Boom-Bust Patterns in the Brazilian Amazon

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Abstract: We revisit the long-standing hypothesis that the process of human development and land clearing in Amazonia follows a boom-and-bust (inverted U) pattern, where early clearing leads to a socioeconomic 'boom' which then turns to 'bust' after the deforestation process has matured. Although the hypothesis has found some empirical support in cross sectional data, a handful of longitudinal case studies have failed to identify incidences of 'busts.' We show that the cross sectional results are a spurious artifact of spatial correlation, driven primarily by the large, multifaceted (and unobserved) differences between municipalities in the states of Amazonas and Maranhão. Furthermore, using new panel data on the Human Development Index (HDI) and deforestation rates from 1991 to 2010 we find no evidence of such boom-bust patterns in the time series. Municipalities categorized as either 'post-frontier' or 'pre-frontier' in 2000 enjoyed equal increases in HDI over the subsequent decade as the rest of the Amazon. Panel data analysis with fixed effects (*within* estimation) robustly rejects the hypothesis that HDI and deforestation follow an inverted-U relationship.

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Key Words: sustainability, deforestation, boom-bust cycles, Brazilian Amazon

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1. Introduction

Understanding the trade-offs associated with differing patterns of development and alternative land uses in the Brazilian Amazon is of critical importance for policy makers concerned with balancing environmental and economic outcomes. One long-standing hypothesis about the relationship between land clearing and economic growth in the Amazon is that human well-being improves ('booms') as land is cleared and agriculture production increases, but that this benefit is then eventually reversed in a 'bust' as deforestation leads to land exhaustion. This hypothesis of an inverted-U pattern of development in the tropics has long been suggested by a number of researchers (for example, Moran 1982, Hecht 1983, Fearnside 1986, Schneider et al. 2002, Barbier 2004). Rooted in the theory of the Tragedy of the Commons (Hardin 1968) and combined with assumptions of weak resilience usually associated with the risks of soil degradation, savannization, and other irreversible changes of the Amazon, the hypothesis implies that economic development in the region may ultimately be a lose-lose outcome, with environmental costs and no economic benefits.

Recently this hypothesis has received increased empirical support in the literature. In an influential study in *Science*, Rodrigues *et al*. (2009) investigate the extent to which deforestation has been associated with changes in human well-being, as measured by the Human Development Index (HDI) in a cross section of 286 municipalities in the year 2000. Celentano *et al.* (2012) extended this cross section approach (also for 2000) in a multivariate spatial model. Both analyses find evidence of a boom-bust relationship as the process of frontier development progresses. For example, Rodrigues *et al*. conclude,

> "What our results suggest is that life expectancy, literacy and standard of living improve more quickly than the national average in municipalities at the early stages of the deforestation frontier, and at below-average rates as deforestation progresses. …This 'bust' is likely to reflect the exhaustion of the natural resources that supported the initial 'boom,' compounded by the increasing human population." (p. 1436)

The impact that the Rodrigues *et al*. *Science* paper has had on environmental policy decisions, especially in Brazil, has been significant and wide ranging, with numerous Brazilian and international scientists, NGOs, journalists, governmental officials, and policy makers repeatedly citing the study in order to influence international and Brazilian public opinion and put pressure upon government and/or legislative decisions involving the Amazon (for example Rodrigues *et al*. 2009 was among the few pieces of *scientific* evidence that Marina Silva, the former Brazilian Minister of the Environment and Presidential candidate, cited to defend her policy agenda in Amazonia).

Nevertheless, a number of case studies (for example Sears *et al.* 2007, Piñedo-Vasquez *et al.* 2001, Guedes *et al.* 2012, Hall and Caviglia-Harris 2013, Mangabeira 2010) that have examined the dynamic trajectories of different Amazonian communities for between 7 to 22 years provide evidence not of boom-bust cycles, but instead either stable or continuing welfare improvements over time. Although a limited number of counter-examples cannot preclude the possibility that boom-bust cycles happen elsewhere, or indeed are the more general phenomenon, the case studies do raise some doubt about the robustness of the cross sectional analyses and definitively show that such dynamic patterns are not inevitable.

In this paper we broadly examine the evidence for the existence of boom-bust cycles in the Brazilian Amazon and provide a novel analysis using time series panel data. Specifically, after briefly reviewing the conflicting cross sectional and case study conclusions, we use panel data to provide an *encompassing* explanation for the disparate results. In particular in our analysis of welfare dynamics we show that, consistent with the case studies, there is no evidence of boom-bust cycles in the time series data. We further illustrate how, despite the lack of inverted-U relationships in the time series, the pattern could still be detected in the cross section. Specifically, we show that the Rodrigues *et al*. results emerge as a spurious artefact of spatial clustering of low-HDI municipalities in and around the states of Amazonas and Maranhão, each with its own distinct historical determinants driving social and economic outcomes.

The paper proceeds as follows. In section 2 we discuss the boom-bust hypothesis and review the existing cross sectional and case study evidence. In section 3 we re-examine the cross sectional analyses, showing how these are artefacts of spatial and sample biases. In section 4 we present our an analysis of the unconditional time series relationships between HDI, economic growth and forest clearing in the Amazon and find no evidence of any boom-bust relationship. Section 5 discusses our overall findings and suggests some policy-relevant interpretations.

2. Boom-bust cycles in the Amazon: some recent evidence

The 'boom-bust' hypothesis states that the level of human welfare increases early in the process of deforestation when forest cover is significant and deforestation rates are high, but then collapses in the post-frontier stage where forests are highly depleted, and, without many remaining trees, deforestation rates fall dramatically or cease entirely. The strong version of this hypothesis that most often appears in the literature is that of an unconditional, bivariate relationship between human welfare and the extent of cleared land; indeed this is the version investigated by Rodrigues *et al.* (2009) in a cross section of Amazonian municipalities in 2000.

