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Poverty dynamics, ecological endowments, and land use among smallholders in the Brazilian Amazon

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ABSTRACT

Rural settlement in previously sparsely occupied areas of the Brazilian Amazon has been associated with high levels of forest loss and unclear long-term social outcomes. We focus here on the micro-level processes in one settlement area to answer the question of how settler and farm endowments affect household poverty. We analyze the extent to which poverty is sensitive to changes in natural capital, land use strategies, and biophysical characteristics of properties (particularly soil quality). Cumulative time spent in poverty is simulated using Markovian processes, which show that accessibility to markets and land use system are especially important for decreasing poverty among households in our sample. Wealtheir households are selected into commercial production of perennials before our initial observation, and are therefore in poverty a lower proportion of the time. Land in pasture, in contrast, has an independent effect on reducing the proportion of time spent in poverty. Taken together, these results show that investments in roads and the institutional structures needed to make commercial agriculture or ranching viable in existing and new settlement areas can improve human well-being in frontiers.

1. Introduction

In recent decades, poverty and inequality appear to have declined across the Amazon, in tandem with rapid, increased deforestation (Guedes et al., 2012; Ludewigs et al., 2009). Because deforestation is an immediate and highly public impact of human activities on the tropical rainforest, environmental and social scientists have expressed concern about its pace across the region. These concerns are focused especially on the conversion of primary forest to land uses such as slash-and-burn agriculture or extensive pasture for cattle (Walker et al., 2000). The environmental impacts of these land-use decisions have pushed some policy makers to propose public and state interventions aimed at curbing deforestation, notably, the reduction of investments in road-building with the aim of reducing accessibility to farms in the Amazon, increasing transportation costs, and decreasing urban–rural interaction (Fearnside, 2005). Despite these efforts, continued recent road network expansion projects have increased market accessibility throughout the Amazon (IIRSA, 2009; Pfaff et al., 2009). The

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expansion of infrastructure projects and agribusiness in the face of political resistance suggests a lack of consensus regarding how to create opportunities for sustainable development (Lima et al., 2011).

In frontier settings, rural poverty and well-being are closely linked to these questions of how human occupation interacts with the natural and built environments, and how these interactions are in turn influenced by contextual factors.[1] If human well-being depends primarily on the natural environment, policies that aim to reduce human impacts on the landscape by making it more difficult for settlers to prosper in environmentally sensitive regions could lead to increased out-migration from frontier regions and effectively discourage further settlement (Carr, 2009). Policies that do so by decreasing accessibility may also create barriers to financial and technical assistance, or decrease the opportunity cost of rural wage labor, with the perverse effect of keeping more frontier households trapped for longer spells in cycles of investment poverty and resource exploitation (Chomitz, 2007; Young, 1998). Slowed in the process of converting natural capital into other, higher return capitals (e.g. human capital through education and physical capital through investments in technology), these households may well be barred from transitioning to more sustainable livelihoods. If incomes depend on use of natural capital, households will have few options other than continued deforestation of new parcels to the extent that frontiers with weak environmental enforcement still exist (Barbier, 2007; Millikan, 1988; Schmink and Wood, 1984).

Reardon and Vosti (1995) label this cycle of poverty a "poverty trap", in which the poor are obliged to forego technology and inputs that could preserve or restore natural capital, instead retaining or adopting ecologically threatening land uses and further depleting already low levels of natural capital (Chomitz, 2007; Reardon and Vosti, 1995). Policies rooted in this perspective would promote land use regulation to prevent further occupation of virgin areas and to discourage unsustainable practices in settled regions (Vosti et al., 2003). An emerging, but complementary, view is that the overexploitation of natural capital by poor Amazonian households in already-settled regions or in new small-scale agricultural frontiers is neither irrational nor permanent, but rather a rational and temporary strategy (when successful) directed at obtaining other forms of capital (e.g. human capital, financial capital or physical capital) that are vital to escaping the investment poverty trap that Reardon and Vosti describe (Lima et al., 2011; De Vreyer et al., 2009; Barbier, 2007).

In this formulation, the unsustainable natural capital depletion observed in many regions of the Amazon may offer poor households a viable strategy for transitioning out of poverty, but only if the households engaged in this pursuit are able to effectively convert natural capital into financial, physical, and other capitals with higher returns (VanWey et al., 2012b; de Sherbinin et al., 2008). This long-term investment strategy may be an intergenerational commitment, with human capital formation being less important for the first generation, but highly valuable for the second generation (Barbieri et al., 2009). Continued reliance on natural capital alone signals ongoing hardship and leads to ongoing degradation of environmental services. Whether aggregate well-being can be increased and natural resource dependence decreased is contingent upon large numbers of households successfully obtaining the high-return capitals that generate upward mobility. In this scenario, the critical policy and scientific question shifts from how to prevent households from deforesting altogether, and focuses instead on identifying those elements of the local context that make it possible for people in the Brazilian Amazon to successfully move out of poverty.

Because the link between rural well-being and the environment is both context and time dependent, a first step towards more coherent and place-adjusted policy making is the examination of what case studies can tell us (Hull and Guedes, 2013; Rindfuss et al., 2007). Understanding how some capitals, such as biophysical or natural capital, affect poverty is an important step toward constructing better policies for the promotion of rural well-being and ultimately rural development. This paper addresses poverty in the Amazon from a multi-capital perspective (Bebbington, 1999) that views capital as more than productive assets and investments, including other assets, entities, and attributes of actors that enhance capabilities (Sen, 1997) and livelihoods. The impact on rural poverty of two types of capital (natural and biophysical) is considered in conjunction with land use, household income, prior wealth, and human capital (education of household head) in one region of the Amazon. We estimate the empirical relationship between these capitals and poverty status as well as the time spent as poor, among rural households deriving their livelihoods from small-scale agropastoral activities. We take advantage of a representative longitudinal sample of rural smallholders in the colonization area of Altamira, Pará State, Brazil. Observing households at two time points allows us to examine the time spent in poverty for households having different endowments of natural capital, market accessibility, biophysical characteristics and land use by using a Markovian approach to estimating the time in poverty. Our estimates of time in poverty are first based on raw transition probabilities followed by conditional probabilities, predicted by a multivariate probit model of poverty status, controlling for socio-demographic characteristics (education and income). The comparison of cross-tabulation and regression-based Markovian estimates of time spent as poor allows us to understand how the association between natural and biophysical capitals and time in poverty is altered when other socioeconomic characteristics are included.

The remainder of this paper is organized as follows. In Section 2, we discuss past research linking poverty and the natural as well as built environment in the Amazon, and further elaborate the theoretical framework in which the present analysis is situated. We then describe the study area in the Brazilian state of Pará in Section 3. Section 4 introduces the methodology used to describe, estimate, and simulate poverty transitions among settler households. Results are presented in Section 5, followed by a discussion in Section 6.

[1] Poverty decline in the Amazon has very complex causes, but studies suggest that in recent years government and private transfers have played an important role (Guedes et al., 2012; Marinho and Araujo, 2010; Barbieri and Bilsborrow, 2009; Brondizio and Moran, 2008; Schwarzer, 2000).

2. Rural poverty and the environment

A link between poverty and low levels of natural capital among smallholders is well-established in both cross-sectional and qualitative longitudinal studies and in multiple contexts (Guedes et al., 2012; Jagger et al., 2012; Murphy, 2001; Barbieri and Bilsborrow, 2009; Swinton et al., 2003; Young, 1998). However, a tension exists in the literature between two dominant views on the relationship between poverty and the environment in the Amazon and elsewhere. The debate focuses on whether environmental degradation is a chronic and persistent complement to rural poverty, or whether it is possible for those who enter a rural frontier with little capital to adopt better conservation practices. It is argued that in the presence of the right supports, these poor households may eventually transition to sustainable livelihoods that cease to be purely extractive (Barbier, 2007). If the association between degradation and poverty is not inevitable, then it is vital to understand the constraints and incentives relating to natural resource management and the factors related to transitions into and out of poverty, as both of these forces act continuously to shape the economic composition of Amazonian populations.

The first view is argued by some Amazonian scholars to be a misconception (Brondizio et al., 2009; Lambin et al., 2001). Nevertheless, it continues to exert a strong influence on conservation policy and the priorities of NGOs and state actors across the Amazon region (Swinton et al., 2003; Young, 1998). In this view, it is poverty itself that is the strong and persistent driving force behind environmental degradation. Therefore, the chief policy imperative is preventing the poor from entering sensitive or ecologically important natural systems altogether.

