LAND REFORM AND DEFORESTATION IN THE BRAZILIAN AMAZONIA

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APRESENTAÇÃO ORAL

Agropecuária, Meio-Ambiente, e Desenvolvimento Sustentável

# Land reform and deforestation in the Brazilian Amazonia

### Grupo de Pesquisa: Agropecuária, Meio-Ambiente e Desenvolvimento Sustentável

**Resumo**

No processo de reforma agrária brasileiro é comum a redistribuição de terra ocorrer por meio de invasões das grandes proprieades pelos sem terra. Esse mecanismo introduz insegurança no direito de propriedade fundiária e, na Região Amazônica, tem como consequência o excesso de desflorestamento. Esse trabalho utiliza um jogo não-cooperativo para mostrar que as interações estratégicas entre proprietários e posseiros em um contexto instittucional onde as florestas naturais são consideradas como recursos de livre acesso implicam o excesso de desflorestamento. A principal implicação analítica do modelo é que a taxa de desflorestamento de determinada área tende a aumentar com o número de posseiros na área. Essa implicação é confirmada quando testada em um painel de dados censitários municipais da Amazônia brasileira no período 1970-96 e esse resultado se mantem mesmo quando se controla o problema da endogeneidade do número de posseiros na especificação de uma equação de desflorestamento. Da perspectiva ambiental, portanto, o resultado permite questionar os mecanismos utilizados pelas políticas de reforma agrária no Brasil.

**Palavras-chaves:** reforma agrária, desflorestamento, insegurança dos direitos de propriedade, econometria de painel.

**Abstract**

In Brazil, the land reform involves redistribution of land plots from large landowners to squatters. It generates property rights insecurity which alters land uses and fosters forest depletion. In this paper, a non cooperative game model is developed where natural forests are considered as an open access resource and the strategic interactions between landowners and squatters lead to an over deforestation. The main theoretical implication is a positive impact of squatters on deforestation. It is successfully tested on a panel data set covering the municipalities of the Legal Amazonia controlling for the endogeneity of squatters in a deforestation equation. The result questions the modalities of the Brazilian state-led land reform

**Key Words:** Land reform, Deforestation, land tenure insecurity, panel estimation.

**Forma de apresentação:** Oral (português)

## 1. INTRODUCTION

Deforestation rates of Brazilian Amazonia in the last decades have been alarming. According to Landsat satellite images, annual deforestation from 1978 to 2004 was 20,000 $km^2$ on average. As a percent of geographic area, deforestation increased from 3% in 1978 to 14% in 2004.

The factors of deforestation in the tropical zones and more specifically in Brazil have been the subject of many theoretical and empirical studies (*e.g.* Bhattarai and Hammig, 2004; Binswanger, 1991; Margulis and Reis, 1991; Pfaff, 1997; Geist and Lambin, 2001). The usually considered causes of deforestation are related to the development of transport infrastructures, agro-pastoral activities and logging industry profitability, income level and inequality, demographic pressure (Barbier, 2001; Andersen, Granger, Reis, Weinhold and Wunder, 2002; Koop and Tole, 2001; Walker, Moran, and Anselin, 2000). Studies also highlight the role played by the macroeconomic environment: the economic growth, the debt burden, the real exchange rate, etc. (*e.g*. Barbier and Burgess, 2001; Foster and Rosenzweig, 2003). In addition, institutional factors and more specifically poorly defined property rights appear to play a key role in the deforestation process (Angelsen, 1999; Deacon, 1994; Mendelsohn, 1994). Weak property rights discourage investment in long-live assets, such as forest, that don't yield immediate returns. When property rights are poorly defined, or enforcement is lacking, capital intensive land uses are discouraged against non capital intensive activities like cattle ranching. Governments thus should aim, via land reform or other means, at setting up a property right system that favors sustainable land uses (Sikor and Muller, this issue).

Paradoxically in Brazil, the state-led land reform increases land tenure insecurity. The Land Statute of 1964 that constitutes the institutional background for land reform allows farmers without titles who make an "effective use" of the land to claim its holding. Land reform thus consists in expropriating and compensating landowners and distributing land to settlers. As a consequence landless farmers are prompt to occupy large and underdeveloped landholdings and to clear the forest since deforestation is usually considered as a proof of land development. Land reform also creates incentives for landowners to clear the forest in order to protect their rights in land.

Land reform in Brazil exacerbates property rights insecurity on forestland and natural forests can be considered as open access resources. Forestlands are the subject of an overexploitation resulting from the competition between landowners and squatters for land access. In this paper, the strategic interactions between landowners and squatters are described in a non cooperative game model that delivers two major restrictions: the total number of farm holders and the relative number of squatters have both a positive effect on deforestation. These implications are tested on a panel data set constituted by the municipalities of the Legal Amazonia.

