Abstract

This paper proposes a framework in which deforestation and rural violence are associated with the poor governance structure in Brazilian Amazon. As there is institutional uncertainty concerning property rights, landholders and squatters engage in a dispute to evict/expropriate each other. In such an environment, violence upsurges. In order to avoid expropriation efforts by squatters, landholders preemptively clear land as a means to attain definite property rights over land, since deforested areas are considered land with productive use, for legal considerations. As a result of deforestation, which increases land value, landholders become more prone to react violently to squatter’s efforts. The result of deforestation for squatters, however, is ambiguous. On the on hand, violent efforts from landholders tend to push them away. On the other hand, the perceived increased value of land attracts squatters, that may, in turn, increase their fight efforts. This paper also presents empirical evidence supporting the model’s predictions, specially that deforestation and rural violence are highly associated in the Brazilian Amazon.

Keywords: Property rights, Rural Violence, Deforestation
I – Introduction

The Amazon Forest is one of the major repositories of carbon in the world and, as such, it assumes an important place on climate change issues. Besides, it is recognized as the ecosystem with the biggest biodiversity in the world. As such, it has a value that goes far beyond the one reckoned by the farmers and squatters that use the land over there. Therefore, deforestation in the Amazon has been subject of concerns for a while. If one takes into account that the Brazilian part of Amazon is about 60% of the total, it is crucial to understand the causes of deforestation in Brazil in order to design public policies to reduce the global damages of Amazon deforestation.

Deforestation in the Amazon is deeply rooted in the process of land property accumulation that, in Latin America, is strongly correlated to rural conflicts and the pattern of colonization in the agricultural frontier. However, deforestation and rural conflicts tend to be dealt with in the literature in a separated way, neglecting the common feature that links both phenomena: the poor definition of property rights.

The literature on deforestation usually focuses on the economic causes of deforestation. On the one hand, there are perverse incentives caused by public policies aiming at the “development” of the region: fiscal incentives, credit subsidies, infrastructure investments, privatization “for free” of extensive public lands, etc. On the other hand, there are economic incentives provided by the increasing profitability of activities associated to deforestation (unsustainable logging, cattle ranching, cultivation), usually leading to land speculation processes that reinforce even further the process of land clearing (for example, Fearnside, 1992; Schneider, 1994; Ozorio de Almeida & Campari; 1995; Young, 1997; Margulis 2003).

One possible way to join rural conflicts and natural resource depletion in the same model is given by Hotte (2001). In this paper, a Stackleberg game is proposed, where each agent makes an effort to evict each other. The central argument in this paper is the role of distance to the state capital city, allegedly, where the courts are. It is shown that conflicts related to land property rights play a major role in the exhaustion of a natural resource.
However, in this model there is no place for the reverse effect. That is to say, the decision to exhaust the natural resource does not affect the result of the game.

Another model of rural conflict is presented by Alston et al (1999). The outcomes, violence and expropriation efforts, are result of a game played by farmers and squatters. The approach has something in common with Hotte (2001), but the focus is mainly on the effects of public policies to reduce rural conflicts, and deforestation plays no role in that model.

In this paper, we will use a modeling approach similar to Alston et al (1999, 2003), exploring the role of property rights for the preeminence of conflicts, but with the crucial difference of incorporating deforestation as a key issue for the results of the model. Put shortly, as property rights are not well defined *ex ante*, where the value of land is relatively high, there is a surge of violence associated with a “race for property rights”. These authors do not neglect these effects on forests. As it is clearly stated, “some landholders deforest as a means to better secure their land” (Alston et al, 20003, p. 22). Deforestation, in that case, represents an investment made by the landowner to improve her property rights. Thus, as proposed by Besley (1995), property rights are endogenous, what, as will be shown, is a central feature of our model.

Thus, this paper aims to reconcile theoretically and empirically these two distinct problems that commonly arise at the Brazilian Amazon. In order to attain its objective, the paper is organized as follows. In section 2, the related literature is brought out. It is shown that, although there is an extensive literature on deforestation and some on rural conflicts, few of them make the case of an intersection. In Section 3, a theoretical model is developed to investigate the relation between deforestation and conflicts. As property rights treated as endogenous and investments on clearing land increase property rights, deforestation has a central role in a model of rural conflicts. Section 4 presents the econometric tests and compares the results with the model’s predictions. Finally, in section 5, the main conclusions of this paper are presented.
II. Model

The model developed here draws heavily on Alston et al. (1999). As in that paper, it is a game between a farmer and a squatter. The agents choose the efforts levels $v$ and $s$, respectively that maximize their expected payoffs. After the characterization of the equilibrium, Alston et al (1999) make some static comparative exercises. They investigate the effects of land value, government will to land reform, level of property rights on the levels of violence offered by farmers and squatters. The approach here is similar. It is developed an analogous game between a farmer and a squatter. Nevertheless, a special assumption is added to the model: deforestation represents an initial investment in order to improve farmer's property rights. Thus, a two-stage game is developed. In the first period, the landholder decides the amount of land to be cleared. Given the deforested area, in the second stage, the agents decide how much of fight efforts to offer.

