Lan Occupations and Deforestation in the Brazilian Amazon

1. Abstract

Researchers are increasingly interested in understanding the impact of contentious social processes on land change. In the Brazilian Amazon, there are often contentious interactions between landholders defending private property rights and squatters who have the right to occupy land that is deemed unproductive. Previous studies suggest that the contentious social processes inherent in the Brazilian land tenure and land reform system cause a significant amount of deforestation. An environment of insecure land title, and policies that value deforested land over forested land, among other factors, encourage both landholders and squatters to deforest more land than is necessary for pasture or crop production. This paper examines the impact that land occupations have on deforestation at the municipal scale across the Brazilian Legal Amazon, from 2000-2009. We show that land occupations have a direct influence on deforestation. We use spatial analysis as well to show that land occupations have a spatial component in the effect on deforestation: occupations in one municipality affect deforestation in adjacent areas.

2. Introduction

The rate of deforestation in the Brazilian Amazon has declined in recent years. Brazil's National Institute for Space Research (INPE) data from 2000-2015 show a high annual deforestation level in 2004 (27,772 km^2), dropping to the third lowest annual amount in 2015 (5,831 km^2). Nevertheless, 413,506 km^2 have been deforested just since 1988 (PRODES 2015), an area slightly larger than Paraguay. Deforestation in the region has global implications for loss of biodiversity, threats to indigenous peoples, and impacts on climate change (Schwartzman and Zimmeran 2005; Foley et al. 2007; Salazar et al. 2015).

Understanding the human drivers of deforestation is a major focus of research (Geist and Lambin 2002). Numerous studies have examined the role of social processes such as land colonization, reform and conflict on deforestation in Latin America, (especially Brazil), and Africa (Rudel 1983; Pichón 1997; Sjaastad and Bromley 1997; Godoy et al. 1998; O'Brien 1998; Futemma and Brondízio 2003; Cullen, Alger and Rambaldi 2005; Rudel 2007; Ludewigs et al. 2009). Environments with social inequality between landholders and landless people, frontier development, violence, and insecure land tenure, can lead to a situation in which much more land is deforested than is needed for livestock or crop production. Knowledge of the mechanisms involved in such land change has come largely from case studies. Considering studies from the Brazilian Amazon, many have focused on Pará state, especially large portions of southern Pará. (Though case studies, they often cover an enormous region.) The goal of this paper is to determine whether there is evidence that deforestation due to contentious social processes identified in Pará is present throughout the Brazilian Amazon, as some have hypothesized. Our paper proceeds as follows. A brief background on the Brazilian Amazon, and review of literature, establish the various mechanisms by which contentious social processes bring about deforestation. Based on this, we develop our own hypotheses to test across the Brazilian Amazon Basin as a whole. We then present the data, variables, and model we use to test the hypotheses. Our results indicate that there is strong evidence that the dynamics identified in Pará are unfolding in similar fashion across the Basin. Finally, we discuss the significance of our findings, our study's limitations, and next steps for research.

3. Regional background and literature

Since European colonization, the Brazilian Amazon has experienced numerous ebbs and flows of spatial interaction with the rest of Brazil, South America, and the world economy. The policies of the military dictatorship of the 1960s, however, are widely considered to have spurred development processes involving road building, regional investment, new government institutions, and in-migration (large landholders–individuals and corporate–as well as smallholder colonist farmers), bringing unprecedented social and environmental change, especially deforestation. Thousands of families participated in both spontaneous and planned settlements over the decades in the Amazon, brought on in part by unequal land distribution in the more populated northeast and south of Brazil. Early works often employed a political economy approach (later an explicit political ecology approach) to explain the unfolding negative social and environmental outcomes of frontier development. This literature demonstrated that the Amazon frontier has been exploited by a rapidly urbanizing, industrializing, and capitalist system driven to appropriate value generated by nature and lower class labor. In this process, what used to be landscapes of relatively sustainable peasant production carried out by indigenous people, rubber tappers, and floodplain fisher communities, is replaced by mines, logging operations, dams, and cattle pasture, among other unsustainable practices (Foweraker 2002; Mahar 1979; Schmink and Wood 1992). Studies on the Amazon frontier eventually played an important role in the development of political ecological research, illustrating the negative human and environmental outcomes of inequality and the struggle over resources (Schmink and Wood 1987; Hecht 1985; Hecht and Cockburn 2011; Robbins 2011).

Research on the Amazon has also focused specifically on the impact of contentious social processes on land change. This work shows how two distinct social groups, large-landholders and landless people, acting according to two long-established and contradictory principles of land tenure, ensure a continuous cycle of conflict: large-landholders, often with privileged access and control over the bureaucracy that produces official documentation of land ownership, have a right to hold what is private property; landless people, though, have a right to land that is considered to be unproductive or that is not fulfilling its "social function". The right of landless people to occupy unproductive land was most recently articulated in the 1988 Brazilian Constitution and in 2002 in Brazil's Civil Code (dos Santos Cunha 2011). Increasingly, dozens of social movements through Brazil have relied on this right to occupy thousands of properties across the country in hopes the land will be expropriated by the Brazilian Federal Land Reform Agency and redistributed for the purposes of land reform, also known as "direct-action land reform" (Simmons and Arima 2010).