Section 2 sets up the background of the study. Section 3 develops the theoretical model of deforestation. Section 4 presents the panel data analysis that is carried out on the Legal Amazonia. Section 4 concludes.

## 2. THE LAND DISTRIBUTION PROCESS IN BRAZIL

A large number of agricultural establishments are cultivated by farmers who do not possess any legal land tenure (squatters or *posseiros*). According to the agricultural censuses, squatters held in the seventies about 48 % of the farms in the Brazilian Legal Amazonia (BLA). The share of squatters then decreased from 35 % in 1985 to 26 % in 1995. In 1995, squatters are particularly numerous in the states of Maranhao, Amazonas and Acre, where they represent, respectively, 43%, 33% and 30% of the farms (Table 1).

**Table 1.** Number of agricultural establishment held by squatters in percentage of total establishments

| | | 1970 | 1975 | 1980 | 1985 | 1995 |
|---|---|---|---|---|---|---|
| Acre | AC | 46 | 45 | 44 | 45 | 30 |
| Amazonas | AM | 47 | 67 | 46 | 39 | 33 |
| Amapá | AP | 43 | 69 | 55 | 75 | 23 |
| Goiás | GO | 22 | 30 | 5 | 5 | 5 |
| Maranhão | MA | 52 | 49 | 38 | 38 | 43 |
| Mato Grosso | MT | 30 | 30 | 22 | 18 | 10 |
| Para | PA | 47 | 49 | 41 | 34 | 16 |
| Rondônia | RO | 44 | 29 | 51 | 28 | 8 |
| Roraima | RR | 23 | 95 | 91 | 43 | 11 |
| Tocantins | TO | 47 | 46 | 30 | 19 | 13 |
| Total BLA | | 48 | 49 | 39 | 35 | 26 |

Source: IBGE. BLA: Brazilian Legal Amazonia

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.

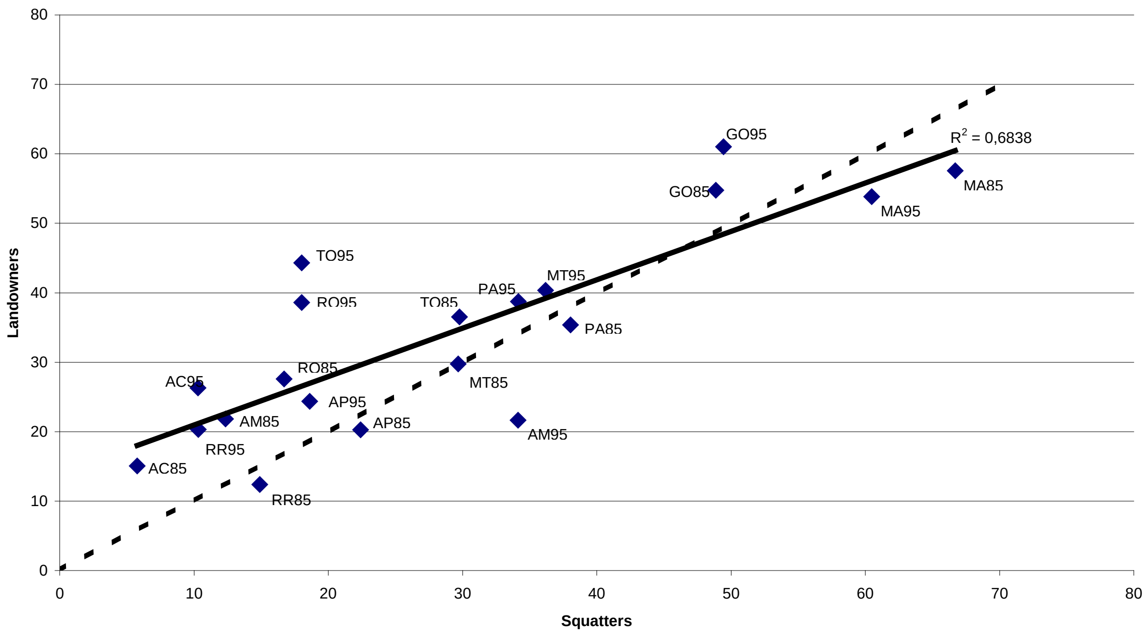
Until the mid eighties, land redistributions were scarce. They consisted mainly of installations of families on public lands within the framework of colonization projects. Land redistributions increased at the end of the eighties, and resulted mainly from squatters' invasions of large private holdings, rather than public lands, and ex post legalization. The number of expropriation 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, 2006) in particular the MST (*Movimento dos Trabalhadores Rurais sem Terra*).