As Besley (1995) points out, there are three arguments for a positive link between land rights and investment decisions. Briefly, there is the security argument, the collateral-based view and the gains from trade perspective. This paper follows the security argument: deforestation is, sometimes, a defensive way to prevent the action of squatters. It is so because a plot of cleared land improves the chance to receive property rights and, therefore, reduces the chance of success by the squatters. On the other hand, a plot of land with better property rights has its value increased and, therefore, attracts the attention of squatters. There is, thus, a direct effect that makes deforestation attractive to squatters, and a strategic effect that may push them away.

II.1 Set up

Suppose, as Alston et al. (1999), that there are two identical agents that differ only in wealth: a farmer and a squatter. The farmer owns a plot of land and the squatter acts in order to expropriate the landowner’s farm.

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1 Note that the motivation by the squatter need not be related by the price of land. The motivation may be related to a higher agricultural or cattle raising profitability once the costs of clearing the plot of land have already been incurred by the farmer.

2 It will be shown latter under what conditions each effect prevails. This story is based on the taxonomy of business strategies as described in Tirole (1988).
The model is developed in two periods. At $t=1$, the farmer decides how much to deforest. Deforestation is seen as an investment made by the farmer to increase its land’s value. It can happen for a variety of reasons, e.g., deforestation increases the chance of acquiring *de jure* property rights, which make it easier and at a better price to transfer those rights. Another reason to consider an increase in deforestation to increase land’s value is related to the inability of the landowner, whoever she is, to internalize the environmental benefits of keeping the forest. That is to say, the possibilities of agricultural and/or cattle raising profits are much bigger than the profits associated with a model of sustainable extraction.

At $t=2$, both farmer and squatter decide how much effort, respectively $v$ and $s$, they should make, simultaneously, in order to evict/expropriate the opponent and keep the land. The efforts determine the probability $\beta$ the farmer has to keep her land and the probability $\theta$ the squatter has to expropriate the farmer. Besides the fight efforts, the probabilities are also related to the local level of governance. Thus,

$$\beta = \beta(v), \text{where } \frac{\partial \beta}{\partial v} > 0; \frac{\partial^2 \beta}{\partial v^2} < 0$$  \hspace{1cm} (1)

$$\theta = \theta(s), \text{where } \frac{\partial \theta}{\partial s} > 0; \frac{\partial^2 \theta}{\partial s^2} < 0$$  \hspace{1cm} (2)

Following Alston et al. (1999), the squatter’s and farmer’s valuation of land are: 0 and L (respectively, squatter and farmer) when the squatter is evicted and L and 0 when land is expropriated. The associated payoffs are

$$\Pi^S = \delta[(1 - \beta(v))\theta(s)R(D) - C^S(s) + \beta v]$$  \hspace{1cm} (3),

The squatter’s payoff is the discounted - by the discount factor $\delta$ – expected land value weighted by the probabilities of not being evicted and being successful in expropriation minus the costs associated with the squatter’s efforts and the wage, with her labor normalized at one, she gets if evicted by the landowner.
The farmer’s payoff is the profits she receives at the first period associated to the use of the cleared land plus the discounted expected value of land weighted by the probability of evicting and not being expropriated minus the costs of providing a violent response.

**II.2 – Equilibrium**

In equilibrium, both will decide the optimal degree of effort to be made. For, the first order conditions are:

\[ \Pi^F = R(D) - C^D(D) + \delta[\beta(v)R(D) + (1 - \beta)(1 - \theta(s))R(D) - C^F(v)] \]  

(4)

\[ \Pi_v^F = 0 = \delta[\beta_v \theta_L - C_v^F] \Rightarrow \beta_v \theta_L = C_v^F \]  

(5)

\[ \Pi_s^S = \delta[(1 - \beta)s_L - C_s^S] = 0 \Rightarrow (1 - \beta)s_L = C_s^S \]  

(6)

Unless the discount rate is infinite, what would drive \( \delta \) to zero, the farmer’s first order condition shows that her marginal benefit, weighted by the probability of expropriation, must equal the marginal cost of supplying a marginal unit of \( v \). For the squatter, the marginal benefit of increasing its effort \( s \), weighted by the probability of not being evicted, must equal its marginal cost.

As both farmer and squatter know each other payoffs, the probability functions, the result of their strategic behavior will be a Nash Equilibrium. The result is analogous to a Cournot game, where they choose their respective fight effort levels at the same time.

