Sustainability in the Amazon: do booms in deforestation lead to busts in development?

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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 deforestation process has matured. Although the hypothesis has recently found some empirical support in cross sectional data (Rodrigues *et al*. 2009, Celentano *et al*. 2012), a handful of longitudinal case studies have failed to identify incidences of 'busts.' In our own analysis we find no evidence of a pattern of boom-bust in the time series data for any municipality in the Brazilian Amazon. Furthermore, we show that the past economic performance of municipalities identified in the cross section as experiencing a 'bust' phase have been economic underperformers since the 1970s, and if anything they have improved their relative economic standing in the years since 2000. We further show 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. The Celentano *et al*. results likewise are fragile to sensible changes in their specification and sample; for example when state fixed effects and forest reserve areas are included the pattern disappears.

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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 land is exhausted. 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)) and 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*. concludes,

> "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[1].

[1] Some examples of this include the fact Rodrigues *et al*. (2009) constitutes the sole scientific evidence that Marina Silva, the former Brazilian Minister of the Environment and Presidential candidate, has repeatedly cited to defend her policy agenda in Amazonia (e.g. see http://www.diplomatique.org.br/artigo.php?id=533). The Brazilian Federal Prosecutor (which wields considerable influence in the shaping and reformulation of policy) has also used the Rodrigues analysis in developing its view of the Forest Code (see

Nevertheless, a number of case studies (for example Sears et al (2007), Piñedo-Vasquez et al (2001), Guedes et al (2012), Simon 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, they 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 our own analysis of time series panel data. Specifically, after briefly review 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 study evidence, 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 Celentano (2012) results, on the other hand, hinge critically on their particular method of measuring of the extent of deforestation and disappear when reasonable, alternative measures are employed and state fixed effects introduced.

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 present our own analysis of the unconditional time series relationships between poverty, growth and clearing in the Amazon and find no evidence of any boom-bust relationship. In section 4 we re-examine the cross sectional analyses and provide an encompassing explanation of both the time series and cross sectional patterns, showing how the latter are artefacts of spatial and sample biases. 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,

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http://4ccr.pgr.mpf.gov.br/documentos-e-publicacoes/trabalhos-cientificos/reforma_codgo_florestal_gisi.pdf).

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). 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 also examined in Celentano *et al*. (2012), who use multivariate regression analysis to control for a number of possible variables that could be correlated with both welfare and forest extent, including climate and soil condition, mining resources, historical population measures and market access (eg roads and river). In the bivariate (unconditional) boom-bust hypothesis we would expect to observe an absolute fall in welfare during the 'bust' phase, while the mechanism driving the pattern remains something of a black box with most explanations focussing on population or mining dynamics, agricultural productivity, micro-climate effects and other ecosystem services of forests. A boom-bust *effect*, on the other hand, 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. Again, 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 settlement dynamics that could theoretically explain the stronger bivariate pattern. In this paper we mostly 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 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 find any 'bust' phase in development (Sears et al (2007), Piñedo-Vasquez et al (2001), Guedes et al (2012), Simon and Caviglia-Harris (2013), Mangabeira (2010)).

In particular, in an influential recent paper on boom-bust cycles in the Amazon, Rodrigues *et al.* (2009) divide a subset of Amazonian municipalities into one of seven categories, 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. They choose municipalities that are ecologically naturally forested and that represent stages of 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[2]. They then compute median Human Development Index (HDI) value and plot them against the median level of deforestation in each their categories A-G for the year 2000. Following their methodology, we recreate their data set and replicate their primary results (Figure 1), 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.

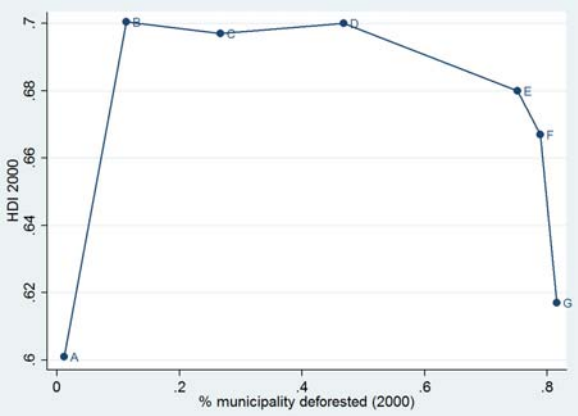

Figure 1. Empirical representation of the boom-and-bust hypothesis, reproduced using the methods and data of Rodrigues *et al.* (2009).

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). 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. We re-examine this assumption more closely in section 4.