A weaker interpretation (which could perhaps be called a 'boom-bust' *effect*) is that, all else initially equal, human welfare will be lower if standing forest has largely been cleared. This weaker form of the relationship is examined in Celentano *et al*. (2012), who use multivariate regression analysis, also on a cross section of municipality data from 2000, to control for a number of possible variables that could be correlated with both welfare and forest extent. A boom-bust *effect* could occur if, starting from equally populated, equally mineral rich municipalities with equal soil and climate conditions, those that deforested more extensively ended up with lower welfare than those that deforested less, even if welfare in both municipalities was considerably higher after the (greater or lesser) deforestation. The precise mechanism for this effect is left obscure, but is arguably more likely to be directly related to ecosystem services of forests, as opposed to the broader socio-economic declines precipitated by environmental collapse that could theoretically explain the stronger bivariate pattern. In this paper we focus on the stronger version of the boom-bust hypothesis, as this has been the version mostly discussed in the literature and which has had the most influence on public policy debates.

The evidence to date on boom-bust patterns in the Amazon is mixed, with large scale, cross section quantitative analyses finding apparently strong evidence of a general inverted-U pattern (Rodrigues *et al.* 2009, Celentano *et al*. 2012), while a handful of longitudinal case studies fail to show any 'bust' phase in development (Sears *et al.* 2007, Piñedo-Vasquez *et al.* 2001, Guedes *et al.* 2012, Hall and Caviglia-Harris 2013, Mangabeira 2010).

Rodrigues *et al.* (2009) in their very influential analysis divide a subset of Amazonian municipalities into one of seven categories based on a combination of the existing degree of land cleared in 2000 and the rate of deforestation over the previous three years. They choose municipalities that are ecologically naturally forested, categorizing them into different stages of a typical frontier development pattern progressing from early settlements in mostly forested areas with rapid deforestation rates, municipalities in an intermediate stage and finally to post-frontier areas that are largely cleared and, with forests depleted, experience relatively little new deforestation. They then compute median HDI values and plot them against the median level of deforestation in each of their categories for the year 2000, finding that municipalities in the agricultural frontier (high deforestation activity) enjoy high levels of human development, while HDI plummets in post-frontier areas that are highly deforested. Rodrigues *et al*. conclude from this pattern that "in net terms, people in municipalities that have cleared their forests are not better-off than people in municipalities that have not" (p. 1436). Rodrigues *et al.* themselves point out, in order to interpret this pattern as indicative of a typical dynamic process within a single municipality it is necessary to assume that those regions in the post-frontier stage are good proxies for the future of areas in pre-frontier stages, and municipalities currently in transition are good proxies for both the future of pre-frontier areas and the past of post-frontier regions. In other words, we need to assume that all municipalities in this sample are following the same dynamic path. We re-examine this assumption more closely in section 4.

Celentano *et al.* (2012) use satellite data from the Brazilian National Institute for Space Research (INPE) from 2000 to calculate the percentage of each municipality deforested, excluding protected areas, and analyse the pattern between measures of human well-being and forest cover among municipalities in the Brazilian Amazon whose original vegetation cover was at least 50% forested. Employing a spatially explicit parametric approach in a multivariate regression framework they find a statistically significant cross sectional estimate of both the 'boom-bust' pattern as well as the weaker, conditional 'boom-bust' effect.

However in our survey of evidence generated from a number of more localized longitudinal case studies (which for the most part did not have as their primary objective to examine the boom-bust hypothesis) we fail to find any boom-bust pattern. Case study evidence may not be easily generalizable, but evidence of this type is nevertheless instructive as the studies follow communities over a period of years, often following the initial settlement and land clearing periods when a classic 'bust' would be expected if there was a true boom-bust relationship. Furthermore, the lack of any evidence of 'busts' among studies conducted at the local level is remarkable, and would be quite unusual if in fact it were as much of a widespread phenomenon as the cross sectional studies seem to suggest.

For example, Sears *et al.* (2007) and Piñedo-Vasquez *et al.* (2001) studied the dynamics of the logging industry in a floodplain area of Amapá, in the Northern extreme of the Amazon, between 1991 and 1998. They document a transition in the logging technologies adopted as deforestation progressed, with a concurrent growth in off-farm labour, that ultimately maintained or improved living standards even as the most valuable timber species were exhausted (threatening a 'bust'). Similarly, Guedes *et al*. (2012) analyse household survey data from 1997 and 2005 in Altamira, Pará, a community that dates back to the early 1970s when colonizers were attracted by the government's provision of roads and infrastructure. Although the authors seem sympathetic to the concept of a boom-bust pattern, their own data (using both conventional and multidimensional measures of poverty and human well-being) shows that over the seven years covered by the study, the share of residents under the absolute poverty line dropped from 60.1% to 36.8% with a similar drop in inequality. Finally, in one of the most ambitious studies, Hall and Caviglia-Harris (2013) examine four waves of household data from six rural municipalities in the region of Ouro Preto, Rondônia, between 1996 and 2009. They find a pattern of growth followed by consolidation and stabilization, but no 'bust' in economic activity or incomes.

A sceptic might point out that Ouro Preto could be an exception to the boom-bust pattern; after all the name means 'black gold,' referring to the above-average quality of the area's rich soil. However, a similar pattern of sustained economic growth and stability is also identified by Mangabeira (2010) in his study of 7 waves of household data from the settlement of Machadinho do Oeste, Rondônia since its foundation in 1986. Soils in Machadinho are relatively low quality, but the settlement was designed to take into account watershed topography and thus (hopefully) be more ecologically sustainable. Although Mangabeira (2010) did not focus on identifying boom-bust patterns, using his data we specifically look for evidence of a 'bust' in human well-being at any time since the founding of Machadinho by examining the dynamic trends in household consumption and agricultural output per capita. Real monthly household consumption expenditures rose steadily from R$ 91 in 1999 to R$ 312 in 2008 (in 2012 R$), with *per capita* agricultural output having risen steeply from 1986 to 1999 and then steadily, but more slowly, through 2008. Housing quality also increased over time.