Under a Nash Equilibrium, the squatter’s best response \( s^* \) will depend on the farmer’s best response \( v^* \) and also the opposite holds. That is to say, there is a reaction curve that, given the opponent’s optimal behavior, the individual will decide its own optimal strategy. If each is playing an optimal strategy, the slope of the reaction curves can be obtained by differentiating, respectively, \( V^F_v \) and \( V^S_s \) with respect to \( s \) and \( v \). This yields:

\[ \frac{dV^F_v}{ds} = \frac{dV^S_s}{dv} \]
Proposition 1: A fight effort made by the squatter will result in an increased violence provided by the farmer, whereas an increase in fight effort made by the farmer will reduce the squatter’s response.

Proof:

Given that the denominators are negative, because of the second-order maximization conditions, the sign of the reaction curves’ slope will depend on the signs of $V^F_{ss}$ and $V^S_{ss}$. Thus,

\[ V^F_{ss} + V^F_{vv} \frac{\partial R^F}{\partial s} = 0 \]  \hspace{1cm} (7)

and

\[ V^S_{ss} + V^S_{sv} \frac{\partial R^S}{\partial v} = 0 \]  \hspace{1cm} (8)

Thus,

\[ \frac{\partial R^F}{\partial s} = -\frac{V^F_{ss}}{V^F_{vv}} \]  \hspace{1cm} (9)

and

\[ \frac{\partial R^S}{\partial v} = -\frac{V^S_{ss}}{V^S_{sv}} \]  \hspace{1cm} (10)

\[ V^F_{ss} = \delta \beta, \theta, L > 0 \Rightarrow \frac{\partial R^F}{\partial s} > 0 \]  \hspace{1cm} (11)

and

\[ V^S_{ss} = -\delta \beta, \theta, L < 0 \Rightarrow \frac{\partial R^S}{\partial v} < 0 \]  \hspace{1cm} (12)
This result, as remarked by Alston et. al. (1999), shows that the squatter’s fight effort is a strategical complement for the farmer and that the farmer’s fight effort is a strategical substitute for the squatter.

In order to improve her property rights over land, the farmer decides, at the first period, the amount of investment – deforestation in that case - she has to do to disincentive the squatter’s effort. Therefore, deforestation becomes a useful way to improve endogenously property rights. The next section analyses, thus, the effects of deforestation on the conflict outcome.

III.3 – Effects of deforestation on violence

After showing the slope of the reaction curves, Alston et al (1999) move on to investigate the effects of policy variables on rural conflicts. In this paper, it is, again, adopted a similar strategy. Nevertheless, besides being the analysis of exogenous policy variables, we move forward to understand how a decision made by the incumbent – the farmer – affects the supply of violence. That is to say, we compute $ds*/dD$ and $dv*/dD$. To find the values of $ds*/dD$ and $dv*/dD$, we must take the same approach utilized to find the slopes of the reaction curves: we must take the total derivative of, respectively $V_S^s$ and $V_F^v$, with respect to deforestation – $D$ – and solve the following system of equations:

\[
\frac{dV_S^s}{dD} = V_{sd}^s + V_{ss}^s \frac{ds^*}{dD} + V_{sv}^s \frac{dv^*}{dD} = 0
\]

\[
\frac{dV_F^v}{dD} = V_{vd}^v + V_{vv}^v \frac{dv^*}{dD} + V_{sv}^v \frac{ds^*}{dD} = 0
\]

Rearranging,

\[
\begin{bmatrix}
V_{ss}^s & V_{sv}^s \\
V_{vs}^v & V_{vv}^v
\end{bmatrix}
\begin{bmatrix}
\frac{ds^*}{dD} \\
\frac{dv^*}{dD}
\end{bmatrix} = - \begin{bmatrix}
V_{sd}^s \\
V_{vd}^v
\end{bmatrix}
\]

\[
\begin{bmatrix}
V_{sd}^s \\
V_{vd}^v
\end{bmatrix} = \begin{bmatrix}
V_{ss}^s & V_{sv}^s \\
V_{vs}^v & V_{vv}^v
\end{bmatrix}^{-1} \begin{bmatrix}
V_{sd}^s \\
V_{vd}^v
\end{bmatrix}
\]
With some algebraic manipulation, it can be shown that

\[
\begin{bmatrix}
\frac{ds^*}{dD} \\
\frac{dv^*}{dD}
\end{bmatrix} = \begin{bmatrix}
V_{sv}^F & -V_{sv}^S \\
-V_{sv}^F & V_{ss}^S
\end{bmatrix} \frac{[\begin{bmatrix}
-V_{vD}^S \\
-V_{vD}^F
\end{bmatrix}]}{|\text{det}|}
\]

which leads to the following proposition:

**Proposition 2:** An increase in deforestation at t=1 will lead to an increase in the farmer’s violence effort – \(v^*\) - to evict the squatter. On the other hand, the effect of an increase in deforestation upon the squatter’s effort – \(s^*\) - is ambiguous and its direction cannot be defined.