Land occupations unfold in many different ways. While it is difficult to generalize, the following stages often occur. Land occupations are usually fairly public affairs. They can involve up to hundreds of landless peasant families who mobilize and appear suddenly within or on the outskirts of a property they wish to have expropriated. Often makeshift structures are built to form an *acampamento*, or encampment. Landowners often seek court orders to have the squatters removed, based on documentation confirming their ownership of the land. This removal may be contested by lawyers representing the squatters, a process that can go on for years. Throughout the process, landholders may intimidate the squatters with various levels of threats and violence. There are many documented cases of direct confrontations, murders, and even massacres (Wright and Wolford 2003). Moreover, a given property may experience repeated occupations and evictions before there is some kind of resolution (Aldrich et al. 2012). Once land is finally set for expropriation, then landholders receive some form of compensation and the land is distributed to the squatters, with the Federal Land Reform Agency establishing an official settlement. Settlers may then receive benefits to help establish their homes and agricultural enterprises (Fernandes 1999).

The conflict inherent in this land reform process, and its specific relationship to deforestation, has been a growing area of research that over time has spanned political ecology and land change science approaches (Turner and Robbins 2008; Brannstrom and Vadjunec 2014). Numerous scholars have identified specific mechanisms by which contentious social relations are linked to deforestation (Fearnside 2001; Alston, Libecap and Mueller 2000; Aldrich et al. 2012). From these studies, mechanisms include the following: 1) Brazilian law itself has long provided an incentive to deforest land in order to show that it is productive, and both landholders and squatters have an interest in demonstrating productive use to attain or maintain ownership as they compete for control over land; 2) under the threat of occupation, landholders may preemptively deforest land, discouraging occupation and raising the value of the land if it is expropriated, lowering a landholder's overall exposure to risk; 3) landholders may collude with squatters and banks to encourage an occupation; 4) squatters may sell land gained by expropriation and move on to occupy land again on the frontier.

The works cited above are case-studies from the most conflict-ridden part of the Brazilian Amazon, the state of Pará, and more specifically, southern Pará (Simmons et al. 2008). Of these, Aldrich et al. (2012) stands out as presenting one of the most precise measures of the significance of preemptive deforestation as a result of contentious social interaction between landholders and squatters. Across 180 large landholdings in southern Pará state, deforestation on each property was measured using satellite remote sensing (dependent variable). Two models were created, one measuring deforestation over the entire study period, and another measuring deforestation only in the two year period before the first land occupation on the property. The independent variable characterized contentious interaction over the study period. Contentious actions include "occupations, road blockades, verbal insults, arsons, beatings, and homicides" related to direct action land reform, as found in local newspaper reports, which were coded by the authors (Aldrich et al. 2012:p. 115). The results indicate that there is a significant direct relationship between contention and preemptive deforestation on the properties. Contentious relations between cattle ranchers and landless peasants lead to higher deforestation levels than would be expected for the establishment of cattle pasture or cropland.

Two questions arise. One is whether the dynamics of Pará are unfolding across the Brazilian Amazon and elsewhere. Fearnside (2001:p. 1362) warns that "The problems of southern Pará are likely to spread to increasingly broader sections of Amazonia". Araujo et al. (2009), in an analysis of state-level data from all states in the Brazilian Amazon from 1988-2000, affirm that land tenure insecurity, undoubtedly an element of contentious social interaction, causes deforestation. Aldrich et al. (2012:p. 120) hypothesize that contentious land change "...probably accounts for an appreciable component of deforestation, basin-wide," suggesting even further that given the land reform situation in other countries, from Latin America to Africa and Asia, contentious land change could be a general phenomena. In short, under contentious conditions, do landholders carry out preemptive deforestation across the Brazilian Amazon?

The second question is whether the independent variable, contentious social interaction, has effects beyond the scale of properties where landholders have direct experience with contentious interaction. Let us assume that Aldrich et al. (2012) are correct that specific landholders become aware of the intentions of landless people to occupy properties, giving those landholders time to carry out preemptive deforestation. We reason that it would also be possible that landholders not directly threatened by an occupation could respond to an overall climate of land tenure instability brought on by occupation activity and preemptively deforest as well. An accompanied sense of greater competition for land and the need to lay claim to land could also exacerbate deforestation, and we would expect this deforestation to have a spatial diffusion component as found in other areas of the Amazon (Rudel 1983). We speculate that this climate could be brought on through a number of mechanisms.

Contagious diffusion processes may be involved, whereby landholders directly communicate contentious experiences with neighbors or other landholders involved in associations such as the Rural Union (*Sindicato Rural.* Hierarchical diffusion processes would involve information spreading across greater distances such as urban centers, with newspaper articles documenting contentious interactions or landless social movement organization members, leadership, and landholders themselves traveling to different areas, spreading word of events and plans. In sum, do the effects of contentious interactions on forests diffuse to locales where there was no immediate, direct experience with contentious interaction?

This paper contributes to our understanding of contentious land change in three significant ways. First, the scale of analysis, (municipal-level, n=642, across Brazil's Legal Amazon), is a middle ground between the state-level analysis of Araujo et al. (2009) and the "case-study," property-level approach of Aldrich et al. (2012). Second, our research focuses on a period subsequent to Araujo et al. (2009), the period from 2000-2009. Third, we specifically model the impact of contentious social interaction (measured by incidence of land occupations) on deforestation (data from INPE/PRODES) in neighboring municipalities that did not directly experience a land occupation, thus accounting for spatial dependencies in the data.