The second view also acknowledges that poverty and environmental degradation are linked, but emphasizes multiple pathways. It further stresses that these linkages are impermanent, bidirectional, and mediated by context, policy, and endogenous development, among other things (Brondizio et al., 2009). In this view, the presence of the poor in frontier regions of the Amazon is itself the consequence of historical processes of capitalist expansion pushing migrants to inhabit "marginal" areas where degradation predominates in the short term (Fearnside, 2008). This position suggests that upward mobility out of poverty is possible through the effective conversion of natural capital into other forms of capital, severing the link between the occupation of frontier regions by settlers and the ongoing depletion of natural capital and ecological resources. Proponents of this view contend that reversing the deforestation trend will at least partially require assisting households to gradually transition[2] away from livelihoods that depend primarily on natural capital conversion and toward commercial land use systems (Caldas et al., 2007). Doing so may paradoxically require that the state make additional investments in helping these settlers to reach markets for produce and livestock, to access technology, make more informed choices regarding land use systems (fine-tuning labor poor, soil quality, market potential and long-term sustainability), and improve human capital investments which can help break the cycle of investment poverty endemic to the region[3] (De Vreyer et al., 2009; Barbier, 2007).

Studies of the impact of poverty status on land use demonstrate that a minimum income level is required for most households to invest in more profitable land use practices (Caviligia-Harris and Sills, 2005; Murphy, 2001). Moreover, higher income levels have been shown to prevent deforestation in some cases by encouraging more intensive use of land rather than extensive low-intensity agriculture (Caviligia-Harris and Sills, 2005; Perz, 2003; Young, 1998; Pichón, 1997). Higher rents from agriculture have the potential to have the opposite effect, to encourage deforestation by increasing its profitability. Our study does not directly speak to this case because it does not examine the replacement of forest with pasture on a landscape level. We focus instead on the improved well-being of households, in contrast to the situation in the past. Studies of settlers in the Brazilian Amazon in the 1980s and 1990s specifically link the precarious situations of farmers, especially those with low levels of access to government assistance, to the persistent failure to accumulate greater levels of wealth. These findings collectively suggest an explanation for the high rate of property abandonment that accompanied frontier development (Moran, 1981; de Almeida, 1992; de Almeida and Campari, 1995). As the natural capital embodied in a property is extracted through clearing and agricultural activities, those managing the property have a limited window of time during which they can successfully transition to a more sustainable livelihood. Those that fail to do so frequently face ongoing declines in the returns to their efforts until reaching the point where they are forced to move onto repeat the cycle elsewhere (VanWey et al., 2012a; Ludewigs et al., 2009; Rodrigues et al., 2009).

These observations may help to explain why poverty, natural capital, biophysical capital and land use have loose, non-linear connections across municipalities in the Brazilian Amazon[4] as compared with other tropical regions (Gaveau et al., 2009; Fearnside, 2008; Barraclough and Ghimire, 2000). A recent study by Rodrigues et al. argues that many municipalities in the Amazon have a deforestation trajectory mimicking boom-and-bust cycles of resource extraction (Rodrigues et al., 2009). Although this story is repeated in many parts of the biome (Barbieri et al., 2009; Ludewigs et al., 2009), not all the frontiers in the region follow

[2] Most experiences over the frontiers development reveal not only ups and downs in terms of household well-being but also that economic well-being and market integration among smallholders are a gradual (Caldas et al., 2007) and non-linear process (Guedes et al., 2009; Browder and Godfrey, 1997).

[3] In the Amazon, as in many frontier regions, human capital plays a more critical role in promoting upward mobility for the second generation (Barbieri et al., 2009). Yet this mobility depends on multiple factors, such as: ability of urban markets to absorb new labor, how effectively land use systems adopted by the first generation can retain family labor, how place-specific rural capital can be matched with improved education of the second generation (for instance, children with degrees in agronomy, chemistry, etc.), ability of first and second generations to solve conflicts on generational worldviews, and land titling issues that affect prospective returns to the second generation (Santos et al., 2012; Ludewigs et al., 2009).

[4] Barbier (2000) suggests that the linear relationship between poverty and deforestation is mediated by the way good and bad policies may affect the economic incentives determining poor African rural household's decisions to conserve or degrade their land. Gaveau et al. (2009) also recognize the multifaceted character of the link between poverty and deforestation, but suggest that long-term trends of coffee-price in Sumatra, Asia, directly affect deforestation rates.

this trend (Brondizio, 2008). Some frontier settings in Pará State, Brazil, for instance, experienced a reemergence of profitable extraction activities after a period of declining productivity (Lima et al., 2011). Castro and Singer (2012) also find that soil quality may be key to avoiding land turnover and impoverishment of agropastoral Amazonian frontiers.

The relation between poverty and deforestation is further complicated by the association of both with land use. The two most common uses of deforested land – pasture and cattle ranching – both have intersectoral economic externalities. For example, the lower demands for labor associated with cattle ranching can harm traditional, diversified livelihoods practiced by smallholders, for whom labor provision is among the few reliable routes to obtaining financial capital (Caviligia-Harris and Sills, 2005; Walker et al., 2000). In time, the welfare of labor suppliers may decline, creating a negative spiral of informal credit and income constraints (VanWey et al., 2012a).

In sum, the need for longitudinal studies of poverty change among smallholders is driven home by the complexity of these causal relationships between land use, market integration, and livelihoods. Furthermore, these relationships are continually subjected to shifts in context that can act to alter the returns to different forms of capital over time. Most notably, the returns to natural capital are not constant, but decline as frontiers develop (VanWey et al., 2012b). This observation provides a simple yet compelling explanation for the poverty trap and for the property abandonment that characterizes the region (Reardon and Vosti, 1995; Ludewigs et al., 2009; Moran, 1981; de Almeida, 1992; de Almeida and Campari, 1995). It is not only that some households are failing to effectively convert natural capital to other forms of capital and thus depleting natural capital stocks until they are exhausted. In addition, the *returns* to natural capital in the frontier context are gradually declining over time for those focusing on diversification strategies.[5] Two idealized paths to frontier development emerge: the first, followed by households that fail to diversify their capital portfolios, leads to the vicious cycle of further degradation and poverty, and the second, for households that do diversify, leading to a virtuous cycle of improved well-being and reinvestment in natural resource management. This focus on the households does not translate directly to a landscape reduction to the extent that the landscape houses heterogeneous actors, in part due to in-migration. Yet, over time as off-farm opportunities increase and market integration proceeds, the premium on non-extensive land uses will increase for all actors. Escaping the poverty trap is facilitated by diversification across economic sectors, including investment in education of the second generation and selected migration of family members (VanWey et al., 2012b; Brondizio and Moran, 2008; Barbier, 2007).

This study is a first step towards the empirical application of the conceptual model developed by VanWey et al. (2012b), using a case study in Altamira settlement area, located along the Brazilian TransAmazon Highway, to estimate the associations between poverty, natural capital, biophysical capital and land use among rural smallholders. Longitudinal studies are a viable way to understand how transitions in and out of poverty may be related to some of these capitals, shedding some light on their implicit returns. We explicitly recognize the limitation of our study to depict the full complexity of poverty dynamics since we are limited to a two-point longitudinal dataset. However, future meta-analyses of case studies of poverty in other frontier regions and stages of development may offer a fuller picture of the tandem evolution of poverty and smallholders' capital portfolios.

3. Altamira settlement area, Pará, Brazil

Despite being one of the strongest economies in Latin America, in 2010 Brazil ranked 73 out of 169 nations on the UNDP Human Development Index and had a GNI of U$884.00 per month[6] (UNDP, 2010). Especially high levels of poverty are encountered in the North where our study area is located. In 2007, the proportion of the population in the Northern states of Brazil that was poor was estimated at 36% (with 13% extremely poor), compared to 23% (8% extremely poor) for Brazil as a whole (IPEA, 2008a). Pará state was considered the poorest of the Brazilian Legal Amazonian states[7] as of 1997 (the beginning of our study period), with fully half of its population designated as living below the poverty line.[8] By 2005 (the end of our study period), this number had improved to 44%, while the proportion living below the extreme poverty line in Pará had decreased from 21% to 16%. By comparison, the percentage of poor individuals in Brazil dropped from 35% to 31% over the same period, while the percentage of extremely poor dropped from 16% to 11%.

