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Does Land Tenure Insecurity Drive Deforestation

in the Brazilian Amazon?

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Does Land Tenure Insecurity Drive Deforestation in the Brazilian Amazon?

Summary

The purpose of this paper is to highlight the detrimental impact of land tenure insecurity on deforestation in the Brazilian Amazon. It is related to recent controversies about the detrimental impact of land laws on deforestation, which seem to legitimize land encroachments. The latter is mainly the result of land tenure insecurity which is a key characteristic of this region and results from a long history of interactions between rural social unrest and land reforms or land laws. A simple model is developed where strategic interactions between farmers lead to excessive deforestation. One of the empirical implications of the model is a positive relationship between land tenure insecurity and the extent of deforestation. The latter is tested on data from a panel of Brazilian Amazon municipalities. The negative effect of land tenure insecurity proxied by the number of squatters on deforestation is not rejected when estimations are controlled for the possible endogeneity of squatters. One of the main policy implications is that ex post legalizations of settlements must be accompanied by the enforcement of environmental obligations.

Keywords: Deforestation, land tenure insecurity, squatters, panel data analysis, Brazil.

JEL Classification: Q23; Q15

1. Introduction

Deforestation rates of Brazilian Amazon in the last decades have been a growing environmental concern. According to official sources, between 1988 and 2008, average annual deforestation rates in Brazilian Amazon were 18.2 thousand square kilometer or 0.36 percent of her geographic area, approximately (INPE 2008). Though there was a significant decline since 2005, future trends will largely depend on the capability of Brazilian environmental policies to restrain the market forces driving the expansion of the agricultural frontier in the region.

Brazilian environmental policies have used a host of instruments to encourage forest preservation. Chiefly among them is a 1996 legislation that increased legally required reserve areas (*reserva legal*) in forest areas in Amazon from 50% to 80% of the agricultural establishments area (farms under 100 ha were exempted, however). Another policy instrument implemented was the establishment of several national parks and forests, extractivist and biological reserve areas, as well as the recognition of Indian territories, each of them subject to diverse kinds of restrictions in what concerns economic activities and their deforestation impacts. Apart from the efficiency considerations that can legitimately be raised, the government capability to enforce both regulatory instruments is weak when confronted with economic and political strength of the main drivers of deforestation (Alston & Mueller 2007).

The drivers of deforestation have been the subject of many theoretical and empirical studies (*e.g.* Andersen et al. 2002; Binswanger 1991; Margulis & Reis 1991; Pfaff 1999). The immediate causes of deforestation are usually related to the development of transport infrastructure and its impact on the profitability of agro-pastoral and logging activities. At broader levels, studies also highlight the roles played by macroeconomic factors like the economic growth performance, real exchange rates, and foreign debt (*e.g.* Arcand et al. 2008; Barbier & Burgess 2001; Foster & Rosenzweig 2003), as well as by structural factors such as demographic pressures, rural poverty and landownership concentration, among other factors (Barbier 2001; Andersen et al. 2002; Koop & Tole 2001; Walker et al. 2000).

Institutions and in particular weakly defined property rights in land are other structural factors that play a key role in the tropical deforestation process (Alston et al. 2000; Angelsen 1999; Angelsen 2007; Araujo et al. 2009; Deacon 1994; Mendelsohn 1994). The reason is that poorly enforced property rights discourage investments in long term assets such as forests which do not yield immediate returns. The land tenure insecurity makes agricultural land less subject to encroachment than forest areas, thus increasing rates of return in agricultural activities viz-à-viz sustainable exploitation of forests.

This paper analyzes the role played by land tenure insecurity on the process of deforestation of Brazilian Amazon. Section 2 describes the Brazilian Amazon institutional framework in what concerns the enforcement of property rights in land. In section 3, an heuristic model develops several consequences of land tenure insecurity on deforestation. In section 4, these consequences are corroborated on a panel data set constituted by the municipalities of the Amazon. Land tenure insecurity is a missing variable and thus the ratio of agricultural establishments hold by squatters over the total number of agricultural establishments is used as a proxy measure.

2. The Brazilian institutional background

The notion that technology and institutional arrangements in agrarian societies are determined by the relative scarcity of land and labor is a classical hypothesis in economics

(Domar 1970). The historical development of Brazilian agriculture is a fertile ground for this hypothesis (Reis & Reis 1988). Indeed, land abundance - defined both by the large availability of land in relation to population and by the open access to land property in frontier areas - was certainly one of the most important historical features shaping the technology and institutions of the Brazilian economy. Thus, the rise of Brazilian slavery in the 15th c. can be explained as the institutional solution which made feasible the emergence of a rentier class in a context of land abundance. Indeed, rent was derived from the ownership of labor, the scarce factor, not from land property. The elastic supply of African slaves up to the mid-19th c. led to the consolidation of a traditional plantation system based upon slash-and-burn shifting cultivation and the continuous incorporation of new lands. For the Brazilian agrarian structure one of the main consequences was the extreme concentration of landownership which persists up to present day. Correlated to that, landowners were able to secure the virtual monopoly of political power for at least three centuries (Carvalho 2006) and as a consequence, Brazilian legal tradition became extremely lenient with the appropriation of public lands and precluded most of the governments' attempts to demarcate regulate and enforce property rights in land. Property rights in land were largely established through non-market illegal mechanisms which in most occasions led to the use of individual coercion and violence (de Carvalho Franco 1969; Dean 1971; Dean 1997; Guedes 2006)