4. Hypotheses

Ideally, we could replicate the work of Aldrich et al. (2012) in dozens of areas across the basin. This is impractical. We have to sacrifice case-study detail linking the variables in a particular place for systematic coverage across a much larger area. As done in Araujo et al. (2009), we take advantage of deforestation data provided by the *Instituto Nacional de Pesquisas Espaciais* (INPE, Brazil's Federal Space Research Agency, roughly the equivalent of NASA in the US), and data on the occurrence of land occupations provided by the *Comissão Pastoral da Terra* (CPT, the Pastoral Land Commission). In addition to testing whether the relationship between occupations and deforestation is significant, we also test whether an indirect, but perhaps more significant, process is at play. We test whether the deforestation in one municipality has ripple effects in others. To both generalize earlier case study results and to account for the indirect effect of occupations on deforestation, we derive the following three hypotheses:

- Hypothesis I: Municipalities that witness land occupations will also observe increased deforestation.
- Hypothesis II: Deforestation in one municipality will result in increased deforestation in neighboring municipalities.
- Hypothesis III: Occupations in neighboring municipalities $j, k, ...$ will have an effect on deforestation in municipality i.

5. Data

5.1. Dependent Variable

The dependent variable is the amount of rainforest lost between 2000 and 2009[1](PRODES 2015). The variable is logged to account for the fact that effects of the independent variables will not be linear across all values of deforestation. To illustrate the geographical pattern of deforestation across the municipalities within Brazil's Legal Amazon[2], we mapped the number of km^2 deforested between 2000 and 2009 (Figure 1). We also provide a histogram of the logged form to indicate how the transformation produces a distribution with nice

[1] From the INPE/PRODES data tables we calculated the total area deforested between 2000 and 2009 by summing the columns labeled "incremento" for each year of the study period, which is the amount of additional deforestation occurring from one year to the next. For the amount of forest at the start of our study period, we used the "floresta até 2000" variable. In a small number of cases, there are zeros in this column, when in fact there is forest, because the forest was not detected until years later. We replaced these zeros with the maximum value for forest found during the study period. The INPE/PRODES dataset has 760 cases. Our analyses were restricted to n=642. We are missing a total of 118 cases in our analyses due to missing data in one or more of our control variables.

[2] The Legal Amazon is a bio-administrative territory comprised of the states of Acre, Amazonas, Amapá, western Maranhão, Mato Grosso, Pará, Rondônia, Roraima, and Tocantins.

properties (Figure 2).

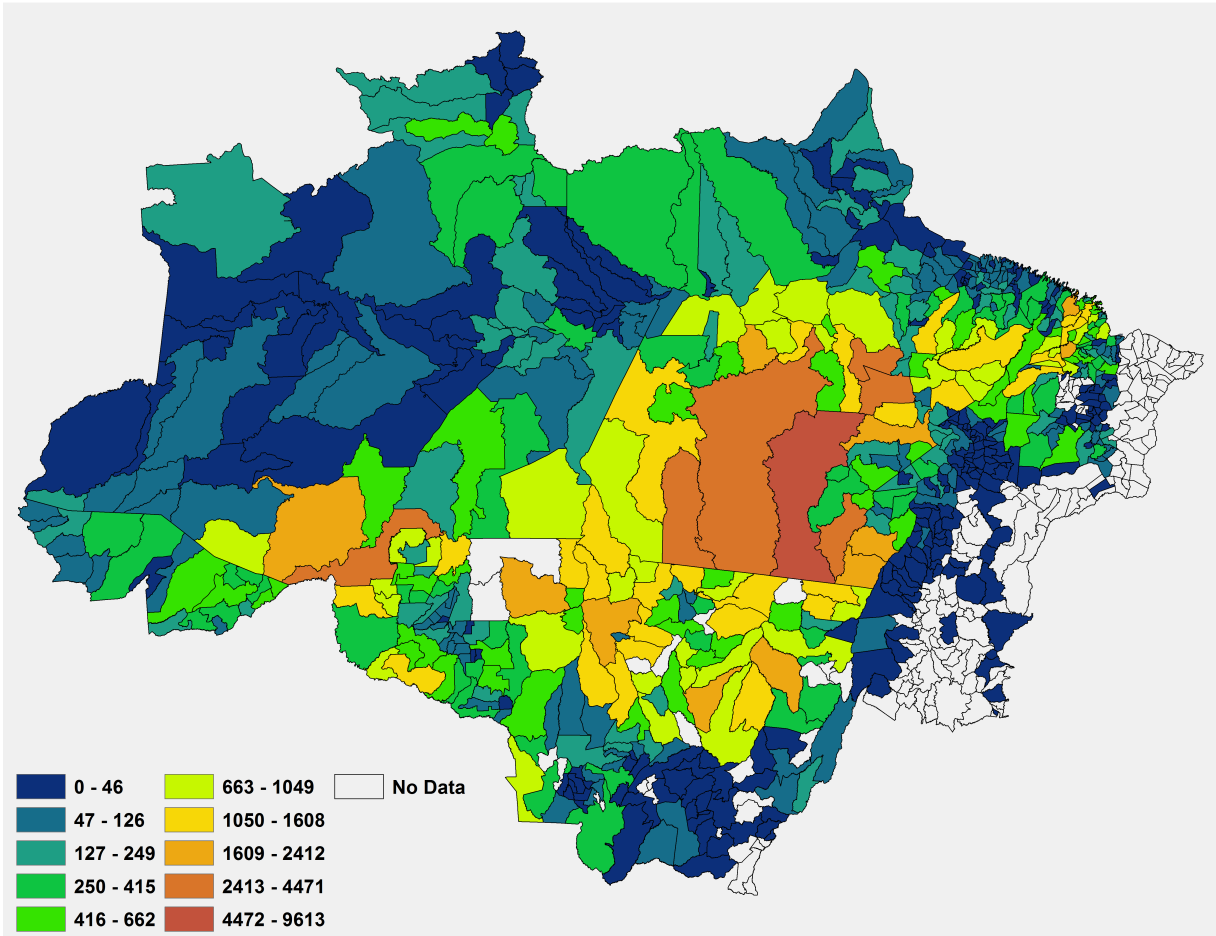

Figure 1: Dependent variable across the municipalities of the Legal Amazon of Brazil: deforestation from 2000-2009, km^2.