3. The cross sectional relationship between poverty and deforestation

The recent cross sectional evidence that has been found in Rodrigues *et al*. and Celentano *et al*. differ in their respective empirical approaches; Rodrigues *et al*. use a non-parametric plot across category averages, while Celentano *et al*. use a parameterised regression analysis. They also differ in the sample of municipalities they include, and in their measure of the extent of deforestation. However in their essence both studies investigate the relationship between measures of human well-being and the extent of deforestation in the year 2000, and so identify the boom-bust pattern in the cross sectional variation. A key assumption for interpreting cross sectional patterns as indicative of time series relationships is that all the municipalities are following a similar dynamic trajectory. The Brazilian Amazon, however, is a highly heterogeneous area with several distinct regions, each with their own history and unique economic, geographic, and climactic characteristics. To the extent that any of these (unobserved) differences are correlated with HDI (or other measures of well-being) and land clearing, this spatial heterogeneity could result in a spurious interpretation of the relationship between deforestation and development.

To investigate the spatial properties of the Rodrigues *et al*. results, we again divide the observations into three main groups; group G1 (pre-frontier municipalities), group G2 (intermediate), and group G3 (post-frontier). We then map out and colour-code the municipalities in each group by degree of HDI, and plot the resulting maps on the HDI by cleared land graph in Figure 1. The map-observations of Figure 1 clearly display the 'boom-bust' pattern, with the coloured municipalities in lesser cleared areas (pre-frontier) displaying low levels (red) of HDI, the coloured municipalities in the middle categories displaying relatively high (green) HDI, and the more cleared municipalities in the post-frontier displaying again low levels of HDI.

Figure 1 clearly illustrates the very high degree of spatial clustering of these municipalities. The municipalities with low levels of HDI in pre-frontier areas are almost exclusively clustered in the far western edge of Amazonas, and, even more striking, the municipalities responsible for the 'bust' part of the relationship - those with low levels of HDI in the post-frontier regions - are tightly clustered in the historically poor Northeastern region in and around the state of Maranhão, whose deep, generalized, and persistent poverty is arguably a phenomenon that has more to do with the secular history of colonization in the Northeast region of Brazil than it does with any particular development path within Amazonia.

We illustrate this point in Table 1, which presents the average percentile rank (within Legal Amazonia) of municipalities in Amazonas and Maranhão, for both 1980 and 2000. For example, in 1980 the average municipality in Amazonas had a higher rural poverty rates than 46% of all municipalities in Legal Amazonia. By the year 2000, they had higher poverty rates than 94% of municipalities, indicating that relative rural poverty had increased; this trend can also be seen using population-weighted averages - in 1980 the population-weighted average rural poverty rate in Amazonas was 4% less than the average for all Legal Amazonia, whereas by 2000 the rate was 113% of the regional figure. At the same time, the average percentile rank of municipalities in Maranhão have remained consistently high for poverty rates (e.g. near the top of the distribution) and near the bottom for median household income (e.g. near the bottom of the distribution). Thus while municipalities in Amazonas have fallen behind as large numbers of poor internal migrants have moved to the region, the relative poverty of Maranhão has remained virtually stagnant over the entire period. In other words, there is no sign of a 'bust' in Maranhão - there was never any height to fall from as the municipalities have persistently ranked near the bottom in human development. In sum, our analysis clearly shows that the Rodrigues *et al*. result is a spurious artefact of spatial correlation, driven primarily by the large, multifaceted (and unobserved) differences between municipalities in and around Amazonas and Maranhão states.

As a cross section analysis, the Celentano *et al.* results are subject to the same general critique as Rodrigues *et al*. In addition, in the Celentano *et al*. case the 'boom-bust' results are also significantly a function of their choice to exclude forest reserves; if regions that are generally poorer are more likely to have protected forest area, this will create a bias in favour of finding 'boom-bust' relationships. Robustness checks confirm that the Celentano *et al.* cross sectional boom-bust pattern disappears when deforestation extent is measured conventionally and state fixed effects are introduced.