For the Brazilian environment, the outcome was the clearing of most of the Atlantic forest in the Northeast, South and Center-South regions of the country by the end of 19th c. (Dean 1997; Furtado 1971). The agricultural settlement of the Center-West and North regions bringing with it the deforestation of the Amazon forest was postponed to the second half of the 20th c. when the building of highways made feasible the inland connection with the rest of the country. In historical perspective, Amazon deforestation is thus the last stage of the expansion of the Brazilian agricultural frontier. Table 1 presents evidence on the evolution of the agrarian structure of Brazilian Amazon and its impact on deforestation since 1970. The figures show that most of the agricultural settlement of the region took place in the last 30 years. In 1970, the area under private farms represented only 12% and deforestation 7% of the geographic of the region. In the same years, almost 50% of the farm holders were squatters (*posseiros*) which had no legal land tenure whatsoever, while farm holders with property titles represented less than 27% of establishments. As the settlement of the region progressed the share of squatters naturally declined but, in 1996, they still represented 26% while proprietors represented 64% of farmers (Map 1). Regionally, squatters were quite important in the states of Maranhão, Amazonas and Acre where they represented, respectively, 43%, 33% and 30%. Figures in Table 1 also show that throughout the whole period landownership concentration was extreme with values of Gini coefficient close to 0.9.

Insert Table 1 and Map 1

At present, however, the region is still very much characterized by land abundance and an open access institutional context. According to IBGE, as late as 2006, as percent of the geographic area, private farms represented 25%; areas under legal protection of the federal or the state governments including units of conservation (national forests or parks, extractivist and ecological reserves, etc.) and Indian territories represented 29%; and the remaining 45% were public wastelands without any kind of demarcation or regulation of uses.

The Land Statute of 1964 (*Estatuto da terra*) gives the landless peasants the right to settle on undeveloped public or private lands. According to a subsequent law adopted in 1980, squatters who have been developing an area of land during five consecutive years without opposition of landowners can claim formal property title over this area. If squatters are evinced, they can obtain compensation on behalf of landowners for all improvements made to the lands. Moreover, the 1988 Constitution and the Agrarian Law of 1993 stated that unproductive establishments may be taken over and redistributed to landless and rural workers (Fearnside 2001). The Brazilian land reform institute (INCRA: *Instituto Nacional de Colonizaçao e Reforma Agraria*) is in charge of landowners' expropriation and land redistribution. Until the mid-eighties, land redistributions were scarce. They consisted mainly of installations of families on public lands within the framework of colonization projects. Land redistributions increased at the end of the eighties, and resulted mainly from squatters' invasions of large private holdings, rather than public lands, and ex post legalization. The number of expropriations and settlements by INCRA has been increasing significantly from the mid nineties with the development of occupations of large private landholdings by landless peasants organizations (Pacheco 2009) in particular the MST (*Movimento dos Trabalhadores Rurais sem Terra*).

This process of land redistribution generates land tenure insecurity on land plots that do not fulfill a socio-economic function especially on forestlands. Indeed, the 1988 Constitution does not provide a clear definition of underdeveloped land. In practice, forestlands are considered as unused so that landowners are encouraged to clear the forest to prevent squatters' invasions. Conflicts between landowners and squatters are exacerbated (Alston et al. 2000) and fuel deforestation.

3. An heuristic model of deforestation

We develop a heuristic model which proposes a plausible story of deforestation in an institutional context characterized by land tenure insecurity and open accessed land. This model adds to the substantial game theoretic literature modeling the "micro-level" drivers of deforestation.[1,2] A body of this literature establishes a link between agrarian structure and deforestation. Bulte et al. (2007) develop a lobbying model which explains how rural subsidies are bribed and favor large scale extensive agriculture thus leading to larger deforestation. Large scale extensive agriculture and deforestation may also be linked by insecure property rights. Angelsen studies strategic interactions in land appropriation between the State and local communities, as well as between farm holders (Angelsen 2001; Angelsen 2007). Hotte (2001) describes the conflict that arises between first settlers and contestants which expand agricultural land at the expense of forested areas. Another body of the literature draws on the analysis of decision-making in common-pool resources (Alix-Garcia et al. 2005; Ligon & Narain 1999).

Our heuristic model belongs to this literature, positing the existence of farmers competing for land holdings and taking into account the open access / common property character of forests and forest produces and local external effects generated by clearing activities as well.

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[1] Game theoretic macro-models of deforestation introduce players, i.e. northern and southern countries, which consider forest as a public good, derive different pay-offs from forest conservation and have to negotiate. These models are not discussed here; we rather concentrate on models where agents play at the local level. Examples of such game theoretic "macro-models" of deforestation are for example: Fredj et al. (2004); Martín-Herrán et al. (2006); Sandler & Sargent (1995)

[2] Angelsen & Kaimowitz (1999) provide a wide review of micro models of deforestation.