5.2. Independent variables

Land occupations. Land occupations are organized and carried out by a number of different social movement organizations in Brazil (Toni 1999; Simmons et al. 2002). While the MST (*Movimento dos Trabalhadores Rurais Sem Terra*) is perhaps the most well-known of these, others include the *Commissão Pastoral da Terra* (CPT), the *Federação dos Trabalhadores Rurais* (FETAGRI) of various states, *Central Único dos Trabalhadores* (CUT), and local *Sindicatos dos Trabalhadores Rurais* (STR). In some regions of the Brazilian Amazon, organizations like the STR are much more active organizers of occupations than the MST.

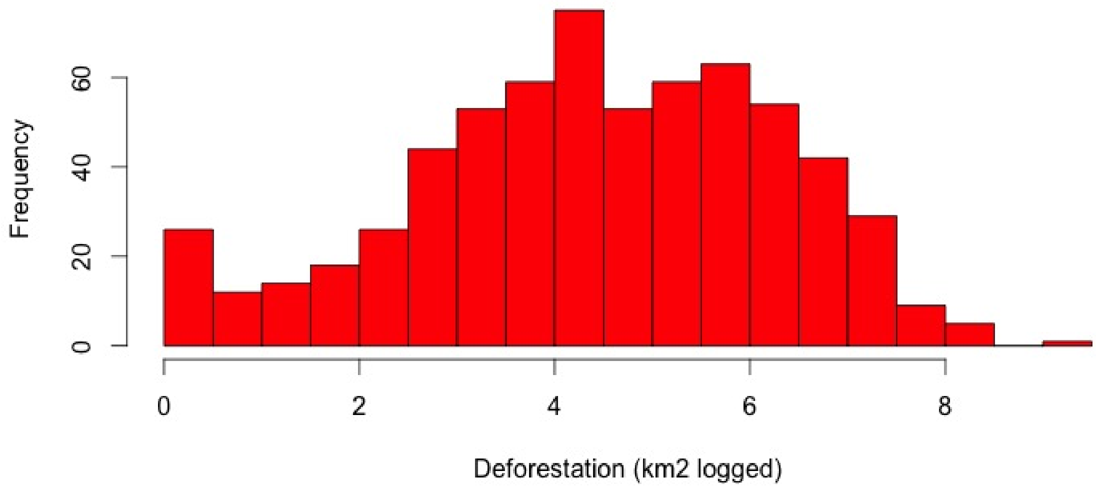

Figure 2: Histogram of deforestation (km2 logged).

Municipal-level data on land occupations by all social movement organizations is available to the public through the Brazilian *Comissão Pastoral de Terra* (Commissão Pastoral da Terra 2015*a*). The key independent variable is a dummy variable for whether or not an occupation occurred in the municipality during the 2000-2009 time period (Figure 3). A count of the total number of occupation-years from 1997-2009 was constructed as a robustness check. The total number of occupation-years records the number of years since the first occupation appeared during the period in question. This measures indirectly the intensity of occupations experienced by a municipality. To further check the stability of results and to render a more straightforward interpretation of the estimated coefficient, we logged the number of occupation years. Consequently, the resulting coefficient can be interpreted as an elasticity (an x-percent change in years under occupation is associated with a x-percent change in the dependent variable).

