses.

the neighborhood of 50 years, which agrees with field observations that substantial field abandonment occurs on properties whose owners have aged beyond 60.[18] This is consistent with theories on the developmental cycles of domestic groups and recent research on these issues in the Altamira region of the Transamazon Highway (Goody, 1962; Walker & Homma, 1996; McCracken et al., 1998, and forthcoming).

(iii) *Spatial autocorrelation*

Spatial autocorrelation diagnostics were calculated on the OLS residuals for the additive land cover model, the production function (in land), and Model 3 of the land creation equation. In all cases, results are based on sample one containing the geo-referenced information ($n = 32$). Table 9 gives Lagrange multiplier statistics, which indicate the presence or absence of the spatial autocorrelation problem. They are computed for three distance-based, contiguity matrices, defined on neighborhoods of 7,000, 20,000, and 40,000 meters. The diagnostics do not indicate the presence of a serious problem, either for *nuisance* spatial autocorrelation associated with error terms, or *substantive* spatial autocorrelation associated with spatial lag relations in the dependent variables. All significance probabilities are sufficiently high that we retain the null hypothesis of no spatial autocorrelation. Although agricultural activities are known to show spatial relations (Casetti & Semple, 1969), the present results may possibly be explained by noncontiguity of the spatial units. Indeed, the average distance between pairs of properties is 21,752 m.

4. DISCUSSION

This paper addresses the controversial issue of how much deforestation to attribute to small and large producers. The results presented are mainly consistent with the view that large landowners may be held accountable for a disproportionate share of the overall magnitude. Our estimates are for specific sites within

Table 9. *The production of land regression results, OLS and two stage least squares*[a] *Sample one*

	Model 1[b]		Model 2[c]		Model 3[d]	
Intercept	−2.02	0.9903	7.54	0.9642	−66.92	0.7824
Wealth, t_0[e]	−9.78	0.7502	13.69	0.3210	24.67	0.2128
Δ Wealth[f]	−29.68	0.4524	1.73	0.8930	0.804	0.9656
Labor_f, t_0[g]	−0.53	0.9067	−1.94	0.6479	9.32	0.0839
Δ Labor_f[h]	−2.64	0.4594	−3.48	0.3156		
Diarios[i]	16.95	0.0001	17.07	0.0001		
Age	4.85	0.5111	2.13	0.7474	2.50	0.7932
Age-squared	−0.095	0.4658	−0.02	0.6925	−0.02	0.7582
Labor_t[j]					9.29	0.0103

[a] Model 1 presents results for two stage least squares, taking wealth creation as endogenous to the process of land reclamation (i.e., deforestation). The exogenous variables used to estimate wealth change are initial wealth (Wealth, t_0), initial family workforce (Labor_f, t_0), additions to family labor (ΔLabor_f), time of occupancy, age of property owner, and age-squared, which yields a quadratic function meant to reflect closing phases of life cycle efforts. Model 2 implements OLS taking wealth change as exogenous. Model 3 implements OLS on a reduced set of independent variables, and uses an aggregated labor force change variable (Labor_t) that combines additions to family labor, ΔLabor_f, and the current yearly demand for hired labor *diarios*.

[b] Adjusted $R^2 = 0.65$; $F = 8.56$ ($\propto = 0.0001$).

[c] Adjusted $R^2 = 0.64$; $F = 8.27$ ($\propto = 0.0001$).

[d] Adjusted $R^2 = 0.24$; $F = 2.53$ ($\propto = 0.049$).

[e] Index variable reflecting durable goods possession upon arrival at the property. See Table 6.

[f] Calculated by comparing current wealth position to initial wealth position, as a difference in the value of the wealth indices.

[g] Initial family labor force, upon arrival at the property (mean = 3.8). Queried as those working "in the fields."

[h] Increment in family field labor (mean = 1.4), between current period (mean = 5.1) and arrival time.