3.1 The setting of the game

The model is built on the intuition that farm holders i (i = 1, …, A) can claim a plot of forested area T^i. They can either clear and convert it for agriculture or cattle activities (N^i) or leave it as forested area (F^i).

$$T^i = F^i + N^i \tag{1}$$

The choice of N^i is influenced by the usual determinants of agricultural and cattle profitability such as prices and costs. Clearing forest especially in the Brazilian context, is also a way to enforce land property (Alston et al. 2000; Araujo et al. 2009) thus giving more incentives to forest clearing. Forest generates benefits while providing firewood or building materials, and non-timber forest products (NTFP) which can be considered as insurance substitutes (Delacote 2007). Forest benefits accruing to farm holders may also be described in terms of ecosystem benefits which are hardly divisible.

To formalize clearing behaviors it is posited that a farm holder chooses N^i considering other farmholders' forest clearing N^j ($j \neq i$) as given and maximizes his profit (π^i):

$$\max_{N^i} \pi^i = R^i\left(N^i, F; \theta\right) - C^i\left(N^i, \tilde{N}\right) \;\; \forall i = 1, \ldots, A \tag{2}$$

Such that equation (1) holds together with the following equalities: $\tilde{N} \equiv \sum_{j=1}^{A} N^j$ and $j \neq i$ and $F \equiv \sum_{i=1}^{A} F^i$. $\tilde{N}$ denotes the other agents' total forest clearing; F is the total amount of forest providing non divisible goods and services. R^i is the agricultural net receipt function; C^i represents forest clearing costs.

Parameter θ denotes all influences on forest clearing decisions: farm holder's factors or "environmental" factors. θ reflects (i) endowments in natural assets; (ii) institutional features that condition land property insecurity and (iii) economic factors that are related to state development level, federal macroeconomic policies and international factors that influence agricultural profitability as well. When considering the total amount of land i.e. $T \equiv \sum_{i=1}^{A} T^i$ equation (2) becomes:

$$\max_{N^i} \pi^i = R^i\left(N^i, T - N^i - \tilde{N}\right) - C^i\left(N^i, \tilde{N}\right) \qquad \forall i = 1, \ldots, A \tag{3}$$

Such that equation (1) holds.

3.2 Forest clearing external effects

The receipt function $R^i(.)$ depends positively on cleared areas catching positive and non increasing marginal agricultural profits: $R_N^i > 0$ and $R_{NN}^i \leq 0$. Natural forest also maintains soil fertility of cleared areas through nutrient, micro-climate, hydrological - purification of water, soil moisture - effects as well as pollinations (Durieux et al. 2003; Moegenburg & Levey 2002; Peters et al. 1989; Rodrigues et al. 2009). Consequently the receipt function $R^i(.)$ of agent *i* depends positively on forested areas: $R_F^i > 0$.

Deforestation, however, can generate externalities in specific contexts. When agents cut forests, natural forest becomes scarcer and its value or implicit price increases: $R_{FF}^i \leq 0$. It is a "natural forest scarcity effect"[1] which reduces all agents' incentives to cut the forest.

[1] Natural forest scarcity effects are also alluded as forest ecosystem effects (Rodrigues et al. 2009; Satake et al. 2007)

Moreover, algebraically, the following equality holds $R^i_{F\tilde{N}} = R^i_{FN} = -R^i_{FF}$ which may be given additional pieces of explanation. For example, maintaining forested areas in upper lands, benefits to farm holders in lower lands, either individually i.e. $R^i_{N^iF} \geq 0$ or collectively i.e. $R^i_{\tilde{N}F} \geq 0$. We can therefore interchangeably consider the following agricultural receipt cross derivatives: $R^i_{F\tilde{N}} = R^i_{FN} = -R^i_{FF} \geq 0$.

The cost function $C^i(.)$ represents forest clearing costs of agent *i*. It is assumed to behave the usual way with respect to its own level of deforestation i.e. be twice differentiable, increasing, and convex in forest clearing:

$$C^i_N > 0\,,\ C^i_{NN} \geq 0 \qquad \forall i\ = 1\ldots A \tag{4}$$

The cost function not only depends on the agent's own deforestation level but also on the other players' one. Their effects are given by $C^i_{N\tilde{N}}$ which is the second cross derivative between agent's *i* forest clearing and other agents' forest clearing. When a farmer starts clearing the most profitable plots of land, he generates an "agricultural land scarcity effect" (Angelsen 1999) which rises up agent *i*'s clearing costs: $C^i_{N\tilde{N}} \geq 0$. Profitable agricultural areas are scarce since their availability depends on infrastructure provision, cleared land natural fertility, importance of flooding areas, or prevalence of diseases as well.[2]

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[2] This scarcity effect may however be contradicted by a "frontier effect". Indeed, it can be argued that deforestation facilitates encroachments of other agents into the natural forest thus generating a local positive externality for agent *i* whose clearing costs are reduced: $C^i_{N\tilde{N}} \leq 0$. Bringing new plots into cultivation induces investments in transport infrastructures of which

3.3 Equilibrium

Let us consider the first-order necessary (FONC) and second order sufficient (SOSC) conditions for profit maximization for the agent *i* assuming that there exists a unique interior solution:[3]