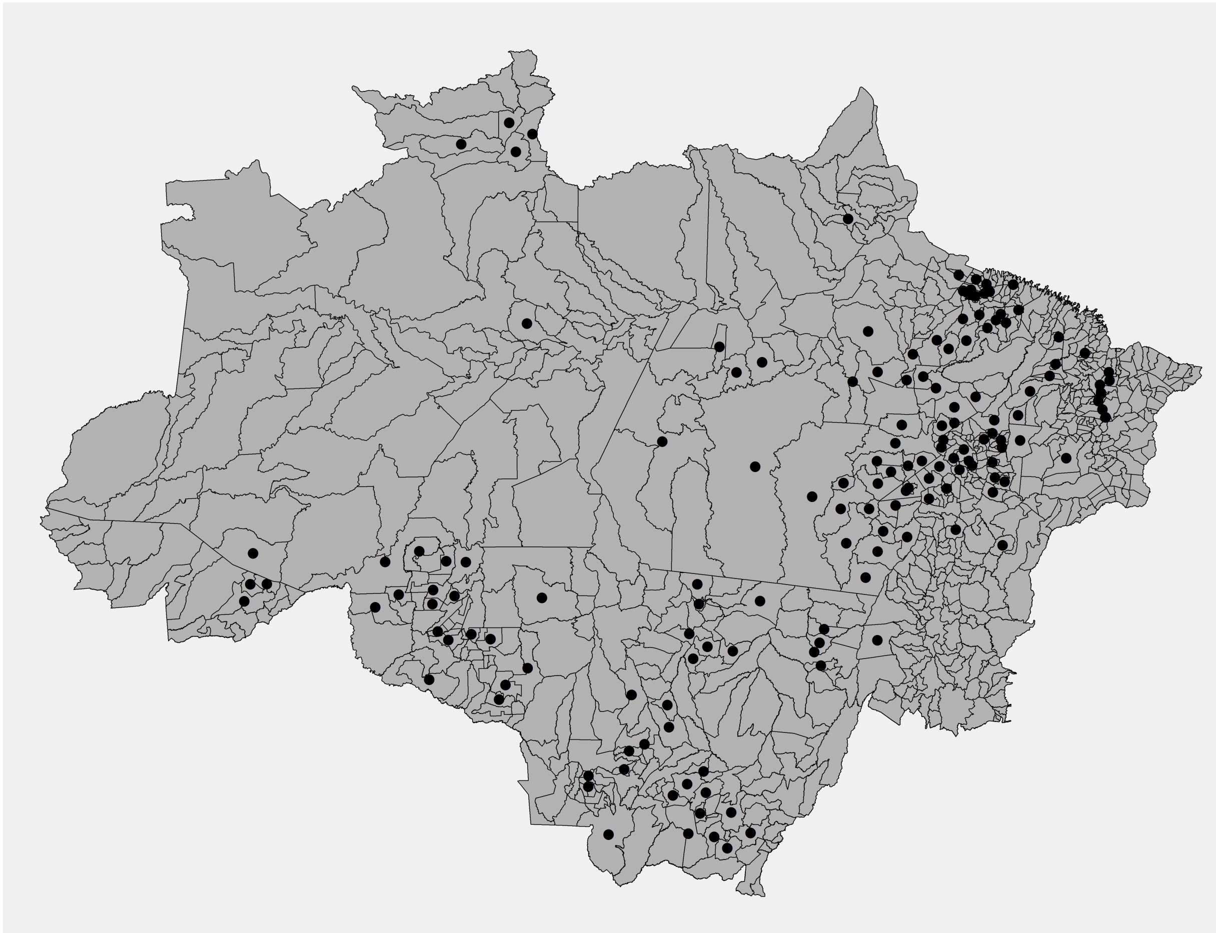

Figure 3: Land occupations across the municipalities of the Legal Amazon of Brazil. Centroids of municipalities experiencing at least one land occupation between 2000 and 2009 are marked with a dot.

5.3. Control variables

Landholding inequality. Landholding inequality is measured using a GINI index of 1998 parcel size (Girardi 2008). Values range from 0 to 1, with higher values indicating more inequality of land distribution. The variable is included to control for the possibility that the pattern of land distribution drives deforestation (see Godar, Tizado and Pokorny (2012) who find that municipalities with more unequal land distribution deforest more than do smallholder-dominated municipalities).

Social development index. The Brazilian Institute of Geography and Statistics (IBGE) produces Municipal Development Indicators (IFDM), a social development index. This index combines education levels, per capita income, and unemployment for each municipality. Change (the difference) in municipal development indicators from 2000 to 2009 is included in the analysis to control for the possibility that deforestation is a function of social development. We use the change in social development index since we have data both in 2000 and 2009. We also ran our basic model with the initial value (the year 2000) of the social development index to maintain consistency with our other independent variables. Using the initial value–from the year 2000–of the social development index had no impact on our results.

Paved roads. To account for the importance of infrastructure, we divided the kilometers of paved road in a municipality by its area (ha). Because of skewness, we used a logarithmic transformation of the data. Data are from 2000.

Land and forest area. Total land (ha) and year 2000 forest area (km^2), each logged to correct their functional form, are included to control for the fact that larger municipalities and municipalities with more forest area are likely to experience more deforestation than are smaller municipalities. We should note at the outset that the inclusion of this variable in the models reported below has no appreciable impact on our variables of interest.

Population and rural population. Total population (logged) and rural population as percent of total (logged) are included in order to control for the impact that population pressures will have on deforestation in a municipality. Data are from the 2000 IBGE census.

Literacy. Percent of the population that is literate is included to control for the impact that literacy has on deforestation. Because educated Brazilians are relatively more likely to support environmental causes, we included the level of literacy in our model separately, even though education is included in the social development index.

6. Results

We restrict the analysis in Table 1 to an OLS model that uses different measures of occupations: 1) Model (1) uses a simple dichotomous variable that registers a 1 if there was an occupation in the municipality between 2000 and 2009; 2) Model (2) records the number of years after the first occupation in a municipality between 1997-2009; 3) Model (3) is simply the log form of the measure used in Model (2). Model (1) tests our first hypothesis, that municipalities with land occupations will experience more deforestation than those with no occupations. This specification has no spatial component, either in the parameters or the estimation. As Table 1 suggests, there is a strong empirical association between occupations and deforestation. According to model (1), the presence of an occupation increases by 118% the amount of forest cut down between 2000 and 2009 when occupations move from 0 to 1.[3] The following calculation–albeit a very crude one–indicates the scope of the problem. Between 2000 and 2009, the Brazilian Amazon lost roughly 203,940 km^2 of forest. Losing 118% of that amount, as implied by our model's estimates, is equivalent to losing a forest slightly bigger than the state of Minnesota in the United States which has 225,171 km^2.

