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Transition in environmental governance in the Brazilian Amazon: emergence of a new pattern of socio-economic development and deforestation

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ABSTRACT

Socio-economic development in the Brazilian Amazon is currently reaching national averages although deforestation activity has been declining for a decade. As a consequence, recent studies rejected the widely agreed boom-and-bust development hypothesis that deforestation first generates an economic boom, which is then followed by a collapse as forest resources are depleted. Here, we confirm these studies that there is no boom-bust cycle and suggest that a new pattern of relationship between deforestation and socio-economic development has emerged following an environmental Kuznets curve (EKC). In this scenario, environmental degradation increases in the early stages of economic development and decreases in later stages as the economy develops and wellbeing increases. To validate this assumption, we conducted the first sub-municipal analysis of socio-economic development and deforestation in the Brazilian Amazon for the 2000–2010 period. Our results confirm the emergence of an EKC relationship with a turning point beyond which socio-economic growth does not appear anymore to be a driver of deforestation. We also emphasize that areas subjected to active deforestation in 2010 present lower socio-economic indicators than stabilized areas, pointing to the precarious socio-economic situation of areas still undergoing active deforestation. We put these results in perspective by considering Brazilian efforts to ensure a transition in environmental governance with the objective of promoting land use sustainability through control of deforestation at the same time as supporting socio-economic development.

1. Introduction

Socio-economic development across the Brazilian Amazon is a controversial research topic. In the late 2000s, seminal studies evidenced a boom-and-bust development pattern (Rodrigues et al., 2009; Celentano and Veríssimo, 2007; Celentano et al., 2012). That is, timber extraction and the conversion of forests into cropland and pasture generate a boom in incomes and jobs in the first years of land occupation, which is then followed by a collapse as forest resources and soil fertility are depleted (Sears et al., 2007). This scenario recalls the historical pattern of economic development in the Amazon when the cycles of extraction of forest products used to follow a boom-and-bust pattern, characterized either by a rapid rise and decline in market prices or by the depletion of resource stocks. Associated with high deforestation rates over the past four decades, the boom-and-bust pattern may be considered as a lose-lose scenario from a long term perspective since it generates high environmental costs and limited socio-economic benefits (Weinhold et al., 2015).

Yet, the last decade has been marked by a dramatic decrease in deforestation rates in the Brazilian Amazon (Nepstad et al., 2014; Arima et al., 2014) and a significant increase in the Human Development Index (HDI) (Caviglia-Harris et al., 2016). As a consequence, important recent studies reviewed the originally widely accepted boom-and-bust development hypothesis. Weinhold et al. (2015) evidenced that pre- and post-frontier municipalities in 2000 have enjoyed an equal increase in their Human Development Index (HDI) across the Amazon during the last decade. Caviglia-Harris et al. (2016) asserted that socio-economic welfare has become decoupled from environmental factors and is converging to rising national averages.

While these studies provide evidence that deforestation has not been followed by a socio-economic decline and thus reject the boom-and-bust hypothesis in the Brazilian Amazon, they provide little insight into the current scenario of socio-economic

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development and deforestation across the Amazon. In this paper, we suggest that the increased socio-economic development associated with a decrease in deforestation activity emphasizes profound changes on the land-use frontier and attests to the emergence of an environmental Kuznets curve (EKC). The EKC hypothesis predicts that environmental degradation may have an inverted U-shaped relationship with development: environmental degradation goes along with development until primary needs are met; then a turning point is reached when concerns for the environment increase and environmental degradation decreases (Dinda, 2004; Pfaff and Walker, 2010).

To validate this assumption, we conducted the first sub-municipal analysis of socio-economic development and deforestation in the Brazilian Amazon with the objective of providing evidence for the transition from a boom-and-bust to an EKC pattern in the Amazon. First, we confirmed the reversal of the boom-and-bust development pattern using different socio-economic data than Weinhold et al. (2015) and Caviglia-Harris et al. (2016). Second, the fine analysis of the relationship between socio-economic and deforestation variables produced evidence for the emergence of an EKC. Finally, we discussed the policies implications of such evolution of the deforestation and socio-economic development pattern, especially with regard to the recent advancements in environmental governance in Brazil.

2. Materials and methods

2.1. Data processing

We crossed socio-economic data from full-population censuses in 2000 and 2010 provided by the Brazilian Institute of Geography and Statistics at census sector scale (IBGE, 2010) with the PRODES deforestation maps provided by the Brazilian National Institute for Space Research (INPE) (INPE, 2014). As IBGE raw data are produced for 37,295 census sectors covering the entire Amazon, whereas there are only 775 Amazonian municipalities, the census sector data presents a finer spatial scale than the municipal data traditionally used in socio-economic studies (e.g. Rodrigues et al., 2009; Celentano et al., 2012; Weinhold et al., 2015).