FONC: $R_N^i\left(N^i,F\right)-R_F^i\left(N^i,F\right)-C_N^i\left(N^i,\tilde{N}\right)=0$ (5)

SOSC: $R_{NN}^i\left(N^i,F\right)-2R_{FN}^i\left(N^i,F\right)+R_{FF}^i\left(N^i,F\right)-C_{NN}^i\left(N^i,\tilde{N}\right)<0 \Leftrightarrow$

$R_{NN}^i\left(N^i,F\right)+3R_{FF}^i\left(N^i,F\right)-C_{NN}^i\left(N^i,\tilde{N}\right)<0$ (6)

The first two terms of the first order condition (equation 5) give the agricultural receipt of an extra unit of cleared forest. It is equal to the difference between the marginal agricultural profit and the marginal receipt of natural forest. This difference is assumed to be positive. The third term is the marginal cost of forest clearing.[4]

The FONC shows that there exists an implicit relationship between the deforestation of agent *i* and the deforestation of other agents written: $N^i=G^i\left(\tilde{N}\right)$ where G^i is the response

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costs are shared by local authorities or by the State. The story of Brazilian agrarian institutions and deforestation may justify that the frontier effect first dominated but progressively vanished with respect to the agricultural scarcity effect.

[3] If N^i maximises π^i, then a global and unique maximum is reached provided that the objective function is strictly concave. Moreover, it is assumed that an interior solution is obtained i.e. equation (1) holds.

[4] In other words the marginal profit of clearing is equal to the natural forest's implicit price which can be considered as a hotellinian scarcity rent: $R_F^i\left(N^i,F\right)=R_N^i\left(N^i,F\right)-C_N^i\left(N^i,\tilde{N}\right)>0$.

function of agent *i*. The existence of G^i is guaranteed by the SOSC (equation 6) and the implicit function theorem. The slope of G^i is obtained after totally differentiating the FONC:

$$\frac{dN^i}{d\tilde{N}} = \frac{R^i_{NF}\left(N^i, F\right) - R^i_{FF}\left(N^i, F\right) + C^i_{N\tilde{N}}\left(N^i, \tilde{N}\right)}{R^i_{NN}\left(N^i, F\right) - 2R^i_{FN}\left(N^i, F\right) + R^i_{FF}\left(N^i, F\right) - C^i_{NN}\left(N^i, \tilde{N}\right)} \tag{7}$$

The latter equation simplifies into:

$$\frac{dN^i}{d\tilde{N}} = \frac{-2R^i_{FF}\left(N^i, F\right) + C^i_{N\tilde{N}}\left(N^i, \tilde{N}\right)}{R^i_{NN}\left(N^i, F\right) + 3R^i_{FF}\left(N^i, F\right) - C^i_{NN}\left(N^i, \tilde{N}\right)}$$

The sign of the denominator is negative (SOSC). Thus, the slope of the response function depends on the sign of the numerator:

$$sign\frac{dN^i}{d\tilde{N}} = -sign\left(-2R^i_{FF}\left(N^i, F\right) + C^i_{N\tilde{N}}\left(N^i, \tilde{N}\right)\right)$$

The numerator is positive when scarcity effects are taken into account. In that case, the response function is downward sloping: the more the other agents clear the forest, fewer agents *i* clear. Forest clearing decisions are strategic substitutes.

Insert Figure 1

3.4 Discussion

Static comparative exercises are with respect to A and θ. The symmetric equilibrium is located in C (Figure 1) where the response function of the player i $G(\tilde{N})$ intersects the symmetric condition line A = 1, 2… where: [5]

$$N^i = \frac{1}{A-1}\left(\sum_{j=1}^{A} N^j\right) \quad \forall i = 1,\dots,A \text{ and } j \neq i \qquad (8)$$

When the number of farm holders A increases, the symmetric condition line rotates clockwise around O. Hence, the Cournot-Nash deforestation rate equilibrium is a positive function of the number of farm holders or agricultural establishments.[6] This result mimics the classical finding of the literature according to which overexploitation of an open access resource is exacerbated by the number of agents in competition (*e.g.*Cornes & Sandler 1996).[7]

Moreover, forest clearing depends on θ :

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[5] Under the assumption that the players share the same characteristics, the unique Cournot-Nash symmetric equilibrium is stable when the slope of the response function of the agent i is less than 1 in absolute value (sufficient condition, *e.g.*Tirole 1990, p.220).

[6] The unique Pareto optimal solution is independent of the distribution of the deforestation rate between the farm holders and of the number of farm holders. Hence, the optimal solution is the curve EE' of which slope is –1 (Figure 2).