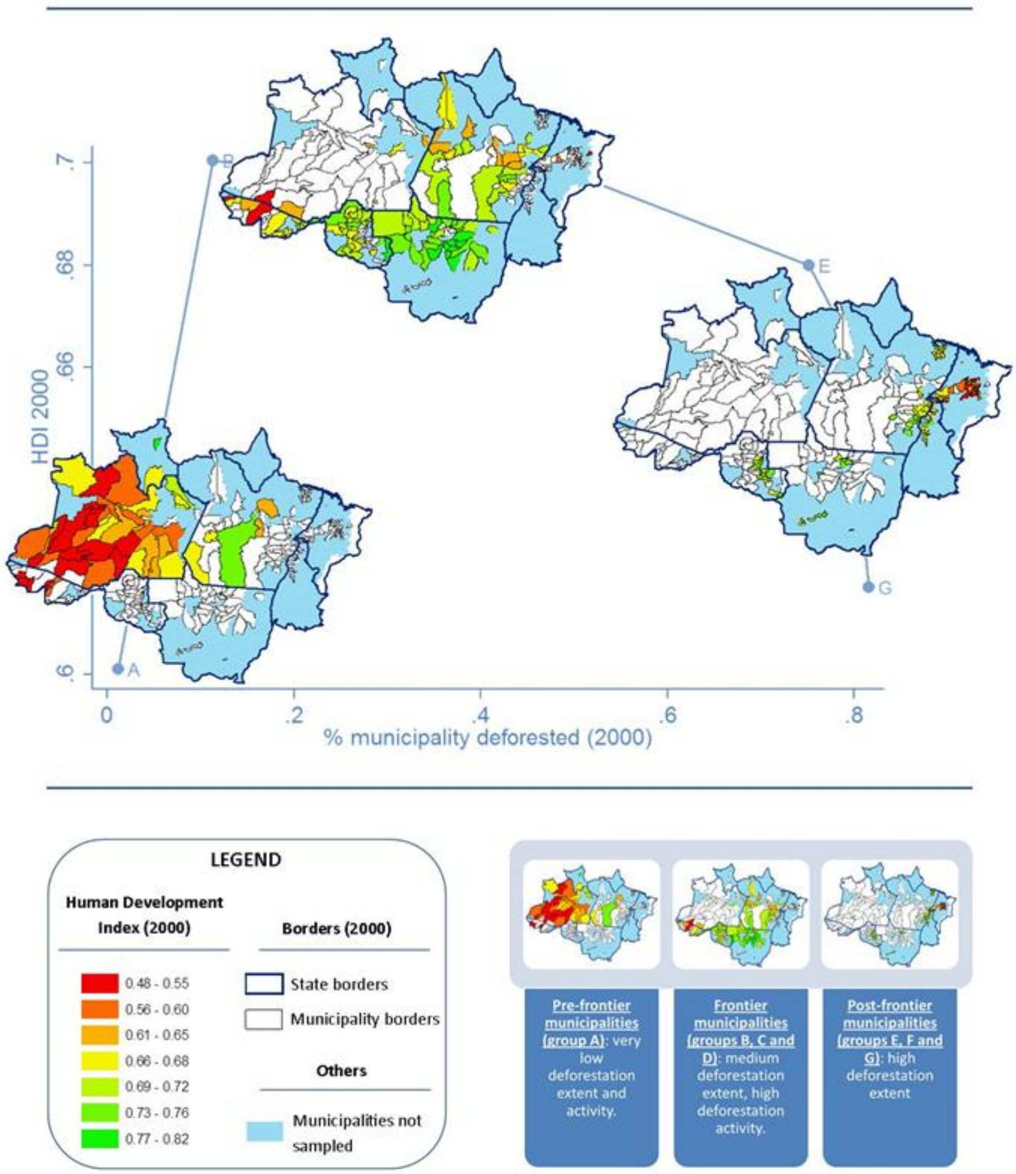


Figure 1. Spatial clusters of HDI and deforestation in the Brazilian Amazon.

4. Boom-bust patterns in the time series

We have shown that cross sectional patterns of land clearing and human well-being can be misleading when the variation across municipalities is not a convincing proxy for the variation through time within municipalities, such as in the case of the Brazilian Amazon with its high degree of historical, environmental, and economic heterogeneity. However by itself this observation is not strong evidence that boom-bust patterns do not occur. Furthermore, while none of the longitudinal case study analyses we identified show evidence of boom-bust patterns, neither can this evidence by itself rule out the possibility that this inverted-U pattern could have occurred elsewhere ('absence of evidence is not evidence of absence').

In this paper we additionally test the time series predictions of boom-bust hypothesis using two alternative datasets. Given that local political borders often shift (especially in a frontier environment with significant demographic changes) it is necessary to create aggregate units of analysis that are comparable over time (*minimum comparable areas*, or MCAs). The further back in time a dataset reaches, the larger these MCAs must be, and generally as a result the smaller the sample size available. The first dataset we use, available from the Brazilian Institute for Applied Economic Research (IPEA) and derived from the Brazilian Agricultural and Population censuses, extends back to 1970 with N=254 MCAs, and includes information on both land clearing and commonly available measures of 'well-being' such as poverty and GDP *per capita* (but does not include HDI). The second dataset, constructed from data from the United Nations Development Program (UNDP) and the Brazilian National Institute for Space Research (INPE), makes use of recently released UNDP data on Brazilian municipality-level HDI from 1991, 2000 and 2010, calculated for 2010 municipality boundaries (with N=773 MCAs), making it feasible to adopt a dynamic approach (with some additional work as described below) that is more directly comparable to the previous cross sectional literature.

While our first dataset is available directly from IPEA, to construct our second dataset we combined UNDP data on HDI with satellite-derived data on deforestation from INPE. Data is available at the current-municipality boundaries for 2000 through 2010, and for a sizeable subset of the municipalities we also obtained net change in deforestation for 1995-1999. However, for 1991 INPE has only released data at the state level. Furthermore, since 1991 the number of municipalities has increased substantially and their respective boundaries shifted. Thus in order to analyze the relationship between HDI and deforestation from 1991 to 2010, we need to both aggregate the municipality-level data to minimum comparable areas (MCAs) as well as estimate the 1991 level of deforestation for each MCA.

Specifically, we use a mapping of 1991, 2000 and 2010 municipality boundaries to MCAs from IPEA, reducing the total sample of comparable MCAs to N=447. Then using our INPE data on changes of deforestation from 1995-1999 we derive estimates of 1995 level of deforestation for the MCAs, although due to matching problems our 1991 sample then reduces to N=306 (see data Appendix), although only 4 of the omitted MCA's include municipalities from the Rodrigues *et al.* dataset. We then use the relative amount of deforestation of each MCA in a state as weights to apportion the 1991 state level INPE data across all MCAs in that state (municipalities divide and join, but states do not change). The full description of this estimation procedure is outlined in the data Appendix. Table 2 presents some summary statistics on the average values of HDI and percent deforested for the MCAs in our full sample and by category of frontier development.

Our time series analysis of potential boom-bust patterns thus takes a multi-pronged approach. First, we use the data from IPEA (N=254) to examine trends in economic measures of well-being such as poverty and GDP per capita across municipalities at different stages of land clearing, from pre-frontier, to intermediate and post-frontier, searching for evidence that well-being speeds up in the early stages of land clearing and then halts or declines in the later stages. Second, we analyse newly released time series data on HDI across Brazilian municipalities over the past 30 years (N=773) to investigate whether we observe any patterns consistent with a boom-bust phenomenon (for any reason). Finally, we more directly test whether there is evidence that land clearing could be associated with booms or busts in well-being by exploiting our newly constructed panel dataset that merges the UNDP HDI data with INPE deforestation data (N=447 and 306, as described above and in the data Appendix).

4.1. Time series analysis using the IBGE agricultural census data

For the first time series approach we exploit the fact that we have data from IPEA on poverty and GDP derived from the Brazilian IBGE agricultural and population census. Specifically, we have demographic data on urban and rural GDP and poverty rates for 1970, 1980, 1991 and 2000, and per capita GDP from 2000 to 2007. As explained above, due to changing municipality borders our unit of analysis is the Minimum Comparable Area (MCA) with a sample size of N=254.