This process of land redistribution generates property rights insecurity on land plots that do not fulfil a socio-economic function especially on forestlands. Indeed, the 1988

Constitution doesn't 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. The state-led land reform thus exacerbates conflicts between landowners and squatters (Alston, Libecap and Mueller, 2000) and fuels deforestation.

Figure 1 highlights two phenomena concerning deforestation. First, the deforestation rate of landowners is generally higher than the deforestation rate of squatters who own smaller farms.[1] This result is corroborated by other studies (*e.g.* Fearnside, 2005; Pacheco, 2006). It can be regarded as the consequence of scale economies in logging activities. Second, a positive correlation links deforestation rates of landowners and squatters that can result from common factors affecting deforestation of both types of agents (cattle ranching profitability, infrastructures…). But these two stylized facts can also be the consequence of landowners' reactions to insecure property rights and to the threat of squatters' occupation.

**Figure 1.** Land cleared by landowners and squatters in percentage of farm area




Source: IBGE, Agricultural censuses, 1985, 1995

## 3. STRATEGIC INTERACTIONS BETWEEN LANDOWNERS AND SQUATTERS

Angelsen (2001) develops a game theoretical model to study strategic interactions in land appropriation between the State and local communities. In this section, a similar model gives some pieces of explanation to the stylized facts depicted above (Figure 1). It is argued that excess deforestation is the result of strategic interactions between landowners and squatters who compete for open access forestlands. In the first model, farm holders choose simultaneously the level of deforestation (Cournot-Nash model). In the second one, a

[1] See in section 4 the calculus of deforestation rates.

temporal asymmetry is introduced with a leader and a follower: the landowner starts clearing forest and then the squatter goes on deforestation (Von Stackelberg model).[2] These models deliver two main econometric restrictions that are tested in section 4.[3]

(a) *The Cournot-Nash model*

(*i*) *The private equilibrium*

Consider an exogenous number of $A$ farm holders $i$ ($i$ = 1, …, $A$) and a plot of forested area $T$ that can be converted into agricultural land (or pasture land) ($F^i$), or can be left as a natural forest ($N$):

$$T = \sum_{i=1}^{A} F^i + N \qquad (1)$$

Clearing forest secures property rights so that $F^i$ ($\forall i$ = 1… $A$) is a private land whereas $N$ is an open access land.

The one-stage non co-operative game is analyzed where each agent chooses $F^i$ simultaneously with $F^j$ ($j \neq i$) treated as exogenous. Each agent maximizes her profit ($\pi^i$):

$$\max_{F^i} \pi^i = R^i\left(F^i, N\right) - C^i\left(F^i, \tilde{F}\right) \ \forall i = 1, \ldots, A; \ \tilde{F} \equiv \sum_{j=1}^{A} F^j \text{ and } j \neq i \qquad (2)$$

$\tilde{F}$ denotes the other agents' total forest clearing. Taking into account equation (1) the problem thus becomes:

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

The natural forest is assumed to generate receipts from non-timber forest products: food products, oils, latex, fibbers, medicines… Natural forest also maintains soil fertility of cleared areas through nutrient, micro-climate or hydrological effects (Peters, Gentry, and Mendelsohn, 1989; Moegenburg and Levey, 2002; Durieux, Machado, and Laurent, 2003). Consequently the receipt function $R^i(.)$ of the agent $i$ depends positively on the cleared forest area and on the natural forest. The function is assumed to be twice differentiable with respect to its arguments. Second derivatives are non-positive. $R^i(.)$ is separable between natural and cleared forest:

$$R^i_F > 0, \ R^i_{FF} \leq 0, \ R^i_N > 0, \ R^i_{NN} \leq 0, \ R^i_{FN} = 0, \ \forall i = 1, \ldots, A \qquad (4)$$

Deforestation generates a (first) local negative externality. Indeed, when agents cut forest, natural forest becomes scarcer and its value or implicit price ( $R^i_N$ ) increases. It is a "natural forest scarcity effect". This mechanism reduces the incentive to cut forest for the agent $i$ and is described by a non negative cross derivative $R^i_{N\tilde{F}} \geq 0$.

[2] The game developed by Alston, Libecap, and Mueller (2000) between landowners and squatters, enlightens the relationship between deforestation, land reform policies and violent conflicts.

[3] The mathematical developments are presented in Appendix I.