[7] This expression is preferred to the so-called Tragedy of the Commons (Hardin 1968). See for instance: Baland & Platteau 1996; Bruce 1998; Feeny et al. 1990

$$\frac{dN^i}{d\theta} = \frac{-R^i_{N\theta}(N^i, F) + R^i_{F\theta}(N^i, F)}{R^i_{NN}(N^i, F) - 2R^i_{FN}(N^i, F) + R^i_{FF}(N^i, F) - C^i_{NN}(N^i, \tilde{N})} \text{ thus}$$

$$sign\frac{dN^i}{d\theta} = -sign\left(-R^i_{N\theta}(N^i, F) + R^i_{F\theta}(N^i, F)\right)$$

θ represents among other factors land tenure insecurity. It is assumed here that property rights insecurity which can either decrease marginal receipts generated by forested areas i.e. $R^i_{F\theta}(N^i, F) \leq 0$ or increase marginal agricultural receipts $R^i_{N\theta}(N^i, F) \geq 0$ as well. In the Brazilian context, an increase in land tenure insecurity creates additional forest clearing incentives. Put differently, an increase in land tenure insecurity decreases the marginal receipts of forested areas with respect to agricultural ones. Forested lands are more subject to land invasions than agricultural ones. In brief, θ catches the effects of land distribution on forested areas that have been considered as underdeveloped areas. [8]

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[8] This static comparative exercise allows taking into account the effect of development levels measured by gross domestic products. During the first stages of development, an increase in gross domestic products which is represented by an increase in θ, is detrimental to natural forests since the demand for agricultural products is important: $R^i_{N\theta}(N^i, F) \geq 0$. Afterwards, an increase in gross domestic products favours the demand for environmental services generated by forests: $R^i_{F\theta}(N^i, F) \geq 0$.

4. Assessing the influence of squatters on deforestation: econometric analysis of Amazon deforestation

4.1 Data set and variables

The main sources of data are the agricultural censuses (*Censo Agropecuario*) realized in 1985 and 1995 by the Brazilian Institute of Geography and Statistics (IBGE: *Instituto Brasileiro de Geografia e Estatistica*). The data are collected for each agricultural establishment which can be a household or a firm, private or public, with different land tenure status: landowner, tenant, sharecropper or squatter. Data are aggregated at the municipal level and the sample used in the econometric analysis is restricted to the municipalities of the Amazon.[9] Changes in the number and area of municipalities required to group the 763 municipalities in 258 Minimum Comparable Areas (MCA) for consistent comparisons in time. The panel set is thus constituted by 516 observations.

Following Andersen et al. (2002), the proxy for deforestation is the land cleared for agro-pastoral purposes. Cleared land is measured as the areas used by the agricultural establishments for annual or perennial crops, planted forests or pastures, short and long fallows. The remaining areas are considered as non cleared: natural forests, natural pastures, non usable lands. Cleared land is divided by the MCA area (*cleared land*) and is presented in Table 2. The most deforested areas are located in the states of Goias, Tocantins, Maranhao

[9] To be precise the sample of municipalities used refer to the so-called Brazilian Legal Amazon which is an administrative area defined for regional development purposes including the states of Rondonia, Acre, Amazonas, Roraima, Para, Amapa, Tocantins, Mato Grosso, and parts of Maranhão and Goias (a very small part in the latter).

and Mato Grosso which cover the "arc of deforestation" along the southern and eastern edges of Amazon. [10]

[Insert Table 2]

The explained variable is *Cleared land*. From the heuristic model presented above, the number of agricultural establishments in the MCA (*Nbets*) and the ratio of agricultural establishments hold by squatters over the total number of agricultural establishments (*Squatters*) have a positive impact on deforestation. Control variables can be added such as the real gross domestic product per capita (*Gdpp*) and its square. This specification is consistent with a deforestation Kuznets curve (Barbier & Burgess 2001; Barbier 2004). Gross domestic product is estimated by the Institute for Applied Economics Research (IPEA: *Instituto de Pesquisa Economica Applicada*). The GDP data are expressed in 2000-Reais using the national accounts implicit GDP deflator.

The econometric estimation is driven in three steps of which results are presented in

[10] Only 79% of Amazon is naturally forested (*cf.* Andersen et al. 2002, chap.2). For instance, in the southern and eastern parts of Amazon, the land is naturally covered with savannah and agricultural conversion cannot be considered as deforestation. To deal with this potential source of bias another measure of deforestation is used. *Cleared land* is weighed by the share of naturally forested land in each municipality (*corrected cleared land*). Municipalities that are not naturally forested are excluded from the sample. The naturally forest cover data come from IBGE. Naturally forested land are areas of low density forests, seasonal forests, dense forests, river banks, mangroves and swamp forests. Econometric results are available upon request.

Table 3: (i) Ordinary Least Squares estimation (OLS – column 1) where all observations are pooled; (ii) Panel Least Squares estimation (PLS – column 2) with double fixed effects that control for municipal and temporal heterogeneities and (iii) Panel Two-Stage Least Squares estimation (PTSLS – columns 3 to 5) with double fixed effects and a control for the endogeneity of *Squatters*.

4.2 Results

Insert Table 3

The OLS estimation (Table 3: 1) displays a negative and significant correlation between *Cleared land* and *Squatters*. Two sorts of biases can however be suspected. Significant explanatory variables which also affect *Squatters* might be omitted. For example, economic policies changes at the federal level (liberalization of the agricultural sector) or international price variations may have an impact both on deforestation and on the number of squatters. Moreover time invariant municipality characteristics (geographical and physical) may also affect both *Cleared land* and *Squatters*.