Our analysis focuses on the Altamira settlement area within Pará. The area was initially settled during the 1970s when the TransAmazon highway was constructed through the city of Altamira and on westward. Settlers from many regions of Brazil subsequently flowed into the region in order to claim plots of land, most of which had 100% primary forest (Brondízio et al., 2002). During the early years of settlement, the Brazilian government designated Altamira as a model settlement area and provided settlers with assistance in traveling to the area and in clearing land to begin production. But because settlers were poorly screened for past agricultural experience in some cases and government support lasted only a few years, the early years of settlement were characterized by many farm failures, high malaria rates, and high rates of outmigration (Barbieri

[5] We recognize that ecosystem services, including the hydrological, nutrient and carbon cycles, are regenerative. However, the *perceived returns* to natural capital in smallholder frontiers tend to decline for those smallholders adopting a risk-aversion strategy (that is, diversification). This happens to the extent that other classes of capital begin to constitute a larger share of a household's portfolio of capitals in later stage of frontier development (VanWey et al., 2012b; Caldas et al., 2007). In agribusiness frontiers the opposite seems to hold true (Lima et al., 2011).

[6] PPP 2008 US$.

[7] Excluding Maranhão, which is only partially included in the Legal Amazon.

[8] The poverty line estimated by IPEA (2008b) is based on the number of Brazilian reals required to buy a basket of essential products to meet caloric needs. The poverty line is regionalized and estimated separately for rural, urban and metropolitan areas. By 2001, for instance, the estimated poverty line was R$115.92 (U$47.70) in the metropolitan area of Belém (Pará state capitol), R$119.86 (U$49.32) in the urban area and R$104.88 (U$43.16) in the rural area.

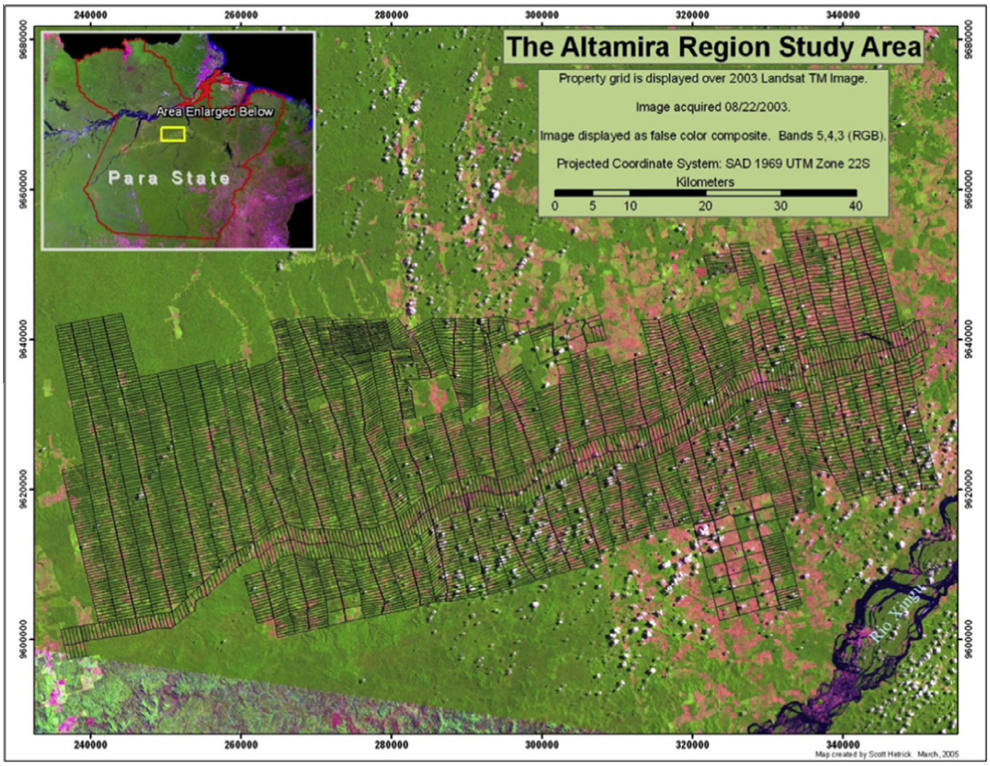

Fig. 1. Altamira study area.

and Sawyer, 2005; Barbieri et al., 2005; de Almeida, 1992; Moran, 1981). Not until the 1990s did the area settle into a stable pattern of production and settlement with continued opening of new land but also successful farming in established areas.

The regional landscape is characterized by steep, but rolling topography. This topography, combined with heavy rainfall during the rainy season leads to swollen rivers and streams annually, which frequently wash out the inadequate wooden bridges which are common in the region. The precarious state of road transportation and accessibility, especially in more remote regions of Altamira, is further aggravated by inconsistent government maintenance of transportation infrastructure. Deforestation in Altamira radiates out from the main road (TransAmazon) to the feeder roads (*travessões*), and has spread westward over time from the area of initial settlement in the east. Properties on the very west of our study area (towards Uruará) and in the back of the feeder roads have the highest proportion of their area in primary forest. Between 1997/8 and 2005, the average proportion of the property in primary forest declined from 45.3% to 31.3%.

Oxisols, which are adequate but not ideal soils for agriculture, predominate in Altamira, with small patches of reddish, high-quality *terra roxa* soil intermixed. The most common land uses are annual food crops (manioc, beans, rice), pasture for cattle, and perennial cash crops (overwhelmingly cocoa, with occasional black pepper or coffee). Cattle raised on these pastures are destined for local and regional markets. National and international markets for these cattle did not exist at the time of our surveys because of uncontrolled endemic foot-and-mouth disease throughout the state of Pará (more recently confined to the northern areas).

Cocoa production, in contrast, is destined for international markets (usually via domestic markets) and has reached the highest productivity per hectare in Brazil. Despite this, local production continues to represent a small share of total national production (CEPLAC, 2009). Spatially, cocoa production is heaviest on patches of *terra roxa*, particularly a large cluster of *terra roxa* around Medicilândia (see Fig. 1), because cocoa requires better quality soil to grow than do other perennials like coffee and black pepper. Pasture, in contrast, is widespread throughout Altamira. The larger and more successful cattle owners cluster close to the Altamira urban area (on the very east of our study area) while small ranches (usually combining cattle and annual production) are clustered on the other end (west) of our study area and represent some of the most impoverished families in the region (Guedes, 2010).

4. Methodology

4.1. Sample

The data used in the following simulation and regression modeling are drawn from a representative panel study of rural properties surveyed in 1997/8 and 2005 in Altamira. We sampled rural smallholders along the Transamazon Highway,

Table 1
Descriptive statistics for variables used in estimation of time in poverty. *Source*: Altamira Dataset (1997/1998, 2005).

Variable	Obs	Mean	Std. Dev.	Min	Max
Poverty status					
Household is poor (2005)	314	16.40	0.37	0.0	1.0
Household is poor (1997/8)	314	53.10	0.49	0.0	1.0
Biophysical capital					
Distance to urban Altamira	314	11.01	0.54	9.8	11.8
Proportion of property with high-fertility soil	314	22.14	34.47	0.0	100.0
Land use					
Proportion of property in pasture	314	34.62	22.78	0.0	100.0
Proportion of property in perennial	314	8.46	13.55	0.0	88.0
Proportion of property in annual	314	2.75	4.38	0.0	41.2
Proportion of property in primary forest	314	45.34	22.79	0.0	94.0
Does the property have on site access to water?	314	0.21	0.41	0.0	1.0
Time of arrival on the property	314	15.17	8.07	1.0	34.0
Does any household member have off-farm employment?	314	0.23	0.42	0.0	1.0
Number of household member	314	5.00	2.13	1.0	12.0
In the household head from the South-Southeast	314	0.39	0.49	0.0	1.0
Property size (ha)	314	109.13	69.45	15.0	540.0
Wealth index upon arrival in the region	314	−0.39	2.96	−6.0	12.0
Education of household head	314	2.62	2.56	0.0	14.0
Age of household head – 1997–98	314	51.43	12.83	24.0	82.0

including the municipalities of Altamira, Brasil Novo, and Medicilândia, Pará State (see Fig. 1). Questionnaires solicited information on household socioeconomic characteristics, biophysical endowments, and land use/cover classes at both the household and property level. In this study we use an analytical sample of 314 observations (households/properties in 1997/1998) with valid information on income (the key variable used to measure who was poor in both years) and other variables in our analyses (e.g. land use/cover classes, prior income, distance to the urban center of Altamira, extent of high fertility soil within the property, property size, educational attainment, and age of household head).[9]

These 314 smallholder households identified in 1997/1998 were intact and surveyed in our follow-up in 2005. We take advantage of this longitudinal design to reduce the potential effect of endogeneity, measuring the independent variables in 1997/8 and poverty in the 2005 follow-up in our probit model (described in the next section). For the Markovian approach (also described in the next section), we additionally use information on poverty status in the initial period (1997/8) to calculate transition probabilities. Table 1 below shows descriptive statistics for all the variables used in the analyses.

