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Sustainability in the tropics: does a boom in deforestation lead to a bust in development?

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Abstract. We revisit the hypothesis tested in Rodrigues *et al.* (2009) that the process of human development in Amazonia follows a boom-and-bust (inverted U) pattern. We show that the 'boom-bust' pattern that Rodrigues *et al*. report 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. We confirm these (non-) results in the time series data; there is no 'smoking gun' dynamic boom and bust associated with land clearing in any municipality data from 1980 to 2000. Furthermore, the past economic performance of municipalities categorised as 'post-frontier' by Rodrigues *et al*. themselves are shown to have been economic underperformers since the 1970s, and if anything they have improved their relative economic standing in the years since 2000. In sum, we find no evidence in either the cross section or the time series data of any 'boom-bust' patterns of development in the Brazilian Amazon.

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. In an influential paper, Rodrigues *et al*. (2009) suggest that there is a 'boom and bust' pattern in the Amazonian frontier; i.e. that human well being does indeed improve ('boom') as land is cleared and agriculture production increases, but that this benefit is reversed in a 'bust' as land is exhausted. Indeed, this hypothesis of an inverted-U pattern of development in the tropics has been suggested by a number of researchers (see, for example, Moran (1982), Fearnside (1986), Schneider *et al.* (2002)) and, if true, suggests that economic development in the region may ultimately be a lose-lose outcome, with environmental costs and no economic benefits.

Rodrigues et. al. (2009) investigate the extent to which deforestation in this region has been associated with changes in human well being, as measured by the Human Development Index (HDI) which aggregates data on income, life expectancy, and literacy. More specifically, they examine HDI indicators for the year 2000 in a cross section of 286 municipalities categorized into seven classes corresponding to degree of cleared land and recent clearing activities (categories A-G corresponding to "pre-frontier to "post-frontier"). Their analysis suggests an inverted-U relationship as the process of frontier development progresses: newly deforested regions (their category A) experience a 'boom' during which HDI climbs from initially low levels; this growth in HDI stabilizes as settlement matures (categories B-D), until the municipalities reach a post-frontier stage (categories E-G). In these later stages of settlement, municipalities have previously cleared much of their land so experience relatively low rates of recent deforestation, and with land exhausted and productivity plummeting, the level of HDI falls back to levels comparable with initial (poor) conditions in pre-frontier areas. The authors conclude that,

> "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)

In this paper we revisit the Rodrigues *et al*. analysis and argue that the data are not consistent with an interpretation of 'boom-bust' patterns in the Amazon. Specifically, we show that their observed inverted-U pattern is an 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. If we examine the relationship between clearing and HDI *within* broad categories, we do not observe patterns consistent with 'boom and bust.' We further show that nonlinearities in the cross sectional correlations between clearing and HDI are, at best, consistent with 'booms' but not with 'busts.' Finally, we examine the time series data and find no evidence of previous 'booms', or subsequent 'busts,' among municipalities categorised by Rodrigues *et al*. as post-frontier. Indeed, out of 254 AMC municipalities in the Amazon for which we have consistent time series data from 1980-2000, we find none that display an inverted-U pattern in poverty rates through time that might be consistent with the 'boom-bust' hypothesis.

The paper proceeds as follows. In section 2 we broadly describe the construction of the Rodrigues *et al*. data set, which we replicate, and reproduce their 'boom and bust' results. In section 3 we then

re-examine their analysis and explore the spatial, disaggregated, and time series relationships between HDI and clearing. Section 4 discusses our results and suggests some policy-relevant interpretations.

2. The Rodrigues *et al*. boom and bust pattern

Rodrigues *et al*. (2009) categorise a subset of Amazonian municipalities into one of seven groups, A-G, based on a combination of the existing degree of land cleared in 2000 and the rate of deforestation over the previous three years (see their associated Supplement for specifics). They choose municipalities that are ecologically naturally forested and that represent stages of what they consider to be a 'typical' frontier development pattern; progressing from early settlements in mostly forested areas with rapid deforestation rates (category A), to post-frontier areas that are largely cleared and, with forests depleted, experience relatively little new deforestation (category G), with categories B-F representing intermediate stages. As this categorization is non-inclusive, only 286 out of 756 total Amazonian municipalities are included in their analysis. Figure 1 below, reproduced from Rodrigues et al. (2009), illustrates and summarises their approach.