The PLS estimation (Table 3: 2) includes MCA and temporal fixed effects that are jointly significant. The coefficient of *Squatters* is not statistically different from zero. This result suggests that the OLS estimation bias induced by omitted variables is negative. There may be a positive correlation between the number of squatters and the distance of the municipality from the main urban centers. Indeed it may be easier for squatters to claim land in remote areas where land is cheaper and property rights harder to enforce. In the same time, the profitability of deforestation decreases with the distance from the main urban centers (Alston et al. 1996).

The PLS result could be the consequence of the endogeneity of *Squatters* which is dealt with the PTSLS estimator. This instrumental variable estimator is justified in three ways: (i) *Squatters* is only a proxy variable of land tenure insecurity. Hence, the induced attenuation bias must be corrected by using instrumental variable. (ii) The instrumentation also protects against the consequence of omitted variables which are correlated with the number of squatters. For instance, squatters may be characterized by a high time preference that could fuel deforestation. (iii) A simultaneous bias can affect the OLS estimations. They may be more difficult for squatters to settle in a municipality where deforestation has been more intense insofar as land property rights are more secure on agricultural lands.

Squatters is instrumented by the number of agricultural establishments owned by churches (*Church*) and by public entities (*Public*) divided by the total number of agricultural establishments in the MCA. The *Church* variable is considered as a proxy of the influence of the church in the MCA. In Brazil, churches and especially the Catholic Church play an active role in defending the interests of landless people (Carter 2002). In 1975, the Catholic Church created the Pastoral Land Commission (CPT: *Comissão Pastoral da Terra*), which supports the action of various landless movements. The CPT defends the land reform, denounces landowners' violence against squatters and provides material and legal assistance to squatter camps. In 1984 CPT actively participated to the foundation of the Brazil's Landless Workers Movement (MST).

The instrumental equations (Table 4) highlight the positive and significant effect of *Church* and *Public* on *Squatters*. It is assumed that public and churches' establishments have the same technology and incentives to clear the forest as other agricultural establishments. The *Church* variable is thus considered as a pertinent instrument which only has an indirect effect on deforestation through the *Squatter* variable.[11] Concerning the *Public* variable, it is assumed that the enforcement of property rights in public establishments is weaker than in private ones. Public establishments are potentially more the subject of squatters' invasions since public lands are usually considered as underprotected.

[Insert Table 4]

The Nakamura and Nakamura test (Table 3: 3 to 5) rejects the exogeneity of *Squatters* and the test of Sargan (Table 3: 5) does not reject the null hypothesis that the overidentification restriction is valid. The partial Shea-Godfrey R^2 excludes the weak instruments bias.

The effect of *Squatters* on deforestation in the PTSLS equations (3) and (5) becomes positive and significant whatever the instrument list. The magnitude of the marginal impact of *Squatters* on deforestation is different according to the instrument list but remains positive and significant. Deforestation responds strongly to a decrease in the relative importance of the squatter ratio with an elasticity calculated of 0.82 between 1985 and 1995

The theoretical model also predicts a positive relationship between the number of agricultural establishments (*Nbets*) and *Cleared land*. The estimated elasticity of deforestation with respect to the number of agricultural establishments lies between 0.44 and 0.59. The

[11] It can be noticed that there is no statistical link between the density of population and the relative number of church owned agricultural establishments. Hence, this instrument does not catch a demographic effect and (or) an urbanization effect on deforestation. Moreover the church and public variables cannot be suspected to be correlated with squatters' characteristics.

control variables Log(*Gdpp*) and Log$(Gdpp)^2$ deliver a non linear effect of the development level of the MCA on deforestation. The turning point is relatively high and only 7% of the observations are located beyond it. This result does not differ from existing empirical literature which generally refers turning point estimates that are significantly higher than average incomes (Barbier & Burgess 2001). For most observations, an increase in *Gdpp* has a positive impact on deforestation: a 1% increase in *Gdpp* implies a 0.39% increase in deforestation. This positive impact can be interpreted as the consequence of the improvement in infrastructures that is tightly correlated with economic development, especially in Brazil (*e.g.* Andersen et al. 2002).[12]

In Amazon, cattle ranching is considered as a main factor of deforestation and an increase in the profitability of this activity is expected to promote deforestation. The cattle price is introduced in the PTSLS equation (Table 3: 4) to take this effect into account. This price is supposed to be exogenous *i.e.* local markets are supposed to be integrated to the national market. In this case, controlling for the double fixed effects implies that the variability of cattle prices catches idiosyncratic transaction costs, *e.g*. transport costs, between local exporting markets and a central market. A cattle price increase thus corresponds to a decrease in transport costs that generates an increase in the profitability of cattle ranching and favors deforestation. The variable Log(*cattle price*) has a significant and positive impact on deforestation and does not affect the other coefficients.

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[12] Deforestation may generate income streams that are taken into account in GDP measures. Nevertheless, gross domestic products depend on the overall economic activity. We thus assume that the exogeneity of *Gdpp* may be a reasonable hypothesis when pertinent instruments are missing.