To test whether deforestation in one municipality influences deforestation in neighboring municipalities, we use the OLS model from Table 1 (model 1) to test for spatial auto-correlation using a spatial weights matrix in R (queen contiguity). The traditional test statistic for spatial auto-correlation is Moran's I, which uses the spatial weights matrix to assess the presence of spatial patterning. We report the Z-score for the Moran's I in Model (1) which indicates positive spatial autocorrelation in the residuals (24.57). With a p-value well below 0.001 we can reject the null hypothesis that spatial autocorrelation is not present in the data.

[3]Because the dependent variable is log transformed and the independent variable is a dichotomous variable, we interpret effects as percentages using a semi-elasticity function, where the effect on deforestation is equal to $100[exp(\beta_{occupations})-1]$ for a change from 0 to 1 in the occupations dummy, or $100[exp(-\beta_{occupations})-1]$ for a change from 1 to 0 (Wooldridge 2009:190, 231).

While Moran's I is helpful in assessing whether spatial autocorrelation is present, it is not helpful in assessing how best to handle it. Since we want to treat the spatial autocorrelation substantively rather than regarding it as a statistical nuisance, we fit a spatial lag model which includes a spatially lagged dependent variable and uses maximum likelihood estimation. The standard set of tests to recommend a spatial lag or spatial error model employ the Lagrange Multiplier test statistics.[4] Model (1) returns significant Lagrange Multiplier statistics for both spatial lag and spatial auto-regressive error, indicating that this specification has multiple dimensions of auto-correlation. Since the Lagrange multiplier tests do not provide much of a guide in terms of which model is more appropriate, we generate estimates using both. In each case, the results remain stable and the conclusions we draw from them remain unchanged.

Table 2 presents our results when we account for spatial dependencies in the data by using Maximum Likelihood Estimation of two spatial autoregressive models along with a spatial error model based on MLE. Model (1) is the spatially lagged version of our basic model. Model (2) uses a spatial lag of the dependent variable but also includes a spatially lagged occupation variable in order to test whether occupations in neighboring municipalities j, k... directly influence deforestation in municipality i. Finally, model (3) represents the spatial error estimates.

We find evidence that confirms hypothesis (2): there is a diffusion effect of deforestation. In both models (1) and (2) in Table 2, the Rho term and accompanying Lagrange multiplier test indicates a strength and magnitude of interdependence. For example, in model (1), the Rho term is .61 with a likelihood ratio test value of 265.32. This produces a p-value that allows us to easily reject the null hypothesis that there is no spillover from one municipality to

[4] "Formally, this model is $y = X\beta + \epsilon$, with $\epsilon = \lambda W\epsilon + u$, where y is a vector of observations on the dependent variable, W is the spatial weights matrix, X is a matrix of observations on the explanatory variables, ϵ is a vector of spatially auto-correlated error terms, u a vector of i.i.d. errors, and λ and β are parameters."(Anselin N.d.:213)

Table 1: (OLS) Regression Results

	Dependent variable:		
	Deforested 2000-2009 (km2 logged)		
	(1)	(2)	(3)
Occupation Dummy Yes=1	0.782***		
	(0.108)		
Years of Occupation 1997-2009		0.128***	
		(0.020)	
Years of Occupation (logged)			0.207***
			(0.034)
Literacy	0.026***	0.027***	0.027***
	(0.005)	(0.005)	(0.005)
Population (logged)	−0.235***	−0.247***	−0.238***
	(0.078)	(0.079)	(0.079)
Development Index (differenced)	0.212	0.244	0.296
	(0.263)	(0.265)	(0.266)
Area (ha logged)	−0.391***	−0.389***	−0.390***
	(0.051)	(0.051)	(0.051)
Gini Coefficient	−0.103	−0.109	−0.146
	(0.166)	(0.168)	(0.169)
Paved Roads (km/ha logged)	0.293	0.459	0.576
	(0.718)	(0.724)	(0.725)
Rural Population (% logged)	0.560***	0.566***	0.550***
	(0.080)	(0.081)	(0.081)
Forest Area in 2000 (km^2 logged)	0.649***	0.653***	0.655***
	(0.028)	(0.028)	(0.028)
Constant	0.371	0.955	0.446
	(0.637)	(0.661)	(0.647)
Observations	642	642	642
R^2	0.642	0.635	0.633
Adjusted R^2	0.636	0.629	0.628
Residual Std. Error (df = 632)	1.128	1.139	1.141
F Statistic (df = 9; 632)	125.674***	121.927***	121.244***
Note:			*p<0.1; **p<0.05; ***p<0.01

another. In both spatial autoregressive models there is a clear indication that deforestation in one municipality influences its neighbors.

Finally, our hypothesis regarding whether occupations in neighboring municipalities influence deforestation is confirmed. Through the feedback implicit in the autoregressive models we can surmise that an occupation's influence filters indirectly through deforestation in neighboring municipalities. In other words, the direct effect of an occupation in a neighboring municipality j on deforestation in that same neighbor j no doubt influences deforestation in municipality i. In addition to that indirect effect, however, we test whether there is a direct influence of occupations in neighboring municipalities $j, k...$ on deforestation in municipality i. We test for that mechanism by including a spatially lagged version of the occupation variable. In both models (2) and (3), we find that the coefficient on the lagged occupation variable is positive and strongly significant. Also note that the non-spatially weighted occupation variable remains strong and significant. We need to treat the coefficients with care since there is an autoregressive term included in model (2). We can nevertheless disregard the simultaneity implicit in the autoregressive model and focus our attention on the immediate short-term relationship between occupations and deforestation without accounting for any feedback. The short term impact, using the coefficient from model (2), indicates that when increasing the average occupation in municipality i's neighbors by 1, there is a 34 percent increase in municipality i's level of deforestation. In the spatial error model, an average increase of 1 occupation in a municipality's neighbors is associated with a 127 percent increase in deforestation. That the two estimates differ significantly is likely the result of including a spatial lag of deforestation in model (2) but not in model (3). Even if we base our substantive interpretation on the lesser of the two, the estimates imply a disturbing effect.