Celentano et al. (2012) use INPE satellite data 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

[2] As this categorization is non-inclusive, only 286 out of 756 total Amazonian municipalities are included in their analysis.

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 you would expect a classic 'bust' 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 government provided 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, Caviglia-Harris *et al*. (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 founding 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[3]. Real monthly household consumption expenditures rise steadily from Rs. 91 in 1999 to Rs. 312 in 2008 (in 2012 Rs), with *per capita* agricultural output rising steeply from 1986 to 1999 and then rising steadily, but more slowly, through 2008. Housing quality also increases over time.

3. 'Strong' unconditional boom-bust patterns in the time series

As discussed above, while none of the longitudinal case study analyses we identified found evidence of boom-bust patterns, by themselves they cannot rule out the possibility that this inverted-U pattern could have occurred elsewhere. The broader quantitative statistical evidence for the boom-bust hypothesis has come from cross sectional analyses of municipality level data (both from the year 2000). However, inferring a time series relationship from a cross-sectional analysis requires a strong assumption that the variation across municipalities is a convincing proxy for the variation through time within municipalities; in the case of the Brazilian Amazon with its high degree of historical, environmental, and economic heterogeneity this assumption requires serious scrutiny, which we examine now in more detail.

One of the reasons previous studies have limited themselves to cross sectional analyses may be the authors' desire to examine the effects of deforestation on a broad definition of human welfare by using the Human Development Index (HDI), which is not generally available over time in the region. However HDI is simply a weighted average of GDP per capita, life expectancy and educational outcomes, and a long literature (for example, see Ravallion 2012) has criticized the approach on a number of grounds, including the use of arbitrary weights that, for example, imply particular trade-offs between education and life expectancy (and income) that are not justified by theory or evidence and make drawing comparisons across different values of HDI problematic.

If we acknowledge that the use of the HDI is not uncontroversial and instead restrict our definition of 'well being' to more commonly available (and commonly accepted) 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 from 286 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.

[3]Results and data available from the authors upon request.

Adopting this time series approach 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 (note that Rodrigues *et al*. and Celentano et al. in fact do assume this is the case as their data is also from 2000).

We adopt an (admittedly ad-hoc) criteria 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[4]. 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 (their 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 highly cleared, post-frontier (group G) 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 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 1. 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. 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.

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

Table 1: 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 (2000) 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. The cross sectional relationship between poverty and deforestation

Having failed to find any robust evidence of a dynamic boom-bust pattern in the time series data, we now turn to the recent cross sectional evidence that has been found in Rodrigues *et al*. and Celentano *et al*. Both studies 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. Concluding that a cross sectional pattern constitutes evidence of a time series relationship requires some strong assumptions, so to provide an *encompassing* analysis that can explain why researchers might simultaneously find a pattern in the cross section that does not exist in the time series, for each paper we first replicate their data and methodology, reproducing their results[5]. We can then both identify precisely the critical assumptions necessary for their cross sectional findings, and investigate how robust their results are to reasonable changes in those assumptions.

As discussed earlier, 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,

[5] Full analysis available from the authors upon request.

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 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 2 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 2 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 2, 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. 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.