[i] *Diarios* represents number of person-days of hired labor used in the entire, preceding year. Diario measures (mean = 198) were divided by 180 to provide an estimate of person-years, the variable used in the model to reflect hired, nonfamilial labor (mean = 1.1).

[j] The variable, Labor_t, is the sum of additions to family work force since initial period and person-years of hired labor, currently used.

one Amazonian state, but they are in rough agreement with region-scale values (Fearnside, 1993). These results are all the more striking when considered in light of the pattern of land concentration in Amazonia. For the State of Pará, only about 1% of all holdings are in excess of 1,000 hectares (IBGE, 1985).

Although large ranches are thus implicated in Amazonian deforestation, the additive land cover estimations suggest that cattle ranching is also a substantial proximate cause of forest impacts among small producers as well. Both estimates point to a statistically strong effect for cattle, but that for the restricted sample ($n = 32$) shows a land-use intensity coefficient about four times greater than for the full sample ($n = 132$) due, presumably, to more accurate measurements of deforestation. Its magnitude, in turn, is consistent with the region's known stocking densities, which tend to be lower than one head per hectare for low levels of technology. This calls into question the reliability of the estimation based on the full sample. Evidently, the deforestation measure implemented for the full sample estimation is substantially underestimated, presumably due to informant concerns about truthfully reporting excessive deforestation, given Brazilian laws on permissible extent of clearance (see Figure 1). This study and other recent ones (e.g., Moran et al., 1994, Moran, Packer, Brondizio & Tucker, 1996; Brondizio, Moran, Mausel & Wu, 1994, 1996; McCracken et al. 1998 and forthcoming) suggest the presence of a potential problem in studies on land-cover change based on recall data only. Statistical findings may differ as a function of how the data are obtained, particularly for measures of forest clearance. An implication is that independent sources of land-cover data should be used when undertaking landcover change analyses at the household level.

If prices were stable, if acts of deforestation and cattle purchases occurred simultaneously and according to property stocking density, and if soil fertility remained constant, then a zero (or marginally positive) intercept term would obtain in the additive land-cover model. These conditions are clearly absent from the region, in which case a variety of effects can be presumed to be loaded into the intercept. Perhaps most pronounced among these are the processes of (a) land occupation whereby claim to land is strengthened by clearance in advance of herd formation; and of (b) pasture degradation, which reduces stocking densities in successive years due to lowered nutritive values of forage grasses—given the low propensity to use fertilizers in the region. Both of these effects would reduce herd sizes per unit of cleared land, thereby leading to a positive intercept term. While the intercept terms are insignificant in both additive estimates, its magnitude for the restricted sample suggests a sizeable component of land cleared independently of any agronomic consideration, an outcome consistent with much commentary on land occupation processes in the region (Mueller, Alston, Libecap & Schneider, 1994; Alston, Libecap & Schneider, 1995). An additive model with expanded sample size and using satellite land cover data could reveal the amount of deforestation occurring in the Brazilian Amazon for institutional and social reasons, beyond the requirements of strictly agricultural production. Proximate causation in the Brazilian case may need conceptual modification to incorporate such behavioral phenomena as farmer responses to insecure land tenure.[19]

The results for the analysis of household drivers are largely consistent with accounts reported in the literature (CAT, 1992; Homma et al., 1993; Walker & Homma, 1996). The land factor is strongly explanatory of herd sizes (eqn. 2) and household production factors account, in large part, for the amount of land created (i.e., deforestation). This latter relationship was investigated in three models that varied in their specification of labor. Of these, the structure of Model 3 is closest to the narratives of farm creation and land clearance. In particular, initial labor force is expected to be strongly explanatory of forest clearance given the early institutional incentives to claim land; then, increments to the farm's overall labor force should lead to additional forest clearance (CAT, 1992).