Proof:

\[
\frac{dv^*}{dD} = \frac{V_{sv}^F V_{sD}^S - V_{sv}^S V_{sD}^F}{|\text{det}|}
\]

As \(V_{sv}^F, V_{sD}^S > 0; V_{ss}^S < 0; V_{vD}^F > 0\) and the value of \(\text{det}\) is positive, it is clear that \(\frac{dv^*}{dD} > 0\).

\[
\frac{ds^*}{dD} = \frac{V_{sv}^S V_{sD}^F - V_{sv}^F V_{sD}^S}{|\text{det}|}
\]

As \(V_{sv}^S, V_{vD}^F < 0\) and \(V_{sD}^S, V_{vD}^S > 0\), both terms - \(V_{sv}^S V_{vD}^F\) and \(V_{sv}^F V_{vD}^S\) - will be negative and, then, the direction of \(\frac{ds^*}{dD}\) depends on the magnitude of the derivatives. Thus, if \(V_{sv}^S V_{vD}^F > V_{sv}^F V_{vD}^S\), or put differently, \(V_{sv}^S V_{sD}^F > V_{sv}^F V_{sD}^S\), the effect of an increase in deforestation made by the landowner on the effort provided by the squatter will be positive.

In the appendix, it is derived the relation that shows under which parameters it will be either positive or negative.

The logic is straightforward for the farmer’s response. If deforestation increases the value of her land, she’ll increase the efforts in order to maintain her tenancy. For the squatter, nevertheless, there are dubious effects: given that deforestation increases land value and that the squatter has a chance to expropriate the farmer, this creates an incentive to increase the squatter’s efforts. By the other hand, an increase in land value will result in a bigger...
violent response by the farmer. As farmer’s effort is a strategic substitute for the squatter, she should, thus, reduce her effort given an increased deforested plot of land.

IV – Violence and deforestation in the Brazilian Amazon: Empirical Analysis

IV.1 – Empirical Strategy

The theoretical model developed in the previous section treats deforestation as an investment in order to produce property rights. As such, the decision to clear land is based on the prospects of land value increase once property rights are acquired. As the land has its value increased, the landowner has more incentives to try to keep its ownership, which implies even the use of force for that. For the squatter, the deforestation she observes acts in a double sense: it attracts her efforts to expropriate the land, once its value has increased, but incurring in more risk given the violent response of the landowner. Therefore, the model predicts that deforestation results in an increase of possible violence by the landowner and a dubious effect on the squatter. Thus, depending on the final sign will depend on the squatter’s response.

The focus of this section is to analyze the interaction between deforestation and homicide rates in the Brazilian Amazon municípios between 2001 and 2006. Besides, the model also considers the impacts of cattle prices and agricultural wages.

Wages represent the cost of opportunity to the squatter: the greater the wage, it is less worth trying to expropriate the landowners. As cattle ranching is the main driver of the deforestation process (Margulis, 2003), the price of cattle is used as a proxy for the profitability of the landowner. Thus, this price must have a positive impact on violence, as it increases the violent efforts by both squatters and landowners.

In order to test whether the model’s predictions have value, it is constructed panel data model based on the informations of 588 brazilian municípios that are located at the Amazon. Certainly, many other factors have an impact on violence. In order to take account of it, some controls are considered in the empirical analysis.
IV.2 – Data description

An empirical test on the relation between rural violence and deforestation in the Brazilian Amazon was carried out using from 588 municípios of the following Amazonian states: Acre, Amapá, Amazonas, Mato Grosso, Pará, Rondônia, Roraima and Tocantins. The data considers the period between 2001 and 2006. Thus, it is developed as a panel data model in order to account for the relations established theoretically.

Homicide rates in each município were used as proxies for rural violence. This rate is the sum of homicides in a determined year divided by the population of the city. Although it doesn’t consider the difference between rural and urban violence, most of the population in the Region is rural, especially in the agricultural frontier. The quantity of rural conflicts, as published by the Comissão Pastoral da Terra, should be a more realistic proxy to rural violence is the Amazon. Nevertheless, as shown by Araujo et al (2009), homicide rates and rural conflicts are positively and significantly correlated. Thus, in this paper, we decided to use the homicide rates, because they are more widespread both geographically and temporally, allowing for a more complete panel. The data was collected at the site of the Health Ministry of Brazil.

The data on deforestation was collected at the Brazilian National Institute of Space Research (INPE), for the period between 2000 and 2007. Both the stock and the flow of deforested area were divided by the total area of the municipal unit. As such, it is an alternative to control for the total area instead of inserting that measure in the regression. In the regressions, we utilized the deforested area at the prevailing year. As the model predicts, the decision to clear additional land is what matters for the race for property rights.

The data on cattle and land prices and agricultural wages were collected at the Getúlio Vargas Foundation (FGV), between 2000 and 2007. These data are published at the state

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3 The state of Maranhão is also considered part of Legal Amazon. Nonetheless, it was not included due to lack of available information at the municipal level.