Both datasets were projected on a 10x10 km regular grid for two reasons (Tritsch and Le Tourneau, 2016). First, the number of census sectors in the Brazilian Amazon grew rapidly from 11,850 to 37,295 sectors during the study period, thus limiting the relevance of an inter-annual comparison at sector level. Second, while deforestation decreased dramatically in the 2000s, we considered the original sector level of the census was not adequate to capture the spatial variability of deforestation across the Amazon, especially in rural areas where census sectors can be very large. The cell's area (100 km^2) was defined to round down the average area of a census sector as observed in 2010 (137 km^2).

For each cell in the grid (n = 51,642 cells), we first retrieved the areas of forest, non forest (i.e. mainly *Cerrado* areas), deforestation (with the corresponding year), water, and cloud from PRODES data. We then discarded cells with large unobserved areas, in other words, a cell was only analyzed if the sum of areas of forest, deforested land and water accounted for more than 70% of the cell's area. Additionally, it is worth mentioning that urban areas were kept in the analysis although they may induce some artifacts due to their high population densities and incomes associated to low deforestation activity. We felt that the bias caused by these urban areas is limited as we applied the same methods on both datasets (2000 and 2010). Overall, discarding urban areas would remove a large part of the Amazonian population and wealth, thus limiting the interest of the study.

The final grid thus contains 30,693 cells for which we computed two deforestation indices also used by Rodrigues et al. (2009):

- *Deforestation extent* is the cumulative proportion of deforestation in a cell in 2000 and 2010;
- *Deforestation activity* is the proportion of land area in a cell that has been cleared during the preceding three years, i.e. 1998–2000 and 2008–2010 time periods.

In addition, we computed different measures of socio-economic development by referring to the standard of living (income per household in Brazilian Real, R$), literacy (proportion of literate heads of household) and access to basic services such as sanitation (proportion of households with toilets). To do this, we proportionally shared out the socio-economic data from each sector across all underlying corresponding cells. As an example, a sector of 1000 inhabitants of which 25% of its area covers a cell *A* and 75% covers a cell *B* will attribute 250 inhabitants to cell *A* and 750 inhabitants to cell *B*. We did not use the HDI as it is only calculated at the municipal scale but not at the census scale. Finally, to avoid any artifact in the socio-economic data, all cells crossing a census sector with *No data* value were deleted so that the final database contains n = 24,068 cells in 2000 and n = 23,123 cells in 2010.

2.2. Boom-and-bust analysis

To ensure continuity with the study of Rodrigues et al. (2009) who evidenced the boom-and-bust development pattern in 2000, we classified the cells in the same seven frontier classes (A to G) based on both the extent of deforestation and deforestation activity (Fig. 1). The classes range from pre-frontier classes (A, B) characterized by a limited area of deforestation and low deforestation activity, through active frontier classes (C, D, E) with increasing area of deforestation and high deforestation activity, up to post-frontier classes (F, G) where the extent of deforestation is high but deforestation activity is low. These seven classes represent the different stages of the process of frontier expansion under which wildlands are converted into highly anthropized areas, as conceptualized by DeFries et al. (2004) and Foley (2005). The stabilized cells with a moderate extent of deforestation and low deforestation activity remain unclassified in this conceptualization of frontier expansion.

To test the existence of a boom-and-bust development pattern, we plotted the socio-economic development variables against the frontier classes in 2000 and 2010 and evaluated the statistical differences among the classes using the Kruskal–Wallis test and Tukey's honestly significant difference test. The first test verifies whether samples originate from the same distribution while the second is used in post-hoc analysis to test if mean values of two samples are significantly different.

2.3. Environmental Kuznets curve analysis

While the boom-and-bust hypothesis analyses a pattern of socio-economic development depending on deforestation, the EKC explores how socio-economic development acts on deforestation. Its application to tropical deforestation has long been debated and appears to be somewhat controversial (Koop and Tole, 1999; Choumert et al., 2013). There is a disagreement between researchers who consider the EKC relevant and present it as one of the hypothesis explaining the forest transition process (Barbier et al., 2010; Mather et al., 1999; Rudel et al., 2005; Culas, 2012) and others who dismiss the EKC (Stern, 2004). In this regard, the lack of consideration for institutional factors while they play an important role in the implementation of environmental policies and, consequently in the relationship between environmental quality and socio-economic development, has especially been emphasized as