Results are stronger for Models 1 and 2, however, in which labor is disaggregated into family and hired sources. The hired labor variable evidently undermines the statistical function of initial labor endowment, which is strong in Model 3. We suggest that contract labor employed by small producers may be dedicated, predominantly, to the specialized services of forest clearance and land preparation. Moran (1981, 1976) found that up to 82% of credit received by individual farmers was used to clear forest. Given the subsistence level of the producers in the sample and their low incomes, such credit may constitute the main outlay for wage payments. If so, deforestation magnitudes are directly related neither to family sizes nor to the amount of physical capital at their disposal, but rather to the availability of financial resources that enable labor contracting. Such resources could be linked to economic performance, but might also reflect the preferences of money lenders, be they private institutions, friends, or government organizations.[20]

5. CONCLUSION

Both large and small producers clear tropical forests in Amazonia to make way for cattle ranches. Large-scale producers are often nonresident in the region, and they bring external resources, financial and managerial, to bear on their agricultural activities. Small producers tend to be locally resident, and forest clearance associated with this group arises both by virtue of in-migration with its initial land claim, and by the ongoing endogenous process of farm creation, occurring over the span of a decade or more. The analysis presented in this paper provides a structural disaggregation of tropical deforestation into components associated with each group and, by implication, into components attributable to external capital and demographic phenomena. The analysis does not address the external forces affecting both the influx of large producer capital (Hecht, 1985) and the in-migration of small producers (Fearnside, 1986b; Skole, Chomentowski, Salas & Nobre, 1994).

Ranchers and small producers have often been held out in opposition, as two sets of fundamentally different actors showing their own unique behaviors and farming system choices (e.g., Fearnside, 1993; Faminow, 1998). In this regard, it is important to emphasize the primacy of the cattle economy across all agrarian sectors. Large producers are specialized in cattle production, but small producers show an evolution in this direction. The recursive model presented, which posits land creation in preparation for herd formation, is supported by the statistical results. Substantially reducing the rate of deforestation in Amazonia can only in part be achieved by policies targeting specific groups, be they large-scale ranchers or small producers. Forest conservation must ultimately address the underpinnings of the cattle economy itself, or continue with the search for viable agricultural alternatives.

NOTES

1. The northern region is reported as comprising Rondônia, Acre, Amazonas, Roraima, Pará, and Amapá.

2. Such social constructions are inherently arbitrary. Note we have left undefined a large category of mid-sized producers. Thus, we are not attempting to account for deforestation in a collectively exhaustive fashion. Producers with between 100 and 1,000 hectares of land in Amazonia can be poor or relatively affluent, depending on location, cropping system, and level of technology deployed.

3. The higher income assertion refers to net present value of earnings. Clearly, pasture degradation leads to reduced income over the planning time horizon. Although *sustainable* land uses such as for extraction of forest products generate theoretically unlimited returns, positive discounting leads to finite present value, the measure of importance to the economic decision maker (Hirshleifer, 1970). Sustainable extraction and ranching have been compared for the case of Brazil nut and *cupuaçú* (Homma, Walker, Carvalho, Conto & Ferreira, 1996). See Serrão and Homma (1993) for a multi-dimensional concept of sustainability applied to cropping systems in Amazonia.

4. The 29% figure is for the 44 households in a sample of 261 near Uruará on the Transamazon Highway that consume all of their rice and bean production.

5. Simmons (1999) has shown in an analysis of SUDAM-funded projects for the municipio of Paragominas that 50% of all properties in excess of 10,000 hectares received government subsidies; moreover, those ranches reporting corporate origins were all from outside the State of Pará.

6. The data in Table 2 were obtained through visual inspection of appropriate Thematic Mapper scenes (1:250,000) at the SUDAM office in Belém, Brazil. This consisted of measuring directly off the images areas of clearing, using a ruler and information on scale. In the absence of property boundaries, determination of deforestation attributable to size classes is problematic (Fearnside, 1993). Nevertheless, for large producer

magnitudes, we typically measured areas in large clearings showing a regular geometry (e.g., rectangular) suggestive of land management units. This measurement probably represents a lower bound for deforestation belonging to the size class, since large land owners may have holdings that, at the time of image acquisition, show up on the image as small, partially cleared, lots. Small producer deforestation was also calculated in an *ad hoc* fashion, on the basis of assumptions about clearance patterns.