5. Concluding remarks

This paper analyses the effects of land tenure insecurity on the process of deforestation of Brazilian Amazon. Land abundance, squatter settlements, and landownership concentration coupled with land tenure insecurity, violence and deforestation, are deep rooted institutional features of Brazilian history. In recent decades, the picture was aggravated by land reform initiatives taken by the governments and the political mobilization of landless peasants. The last stage is the Amazon frontier where, on top of the equity issues, trade offs are aggravated by environmental concerns. The main thesis of this paper is that deforestation is dramatically featured by the land tenure insecurity. A simple model is derived from this peculiar institutional framework. The decisions of agents are modelled in a game theoretic framework characterized by strategic substitutability in deforestation decisions. The main econometric result is obtained on a municipal panel data set where land tenure insecurity is approximated by the number of squatters. Taking into account the potential endogeneity of this variable, our result corroborates the detrimental effect of land tenure insecurity on deforestation in the Brazilian Amazon.

The theoretical framework is obviously a simplification of complex relationships between numerous factors involved in the deforestation process. However the results evidence a limit of the Brazilian state-led land reform which can raise environmental concerns. Though land reform may be promoted on equity and efficiency grounds, a legal framework which implicitly recognizes deforestation as a proof of land development is socially costly. Environment preservation imposes to recognize that natural forest is not an “ineffective” use of land. Until recently however some mechanisms contained in new land regulations of 2009 seem to impediment conservation incentives: they allow among other things that maximum sizes of ex post legalization of land is extended from 100 to 1,500 hectares or that 3 years after legalization, lands over 400 hectares can be sold, thus fueling the land market and thereby deforestation.

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7. Tables, Maps and Figures

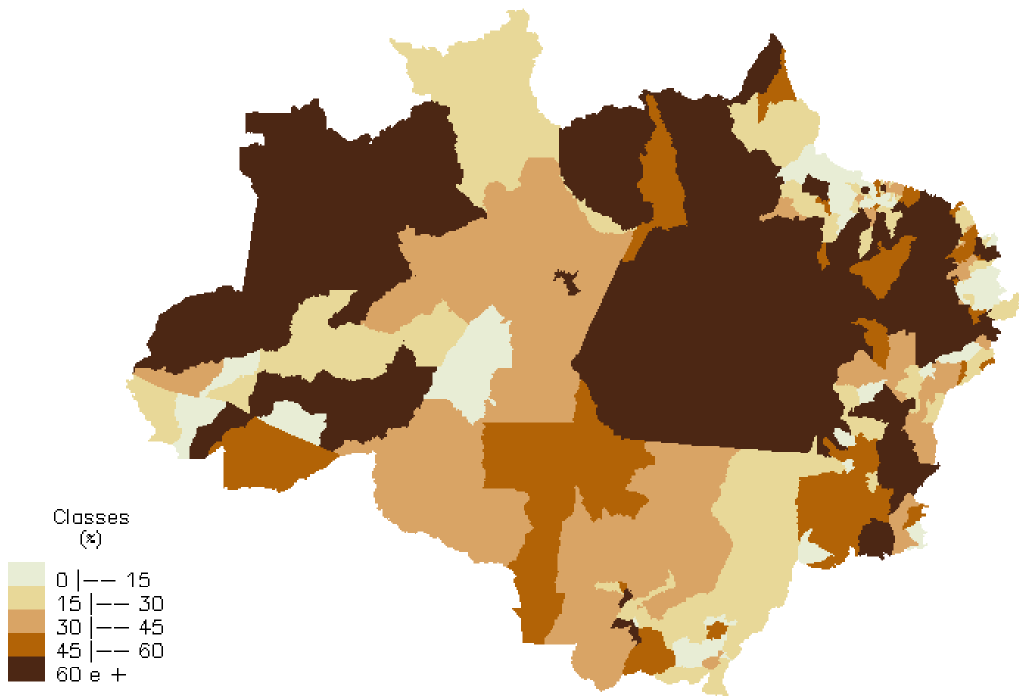
Table 1. Evolution of the agrarian structure and deforestation from 1970-2006 in Brazilian Amazon: Evolution of the agrarian structure and deforestation from 1970-2006

Year	*Number of farms*	*Farm area (% of geographic area)*	*Deforested area (% of geographic area)*	*Forest area inside farms (% of geographic area)*	*Number of squatter farms (% of farms)*	*Gini index of farm size*
1970	673,715	12.2	7.0	4.6	47.8	0.90
1975	851,463	15.5	8.5	7.0	49.1	0.92
1980	920,399	20.5	11.3	9.2	39.5	0.90
1985	1,059,274	22.7	12.4	9.2	34.6	0.89
1995	822,488	23.8	13.1	9.9	26.1	0.88
2006	na	25.0	15.2	9.3	na	na

Source: IBGE

Map 1. Number of agricultural establishments hold by squatters in Brazilian Amazon, 1970 and 1995, percentages