Figure 1: Rodrigues *et al*. categorisation of municipalities from Pre-frontier to Post-frontier

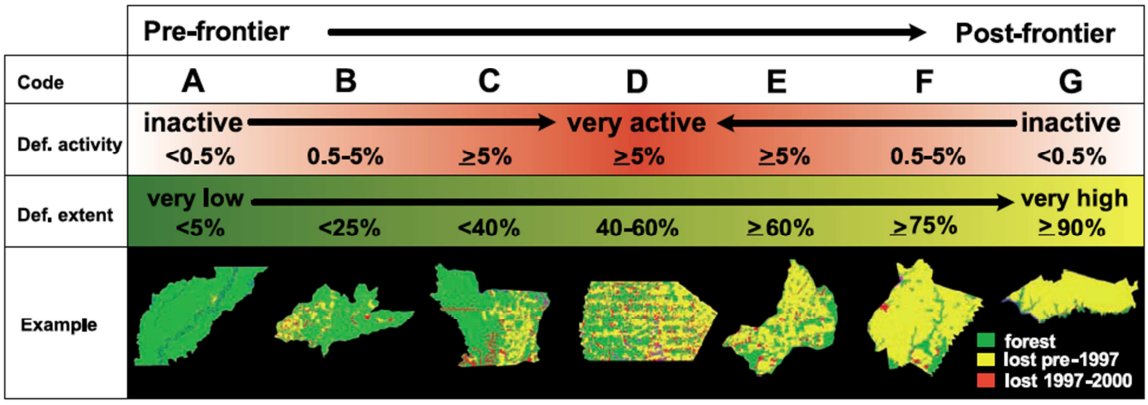

Fig. 1. Definition of frontier classes A to G according to recent deforestation activity (percentage of municipality area deforested between 1997 and 2000) and deforestation extent (percentage of the original forest that had been lost by 2000). A representative municipality is mapped as an example of each class (spatial scale variable) (*5*, *13*).

Source: reproduced from Rodrigues et al. (2009), p. 1435

For each category A-G Rodrigues *et al.* compute median Human Development Index (HDI) value and plot them against the level of deforestation. Following their methodology (outlined in the Rodrigues *et al.* (2009) Supplement), we recreate their data set and replicate their primary results (Figure 2), which indeed seem to show that municipalities in the agricultural frontier (high deforestation activity) tend to see a boom in development, while HDI plummets in post-frontier areas that are highly deforested.

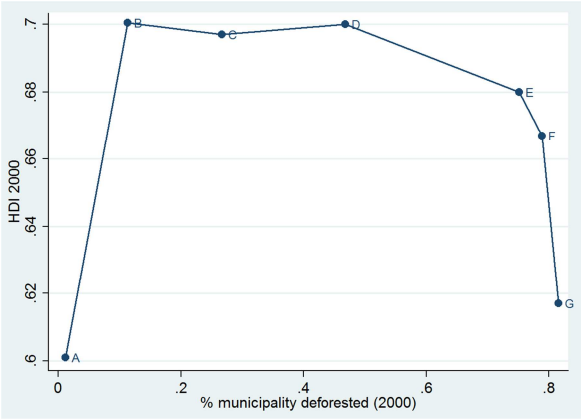

Figure 2. Empirical representation of the boom-and-bust hypothesis, reproduced using the methods and data of Rodrigues *et. al.* (2009).

The results are roughly maintained when the three components of HDI, income, education, and longevity, as well as the gross value of production of timber, cattle, and crops are examined separately (see Rodrigues *et al*. 2009). 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). In the next several subsections we will revisit this conclusion.

3. Revisiting the 'boom-bust' hypothesis

3a. The spatial distribution of HDI and land clearing

The relationship reproduced in Figure 2 is a cross sectional correlation among a subset of all Amazonian municipalities. As 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 category F or G are good proxies for the future of areas in category A or B, and that categories C, D, and E are good proxies for the interim conditions in the transition. In other words, we need to assume that all municipalities in this sample are following the same dynamic path.