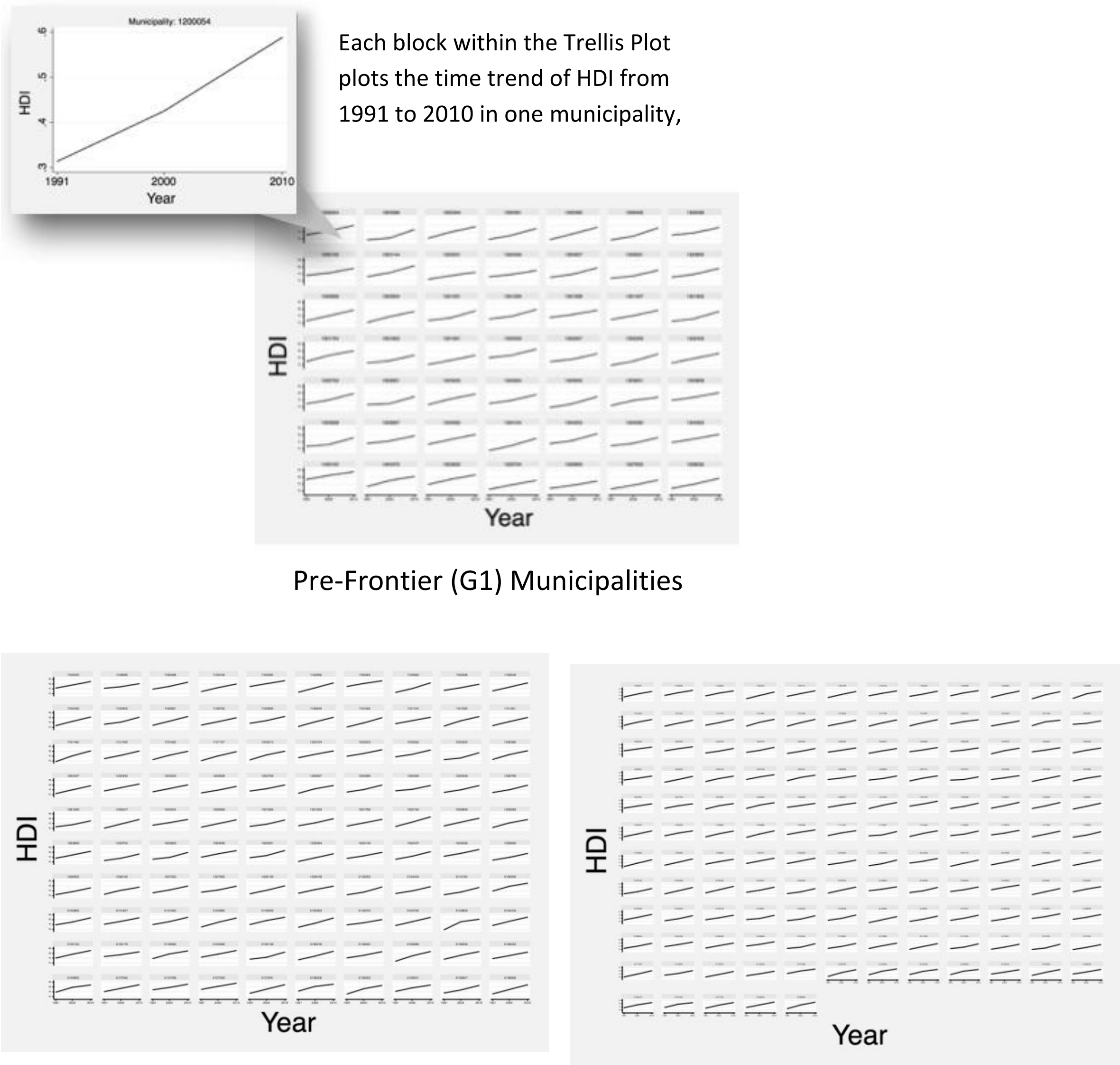
We first check to see whether we observe *any* 'boom-bust' pattern in poverty rates (for *any* reason) over this time frame in any Amazonian municipality. Of course, we should exercise caution as the boom and bust may have occurred with a different enough periodicity that we cannot detect it, and we will not detect 'busts' that occurred post-2000. However, as settlement has been progressing apace since the 1970's in the Amazon, at least some of those areas that originally boomed in the early years should have experienced their 'bust' by 2000 - in fact this is a key assumption of the previous cross sectional studies that found 'boom-bust' patterns.

We adopt an (admittedly ad-hoc) criterion for a 'boom-bust' pattern: that poverty rates must have fallen between 1980 and 1991 by at least 5 percentage points (the 'boom'), and then risen again by 2000, again by at least 5 percentage points (the 'bust'). Furthermore, to cast as wide a net as possible, we do not even insist that this 5% change be statistically significant. Of the 254 Amazonian municipalities for which we have data, using these criteria there were 9 boom-bust cycles in urban poverty and 3 boom-bust cycles of rural poverty within the sample period. One municipality experienced boom-bust patterns in both urban and rural poverty rates, so the total number of municipalities in our list of candidates is eleven. Cross referencing this list with INPE deforestation data from 2000 and the Rodrigues *et al.* categorisation of different degrees of clearing, however, we find none of the identified municipalities have any significant degree of clearing (the highest is 7% of area deforested). Two out of eleven were categorised in the Rodrigues *et al*. dataset as being relatively uncleared in 2000 (at the pre-frontier stage), respectively, with the rest uncategorised. We conclude that none of these seem likely candidates for a convincing boom-bust story.

Next we examine the pre- and post- 2000 economic performance of municipalities categorised as highly cleared, post-frontier in the year 2000 by Rodrigues *et al*. These are the municipalities that are most likely to be experiencing the 'bust' phase, so we search for evidence that economic growth, measured by urban and rural GDP per capita, is stagnating in the post-2000 period and boomed sometime in the pre-2000 period. We compare urban and rural GDP per capita growth rates of this post-frontier group to the entire Rodrigues *et al*. sample, to all Legal Amazonia, and to all Brazil in the periods 1970-1980, 1980-1991, 1991-2000, and 2000-2007. The results of this exercise are presented in Table 3. The post-frontier group of municipalities grew almost exactly as much in 2000-2007 as the rest of the Amazon, and more than for all of Brazil. This was an even more impressive achievement given that this region has underperformed economically for decades. Furthermore, there is no evidence of any boom in the pre-2000 period; until very recently these municipalities have had worse economic outcomes than the rest of Brazil, and the rest of the Amazon, since the 1970s.