Table 2: Spatial Regression Results

	Dependent variable:		
	Deforestation 2000-2009 (km2 logged)		
	spatial autoregressive	*spatial autoregressive*	*spatial error*
	(1)	(2)	(3)
Occupation Yes=1	0.524***	0.458***	0.447***
	(0.098)	(0.090)	(0.080)
Occupation Lag		0.294*	0.818***
		(0.152)	(0.195)
Literacy	0.019***	0.014***	0.006
	(0.004)	(0.004)	(0.005)
Population (logged)	−0.107	−0.119**	−0.087*
	(0.070)	(0.060)	(0.049)
Development Index (differenced)	−0.108	0.378*	−0.219
	(0.237)	(0.203)	(0.155)
Area (ha logged)	−0.477***	−0.167***	−0.212***
	(0.053)	(0.040)	(0.053)
Gini Coefficient 1998	−0.130	0.125	0.105
	(0.150)	(0.128)	(0.108)
Paved Roads (km/ha logged)	1.400**	0.261	−0.263
	(0.649)	(0.551)	(0.514)
Rural Population (% logged)	0.228***	0.367***	0.394***
	(0.074)	(0.062)	(0.055)
Forest Area in 2000 (km^2 logged)	0.151***	0.366***	0.618***
	(0.025)	(0.029)	(0.027)
Constant	1.597***	−1.653***	−0.321
	(0.576)	(0.491)	(0.483)
Observations	642	642	642
Log Likelihood	-950.969	-838.039	-731.799
σ^2	1.036	0.746	0.481
Akaike Inf. Crit.	1,925.937	1,702.078	1,489.597
Wald Test (df = 1)	343.218***	302.148***	903.474***
LR Test (df = 1)	265.319***	256.577***	469.057***
Note:			*p<0.1; **p<0.05; ***p<0.01

7. Endogeneity

Although we have established a strong empirical relationship exists between land occupations and deforestation, we should tread carefully since our treatment (land occupations) is not distributed randomly to municipalities throughout Brazil. If the decisions to occupy land occur in areas that are being quickly deforested, land occupations are not the cause but an important symptom of deforestation itself. The oft-perscribed econometric solution is Instrumental Variables (IV) estimation where the process of selection–in our case the decision regarding which land to occupy–is modeled explicitly. Predicted values of the selection equation are then used to instrument for land occupations in a second regression to achieve unbiased results. To identify the system of equations, it is important to find a variable that helps explain where land occupations occur but is not related to the errors in the second–or outcome–equation. This is a difficult task in our case since we would need something that helps explain the location of occupations but is not related to deforestation. Since no readily identifiable variable exists to serve this purpose–and if it did, would not be available for all municipalities in the legal Amazon–we employ a different strategy.

If endogeneity exists, the most straightforward explanation would be that the decision to occupy certain land is based on whether the land is easily cultivated: land in which the forest has already been cut down. If that is an important factor in deciding where to establish an occupation, our results merely reflect that decision. Land occupations, in that case, would be more of a symptom of deforestation than the cause. To test whether that explanation has any empirical grounding, we respecified our basic regression model so that the dependent variable (deforestation) happened long after the independent variable (land occupations). The dependent variable in the regressions reported below in Table 3 represents deforestation that happened between 2003-2009. Land occupations in Table 3 are characterized three ways: a dummy variable for municipalities where there was an occupation between 1997-2003 (1), an occupation between 1997-2000 (2), and occupation years between 1997 and 2003 (3)–in order to show the results were not dependent on the cutoff date. As can be observed, the estimates generated by the regressions in Table 3 indicate the relationship only gets stronger as we expand the length of time between land occupations and deforestation. Though not definitive, the results provide circumstantial evidence that land occupations are one of the causes and not a symptom of deforestation.

In addition to the circumstantial evidence provided above, there is evidence from previous literature (Fearnside 2001; Araujo et al. 2009) that squatters actually prefer to occupy lands that are forested for a number of reasons, including: the risk of violence is lower occupying forested land, since its value is less than cattle pasture; it is easier to convince authorities that land is unproductive if it is forested; forested land provides access to timber, an important income source for squatters; forested land, once cleared, is easier to farm than cattle pastures, which often suffer from heavy soil compaction. Aldrich (2015) sought to determine what are the characteristics of a property that raise the likelihood it will be occupied by members of a social movement organization, in the region of his previous studies in southeastern Pará. Based on a review of literature and interviews, he came up with a list of 10 variables. The variable that stood out the most was the percent of the property covered by forest. The results showed that a 10 percent increase in forest cover increases the likelihood of an occupation by half. If squatters seek out the most forested areas, that we find a positive correlation between occupations and deforestation only strengthens our argument.