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 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 divide the observations into three main groups; category A, categories B-D, and categories E-G. 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 2. The map-observations of Figure 3 clearly display the 'boom-bust' pattern, with the coloured municipalities in lesser cleared areas (category A) displaying low levels (red) of HDI, the coloured municipalities in the middle categories displaying relatively high (green) HDI, and the more cleared municipalities in categories E-G displaying again low levels of HDI.

Figure 3 clearly illustrates the very high degree of spatial clustering of these municipalities. The municipalities with low levels of HDI in category A 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 categories E,F and G - are tightly clustered in the historically poor North-eastern 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 then it does with any particular development path within Amazonia.

We illustrate this point in Table 1, which presents the average relative percentile rank of rural and urban median household income and poverty among municipalities in Amazonas and Maranhão compared to all other municipalities in Legal Amazonia in both 1980 and 2000. The figures show that 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' - there was never any height to fall from as the municipalities have persistently ranked near the bottom in human development.

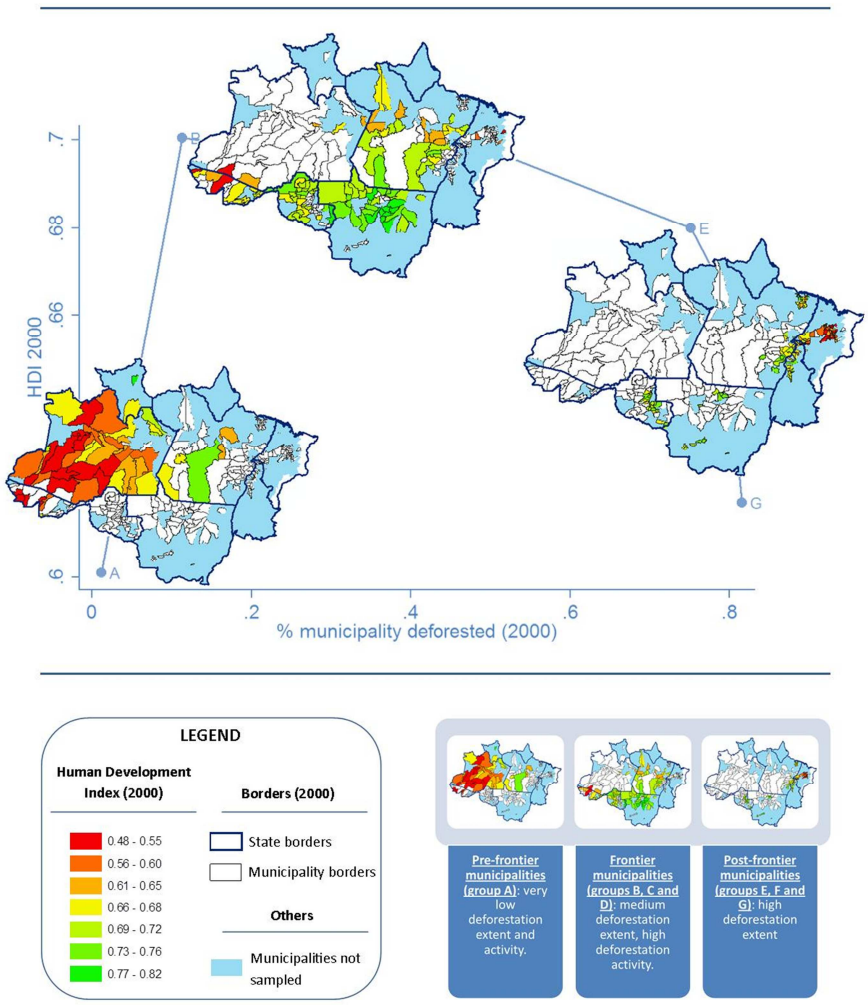

Figure 3. Spatial clusters of HDI and deforestation in the Brazilian Amazon.

Table 1: Average percentile rank of municipalities within Legal Amazonia (percent below).