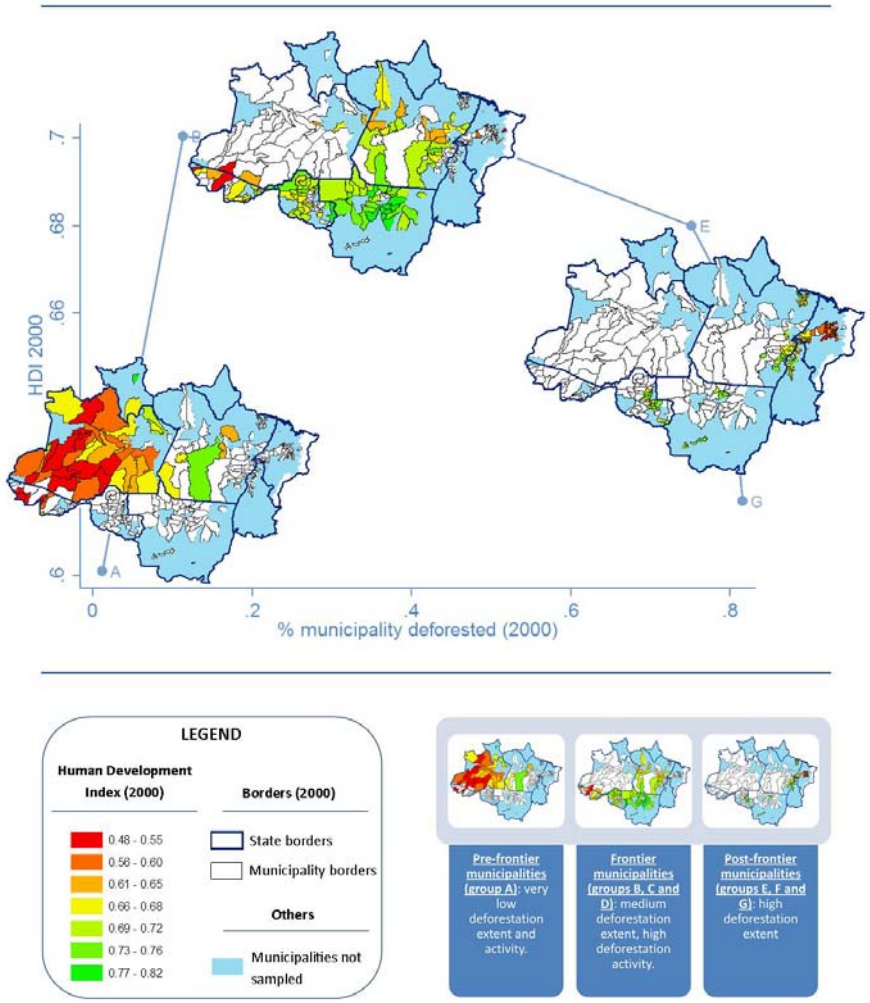

Figure 2. Spatial clusters of HDI and deforestation in the Brazilian Amazon.

Table 2: 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

Lastly, we further examine the validity of the assumptions underlying the cross sectional results by exploring additional testable auxiliary hypotheses of the boom-bust hypothesis. 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:

$$(1)\quad HDI_{i,00} = \beta_1\left(pdef_{i,97} * G1_i\right) + \beta_2\left(pdef_{i,97} * G2_i\right) + \beta_3\left(pdef_{i,97} * G3_i\right) + \alpha_1 G1_i + \alpha_2 G2_i + \alpha_3 G3_i + \varepsilon_i$$

where G1, G2, and G3 are dummy variables corresponding to pre-frontier, intermediate, and post frontier municipalities, respectively. We then 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 3. 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 3 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 regression (3) there is indeed a negative relationship among category G municipalities, but among category F municipalities the relationship is *positive* and highly statistically significant. 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 3 column (4) we split the sample of G-category municipalities in half by the percentage of 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 3, 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.

Table 3: dependent 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%

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, even in the cross section, the within-sample pattern of correlations are not consistent with the boom-bust hypothesis of deforestation and development.

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 the peculiar sample definitions they have adopted. Usually, the extent of deforestation is calculated as the ratio of total area deforested/total area of the municipality (eg Rodrigues *et al*.). Celentano *et al*. exclude protected areas from this calculation, but since deforestation in protected areas is very small or zero in most municipalities, excluding protected areas doesn't change the numerator in most cases but does affect the denominator. As a result, municipalities with significant forest cover because they have a lot of protected areas are measured as highly cleared. Econometrically, 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. Furthermore, even if we take the results at face value (which we shouldn't) that these 'highly cleared' municipalities have suffered 'busts', the peculiar policy implication is that greater protection of forests is an ineffective policy with respect to human welfare.

In Table 4 we reproduce the Celentano results using their sample and their measure of deforestation but additionally including state fixed effects (columns 1 and 2), and then repeat the exercise using the same municipalities but calculating the extent of deforestation in the more conventional manner (columns 3 and 4)[6]. As is very clear, the finding of a 'boom-bust' pattern disappears in the latter two specifications. We can recover a cross-sectional 'boom-bust' relationship only by eliminating the state fixed effects (suggesting the relationship is driven only by between-state variation) and using their peculiar measure of deforestation extent.

Table 4: Modelling HDI in 2000 using the Celentano *et al.* sample

	Celentano et al. definition of deforestation extent		Conventional definition of deforestation extent	
	(1)	(2)	(3)	(4)
Deforestation	0.247*** (.0714)	0.183*** (3.208)	0.099 (0.063)	0.085* (1.682)
Deforestation^2	-0.476*** (0.167)	-0.352*** (-2.632)	-0.196 (0.156)	-0.161 (-1.295)
Deforestation^3	0.273** (.109)	0.207*** (2.390)	0.129 (0.108)	0.108 (1.277)
*S**w		0.689*** (9.051)		0.695*** (9.09)
Constant	0.634*** (.009)	0.270*** (4.858)	0.648*** (0.008)	0.284*** (5.124)
Controls	no	Yes	no	yes
State FE	yes	Yes	yes	yes
N	399	399	399	399
R-sq	0.473		.4613	
Psuedo-Rsq		0.700		0.696

[6] Results excluding state fixed effects not included to save space but available from the authors.