8. Conclusion

We find that land occupations and deforestation in the Brazilian Amazon are correlated. The study provides evidence that is consistent with what other researchers have found at other scales of analysis and time periods. As direct-action land reform processes unfold with land occupations, landholders likely respond with preemptive deforestation to lay stronger claim to the land and/or to ensure higher compensation is paid by the government when

Table 3: (OLS) Regression Results

	Dependent variable:		
	Deforestation 2003-2009 (km2 logged)		
	(1)	(2)	(3)
Occupation Before 2003 Yes=1	0.687^{***}		
	(0.163)		
Occupation Before 2000 Yes=1		0.528^{**}	
		(0.211)	
Years of Occupation Before 2003			0.266^{***}
			(0.075)
Literacy	0.027^{***}	0.027^{***}	0.028^{***}
	(0.006)	(0.006)	(0.005)
Population (logged)	-0.196^{**}	-0.159^{*}	-0.217^{***}
	(0.093)	(0.093)	(0.081)
Development Index (differenced)	0.184	0.196	0.310
	(0.310)	(0.313)	(0.271)
Area (ha logged)	0.147^{**}	0.146^{**}	-0.378^{***}
	(0.064)	(0.065)	(0.056)
Gini Coefficient	-0.324	-0.327	-0.097
	(0.197)	(0.199)	(0.172)
Paved Roads (km/ha)	3.378^{***}	3.415^{***}	0.672
	(0.858)	(0.866)	(0.750)
Rural Population (% logged)	0.294^{***}	0.272^{***}	0.544^{***}
	(0.096)	(0.097)	(0.084)
Forest Area in 2000 (km^2 logged)	0.480^{***}	0.478^{***}	0.655^{***}
	(0.034)	(0.034)	(0.030)
Constant	-4.453^{***}	-4.533^{***}	0.124
	(0.905)	(0.914)	(0.794)
Observations	642	642	642
R^2	0.504	0.495	0.615
Adjusted R^2	0.497	0.488	0.610
Residual Std. Error (df = 632)	1.331	1.343	1.164
F Statistic (df = 9; 632)	71.447^{***}	68.931^{***}	112.315^{***}
Note:			*p<0.1; **p<0.05; ***p<0.01

it is eventually expropriated for land reform. Land is eventually being redistributed in this process, but this contentious and often violent process also leads to significant environmental impacts. It is likely that much more land than necessary is being deforested, when the end result desired is a place for people to farm to feed their families. Taken as a whole, this land reform process is inefficient, is often violent, and it holds substantial environmental consequences. Moreover, our results indicate that the dynamics underlying the observed relationship between occupations and deforestation diffuse to neighboring municipalities that did not even experience an occupation event directly.

The limitations of this study are typical of an estimation procedure that identifies an important relationship but is based on the reduced form of the underlying causal mechanisms. We observe an empirical correlation between land occupations and deforestation based on some assumptions, or guesses, about what connects the two. Without survey data of landowners which can measure the impact occupations have on their land use behaviors, we are limited to some conjecture. We are also limited by the fact that land occupations do not happen randomly, prohibiting us from treating this as an experiment. Although we can think of no reasons social movement organizations would choose to occupy land in areas where deforestation is most likely to happen, we realize these social and political phenomenon are rarely orthogonal to each other. Our results, therefore, identify an important empirical pattern and suggest there is a relationship between contentious political action and deforestation.

Future work could attempt to model more tightly in time and space the coupling between land conflict-related events (occupations, assaults, murders, etc.) with specific deforestation pulses, as Aldrich et al. (2012) has done, but at the municipal, Brazilian Amazon-wide scale. In addition, investigating how these events are related to policies and directives at the national level would provide important insights into the multi-scale dynamics of the process. This could add a deeper understanding to the dynamics of contentious land change over various periods of time, like those identified by Ondetti (2008).

There are a few limitations to mention regarding the main data sources for this study. PRODES is based on data from satellite remote sensing. Clouds obscure significant areas over the Amazon, and only by waiting a year or more for a cloud-free image can deforestation in some isolated areas be confirmed. PRODES data also has a spatial resolution of approximately 30 meters, so deforestation smaller than this may go undetected. Finally, PRODES does not track forest re-growth, so should a forest that has significantly regrown since 1988 be cut down, it would not register as deforestation. That said, PRODES data has been used routinely in numerous studies over the years in the social and natural/physical sciences. Recent independent evaluations of the accuracy of PRODES data to identify deforestation has affirmed it is a high quality product (Gainey 2014; Hansen et al. 2013). Regarding the data from the *Commissão Pastoral da Terra* (CPT), a rigorous methodology is followed to document the numerous elements of land-related conflict in the building of the CPT datasets (Commissão Pastoral da Terra 2015*b*). CPT field agents conduct interviews to confirm incidences of conflict of various types, including land occupations. These are also confirmed via secondary sources before an official registry is made in their database. Simmons (2004), however, examined previous studies from southern Pará and discovered large discrepancies in reports of land conflict-related murders (Almeida 1994; Barata 1995). The data seem to follow similar trends, but she suggests that CPT may under-report murders, largely because CPT field agents are unable to accompany land conflict over such large areas. We have no independent evaluation of the CPT's land occupation data, but we believe it is less likely to suffer under-reporting: land occupations are carried out by large numbers of people over relatively large areas; they attract attention from numerous sources; they can be confirmed more easily because they remain relatively in place.

Despite these caveats, there is an important relationship between land occupations and deforestation that researchers, activists, and policy makers in Brazil must confront. Given the problem of land inequality throughout the developing world, and the environmental importance of forested land, there is considerable opportunity for these findings to inform the way land distribution is carried out in the developing world. More generally, policies that produce incentives for contentious social interaction are inefficient and hold important externalities, including detrimental effects on the environment.

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