	Amazonas		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

Source: IPEA

3b. The within-group relationship between HDI and land clearing

In addition to the implications for differences between the median values of broad categories of municipalities, the 'boom-bust' theory also gives rise to some additional testable auxiliary hypotheses that the Rodrigues *et al*. analysis fails to investigate. In particular, if the boom-bust theory is correct, we should not only detect the inverted U pattern *between* category medians, but we would also expect that *within* each group, as clearing increased, HDI would (a) increase in the pre-frontier areas; (b) flatten out in the intermediate areas; and (c) fall in categories post-frontier areas. We test this auxiliary hypothesis by running the regression:

equation 1:

$$HDI_{i,00} = \beta_1\left(pdef_{i,97} * G1_i\right) + \beta_2\left(pdef_{i,97} * G2_i\right) + \beta_3\left(pdef_{i,97} * G3_i\right) + \alpha_1 G1_i + \alpha_2 G2_i + \alpha_3 G3_i + \varepsilon_i$$

where G1, G2, and G3 are dummy variables corresponding to pre-frontier, intermediate, and post frontier municipalities, respectively. We further test whether $\beta_1 = \beta_2$ and whether $\beta_2 = \beta_3$; if the 'boom-bust' theory is correct, we expect, $\beta_1 > \beta_2$, $\beta_2 > \beta_3$, and for these differences to be statistically significant. The results of this exercise are presented in Table 2. In column (1) we assign pre-frontier status to category A; intermediate status to categories B, C, and D; and post-frontier status to categories E, F and G. In columns (2)-(4) we test the robustness of the results to changing these assignments.

In all regressions presented in Table 2 we find that within the pre-frontier municipalities (categorised either as A or A and B), the relationship between HDI and percentage cleared is indeed positive; the more cleared land the higher is HDI and this is statistically significant. Within the intermediate-stage municipalities the relationship is positive in regression (1) and negative in regressions (2), (3), and (4), but none of these is statistically significant. Within the post-frontier municipalities in both regressions (1) and (2) the relationship between cleared land and HDI is indeed negative, but not statistically significantly different from zero. Furthermore, in both these regressions we reject the

hypothesis that $\beta_{Intermediate} = \beta_{Post-Frontier}$, in other words we find no evidence that the relationship between HDI and deforestation extent is different in intermediate-stage municipalities and post-frontier municipalities.

In Table 2, regression (3) we disaggregate our 'post frontier' municipalities into category F and G. If the boom bust theory is correct, the relationship between HDI and deforestation extent should be negative (or at best flat) within both, with the 'bust' perhaps steeper in the most cleared regions categorised in G. Indeed, we find a sharply negative (cross sectional) correlation between HDI and deforestation extent among category G municipalities. However, among the category F municipalities the relationship is *positive*, highly statistically significant, and statistically different from the intermediate-stage municipalities.

Furthermore, the relationship among category G municipalities is not itself uniform throughout the sample, but again - as with the median results - driven by the (arguably time invariant) differences between broad categories of municipalities. Figure 4 illustrates this graphically; among post-frontier ("G" category) municipalities, those with low-HDI are all clustered together in the historically poor state of Maranhão bordering the Northeast region. In table 2 column (4) we split the sample of G-category municipalities in half by the percent cleared area, denoting these two halves of the split sample as G^1 and G^2. The results are presented in column (4); we see that the relationship between HDI and deforestation extent *within* each of these split-samples is statistically equivalent to each other - and not statistically significantly different from zero. Overall, across all the regressions in Table 2, instead of finding a relatively uniform and increasingly negative relationship between HDI and deforestation extent among municipalities approaching and in the post-frontier stage, for slight changes in the sample we find inconsistent estimates lurching from negative but insignificant, to positive and significant, and back to (slightly) negative and statistically insignificant.

Thus, in sum, we find some (cross sectional) evidence in consistent with a 'boom,' but no robust statistical evidence of a 'bust' within the sample. Care must be taken not to over-interpret *any* of these results as indicative of any causal relationship between HDI and deforestation extent, however; all of these relationships are still cross sectional and potentially driven by same spatial clustering and omitted variable biases discussed above. Our results nevertheless do show that, in the cross section, the within-sample pattern of correlations are not consistent with the boom-bust hypothesis of deforestation and development.