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, currently in Brazil the heated debate over the new Forest Code 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 use time series panel data covering the entire Brazilian Amazon since the 1970s to search for time series evidence of boom-bust patterns. We find no evidence that any boom-bust has occurred in any Brazilian municipality over the past 30 years. Furthermore, the past economic performance of municipalities most likely to be in the 'bust' phase of the cycle, 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 performance and standing in the years since 2000.

In addition to our own time series investigation, we have revisited both the Rodrigues *et al.* (2009) and the Celentano *et al*. 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 know that in general drawing a dynamic conclusion from cross sectional variation can be highly problematic absent a set of highly restrictive (and often unrealistic) assumptions, but in this case we investigate specifically how those assumptions have shaped the studies' conclusions. Using their own data and their own (non-parametric bivariate and parametric multivariate) cross section approaches, we show that the 'boom-bust' pattern observed in both studies is quite fragile to relatively modest and reasonable modifications of their underlying assumptions. In particular we find the Rodrigues *et al.* results to be a spurious artefact of spatial correlation, driven primarily by the large, multifaceted (and unobserved) differences between municipalities in and around Amazonas and Maranhão states. The Celentano *et al.* results are also sensitive to their (rather peculiar) definition of extent of deforestation and the inclusion of state fixed effects, and disappear when a more conventional definition and functional form are adopted.

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. 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 opportunities 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.

References

Anselin, Luc (2002) "Under the hood issues in the specification and interpretation of spatial regression models" Agricultural Economics, Vol. 27, issue 3, November pp. 247-267

Barbier, Edward (2004) "Agricultural expansion, resource booms and growth in Latin America: Implications for long run economic development" *World Development* Vol. 32, No. 1, pp. 137–15

Batistella, M., & Moran, E. F. (2005). Human dimensions of land use and land cover in the Amazon: A contribution from LBA. *Acta Amazonica*, 35(2), 239-247.

Celentano, Daniel, Erin Sills, Marcio Sales, and Adalberto Verissimo (2012), "Welfare outcomes and the advance of the deforestation frontier in the Brazilian Amazon" *World Development* Vol. 40, No. 4, pp. 850–864.

Fearnside, Philip (1986) *Human carrying capacity of the Brazilian rainforest*. New York: Columbia University Press

Guedes, G., Brondízio, E., Barbieri, A., Anne, R., Penna-Firme, R., & D'Antona, Á. (2012). Poverty and Inequality in the Rural Brazilian Amazon: A Multidimensional Approach. *Human Ecology*, 40(1), 41-57.

Hall, S. C., & Caviglia-Harris, J. (2013). Agricultural development and the industry life cycle on the Brazilian frontier. *Environment and Development Economics*, 18(03), 326-353.

Hecht, S.B. (1983) “Cattle ranching in the eastern Amazon: environmental and social implications” in E. Moran (ed.) The Dilemma of Amazonian Development, Westview Press, Denver

Mangabeira, J. A. (2010). *Serviços ecossistemicos e trajetoria de capitalização agricola: o caso de Machadinho do Oeste*. (PhD), Unicamp, Campinas, Brazil.

Moran, Emilio (1982) “Ecological, anthropological, and agronomic research in the Amazon basin.” L*atin American Research Review*, (17) 1, pp. 3 – 41.

Pinedo-Vasquez, M., Zarin, D. J., Coffey, K., Padoch, C., & Rabelo, F. (2001). Post-boom logging in Amazonia. *Human Ecology*, 29(2), 219-239.

Ravallion, Martin (2012) “Troubling trade-offs in the Human Development Index,” *Journal of Development Economics*, Volume 99, No. 2, November, pp. 201-209

Rodrigues, Ana, R. Ewers, L. Parry, C. Souza, A. Veríssimo & A. Balmford (2009) “Boom-and-bust development patterns across the Amazon deforestation frontier.” *Science*, (324), pp. 1435 – 1437.

Schneider, Robert, E. Arima, A. Veríssimo, C. Souza, and P. Barreto (2002) “Sustainable Amazon: Limitations and opportunities for rural development.” World Bank technical paper no. 515.

Sears, R. R., Padoch, C., & Pinedo-Vasquez, M. (2007). Amazon forestry tranformed: integrating knowledge for smallholder timber managemet in Eastern Brazil. *Human Ecology*, 35(6), 697-707.