4.2. Estimation and modeling

Our aim in this paper is to estimate how the length of time households spend in poverty differs according to key household and plot characteristics, focusing here on natural and biophysical capital and land use, all of which have been identified as important in overall household well-being and poverty in rural, agricultural settings (Hull and Guedes, 2013; Guedes et al., 2012; de Sherbinin et al., 2008; McSweeney, 2005; Ellis, 1998; Young, 1998). We ultimately wish to understand the importance of these different types of resources for enabling households to rise up out of poverty. In order to address this objective, we take advantage of the longitudinal design of the dataset by using the transition probability matrix of poverty status in two points in time to estimate the time allocation in poverty and non-poverty status for different levels of these capitals and other household attributes. In simulating time in poverty, we go one step further, trying to capture what the effect of these characteristics would be depending on whether a household was poor or non-poor in the first period. We rely on a transition-matrix approach based on Markovian processes to estimate the duration spent in poverty and non-poverty, using the observed probabilities of transitioning from one state to the other. The observed transition probabilities are calculated in two ways: (1) we first calculate raw transition probabilities for selected groups using the empirical data from Altamira (cross tabulations), and (2) we second calculate probit-regression-based predicted conditional probabilities from these data which control for additional household characteristics, including prior wealth, educational attainment, and age of the household head.

Using these transition probabilities, we explore the importance of key independent variables and the relationships between them with simulations of the time spent in poverty for groups with different levels of initial characteristics. Our simulations vary both initial characteristics – i.e. taking the counterfactual of having a high endowment of a resource – and transition probabilities – i.e. using the estimated probabilities for the poor vs. non-poor and for those with and without high endowments of given resources.

[9] Through imputation (both average and random procedures were tried), we were able to boost the sample size to 324 (81% of the original sample). However, sensitivity analysis revealed that, despite a larger sample size, the sample with imputed income cases produced poorer model fits, especially for the regression-based simulations. Thus, these cases are left out.

4.2.1. Matrices of transition probabilities

We apply the methodology proposed in Clark and Summers (1990) to analyze the dynamics of transitions between poor and non-poor. These authors begin by describing individual behavior using a matrix of transition probabilities, p^i given by:

$$p^i = \begin{bmatrix} p^i_{nn}\, p^i_{np} \\ p^i_{pn}\, p^i_{pp} \end{bmatrix} \tag{1}$$

where p^i_{jk} represents the probability that individual i occupies state k (p = poor n = non-poor) in period $t + 1$, conditional on having been in state j in period t. Departing from the matrix of transition probabilities p^i, we can estimate the proportion of time spent in each state for each individual i. Taking π^i_j as the proportion of the time individual i spent in state j, we have:

$$\pi^i_j = \begin{bmatrix} \pi^i_n \\ \pi^i_p \end{bmatrix} \tag{2}$$

Given that π^i_j is non-observable, we assume that transitions between the two states (poor and non-poor) follow a Markovian process, in which the future development of the process depends solely on the state where an individual is, independent of her trajectory up to that state. Therefore, the use of Markovian transition matrices involves the assumption that movement from one state to another does not depend on the time spent in each state.[10]

The Basic Theorem of Markovian Chains further assumes that any system defined by such a matrix will reach a steady state that is independent of initial conditions. The steady state portion of the time in each state must be solved as a function of the entire transition matrix.

The relation between π^i_t and π^i_{t-1} can be written in matrix format as:

$$\pi^i_t = p^i \pi^i_{t-1} \tag{3}$$

In steady state, $\pi^i_t = \pi^i_{t-1}$. Thus, $\pi^i_t = p^i \pi^i_t$.

If the two above assumptions hold, then it follows that:

$$p^i_{\prime} \pi^i_t = \pi^i_t \Rightarrow \begin{bmatrix} p^i_{nn} & p^i_{pn} \\ p^i_{np} & p^i_{pp} \end{bmatrix} \begin{bmatrix} \pi^i_n \\ \pi^i_p \end{bmatrix} = \begin{bmatrix} \pi^i_n \\ \pi^i_p \end{bmatrix} \tag{4}$$

$$\begin{aligned} &\Rightarrow p^i_{nn}\pi^i_n + p^i_{pn}\pi^i_p = \pi^i_n \\ &\Rightarrow p^i_{np}\pi^i_n + p^i_{pp}\pi^i_p = \pi^i_p \end{aligned} \tag{5}$$

Any equation of the above linear system is linearly dependent on the others. However, because $\pi^i_n + \pi^i_p = 1$, we can solve the system. The distribution of population (N) under each steady state condition can be found by averaging individual probabilities, that is,

$$\Pi_j = \frac{1}{N}\sum_{i=1}^{N} \Pi^i_j \tag{6}$$

4.2.2. Simulations

We use simulation to evaluate the potential impact on smallholders' well-being of varying key environmental and biophysical characteristics, and natural capital allocations in particular, through the use of two hypothetical states for each dimension. For intuition, imagine two 2×2 transition matrices, one for those with low levels of a capital or other attribute (LL) and one for those with high levels (HL) of a that asset or characteristic. For each of these two matrices we use both methods (raw and regression-based) to separately calculate the probability of transitioning from each of two states to the other: from poor to poor (P–P), poor to non-poor (P–NP), non-poor to poor (NP–P), and non-poor to non-poor (NP–NP). We then calculate the hypothetical states necessary to address our major questions using the accompanying formulae:

(1) If the poor at lower levels (LL) of a selected dimension take on the transition probabilities of the *poor* at higher levels (HL) of that dimension, what happens to the proportion of time spent in each state (poor and non-poor) between 1997/8 and 2005?

$$\begin{aligned} {}^{S}\pi^i_n &= {}^{LL}p^i_{nn}\pi^i_n + {}^{HL}p^i_{pn}\pi^i_p \\ {}^{S}\pi^i_p &= {}^{LL}p^i_{np}\pi^i_n + {}^{HL}p^i_{pp}\pi^i_p \end{aligned}$$

[10] A poverty trap argument might imply that movement out of the poverty state may depend on time in the state, and this would argue against the use of Markovian transitional models. However, the theoretical pathways through which time spent in poverty operate are captured in our models. Empirical results from the probit model also suggest that this might be the case: when we model time dependency of being poor with no additional control in a probit model, the estimated coefficient is indeed statistically significant (being poor in 1997/8 is a strong predictor of being poor in 2005). However, when additional control variables are added, the coefficient on time is no longer statistically significant.

Table 2
Key forms of natural capital and land uses assessed in simulations.

Factor	Dimension	Measurement
Biophysical capital	Distance	Natural logarithm of the distance to the urban center of Altamira[a]
	Soil quality	What proportion of the property contains *terra roxa* (alfisols)?[b]
Land use	Pasture	What proportion of the property is pasture?[b]
	Perennials	What proportion of the property is perennials?[b]
	Annuals	What proportion of the property is annuals?[b]
Natural capital	Primary forest	What proportion of the property is primary forest?[b]
	Water access	Does the property have on-site access to water?[c]

Notes:
[a] Quintiles (1, 2 = closer/LL, 3, 4, 5 = more distant/HL).
[b] Quintiles (1, 2, 3 = LL, 4, 5 = HL).
[c] Dichotomous Measure (No = LL, Yes = HL).

(2) If the poor at lower levels (LL) of a selected dimension take on the transition probabilities of the *non-poor* at higher levels (HL) of that dimension, what happens to the proportion of time spent in each state (poor and non-poor) between 1997/8 and 2005?

$$^{S}\pi_n^i = {}^{LL}p_{nn}^i \pi_n^i + {}^{HL}p_{nn}^i \pi_p^i$$
$$^{S}\pi_p^i = {}^{LL}p_{np}^i \pi_n^i + {}^{HL}p_{np}^i \pi_p^i$$

The use of both simulated scenarios allows us to test the influence of changing the initial characteristics and the level of the selected dimension of capital on time spent in states. In order to simplify an already complicated presentation, we select three blocks of dimensions to use in this empirical analysis. These three blocks of dimensions are presented in Table 2, along with a description of the measures on which they are based. The results of the raw estimation, the probit-based regression, and the simulation of time spent in poverty are all presented in results section.