Finally, if we are willing to empirically interpret the 'boom bust' hypothesis slightly more widely than Rodrigues *et al.*, we can investigate the extent to which their cross sectional results generalize to the entire sample of Legal Amazonian municipalities in 2000. As mentioned above, Rodrigues *et al.* choose a subsample of 286 of a possible 756 municipalities in legal Amazonia that fit into their specific categorization. Figure 5 shows two scatterplots between HDI in 2000 and the percentage of municipality area that is deforested land in 1997, the far left graph includes only the subsample observations in the Rodrigues *et al*. analysis, while the far right graph includes the entire sample. Although it is much less pronounced than in the plot of group medians, the scatterplot of the Rodrigues *et al*. data still displays some of the cross sectional pattern they interpret as evidence of a dynamic 'boom-bust' trajectory. However, once we include the full dataset of municipalities even the cross section pattern is much less clear.

Table 2: Dep. variable= HDI in 2000

	(1)	(2)	(3)	(4)
$pdef_{97}$*(A)	2.89* (3.01)			
$pdef_{97}$*(BCD)	0.069 (1.61)			
$pdef_{97}$*(EFG)	-0.016 (0.490)			
$pdef_{97}$*(AB)		0.862* (6.81)	0.862* (6.78)	0.862* (6.76)
$pdef_{97}$*(CDE)		-0.488 (-1.74)	-0.488 (-1.73)	-0.488 (-1.73)
$pdef_{97}$*(FG)		-0.050 (-0.68)		
$pdef_{97}$*(F)			0.121* (3.71)	0.121* (3.69)
$pdef_{97}$*(G)			-0.214* (-7.01)	
$pdef_{97}$*(G^1)				-0.035 (-0.42)
$pdef_{97}$*(G^2)				-0.024 (-0.21)
R-sq	0.220	0.237	0.333	0.350
no obs	286	286	286	286
group dummies	yes	yes	yes	yes
p-value $\beta_A = \beta_{BCD}$	.004			
p-value $\beta_{BCD} = \beta_{EFG}$	.119			
p-value $\beta_{AB} = \beta_{CDE}$		0.000	0.000	0.000
p-value $\beta_{CDE} = \beta_{FG}$		0.602	0.000	0.000
p-value $\beta_F = \beta_G$			0.000	.081
p-value $\beta_{G^1} = \beta_{G^2}$				0.942

Note: robust t-statistics in parentheses, *significant at 1%,
** significant at 5%

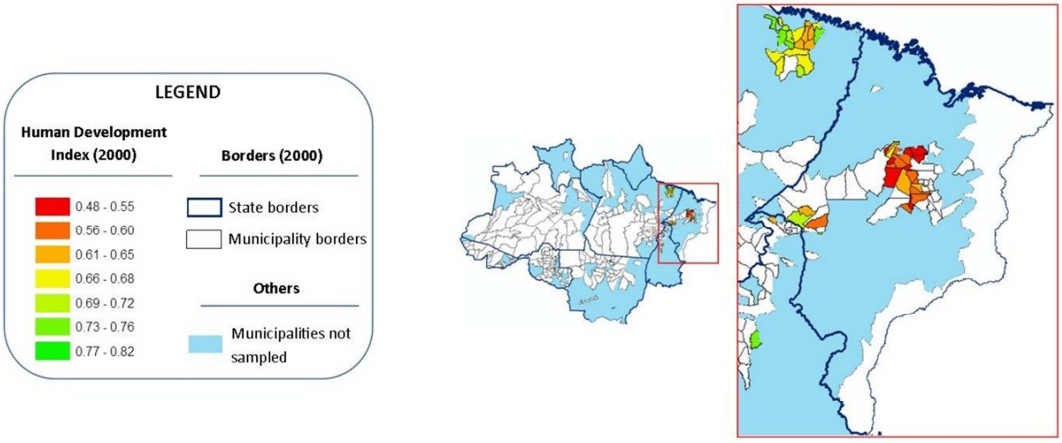

Figure 4. Post-Frontier municipalities (group G of Rodrigues *et. al.*, 2009).