4.2. Time series analysis using the UNDP Human Development Index (HDI) data

As discussed above, in our second dataset we have comparable UNDP data on HDI across 773 municipalities in the Legal Amazon for 1991, 2000 and 2010. As we did with the IPEA data, we first examine the data for evidence of a 'boom-bust' pattern in HDI for any municipality, for any reason. We use a subset of the original UNDP data that correspond to the Rodrigues analysis, and divide the Rodrigues *et al*. sample of municipalities into three groups according to their degree of frontier development. Relatively uncleared municipalities in the pre-frontier stage are categorized as group G1 (Rodrigues category A), those in the intermediate stages are group G2 (Rodrigues categories B-D), and those in the highly cleared, post-frontier stages are categorized as group G3 (Rodrigues categories E-G). Figure 2 presents Trellis Plots of the trend lines in HDI from 1991 to 2010 for all municipalities within groups G1, G2 and G3. As illustrated by the blow-up cut-out, each block within a Trellis Plot plots the time trend of HDI in one municipality, with HDI on the vertical axis and time on the horizontal axis; thus to read the remaining Trellis Plots it is only necessary to note the slope of the lines. As can be easily seen by observing the monotonically upwards slope of all plot lines, we find none of municipalities displaying any kind of boom-bust inverted-U trend; on the contrary, and quite remarkably, since 1991 HDI has been uniformly trending upwards across *all* municipalities. Furthermore, there are no clear systematic differences in this upward trend between municipalities categorized by Rodrigues *et al.* as in different stages of frontier development.



Intermediate (G2) Municipalities
Post-Frontier (G3) Municipalities

Figure 2: Trellis Plots of trends in HDI of Pre-Frontier (G1), Intermediate (G2), and Post-Frontier (G3) Municipalities, 1991-2010.

Although it is clear from the Trellis Plots from Figure 2 that 'boom-bust' patterns in HDI (for any reason) are not a feature during our sample period, it is interesting to more systematically explore what time series properties we *do* observe. In particular, an interesting question is the extent to which HDI across municipalities displays convergence, where regions with lower HDI levels experience faster increases than those with higher initial levels. We can simply model this process as:

(1) $\Delta HDI_{it} = a + bHDI_{t-1} + e_{it}$

If there is convergence then we should observe $\hat{b}$ negative and statistically significant.

Table 4 presents the results of just such an analysis of the change in HDI as a function of the initial level of HDI. We use the full UNDP dataset of 773 municipalities as detailed above. Column (1) presents the results of simple regression of the change in HDI on its lagged level over the sample period, controlling for common year effects with a dummy for 2010; we thus have two time periods and a sample size of 1546. The lagged HDI term is negative and highly statistically significant, indicating a strong tendency towards convergence, and the year dummy for 2010 is positive, indicating that on average HDI increased more between 2000-2010 than between 1991-2000 (though the more recent period was also 1 year longer). In column (2) we additionally introduce dummy variables for the sub-sample of municipalities categorized (in 2000) as in groups G1 (pre-frontier), G2 (intermediate) and G3 (post-frontier); municipalities not in the Rodrigues sample are the control group. Contrary to prediction from Boom-Bust theory, the coefficient on pre-frontier municipalities (G1) is negative and significant, indicating that the change in HDI for this group was actually lower than average. Conversely, the coefficient on the post-frontier group (G3) is positive and significant, contrary to any 'bust' in human development. In regression (3) we limit the sample to only those municipalities in the Rodrigues *et al.* sample (thus the sample size drops to 572) and find that the average increase in HDI higher, and the tendency towards convergence is somewhat stronger, than in the general sample.

Finally, because Rodrigues et al. classified the municipalities in 2000, it is difficult to predict what the change in HDI should be over the full sample period. Thus in Table 4 column (4) we restrict the sample to 2000-2010 only and drop observations from 1991, so that we model the change from 2000-2010 as a function of the level of HDI in 2000, with a sample size of 773. Thus in column 4 we have only cross sectional variation in the change as a function of initial levels. In this case the boom-bust hypothesis would unambiguously predict that HDI would increase faster in municipalities in the pre-frontier category (G1), and either decrease (for strong boom-bust) or increase more slowly (for a weaker boom-bust *effect*) in the post-frontier (G3) municipalities. However, as the results from table 4, column (4) illustrate, the coefficient on the G1 dummy variable is negative and significant, the opposite of the boom-bust prediction, while neither the G2 nor G3 dummies are statistically different from zero.

4.3. Time series analysis using merged INPE deforestation and UNDP HDI panel data

As discussed above, we deal with issues of comparability and aggregation between spatial units by using 447 common minimum comparable areas (MCAs) for 1991-2010 and 306 MCAs in 1991 (see the data appendix for a detailed description of the estimating procedure.). Having constructed a panel data set on deforestation and HDI we can directly test for a non-linear relationship between HDI and the extent of deforestation in the time series by estimating a panel fixed effects (or *within*) regression controlling for both the level of deforestation as well as its squared term:

(2) $HDI_{it} = b_1 per\_def + b_2 \left(per\_def\right)^2 + a_i + d_t + h_{it}$

where *per_def* is the proportion of a MCA deforested, δ_t is a year effect, and α_i is an unobserved, time-invariant MCA-specific effect. Hausman tests reject random effects (RE) estimation ($p<0.001$) so a fixed effects (FE) functional form is adopted. If a boom-bust pattern exists, it should manifest as a negative coefficient estimate on the squared deforestation variable, $\hat{b}_2$. By controlling for MCA fixed effects we capture all time-invariant characteristics of each MCA and ensure that we observe only the relationship between HDI and deforestation within MCA's over time.