7. Within 20 km of Altamira can be observed a substantial amount of contiguous clearings. Much of this is probably accounted for by large holdings, but the developmental in-filling of the landscape close to the city does not allow an easy partition of deforestation by land-holding sizes on account of the clearance pattern.

8. Seventeen crossroads were analyzed for small producer deforestation. Clearance on crossroads taken as the product of road length and an estimate of average width of cleared land. On the Transamazon Highway, the amount of deforestation is roughly 60% of a strip two kilometers wide, on the north side of the road. Clearing to the south of the highway is neglected due to interpretative difficulty.

9. The figure is an upper bound because the large producer number is a lower bound, and because mid-size ranchers may be in evidence, although for the Altamira sites, mid-size holdings often belong to individuals with relatively few economic resources. Our data show that poor migrants to Amazonia may concentrate holdings to 10 lots (1,000 hectares) over a decade or more, which in other parts of Brazil would represent a sizeable property.

10. It was not feasible to determine property boundaries using GPS instrumentation. The INCRA colonization scheme provided for 100-hectare properties, with 500 m $\times$ 2000 m rectangles along the main axis of the Transamazon Highway, and 400 m $\times$ 2500 m rectangles along the crossroads, or the so-called spines of the fish. To measure one property's boundaries would require carrying a GPS device along a perimeter of at least 5 km, difficult to accomplish even without the obstruction of primary forest.

11. Calculated by estimating yearly beef production associated with one animal and dividing this by regression coefficient. We assume a young bull weight of 200 kg, and a 20% offtake rate for herds.

12. Arima and Uhl (1996) show that labor costs are a small fraction of total costs for all scales of farming. Cordeiro de Santana (1997) and Cordeiro de Santana et al. (1997) give employment multipliers for agropecuária in the aggregate for the State of Pará, which is mainly a cattle economy.

13. This number may be substantially underestimated, as suggested by the regression results of Table 3 and the areas of deforestation presented for the two estimates. On the other hand, our classification themes are coarse, and secondary regrowth may be showing in the cleared land (Skole et al., 1994).

14. Regression using logs of the deforestation values suggested curvature. We remained with linear forms in the interest of consistency across regressions.

15. Two-stage least squares was performed taking both wealth and labor increments as endogenous, a specification that did not perform well and is not reported in the table. The weak performance of the specification with full endogeneity may reflect the relationship between fertility decisions and the economic environment. In particular, the exogeneity of a fertility decision is likely to be enhanced in the absence of family planning and without ready access to reliable contraceptives.

16. Results for the models in Table 9 must be interpreted in a cautionary light, given a high leverage observation. Omission of the observation reduces R^2 to 0.17 in Model 2.

17. The results invite speculation on the relationship between wealth and use of hired labor, which can be costly. We assume the wealth variable so constructed provides a proxy for physical capital. The use of hired labor is indicative of liquid capital, which may not be highly correlated with economic resource endowments due to government policies. It is presently possible to obtain loans under the Fundo Constitucional de Financiamento do Norte (FNO) without secure land title, a major subsidy to poor farmers (Cordeiro de Santana et al., 1997).

18. This maximum may be found by writing the age function as a parabola and maximizing the function for the variable, age. Thus, Model 2 indicates the equation, $y = 2.13 *$ age – $0.02*$ age^2, *ceteris paribus*. Solving the calculus problem yields a maximizing age of 53 years.

19. Land tenure is more secure on the Transamazon Highway than in other parts of Pará. Nevertheless, land title is not necessarily easy to come by, and clearing land has traditionally been used to demonstrate land possession. In a sample of 347 physical lots (100 hectares each) undertaken in Uruará in 1996, only 135 possessed a definitive land title.

20. These comments are suggestive in nature, given the presence of the high leverage observation. More research is needed to address the role of credit and local labor markets on rates of deforestation.

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