4.3. Measuring income and poverty

We focus here on income poverty based on monthly per capita household income. We sum different sources of income reported in the questionnaire to create this measure of total household income: off-farm income obtained by each member on the household roster, income derived from rural retirement transfer programs for all eligible household members, agricultural income, and the equivalent value of agricultural production for self-consumption.[11]

Income from off-farm employment is measured directly in the questionnaire. Retirement income is computed rather than reported.[12] It is a federal benefit pegged to the minimum salary, and we computed income from this source for each household by multiplying the number of people receiving the benefit in the household by the typical value of the benefit in the year of the interview (R$125.00[13] in 1997/8, and R$ 300.00 in 2005). Income from agricultural production was estimated as follows. First, a table was completed for each household, detailing for the year prior to the interview each agricultural crop and animal produced, the quantity, the destination of production (self-consumption or market sale), the amount sold at market, the price per unit sold, and any portion distributed to sharecroppers. Next, agricultural production measured in different units was converted to a kilo-equivalent measure of production for each source. From this total, the amount held back from market for household production plus the amount distributed to sharecroppers was subtracted, and the remaining sum multiplied by the price per kilo at market to produce a measure of the total financial income derived from agricultural produce.[14]

Agricultural produce that is consumed by the household is often excluded from analyses of income in rural areas, but as Barbieri and Bilsborrow (2009) suggest, production for self-consumption represents a significant alternative income source for a considerable portion of rural households, some of which depend almost exclusively on such non-monetary income.

[11] Although we also collected information on other cash transfer programs (such as Bolsa Família, Benefício de Prestação Continuada, and Vale-Gás) for the 2005 wave, this information was not available for the 1997/8 wave, so we excluded this income source from our analyses in order to preserve comparability over time. Bias because of this omission is minimal because of the rarity and low value of these transfers in 1997/8.

[12] In the questionnaire, there is a question that allows us to estimate the retirement income. The question asks how many persons in the household receive retirement income. However, there is no question about the amount received. So, we estimate the total amount of retirement income received in the household by assuming that each person receives one minimum salary, which corresponds to the typical value of the non-contributory rural retirement benefit. We acknowledge that this assumption may underestimate the total amount received by beneficiary households in the cases where beneficiaries may have contributed to the urban retirement income to receive more than one minimum salary and have moved to the rural area after retirement. The underestimation, however, is likely to be very small (Schwarzer, 2000).

[13] We averaged the minimum salary in 1997 (R$120.00) and 1998 (R$130.00).

[14] A number of households had missing data for various parts of agricultural production and income, suggesting we might want to impute this income. However, preliminary work with income as a dependent variable in regression models (not shown) suggested that the imputed data were less consistent. In this paper we use non-imputed agricultural income.

Table 3
Poverty in Altamira study area and Pará State, 1997/8 and 2005. *Source*: Altamira Study Area dataset (1997/1998, 2005); Brazilian National Household Survey – PNAD (1997, 2005).

FGT measure of relative poverty	Smallholders (Altamira)		Pará State (2005)	
	1997/98	2005	Urban	Rural
	Relative poverty line (60% median)			
Headcount ratio %	36.4	33.1	34.7	25.0
	Absolute poverty line (1/2 minimum salary)			
Headcount ratio %	53.1	16.4	38.6	59.4

Excluding self-consumption when computing incomes therefore leads to dramatic underestimates. Thus, while self-consumption is excluded from the direct calculation of agricultural income, we use the following procedure to estimate this missing quantity, using a variation on counterfactual analysis. We start by asking what levels of poverty and income inequality would obtain should the production for self-consumption be instead completely sold and converted into money (Brazilian reals)? To answer this, we use the reported market prices for each product and the amount of each crop or animal used for self-consumption to estimate the total value of this self-consumption for each product, which are then summed. Preliminary results (not shown) indicate that monetizing the portion of agricultural production used for self-consumption and including this quantity in the estimate of total household income reduces poverty in our sample by 58%. We compute total household income by summing each of these income sources at the household level: off-farm income, retirement income, agricultural income, and monetized self-consumption equivalent. Lastly, annual household income is converted to income on a monthly basis, and divided by the number of household members to obtain the monthly per capita household income.

We set the poverty threshold at 60% of the median of the cumulated per capita monthly household income distribution, as suggested by Iceland and Bauman (2007). Descriptive statistics on this relative measure of poverty are presented in Table 3, alongside an alternative absolute poverty measure and values for the state of Pará for comparison. The poverty rate is dramatically reduced in Altamira when the alternative measure of less than half of the minimum salary is considered. However, if we consider the relative income distribution, this reduction in poverty is a modest 3% over 8 years. Thus, in keeping with the sizeable literature preferring relative measures of poverty (Iceland, 2005; Iceland and Bauman, 2007), we employ the first measure in the analyses which follow.

5. Results

5.1. Transition probabilities and simulations

The first panel of Table 4 shows the proportion of time poor and non-poor using baseline transition probabilities for the entire sample. We estimate that, on average, smallholders in our study area spent 89.2% of the seven-year time-window as non-poor and 10.8% as poor. This result reflects the high probability of moving out of poverty between waves. 91.3% of the non-poor in 1997/8 remained non-poor in 2005. Among the poor in 1997/8, 72.5% had left poverty by 2005. This is a remarkable change in the distribution of well-being among smallholders, higher than in other Amazonian frontiers (Barbieri and Bilsborrow, 2009).

However, when we disaggregate by specific biophysical constraints, a very different picture emerges. The first panel of Table 5 presents results for the two selected biophysical characteristics of the property: (a) distance from the rural property to the urban center of Altamira, and (b) proportion of the property in *terra roxa*. While households distant from urban Altamira spent, on average, 18.7% of the period in poverty, those closer to the city center spent only 1.3% of their time as poor (roughly 14 months less time in poverty, on average). Households with low proportions of the high quality soil spent 15.7% of their time as poor, compared to only 5.5% among the households with a large proportion of the property in *terra roxa* (roughly 9 months less time in poverty, on average).

Turning to land use classes, the baseline difference between those with high and low levels of pasture is larger than the baseline difference based on levels of perennials and annuals. Among those with high levels of pasture, only 5.3% of the period was spent in poverty, while the same figure for high levels of perennials was 10.5%. For annuals, the pattern is reversed, with those households having high levels of annual crop production on their properties facing a higher proportion of time in poverty over the study period, roughly 12.3%.

The bottom panel of Table 5 presents the results for the two indicators of natural capital. Those households with high proportions of their property in forest (natural capital) spend considerably more of their time in poverty (21.3%, or about 13 months more on average). On-site access to water was associated with a reduced time spent in poverty, but in raw terms, this difference was approximately as large as for other land use/cover classes.

Because these use the transition probabilities estimated for the whole sample, the differences between the low level (LL) and high level (HL) of each resource endowment combine differences due to correlation between initial poverty and resource endowment and differences due to the impact of the resource endowment on transitions during the study period. To tease apart these two sources of differences, we turn now to estimating the proportion of time spent in and out of poverty

Table 4
Transitional probabilities matrix for poverty analysis – Altamira Study Area (1997/98 and 2005). *Source*: Altamira Study Area dataset (1997/98, 2005).

	Non-poor (2005)	Poor (2005)	Total
Non-poor (1997/8)	91.3	8.7	100.0
Poor (1997/8)	72.5	27.5	100.0
Obs (1997/98)	183	131	314
Obs (2005)	262	52	314

Table 5
Observed and simulated proportions of time spent in and out of poverty, by key characteristics of the property, Altamira study area, 1997/8 to 2005 ($N = 314$). *Source*: Altamira Study Area dataset (1997/8, 2005).

Status	LL	HL	S1	S2	ΔLL_1	ΔLL_2
Biophysical capital						
Distance to urban Altamira						
Non-poor	81.3	98.7	86.0	87.0	4.7	5.7
Poor	18.7	1.3	14.0	13.0		
% of the property with terra-roxa soil						
Non-poor	84.3	94.5	87.3	88.1	3.0	3.8
Poor	15.7	5.5	12.7	11.9		
Land use classes						
% of the property in pasture						
Non-poor	84.7	94.7	87.7	88.8	3.0	4.1
Poor	15.3	5.3	12.3	11.2		
% of the property in perennial						
Non-poor	89.7	89.5	89.0	91.8	−0.7	2.1
Poor	11.4	10.5	12.1	9.4		
% of the property in annual						
Non-poor	90.2	87.7	89.8	91.8	−0.4	1.6
Poor	9.8	12.3	10.2	8.2		
Natural capital						
% of the property in primary forest						
Non-poor	93.8	78.7	92.7	94.0	−1.1	0.2
Poor	6.2	21.3	7.3	6.0		
On the property access to water						
Non-poor	88.9	90.6	89.1	91.1	0.3	2.2
Poor	11.1	9.4	10.9	8.9		

Note: LL = Low Level; HL = High Level; S = Simulated; Δ = Simulated – Observed.

assuming that all have high levels of resource endowments. These results are shown in the fourth and fifth columns of Table 5. The sixth and seventh columns of Table 5 are the absolute difference in the percentage of time spent as poor and non-poor according to simulations 1[15] and 2.[16]

When we apply the transition probabilities associated with closer distance from urban Altamira (for both the poor and non-poor) to those poor living in further properties, the proportion of time spent out of poverty increases 4.7% and 5.7% respectively. Because there is little difference in effect between using the probabilities for the non-poor and the poor, as long as the matrix for high accessibility is used, the bivariate association between distance to markets and poverty is somewhat independent of initial conditions. That is, distance did not act primarily through its effect on 1997/8 status but rather has an effect throughout the study window. The same pattern can be observed for the other biophysical indicator. When poor households with low levels of *terra roxa* were given the same transition probabilities as either poor or non-poor households with high levels of *terra roxa*, their time spent out of poverty increases 3.0% and 3.8%, respectively. Again, it is not the initial poverty state that matters, but the difference between transition probabilities for low and high soil quality.