4 We consider land prices for cattle ranching activity, which are more related to deforestation than agriculture.
level. In order to produce a municipal vector, we divided the prices obtained by the distance to São Paulo and to the state capital, respectively.

As it was said before, we considered some variables as controls. The initial income distribution, as measure by the Theil index, the initial income per capita, the population density, distance to capital and initial deforested area were all used as controls. All these variables, except for the initial deforested area, were collected at the Institute of Applied Economic Research (IPEA).

Table 1 presents the descriptive statistics of the variables to be used in this paper.

Table 1 – Descriptive statistics

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>Median</th>
<th>Maximum</th>
<th>Minimum</th>
<th>Std. Dev.</th>
<th>Obs</th>
</tr>
</thead>
<tbody>
<tr>
<td>HOMICI_RATE</td>
<td>18.27</td>
<td>10.51</td>
<td>297.77</td>
<td>0.00</td>
<td>23.92</td>
<td>3528</td>
</tr>
<tr>
<td>DEFOREST</td>
<td>0.69</td>
<td>0.15</td>
<td>55.89</td>
<td>0.00</td>
<td>1.84</td>
<td>3528</td>
</tr>
<tr>
<td>PCATTLE</td>
<td>0.02</td>
<td>0.02</td>
<td>0.06</td>
<td>0.00</td>
<td>0.01</td>
<td>3264</td>
</tr>
<tr>
<td>PLAND</td>
<td>0.41</td>
<td>0.33</td>
<td>2.06</td>
<td>0.01</td>
<td>0.32</td>
<td>3360</td>
</tr>
<tr>
<td>WAGR</td>
<td>0.76</td>
<td>0.39</td>
<td>63.91</td>
<td>0.00</td>
<td>2.44</td>
<td>3444</td>
</tr>
<tr>
<td>INITIAL_AREA</td>
<td>21.57</td>
<td>7.07</td>
<td>95.86</td>
<td>0.00</td>
<td>27.27</td>
<td>3528</td>
</tr>
<tr>
<td>INCPC</td>
<td>143.63</td>
<td>124.88</td>
<td>514.43</td>
<td>34.53</td>
<td>75.54</td>
<td>3450</td>
</tr>
<tr>
<td>DIST_CAP</td>
<td>1050.39</td>
<td>927.50</td>
<td>5949.01</td>
<td>0.00</td>
<td>874.86</td>
<td>3450</td>
</tr>
<tr>
<td>DENSITY</td>
<td>15.91</td>
<td>3.18</td>
<td>2127.40</td>
<td>0.13</td>
<td>107.12</td>
<td>3450</td>
</tr>
<tr>
<td>INEQ</td>
<td>0.58</td>
<td>0.57</td>
<td>1.13</td>
<td>0.29</td>
<td>0.11</td>
<td>3450</td>
</tr>
</tbody>
</table>

IV.3 – Econometric model

The theoretical model predicts that, as deforestation represents an attempt to achieve property rights over the land, which increases its value, it must have a positive impact over violent efforts to evict (expropriate) squatters (landholders). Additionally, we consider other variables that should influence the decision to offer violence: cattle prices, land prices and agricultural wages. Both cattle and land prices affect the payoffs expected by landholders and squatters and violence should increase with them. As for agricultural wages, it represents an opportunity cost for the squatter. Therefore, it should be negatively related to the violence level. Thus, the model to be estimated can be represented by:

5 Cattle and land prices were divided by the distance to São Paulo because it is assumed to be the main market to cattle beef. Even if one assumes the great majority is exported, the southeast region, where São Paulo is located, has the main ports. Agricultural wages, by the other hand, were divided by the distance to the state capital because it is assumed that for this job market, the relevant decisions are local ones.
\[ \text{Homic}_{i,t} = \alpha + \beta_1 \text{Defor}_{i,t} + \beta_2 \text{PCattle}_{i,t} + \beta_3 \text{AgricWag}_{i,t} + \beta_4 \text{PLand}_{i,t} + \lambda_j X_{i,t} + \epsilon_{i,t} \]

(1)

Where Homic\_rate is the homicide rate, Defor is the deforestation rate, PCattle is Cattle Price, AgricWag is Agricultural Wages, PLand is Land Prices for cattle ranching and \(X\) is a vector with control variables.

A panel data model was developed, based on 588 municípios of eight Brazilian states between 2001 and 2006. Two estimation procedures were considered. First, it was used a simple panel data OLS model, with the addition of control variables described before. Then, it was used a panel data with fixed effects model. We introduced fixed effects both for the cross-sections and for the time period models. As the model deals with more than 500 cross-sections with so many different geographical and institutional characteristics, it is important to use fixed effects estimation in order to account for these particularities. Clearly, in that case, the time invariant variables need not stay; once their objective was exactly do take those particularities into account. As for the time fixed effects, the intention is to capture specific year related changes that are not related do deforestation, cattle prices and agricultural wages. It can be, for example, a new law on agrarian reform.