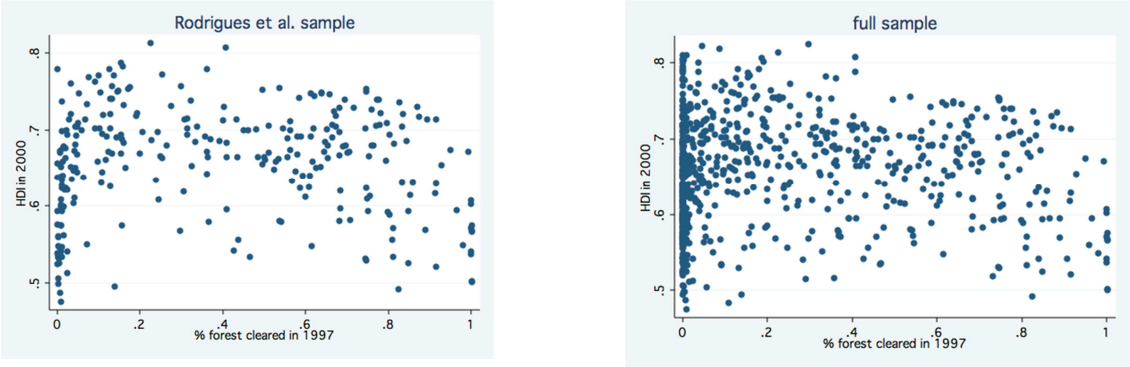

Figure 5: the relationship between HDI and percentage cleared forest in the Rodrigues *et al*. sample of 286 municipalities and in the full sample of 756 municipalities

3c. Dynamic analysis using time series data

The 'boom and bust' hypothesis ultimately is a theory about the pattern of development through time within a particular region. As we have discussed above, inferring a time series relationship from a cross-sectional analysis requires a number of strong assumptions, and in the case of the Rodrigues *et al.* boom-bust results we have shown that many of those assumptions are violated.

However, if we restrict our definition of 'well being' to more commonly available measures of poverty and GDP *per capita*, we are not necessarily restricted to cross sectional analysis; for example 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. Due to changing municipality borders our unit of analysis is the Minimum Comparable Area (MCA), which roughly correspond in many cases to the municipalities in the Rodrigues *et al*. dataset but not exactly, and the full sample size falls to 254. However the advantage is that using the panel data we can explore the extent to which any boom-bust patterns can be observed over time within particular municipalities.

First, we 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, this is not any sort of definitive test 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 (note that Rodrigues *et al*. in fact do assume this is the case as their data is also from 2000).

Our (admittedly ad-hoc) criteria for a 'boom-bust' pattern is that poverty rates must have fallen from 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'). Of the 254 Amazonian municipalities for which we have data, using this 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[1]. Cross referencing this list with INPE deforestation data from 2000 and the Rodrigues et al. categorization, 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 type A and B, 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 post-frontier (group G) 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 group G 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 4. The post-frontier group G 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 (and as was further illustrated in Table 1). 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 than the rest of the Amazon, since the 1970s.

[1] List not reported but available from the authors upon request.

Table 4: Time Series 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 sample (category G)	123.1	33.2	62.3	70.3	-59.6	7.5	34.7

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

4. Discussion

We have revisited the Rodrigues *et al*. results using their own data and their own bivariate, cross section approach and have shown that the 'boom-bust' pattern that they observed was a spurious artefact of spatial correlation, driven primarily by the large, multifaceted (and unobserved) differences between municipalities in and around Amazonas and Maranhão states. Within some groups of municipalities we did indeed observe cross sectional patterns consistent with a 'boom' hypothesis, but ultimately we found no robust evidence in their data of any 'bust.' We confirm these (non-) results in the time series data; there is no 'smoking gun' dynamic boom and bust associated with land clearing in any municipality data from 1980 to 2000. Furthermore, the past economic performance of municipalities categorised as 'post-frontier' by Rodrigues *et al*. themselves are shown to have been economic underperformers since the 1970s, and if anything they have improved their relative standing in the years since 2000. In sum, we find no 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 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.

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