NUMERO DE ESTABELECIMENTOS – OCUPANTE
1970



NUMERO DE ESTABELECIMENTOS – OCUPANTE
1995

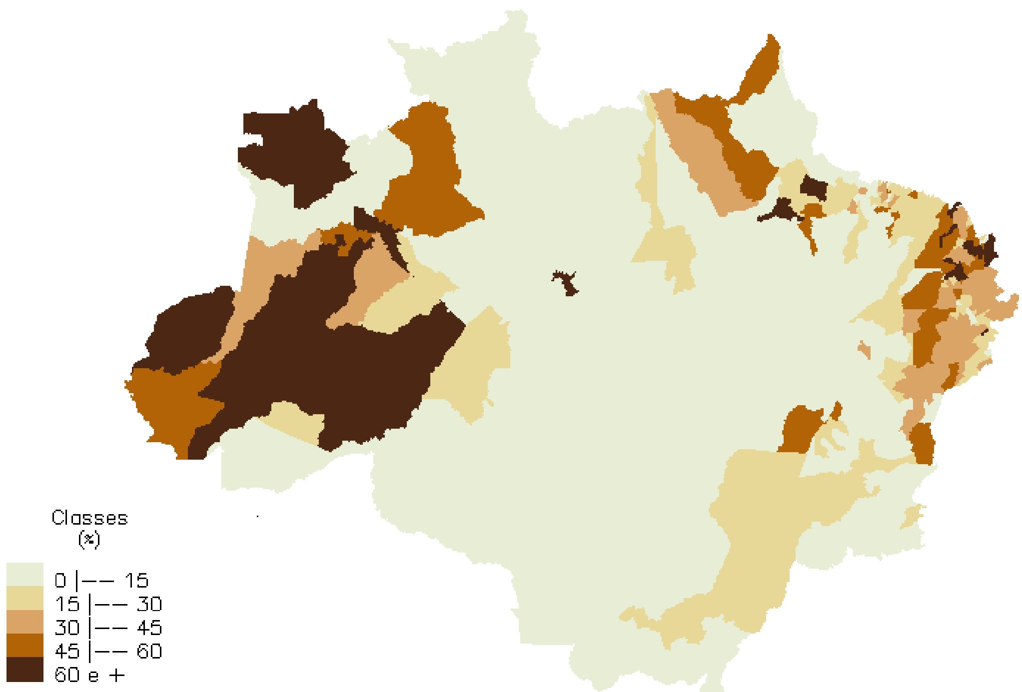


Table 2. Cleared land in percentage of the state area (*cleared land*)

	1970	*1975*	*1980*	*1985*	*1995*
Acre	1	1	3	3	5
Amazonas	0	1	1	1	0
Amapa	0	1	1	2	1
Goias	21	35	46	48	54
Maranhao	16	19	26	29	21
Mato Grosso	3	6	10	13	22
Para	3	3	6	7	7
Rondonia	2	2	4	7	17
Roraima	0	0	1	1	3
Tocantins	9	12	17	22	26
Total BLA	3	4	6	8	10

Source: IBGE

Table 3. Estimation results (explained variable: Log[*cleared land*])

	OLS (1)	*PLS* (2)	*PTSLS* (3)	*PTSLS* (4)	*PTSLS* (5)
Constant	-2.71***	-6.91***	-6.53***	-6.18***	-6.86***
	(-4.28)	(-8.44)	(-7.85)	(-5.78)	(-8.61)
Log(Nbets)	0.21**	0.61***	0.44***	0.34**	0.59***
	(2.54)	(5.44)	(3.61)	(2.20)	(5.42)
Squatters	-3.29***	0.13	2.88***	3.65***	0.50**
	(-8.84)	(0.57)	(2.97)	(2.56)	(2.31)
Log(Gdpp)	-0.47**	0.28***	0.39***	0.43***	0.29***
	(-2.44)	(3.13)	(3.66)	(3.72)	(3.26)
Log(Gdpp)²	0.06	-0.12***	-0.13***	-0.16***	-0.12***
	(0.60)	(-2.92)	(3.36)	(-3.01)	(-3.06)
Log(cattle price)				0.43**	
				(2.06)	
Number of observations	516	516	516	472	516
Adjusted R²	0.17	0.91	0.85	0.78	0.91
Cross-section/Period		Yes	Yes	Yes	Yes
Fixed effects (F) P-value		(0.00)***	(0.00)***	(0.00)***	(0.00)***
Instrument list			Log(Nbets) Log(Gdpp) Log(Gdpp)² Church	Log(Nbets) Log(Gdpp) Log(Gdpp)² Log(cattle price) Church	Log(Nbets) Log(Gdpp) Log(Gdpp)² Church Public
Exogeneity test (P-value)			0.0001 ***	0.00 ***	0.06 *
Shea-Godfrey partial R^2			0.40	0.40	1.05
Overidentification test (P-value)					0.91

t-statistics (in parentheses) are robust to observation specific heteroskedasticity in the disturbances (White diagonal correction). *: significant at 10 % level; **: significant at 5 % level; ***: significant at 1% level

Table 4. Instrumental equations (explained variable: *Squatters*)

	PLS	*PLS*
Constant	-0.13 (-0.67)	0.00 (0.02)
Log(Nbets)	0.06** (2.21)	0.03 (1.53)
Log(Gdpp)	-0.04 (-1.59)	-0.03 (-1.43)
Log(Gdpp)²	0.00 (0.40)	0.00 (0.02)
Church	2.63*** (4.39)	2.28*** (3.83)
Public		0.91*** (15.14)
Cross-section and period Fixed effects	Yes	Yes
Number of observations	516	516
R^2	0.77	0.88

t-statistics (in parentheses) are robust to observation specific heteroskedasticity in the disturbances (White diagonal).

Figure 1. Farm holder *i*'s response function with negative externalities (scarcity effects)