**IV.4 – Results**

Table 2 below shows the results with OLS, Fixed Effects (FE) and GMM estimation. Instead of using the price variables at the level, we chose to use them in differences. For, we also used a dynamic panel estimation based on orthogonal deviations\(^6\). It has been so for two reasons. Firstly, theoretically, it is assumed that individuals will respond with more or less violent efforts to changes in prices. Secondly, the results, albeit go in the same direction, have a much worse fit.

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\(^6\) According to Hayakawa (2009), the GMM estimator of the model transformed by orthogonal deviation tends to work better than the transformed by the first difference. Anyway, the results with first difference are quite similar.
Table 2 – Determinants of rural violence in the Brazilian Amazon: OLS, FE and GMM results

<table>
<thead>
<tr>
<th>Dependent Variable: Homic_rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Independent Variable</td>
</tr>
<tr>
<td>C</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Deforest</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>D(PCattle)</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>D(Wagr)</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>D(PLand)</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Initial Area</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Incpc</td>
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<tr>
<td></td>
</tr>
<tr>
<td>Ineq</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Density</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Dist_Cap</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Dist_Cap^2</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Homic_rate (-1)</td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>

Fixed Effects  | No | No | Yes* | Yes** | Yes** |
| R²             | 0.15 | 0.24 | 0.63 | 0.63 |  |
| Observations   | 2715 | 2715 | 2715 | 2715 | 2172 |

Note: Standard errors are in parentheses. *Indicates variables significant at 10% level, ** Indicates variables significant at 5% level and *** indicates variables significant at 1% level. + Model (3) has only cross-section fixed effects. ++ Models (4) and (5) have cross-section and period fixed effects.

The columns (1) and (2) report estimates of the OLS model, whereas column (3) and (4) report FE results, with cross-section; cross-section and period fixed effects, respectively. In column (5), we present GMM estimators.
In (1), all variables are statistically significant, although cattle prices and agricultural wages variations have unexpected signs. Deforestation, however, has a coefficient economically and statistically significant. The same applies for land prices changes.

Taking into account other factors specific to each município, as initial deforested area, initial inequality and income per capita, initial population density and distance to state capital increases the explanatory power of the model. Ideally, other variables of control should be included in order to take into account specific geographical and institutional factors that might affect rural violence. Even considering the vector of control variables described above, deforestation maintains its statistical and economical significance. It is worth noting that changes in cattle prices and agricultural wages resist with unexpected signs and that changes in land prices lost its significance. On the other hand, initial deforested area, income per capita, population density and distance to capital are all significant.

The positive impact of initial deforested area must be a sign that the “race for property rights”, represented by the process of deforestation, generates a weak governance structure. That is to say, municípios that were, initially (in 2000), more deforested have, on average, more violence. Given that, we control for population density, that result could be due to a lack of governance associated with the process of deforestation.

As the economy structure in the Amazon region is mainly based in agriculture and cattle ranching, initial income per capita reflects, in part, the same process of land occupation. Thus, as for initial deforested area, it should not be a surprise that initial income has a positive coefficient in the model above. Initial income inequality, nevertheless, has a positive but not statistically significant coefficient. Perhaps, it should be allowed for land inequality instead of income inequality, as it would be a more direct way to kink violence and the process of land occupation and its initial conditions.

The two remaining controls, population density and distance to state capital, have, both, statistical significance. In a vast and low inhabited area as it is Amazon, population density

7 Fajnzylber and Piquet (2001) present evidence that income has positive effects on crimes against property and negative on crimes against individuals. Although our model estimates income against homicide rates, it is assumed that these function as proxies to rural conflicts, which are addressed on properties.
might be a condition for the existence of violence. Some regions of Amazon are inhabited only by traditional communities. In these regions, there is a prevalence of small communities where local social organization is more commons than market-based. Deforestation-violence cycle only starts when the race for property rights is started caused by migrating wave coming from the agriculture frontier, commonly referred to as the “arc of deforestation”, or encouraged by infrastructure investments, in which the process for transforming the commons into privately owned properties.

Distance to capital - measured by cost of transportation to state capital - has a non linear effect: initially, violence should increase with distance because of reduced governance. Nevertheless, after some distance, the process of land occupation becomes non economically feasible and violence should be reduced. That is the reason for the quadratic and linear terms on the model. The negative and positive coefficients for quadratic and linear terms reassure the thesis that distance to market is associated to violence in the form of an inverted U shaped curve.

The model, when included the control variables, gains in explanatory power (R² from 0.15 to 0.24). Nevertheless, the municipios considered might have other important effects apart from those considered above. In this case, OLS estimators would be biased and inconsistent.

In order to take into account cross-sections specificities, we estimated a model using fixed-effects. Additionally, we introduced period fixed-effects. The regression (4) in table 1 reports results with both cross-section and period fixed-effects. The main difference from a model with only cross-section fixed effects – model (3) - is that coefficients on price changes vary significantly, especially PCattle and Wagr.