We now turn to the simulation results for land use classes. Among those with high levels of perennials and annuals, transition probabilities of the non-poor produce lower levels of time spent in poverty (2.1% and 1.6% reduction in time as non-poor, respectively), suggesting that perennials and annuals are both related to the initial poverty status. However, while higher levels of perennials themselves are associated with better-off households, higher levels of annuals are associated with worse-off households (comparison of the second and third columns of Table 5), reflecting the low profitability and self-consumption nature of annuals in the region and indicating low levels of integration into markets. In contrast, differences between the poor and non-poor are virtually eliminated among those with HL of pasture on their property, suggesting that pasture area is exogenous to initial conditions and also that pasture continues to have a strong effect through the study

[15] Had the initial poor with low endowments experienced the transitional/stationary probabilities of the poor with high levels of resources.
[16] Had the initial poor with low endowments experienced the transitional/stationary probabilities of the non-poor with high levels of resources.

period. This is consistent with work drawing attention to the significance of cattle to livelihood strategies among rural households of Amazonian frontiers (VanWey et al., 2007; Walker et al., 2000).

The final panel of Table 5 summarizes results for primary forest and on-site access to water. A strong association exists between forest and poverty status at both time points. Time spent in poverty is higher when all households are assigned HL of forest cover, but time spent in poverty is higher still for those who start in poverty. In contrast, households with high levels of access to water are associated with less time out of poverty, with the impact being slightly contingent upon the initial poverty status.

In all, poverty is significantly reduced when biophysical constraints are reduced. These initial descriptive results also suggest that perennials are poverty-reducing, but only for households already non-poor early on. Pasture shows the opposite pattern – with little difference by initial poverty status, but a considerable improvement from additional pasture. Annuals, far from improving poverty, actually *increase* time in poverty as shown earlier. Regarding the proportional area in forest, we see the large, negative bivariate association between well-being and increased primary forest, which is reduced, but still substantial even for those households in the non-poor category to begin with. Lastly, much like proportion in pasture and biophysical capital, on-site access to water provides a similar reduction in poverty. The small differences observed for the impact of simulation 1 and 2 on time in poverty suggests that the initial state is somewhat irrelevant in comparison to household characteristics to define prospective well-being.[17] We should then expect that regression-based impact of initial status on poverty is non-significant, acting through past influences on the level and relative distribution of household attributes currently observed.

5.2. Regression-based results

Simulations using non-parametric discrete Markovian processes based on raw transition probabilities are an illustrative way to describe the influence of selected characteristics on time spent in poverty between two points in time, and are suggestive of which factors act exogenously and which are endogenous to initial poverty status.[18] However, they do not control for other characteristics that might create a spurious observed relation in the simulated results or for the correlation between key characteristics. In this section we present a probit model of poverty status used to test if the correlations between natural and biophysical capital as well as land use classes and poverty previously found hold when prior wealth, human capital (educational attainment of household head) and age of the household head are included.[19] The estimated coefficients are then used to predict the conditional probabilities of transition into and out of poverty (and immobility in or out of poverty) for the same dimensions used in the cross-tabulation-based Markovian simulations. The dependent variable in the probit model corresponds to being poor in 2005 (based on the relative poverty line). To estimate the conditional probabilities, we included a dummy for poverty status in 1997/8 as an independent variable, rendering the following statuses from first wave (1997/8) to the second (2005): poor in both waves (P–P), transition to poverty (NP–P), transition away from poverty (P–NP), non-poor in both waves (NP–NP).

The model of poverty status confirms that distance to urban Altamira has a statistically significant effect, reducing the probability of smallholders being poor, after controlling for other factors (Table 6). *Terra roxa*, however, becomes statistically non-significant, suggesting that its bivariate effect is reflecting other characteristics of the property. Among the land use classes, only the areas in pasture and annuals are statistically significant, both corresponding to reduced poverty as their proportion of the total property increases.[20] Neither forest nor on-site access to water, the proxies for natural capital, was statistically significant, although the proportion of the property in primary forest is associated with less poverty at the less restrictive significance level of $p < 0.1$. As previously suggested by the comparison of simulations 1 and 2 in the descriptive section (Table 5), initial poverty status (in 1997/8) is not a statistically significant predictor of poverty status in 2005. This suggests that between 1997/8 and 2005 household and property characteristics are dominant in explaining poverty at the end of the interval (2005). Among the controls, only property size and age of household head are statistically significant, acting in the expected way: larger properties and older households are associated with better-off smallholders.[21] To control for long term impact of wealth on current poverty we also included a wealth index upon smallholder's arrival on the property and the owner's educational attainment in 1997/8. None of these variables was significant. As in other small-scale agricultural frontiers of the Amazon (Barbieri et al., 2009; Murphy, 2001), educational attainment is typically low in level and heterogeneity among the first

[17] This irrelevancy condition is contingent upon the time window between the initial and prospective points in time.

[18] As mentioned earlier in the text long-term strategies may cause endogeneity bias in the estimation because of the limited time window of our data.

[19] As previously mentioned (methodology section), we estimated a probit model for 2005, measuring all covariates in 1997/8.

[20] The average proportion of each land use/cover class is defined for our analytical sample (314) as follows: % of pasture = 34.6; % of perennials = 8.5%; % of annuals = 2.7%, and % of primary forest = 45.3%. These classes together sum 91.1%. The residual represents areas in secondary succession, water surface, area of the house and the orchard. The residual per se is larger than some land use classes, such as perennials and annuals. Thus, there is a 9.9% of area as a baseline for comparison. But predicted probabilities of transiting into and out of poverty as well as predicted probabilities in steady-state (see Figs. 3 and 4a) are interpretable only if these predicted probabilities by each land use/cover class is within its "allowable range". For instance, primary forest can increase from 0 up to 54.2%, holding the other land use classes constant at their mean values, in order to be interpretable.

[21] We performed several calibration tests, such as jackknife (314 replications) and bootstrap (5000 replications) standard deviations as well as likelihood ratio tests for several specification variables (changing land use classes from proportions to hectares). We additionally performed some residual analyses to try to identify influential cases, but no observations excluded from these regression analyses seriously altered model estimates and these cases are included in the models reported here.

Table 6
Probit coefficients of poverty status in Altamira, 2005 (dependent variable: 1 = Poor/ 0 = Non-poor). *Source*: Altamira Dataset (1997/1998, 2005).

Variables	Partial	Full
Biophysical capital (measured in 1997/8)		
Ln(distance to urban Altamira)	0.932***	0.677***
	(0.204)	(0.208)
Proportion of property with high-fertility soil	−0.006	−0.005
	(0.005)	(0.005)
Land use classes (measured in 1997/8)		
Proportion of property in pasture	−0.024***	−0.021**
	(0.008)	(0.008)
Proportion of property in perennial	−0.028**	−0.025*
	(0.014)	(0.014)
Proportion of property in annual	−0.036*	−0.050**
	(0.021)	(0.024)
Natural capital (measured in 1997/8)		
Proportion of property in primary forest	−0.014**	−0.013*
	(0.006)	(0.007)
Does the property have on site access to water?	0.021	0.121
	(0.224)	(0.237)
Control variables (measured in 1997/8)		
Is the household poor?		0.264
		(0.224)
Does any household member have off-farm employment?		−0.133
		(0.258)
Is the household head from the South/Southeast regions?		−0.421**
		(0.211)
Property size (ha)		−0.012**
		(0.005)
Index for household wealth upon arrival on the property		0.020
		(0.034)
Household head's educational attainment (years)		−0.239
		(0.172)
Age of the household head		−0.029***
		(0.010)
Constant	−9.553***	−3.907
	(2.304)	(2.691)
Pseudo R^2	0.2007	0.2906
Prob > Chi2	0	0
Observations	314	314

Notes: Robust standard errors in parentheses.
* $p < 0.1$.
** $p < 0.05$.
*** $p < 0.01$.

generation. Only among the second and subsequent generations does education begin to take on a prominent role in shaping life course opportunities and well-being.