The results of the fixed effects analysis are presented in Table 5. In column (5) we present the baseline model controlling only for extent of deforestation, which is positive and statistically significant. In column (6) we additionally control for the square of deforestation, but contrary to the boom-bust prediction we find the squared term to be *positive* and significant. In column (7) we additionally control for whether an MCA was in (or encompasses municipalities that were in) the Rodrigues *et al.* sample by interacting our key variables, *per_def* and *per_def_sq* with a dummy for inclusion in Rodrigues *et al.*. These are the regions most likely to display a boom-bust pattern, if one exists. We find that although the interacted squared term now displays the boom-bust negative sign, it is not statistically different from zero.

Finally, in Table 5 column (8) we interact *per_def* and *per_def_sq* with dummies for MCA's in a (or with constituent municipalities in a) pre-frontier stage (G1), intermediate stage (G2), or post-frontier stage (G3) in 2000. Boom-bust theory would predict that we would not observe a boom-bust pattern in those MCAs that were pre-frontier in 2000, but perhaps in those that were in intermediate stages, and that an inverted-U effect would be most likely and most pronounced in the post-frontier MCAs, who are presumably more likely to be experiencing a decrease (or smaller increase) in HDI post-2000. However, we observe none of these predictions. None of the squared terms are statistically significantly different from zero. In all, the results are actually more consistent with a positive time series correlation between HDI and deforestation, especially in those areas that are in their post-frontier stage of development.

The results from our analyses of GDP and poverty census data, HDI time trends, and fixed effects panel data estimation of deforestation and HDI all strongly and robustly point to the same conclusion: there is no time series evidence of boom-bust patterns in either incomes or HDI, in relation to deforestation or anything else. Human well-being in the Amazon has been steadily increasing over the last 25 years (at least) and the rate of this increase is a function of both convergence dynamics and a host of other causal factors that we have not analyzed here. It is important to strongly point out that although some of our results from the panel data analysis may seem to suggest that increased deforestation is correlated with *increases* in human well-being, the analysis is not designed to draw any causal conclusions to that end. Our results robustly show that the time series patterns are not consistent with the boom-bust relationships found in the cross-sectional patterns, however we cannot say what the underlying drivers of human well-being are (beyond that they display a tendency towards convergence), or even if deforestation is one of them.

5. Discussion

Accurate information about the economic and social impacts of deforestation is critical for the effective design of environmental and development policy. For example, recently in Brazil the heated debate over the Forest Code has had repercussions that will significantly shape the future trajectory of land use in the region. One hypothesis that has been very influential in this regard is the idea that there could be a 'boom-bust' relationship between human well-being and deforestation, with early high rates of deforestation fuelling a 'boom' and later, depleted forest stocks leading to a 'bust' that leaves human well-being as poorly off as it was initially.

While this idea has recently seen some empirical support in cross-sectional analyses, longitudinal case studies have repeatedly failed to find evidence of post-clearing 'busts.' In this study we analyze data covering the entire Brazilian Amazon since the 1970s and construct a new panel dataset on HDI and deforestation from 1991-2010 in order to search for time series evidence of boom-bust patterns. We find no evidence that any boom-bust in HDI has occurred in any forested municipality in the Brazilian Amazon over the past 30 years. To the contrary, we show that municipalities most likely to be in the ‘bust’ phase of the cycle, categorised as ‘post-frontier’ by Rodrigues *et al*. themselves, have improved their measures of HDI at least as much as the rest of the region, despite having been economic underperformers since the 1970s. Furthermore, a fixed effects panel data analysis of the relationship between HDI and deforestation controlling for time-invariant fixed effects fails to find any evidence of *within* time-series inverted-U patterns that would be consistent with deforestation-moderated socio-economic booms and busts.

Finally, in addition to our own time series investigation, we have revisited the cross sectional studies in an attempt to find an encompassing explanation of why researchers might find no inverted-U pattern in the time series, but observe one in the cross-section. We show that the 'boom-bust' pattern observed in these studies is quite fragile and most likely a spurious artefact of spatial correlation, driven primarily by the large, multifaceted (and unobserved) differences between municipalities in Amazonas and Maranhão states.

In sum, we conclude that there is no robust evidence in either the cross section or the time series data of any ‘boom-bust’ patterns of development in the Brazilian Amazon. This should be very good news indeed for environmentalists and development economists alike. If the ‘boom and bust’ hypothesis were true, it would imply that settlements would need to continually expand into previously uncleared regions in an (ultimately futile) effort to sustain economic progress. On the other hand, if human well-being can continue to improve even after a region has experienced significant settlement and land clearing, as our analysis suggests, there is less pressure to open up new virgin forests and it should be easier to protect and preserve these ecologically valuable areas. Our result is an important finding for policy makers as well; if attention is diverted (for example, due to belief in an inevitable 'boom-bust' dynamic) from considering how areas that have already been cleared could better be harnessed to provide economic benefits for the local population, many opportunities to improve economic conditions may be lost and more pressure will ultimately be brought to bear on virgin forests. Further research is surely needed into the complex dynamic relationship between land use and human well-being.

Tables

Table 1: Percentile rank* of municipalities within Legal Amazonia, average by state

	State of Amazonas		State of Maranhão	
	1980	**2000**	**1980**	**2000**
Rural poverty Rate	46	94	73	68
Urban poverty Rate	38	60	71	69
Rural median household income	63	19	26	32
Urban median household income	61	41	30	31

Data Source: IPEA

* percentile rank is the percentage of scores that fall below a given score.

Table 2: Summary of mean HDI and percent of deforestation (p_def) of MCAs, by year and stage of frontier development

	Whole sample $N_{2000,2010}$=447 N_{1991}=304		**Pre-Frontier** $N_{2000,2010}$=44 N_{1991}=42		**Intermediate** $N_{2000,2010}$=56 N_{1991}=54		**Post-Frontier** $N_{200,2010}$=87 N_{1991}=86	
year	HDI	p_def	HDI	p_def	HDI	p_def	HDI	p_def
1991	.327	21.4	.293	1.5	.339	13.9	.322	46.5
2000	.453	21.6	.398	1.7	.469	21.8	.461	67.0
2010	.613	28.5	.558	2.7	.630	30.6	.623	74.5

Data Source: UNDP and INPE

Table 3: Summary of urban and rural per capita GDP growth rates for selected groups of municipalities.