As expected, the model under FE explains much more of the variance in homicide rate than the OLS model (R² from 0.24 to 0.63). More interesting, however, is the fact that, in model (4), every coefficient presents the expected sign under FE estimation. Deforestation keeps with a positive and statistically significant coefficient, indicating that deforestation and violence are, indeed, associated in the Brazilian Amazon. An increase of one standard

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8 Estimated coefficients generate an inverted U shaped curve for the relevant range of the independent variable.
deviation on deforestation would result in an increase, on average, of 2.8 homicides in the homicide rate of municipios located at Legal Amazon.

The variation in cattle prices, under a FE estimation, becomes positively associated – and statistically significant - with the dependent variable, as predicted theoretically. A one percent increase in cattle prices average is associated with a 1.43% in homicide rates average, implying elasticity bigger than one for cattle prices. This result illustrates the importance and impacts of cattle ranching for the region (Margulis, 2003).

Though agricultural wages changes’ coefficient does not have statistical significance, its negative sign is in accordance with theoretical predictions. The same applies for the difference in land prices. As Ferraz (2001) argues, land prices may have a dual role in incentives. On the one hand, higher land prices decrease demand for land as an input for agriculture or cattle ranching. On the other hand, higher prices mean increased wealth and may attract both squatters and landholders, stimulating fight efforts. As have been seen from the estimates, which force prevails is not clear.

As for GMM estimation, the main results prevail. That is to say, deforestation and changes in cattle prices do have a statistically significant association with violence in the brazilian amazon.

IV.5 – Robustness checks

In order to check the robustness of our results, an additional model was estimated using random instead of fixed effects for specific cross-section and period level effects. According to Ferraz (2001) random effects models are more efficient, when its assumptions are satisfied, because they preserve more of the information in the data.

Table 3 presents fixed effects and random effects comparisons for the coefficients, based on model (4). As proposed in Hausman test, a statistically significant difference in the estimates is interpreted as evidence against the random effects (Woodlrdige, 2002).

<table>
<thead>
<tr>
<th>Variable</th>
<th>Fixed</th>
<th>Random</th>
<th>Var(Diff.)</th>
<th>Prob.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deforest</td>
<td>1.512</td>
<td>4.254</td>
<td>0.068</td>
<td>0.000</td>
</tr>
<tr>
<td>D(PCattle)</td>
<td>1209.506</td>
<td>-31.047</td>
<td>69256.224</td>
<td>0.000</td>
</tr>
<tr>
<td>D(PLand)</td>
<td>8.142</td>
<td>10.293</td>
<td>7.590</td>
<td>0.435</td>
</tr>
<tr>
<td>D(Wagr)</td>
<td>-0.019</td>
<td>1.611</td>
<td>0.092</td>
<td>0.000</td>
</tr>
</tbody>
</table>
As can be shown from table 2, estimates are statistically different, what, in addition to the result for the test-statistic for the Hausman test (equal to 186.2), the null hypothesis of zero correlation must be rejected. Therefore, the use of the fixed-effect model is more appropriate.

One problem that may arise with the use of panel data is that there may exist spatial and time-series autocorrelation. As the process of land occupation that affects rural violence is intrinsically geographical and temporal, it is possible that prior violence may affect current homicide rates in the same municipality and that rural violence in one place may affect homicide rates in neighboring municipalities.\(^9\)

In such a case, as remarked by Ferraz (2001), it is necessary to correct standard errors for heteroskedasticity, panel correlation and autocorrelation. Following Ferraz (2001), we present an alternative estimation method based on panel corrected standard errors (PCSE) methodology. Table 4 presents the same models estimated in Table 1, now accounting for corrected standard errors.

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\(^9\) Silva (2009) points to this problem in relation to the deforestation process.
Table 4 – Determinants of rural violence in the Brazilian Amazon: OLS/PCSE, FE/PCSE and GMM/PCSE results