Figs. 2a–4b present the results of this probit model using predicted probabilities of being in each of the outcome categories as the key independent variables vary over their entire range. Confirming the earlier simulation results, lower levels of these forms of capital increase the probability of remaining in poverty or transiting into poverty over the period.[22] Even after introducing the covariates, accessibility of the property measured by distance to the city center was significantly related to poverty decline, *regardless of* the initial poverty status. The proportion of property in highly fertile *terra roxa*, however, was not significantly related to poverty status, as shown by the inelastic response of poverty status across the range of values on this variable.

Figs. 2a and 2b shows the non-linear relationship between the probability of being poor and distance to the main urban center of our study area. This may reflect a spatial association between distance to Altamira and land use systems based on perennial production. The bulk of cocoa production is concentrated around the municipality of Medicilândia, approximately in the center of the study area. Increase in the price of cocoa during the survey years may also help to explain the logistic relationship between poverty status and distance to Altamira.[23]

[22] The predicted probabilities in Figs. 2a–4b are actually the conditional probability of being poor or non-poor in 2005, given that the person was poor or non-poor in 1997/8. Using the total sample size (N = 314), the reader can easily calculate transitional probabilities summing up 100% over the four subcategories. However, we have left the predicted probabilities in the current format to facilitate comparison with the Markovian approach shown earlier.

[23] To test for the possibility that perennials and *terra roxa* could have a potential interactive effect on poverty, we included an interaction between these variables in one run of the model, but this term was not significant and fit declined. Further, no evidence was found for multicollinearity between *terra roxa* and percent in perennials.

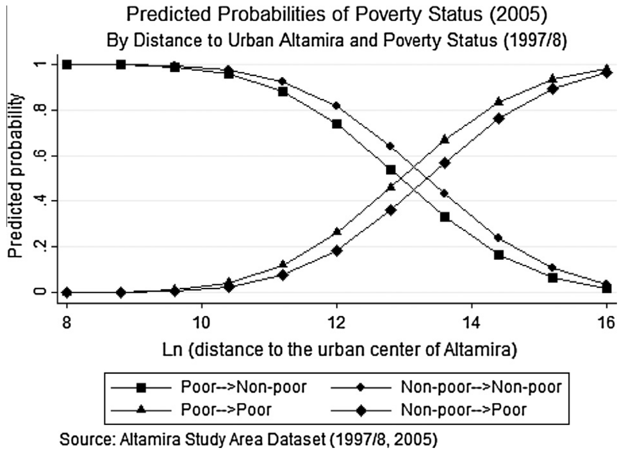

Fig. 2a. Predicted probabilities of poverty status by distance to urban center.

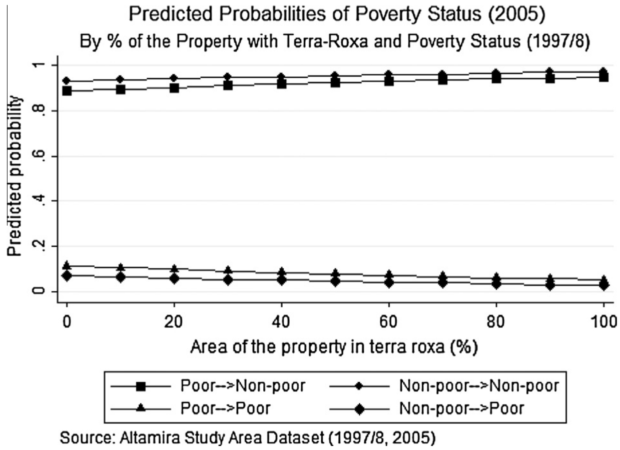

Fig. 2b. Predicted probabilities of poverty status by area in *terra roxa* (%).

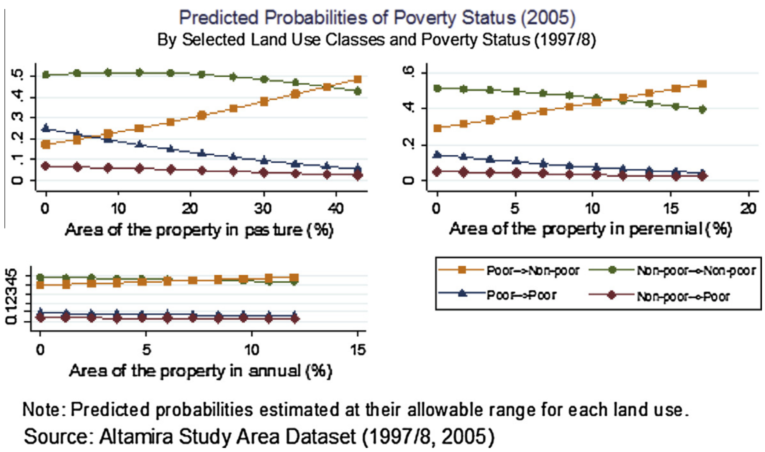

Fig. 3. Predicted probabilities of poverty status by level of Land Use Classes.

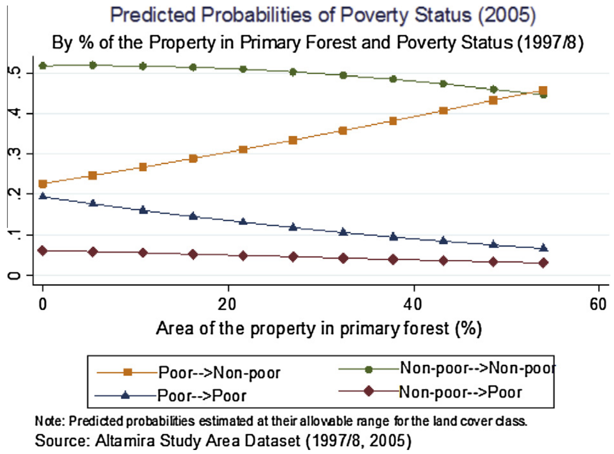

Fig. 4a. Predicted probabilities of poverty status by area in primary forest (%).

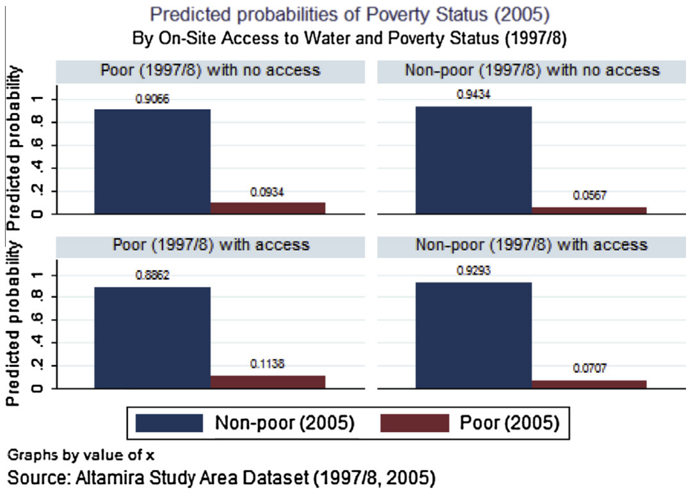

Fig. 4b. Predicted probabilities of poverty status by water access.

Fig. 3 shows changes the predicted probabilities of poverty status across values of the three main land use classes in our study area. Only pasture and annuals are significantly related to poverty status after controls are introduced – perennials are only marginally related to poverty. Higher proportions of the property in pasture and annuals increase the probability of being non-poor in 2005, regardless of poverty status in 1997/8. Reflecting the very small negative coefficients from Table 6, Fig. 3 reveals a very modest increase in the probability of being non-poor with the increase in all three land use classes.

Figs. 4a and 4b tells a different story from the one suggested by the Markovian simulation. Whereas the simpler simulation showed that time spent in poverty was higher among households with higher proportions of the property in forest (Table 5), the regression results appear to make the opposite prediction.[24] In these results, increased primary forest is associated with a higher probability of staying out of poverty, but the effect is very small in size and only marginally significant ($p < 0.1$). These seemingly contradictory findings can be reconciled by recalling that in the bivariate Markovian simulation it was suggested that much of the effect of forest was due to the association of initial forest cover with initial poverty level (and presumably with other variables controlled in the regression model). Households with smaller proportions of area in forest have a higher probability of leaving poverty while households with larger shares of the area in forest have a higher chance of remaining out of poverty for the whole period. Lastly, on-site access to water (Figs. 4a and 4b – right panel) has no significant effect on transition on poverty during the period under analysis, with the inclusion of covariates erasing the impact observed in the simpler Markovian simulation. Additional estimates of time in and out of poverty from regression-based Markovian simulations can be found in the appendix (Table A1).