	Percent average growth of urban GDP *per capita*			**Percent average growth of rural GDP *per capita***			**Percent average growth of GDP *per capita* (urban+rural)**
	1970-1980	**1980-1991**	**1991-2000**	**1970-1980**	**1980-1991**	**1991-2000**	**2000 – 2007**
All Brazil	132.2	17.3	78.3	75.3	-52.2	36.5	23.9 *
All Legal Amazon	140.0	38.9	80.5	83.2	-53.5	8.7	33.7
Rodrigues *et al*. sample	153.2	39.1	78.3	86.3	-60.0	9.1	34.6
Post-frontier (2000) sample	123.1	33.2	62.3	70.3	-59.6	7.5	34.7

Data Source: data from IPEA, derived from the Brazilian statistical agency (IBGE).
* Based on estimates of population for municipalities with more than 170,000 inhabitants.

Table 4: Convergence Dynamics in HDI, Dependent Variable= Change of HDI

	(1) Full Sample: 1991-2010	(2) Full Sample: 1991-2010	(3) Rodrigues-only Sample: 1991-2010	(4) Full Sample: 2000-2010
Lag(HDI)	-0.211***	-0.223***	-0.241***	-0.294***
	(0.010)	(0.011)	(0.019)	(0.012)
Year=2010	0.056***	0.057***	0.061***	
	(0.002)	(0.002)	(0.004)	
G1		-0.028***	-0.031***	-0.020***
		(0.003)	(0.004)	(0.004)
G2		0.002		0.002
		(0.003)		(0.003)
G3		0.005**	0.002	0.002
		(0.002)	(0.003)	(0.002)
Constant	0.205***	0.209***	0.217***	0.298***
	(0.004)	(0.004)	(0.008)	(0.006)
R^2	0.26	0.29	0.34	0.44
Municipalities	773	773	286	773
Total Obs.	1,546	1,546	572	773

Data Source: UNDP

Please Note: robust standard errors clustered by municipality in parentheses

Table 5: Fixed Effects Panel Estimation of the Relationship between HDI and Deforestation, 1991-2010, Dependent variable = HDI

	(5)	(6)	(7)	(8)
per_def	0.051***	0.013	0.010	0.002
	(0.009)	(0.021)	(0.034)	(0.033)
per_def_sq		0.041**	0.015	0.025
		(0.020)	(0.044)	(0.042)
per_def* Rodrigues Sample			0.104**	
			(0.052)	
per_def_sq* Rodrigues Sample			-0.039	
			(0.054)	
per_def*G1				0.200
				(0.357)
per_def*G2				0.032
				(0.061)
per_def*G3				0.162***
				(0.061)
per_def_sq*G1				-1.805
				(1.458)
per_def_sq*G2				0.039
				(0.069)
per_def_sq*G3				-0.091
				(0.057)
Year=2000	0.121***	0.121***	0.119***	0.119***
	(0.002)	(0.002)	(0.002)	(0.002)
Year=2010	0.278***	0.278***	0.276***	0.276***
	(0.003)	(0.003)	(0.003)	(0.003)
Constant	0.321***	0.324***	0.317***	0.315***
	(0.002)	(0.003)	(0.003)	(0.004)
Fixed Effects	yes	yes	yes	yes
Rho	0.8944	0.8951	.9023	0.9077
R^2	0.9691	0.9693	0.9699	0.9702
MCAs	447	447	447	447
Total Obs.	1,198	1,198	1,198	1,198

Data Source: UNDP and INPE

Please Note: MCAs are Minimum Comparable Areas. Robust standard errors clustered by MCA in parentheses. Rho is the percent of the variance due to differences across MCAs (the intraclass correlation)

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Data Appendix

In this section we provide more detail on how we constructed a new panel dataset on HDI and deforestation extent in 1991, 2000 and 2010.

There were two primary difficulties when building the panel dataset. First, because new Brazilian municipalities are created almost every year it is not possible to compare them over time in a consistent way. For this purpose it is necessary to aggregate neighbor municipalities to get *minimum comparable areas* (MCAs). Ipeadata provides minimum comparable areas for inter-census periods from 1872 to 2010.

The data on HDI is publicly provided by the UNDP at 2010 municipality boundaries. We combined HDI data into minimum comparable areas for the period 1991-2010 (MCA1991-2010) using population weights.

INPE data on deforestation from satellite images is publicly available at current-year municipality boundaries from 2000 onwards. In addition the authors had INPE municipality-level data on annual change in deforestation from 1995-1999. However no municipality-level deforestation data is available for 1991; for years before 1995, INPE only provide data at state level.

A second problem was thus to estimate 1991 deforestation data. Using the minimum comparable areas from 1991 to 2000, (MCA1991-2000) the change-in-deforestation data was converted to extent of deforestation in 1995 after deleting some observations that, according to our evalutation, did not match well with the data on extent of deforestation starting in 2000. This reduced the sample from 447 to 306 MCAs, but only 4 of the omitted MCAs included municipalities from the Rodrigues *et al.* sample so this only minimally affected the analysis. We then estimated 1991 levels of deforestation by distributing the state level deforestation across minimum comparable areas (MCA1991-2000) in 1991 by the MCA share of deforestation in 1995.

The 1991 minimum comparable areas (MCA1991-2000) level deforestation estimates thus obtained appear sensible and in line with our expectations. Nevertheless there are three key assumptions behind our procedure: (1) that we have been able to match the INPE change-in-deforestation data sufficiently well to the main INPE data set; (2) that the distribution of 1995 MCA deforestation derived from this merging is strongly correlated with the actual distribution across MCAs of deforestation in 1991; and that (c) deforestation rates in the municipalities that we dropped due to merging difficulties was not significantly and systematically different from municipalities that we retained.