<table>
<thead>
<tr>
<th>Dependent Variable: Homic_rate</th>
<th>Independent Variable</th>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
<th>(4)</th>
<th>(5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td></td>
<td>11.644</td>
<td>-6.536</td>
<td>17.059</td>
<td>17.493</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.50)***</td>
<td>(1.92)***</td>
<td>(0.48)***</td>
<td>(0.51)***</td>
<td></td>
</tr>
<tr>
<td>Deforest</td>
<td></td>
<td>7.986</td>
<td>5.902</td>
<td>1.188</td>
<td>1.512</td>
<td>1.378</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.64)***</td>
<td>(0.63)***</td>
<td>(0.54)**</td>
<td>(0.55)***</td>
<td>(0.64)**</td>
</tr>
<tr>
<td>D(PCattle)</td>
<td></td>
<td>-697.778</td>
<td>-18.167</td>
<td>298.573</td>
<td>1209.506</td>
<td>1252.515</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(311.91)**</td>
<td>(308.28)</td>
<td>(239.56)</td>
<td>(317.93)***</td>
<td>(335.69)***</td>
</tr>
<tr>
<td>D(Wagr)</td>
<td></td>
<td>3.260</td>
<td>1.596</td>
<td>0.735</td>
<td>-0.019</td>
<td>0.029</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.97)***</td>
<td>(0.52)***</td>
<td>(0.36)**</td>
<td>(0.38)</td>
<td>(0.38)</td>
</tr>
<tr>
<td>D(PLand)</td>
<td></td>
<td>27.481</td>
<td>1.319</td>
<td>7.055</td>
<td>8.142</td>
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<td></td>
<td></td>
<td>(6.30)***</td>
<td>(6.45)</td>
<td>(5.72)</td>
<td>(5.91)</td>
<td>(6.16)</td>
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<tr>
<td>Initial Area</td>
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<td></td>
<td></td>
<td>(0.02)***</td>
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<td></td>
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</tr>
<tr>
<td>Incpc</td>
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<td>0.100</td>
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<td></td>
<td></td>
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</tr>
<tr>
<td></td>
<td></td>
<td>(0.01)***</td>
<td></td>
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<td></td>
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<tr>
<td>Ineq</td>
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<td>2.223</td>
<td></td>
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<td></td>
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<tr>
<td></td>
<td></td>
<td>(3.36)</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Density</td>
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<td>0.009</td>
<td></td>
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</tr>
<tr>
<td></td>
<td></td>
<td>(0.00)***</td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>Dist_Cap</td>
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<td>0.005</td>
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<tr>
<td></td>
<td></td>
<td>(0.00)***</td>
<td></td>
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<td></td>
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<tr>
<td>Dist_Cap^2</td>
<td></td>
<td>-0.000001</td>
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<tr>
<td></td>
<td></td>
<td>(0.00)***</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Homic_rate (-1)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.019</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(0.08)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Fixed Effects</th>
<th>No</th>
<th>No</th>
<th>Yes*</th>
<th>Yes**</th>
<th>Yes***</th>
</tr>
</thead>
<tbody>
<tr>
<td>R²</td>
<td>0.15</td>
<td>0.24</td>
<td>0.63</td>
<td>0.63</td>
<td>2172</td>
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<tr>
<td>Observations</td>
<td>2715</td>
<td>2715</td>
<td>2715</td>
<td>2715</td>
<td>2715</td>
</tr>
</tbody>
</table>

Note: Standard errors are in parentheses. *Indicates variables significant at 10% level, ** Indicates variables significant at 5% level and *** indicates variables significant at 1% level. + Model (3) has only cross-section fixed effects. ++ Models (4) and (5) have cross-section and period fixed effects.

Basically, when one takes into account estimations with PCSE, the results remain the same. The only remarkable difference is that changes in agricultural wages gain statistical significance in equations (2) and (3).

Arguably, the results of the different models estimated point that deforestation and violence, proxied in this paper by homicides, are associated phenomena in the Brazilian Amazon.
V – Concluding remarks

Brazil has many challenges concerning the Amazon. Clearly, the most visible one is to halt the process of deforestation. Although the rates of deforestation have considerably diminished in very recent years, its fundamental causes are yet to be extinguished. After all, it derives from the historic process of land occupation in the region: as property rights are not well defined, deforestation arises as a measure to acquire property rights that could be efficient from the private perspective, but that causes profound social and environmental externalities.

The lack of a good structure of governance to reduce uncertainties regarding property rights is also a main cause for the region’s high rate of homicides. As there is not a good definition in relation to property rights, there is an incentive for different groups to organize in order to claim for land titles. Such a situation is prone to generate violent conflicts over land.

As the Brazilian legislation favors the “productive” (i.e., cattle ranching or cultivation) use of land when conceding land titles, and the conservation of native forests and associated ecosystem services are not yet recognized as productive use, the decision to clear land is strategical to acquire property rights. Thus, the decision to deforest arises as a rational response to the incentives provided by the institutional framework. Additionally, for the landholder, a cleared land signs to possible squatters that it is of her interest to keep the property, even with the use of force. On the other hand, squatters perceive deforested areas have more value than forested ones and, given their opportunity cost – agricultural wages -, they are also more prone to act violently in cleared lands.

It is this process of land occupation, based on poor property rights, that creates a positive association between deforestation and violence in the Brazilian Amazon. Clearly, it is a case of negative externalities where there is much room for efficiency gains. Thus, it is urgent to improve the design of the institutional framework in the region, mainly, reducing the incentives to clear land that are linked to a speculative behavior looking for land price increases.
VI – References


FGV, www.fgv.br, accessed 08/03/2009


INPE, Prodes: www.inpe.br accessed 03/03/2009.