[24] The simulated time out of poverty has its impact reversed when one compares high and low levels of forest; however, the regression coefficient for the proportion of primary forest is consistent with the cross-tabulated results.

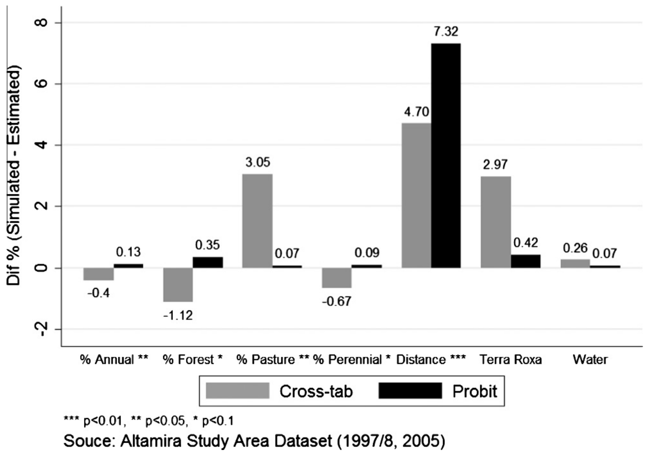

Fig. 5. Summary of impacts of variables on time out of poverty using both cross-tabulation and regression predictions, Altamira, 1997/8 to 2005 (changes in percentages are shown).

5.3. Comparing time spent in poverty across simulations

To assess the simultaneous impact of each of the key environmental dimensions on the time spent as poor and non-poor between 1997/8 and 2005, we re-estimated the Markovian matrices replacing the cross-tabulated values used in the first part of the paper with the predicted transition probabilities derived from the binomial probit model. The results shown in Fig. 5 highlight several contrasts between the two simulation exercises (for detailed estimates refer to Table A1, in the appendix). In the tabulation-based Markovian simulation, increased proportion of the property in annuals, perennials and forest led to a longer time spent as poor. After inclusion of control variables, the impact of these land use/land cover classes on time out of poverty was nearly eliminated. As reported in numerous other studies of other Amazonian populations (Barbieri and Bilsborrow, 2009; Murphy, 2001; Reardon and Vosti, 1995) the impact of having high levels of primary forest and annuals is to reduce time spent in poverty. This finding is consistent with the interpretation that poor households are likely utilizing the additional natural capital embodied in primary forest (i.e. increased soil nutrients, timber, and other non-timber forest products) and some surplus of annual production (such as manioc and corn) in order to escape poverty through local markets.[25]

Having a property with larger areas in pasture, more *terra roxa* and on-site access to water remains associated with spending less time in poverty, although only the coefficient for pasture is significant. The size of all three coefficients is reduced following the introduction of controls, suggesting that properties with more pasture, *terra roxa* and water are also the ones with higher levels of other capitals and resources. The influence of accessibility – distance to Altamira – is actually more pronounced in the probit-based simulations. Based on Fig. 5, we estimate that if an initially poor household located far from Altamira center was instead given the probability of a initially poor household located closer to the city, its time spent out of poverty would increase by 7.32% on average (against 4.70% from the cross-tab simulation).

Taken together with the factors listed above, the probit simulation results support the contention that greater natural capital stocks and accessibility and particular livelihoods such as cattle ranching are all capable, independently, of shortening the length of time that households spend in poverty in our Amazonian study area.

6. Concluding remarks

Our analysis uses longitudinal data on rural farmers and a novel simulation method to investigate the impact of natural and biophysical capitals on poverty dynamics among rural smallholders. The methodology employed here is readily generalizable to research questions necessitating simulations among small samples (stopping after the cross-tabulations, if insufficient degrees of freedom are a concern) and to large datasets including national censuses and longitudinal datasets from other regions of the Amazon and beyond. Substantively, we find that higher levels of market accessibility and market-oriented land use classes are associated with higher standards of living, reflected in households spending less time in poverty, even when educational status and wealth are both taken into account. These results confirm findings from research on poverty elsewhere in the Amazon (Guedes et al., 2012; Börner et al., 2007; Murphy, 2001). As infrastructure development expands, market integration becomes even more important, making room for further improvement in smallholders' living standards in the years to come. Different from the Ecuadorian Amazon case (Murphy, 2001; Barbieri et al., 2009), among

[25] It is also possible that surplus of annual production, beyond immediate consumption needs for nutritional intake of family members, may have been used to feed the cattle or other livestock on the property, indirectly yielding more money to the household unit when these animals are sold in the local and regional markets.

Table A1
Predicted and simulated proportions of time spent in and out of poverty, by key characteristics of the property, Altamira study area, 1997/8 to 2005 (*N* = 314). *Source*: Altamira Study Area dataset (1997/8, 2005).

Status	LL	HL	S1	S2	ΔLL_1	ΔLL_2
Biophysical capital						
Distance to urban Altamira						
Non-poor	88.9	98.7	96.2	98.5	7.3	9.6
Poor	11.1	1.3	3.8	1.5	−7.3	−9.6
% of the property with terra-roxa soil						
Non-poor	93.1	96.8	93.5	93.8	0.4	0.7
Poor	6.9	3.2	6.5	6.2	−0.4	−0.7
Land use classes						
% of the property in pasture						
Non-poor	94.4	95.1	94.5	94.8	0.1	0.4
Poor	5.6	4.9	5.5	5.2	−0.1	−0.4
% of the property in perennial						
Non-poor	94.5	95.4	94.5	94.8	0.1	0.4
Poor	5.5	4.6	5.5	5.2	−0.1	−0.4
% of the property in annual						
Non-poor	94.0	95.3	94.1	94.4	0.1	0.4
Poor	6.0	4.7	5.9	5.6	−0.1	−0.4
Natural capital						
% of the property in primary forest						
Non-poor	92.8	95.9	93.2	93.5	0.4	0.7
Poor	7.2	4.1	6.8	6.5	−0.4	−0.7
On the property access to water						
Non-poor	94.2	95.0	94.3	94.6	0.1	0.4
Poor	5.8	5.0	5.7	5.4	−0.1	−0.4

Note 1: LL = Low Level; HL = High Level; S = Simulated; Δ = Simulated – Predicted.
Note 2: Predicted values based on mean values of control variables for a probit model of poverty status.

our sample of Altamira smallholders, prior wealth is not a significant inducement out of poverty, leaving more room for exogenous interventions. Smallholders in this region appear to already be taking advantage of increasing market integration by adjusting their land use systems, ultimately reducing their time in poverty (VanWey et al., 2012a,b; Börner et al., 2007).

Our results further show that the profitability of land use systems is important for raising households out of poverty. In Altamira, this depends in part on the confluence of soil quality (*terra roxa*) and the institutionalization of cacau production in the region. Accessibility to local and regional markets proved to be the most consistent and strong predictor of greater household well-being in this advanced frontier context. This result reinforces the importance of providing accessibility to small farmers to encourage development of diversified and more profitable household livelihoods. We suggest that this will also prevent horizontal deforestation (Pfaff et al., 2009) and high land turnover (Ludewigs et al., 2009).

The chief question raised by our simulation is why each of these measured factors has a beneficial impact on time spent in poverty. We have suggested a number of plausible responses to this question, based upon empirical analysis combined with our experiences in the field in and around Altamira, and elsewhere in the Brazilian Legal Amazon. We have sketched here a story in which households are better able to transition out of poverty when commercial land use systems are fully realized and accessibility to urban areas is improved. These developments allow the more efficient use of land and at the same time promote accountability to consumers regarding compliance with environmental regulations (Nepstad et al., 2006). The path to this future of higher productivity of land with greater environmental protections can come from the outside, with investment capital and government development projects promoting integrated construction of roads, linkage to markets, and local institutional investment. We argue that it can also develop *in situ*, with investments in roads or accessibility combined with the growth of regional urban centers encouraging commercialization of agriculture. Resulting income allows farmers to invest in other forms of capital and to diversify into urban economic activities.

As the Brazilian government looks to improve well-being in the Amazon among existing settlers and new settlements, our results suggest two courses of action. Improving existing road networks seems a promising avenue in this regard, since it reduces transportation costs at the same time that it enables larger profits to be made from selling the produce from a fixed, or even a smaller cultivated area. In new settlements, the government should invest in agronomic research to match settlement area endowments (soil, topography, water availability, etc.) with commercial crops. Settlements can then be strategically designed both geographically and institutionally to support specific forms of commercial land uses that will raise settlers out of poverty more rapidly than will settler experimentation or a focus on subsistence crops.

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Appendix A

See Table A1.

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