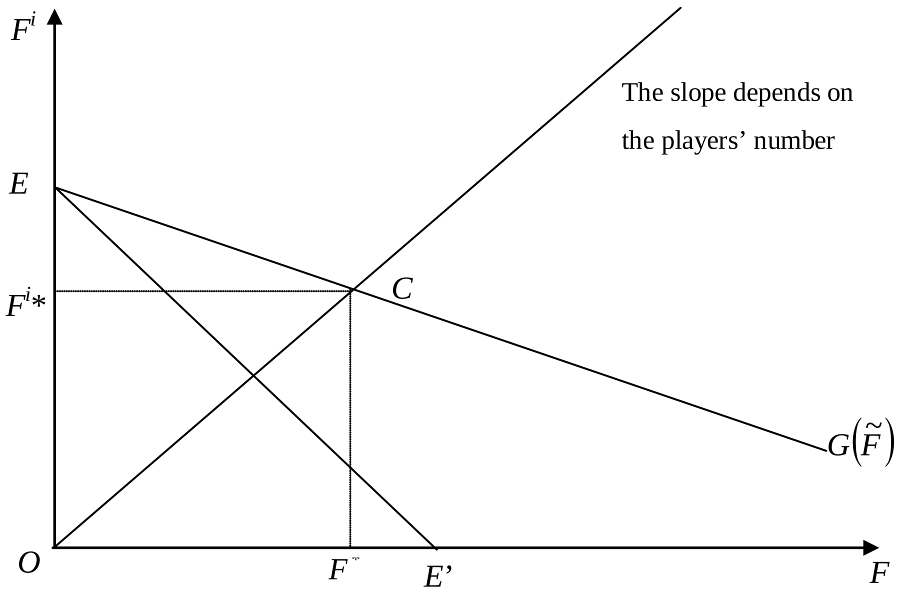
The cost function $C^i(.)$ of the agent $i$ represents the clearing costs. It is assumed to be twice differentiable, increasing, and convex in forest clearing:

$$C_F^i > 0, \; C_{FF}^i \geq 0 \qquad \forall i = 1 \ldots A \tag{5}$$

The cost function is assumed to depend not only on the own agent's level of deforestation but also on the other players' one. Other externalities are thus introduced in the game through the cost function. Their effects are given by $C_{F\tilde{F}}^i$, the second cross derivative between agent's $i$ forest clearing and other agents' forest clearing.

Indeed, deforestation may facilitate the penetration of other agents into the natural forest generating a local positive externality for agent $i$ whose clearing costs are reduced. It is a "frontier effect" with $C_{F\tilde{F}}^i < 0$. Bringing new plots into cultivation induces investments in transport infrastructures which costs are shared by local authorities or by the State. Individual costs of deforestation are thus reduced. However, this frontier effect may vanish in the presence of an "agricultural land scarcity effect" (Angelsen, 1999) that is a (second) local negative externality. The latter may occur in a situation where an agent starts clearing the most profitable plots of land for agricultural and pasture purposes in so far as these plots are relatively more fertile, more accessible, etc. This rises up agent $i$'s clearing costs and $C_{F\tilde{F}}^i$ is positive. The net effects on agent $i$'s cost of other agents' deforestation are thus *a priori* ambiguous.

**Figure 2.** Farm holder $i$'s response function with negative externalities (scarcity effects)




In the following, the scarcity effects are supposed to dominate the frontier effect. Indeed, economically profitable areas are limited by the lack of infrastructure supply, the soil fragility of cleared lands, the importance of flooding areas, the prevalence of diseases, etc. These viable areas are thus characterized by an intensive competition for land access and the natural forest in these areas is the subject of an intense depletion.

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, 220)).
The Cournot-Nash symmetric equilibrium is located in *C* (Figure 2) where the response function of the player *i* $G(\tilde{F})$ intersects the symmetric condition line[4] $A = 1, 2\ldots$ where:

$$F^i = \frac{1}{A-1}\left(\sum_{j=1}^{A} F^j\right) \qquad \forall i = 1, \ldots, A \text{ and } j \neq i \qquad (6)$$

A positive exogenous shock in the marginal profitability of deforestation induces an increase in the deforestation rate equilibrium. Moreover, when the number of farm holders increases, the symmetric condition line rotates clockwise around point *O*. Hence, the Cournot-Nash deforestation rate equilibrium is a positive function of the number of farm holders.

(*ii*) *Pareto optimal solution*

The Pareto optimal level of deforestation is found by choosing the level of deforestation (*F*) that maximizes total profit:

$$\max_F \Pi = R(F, N) - C(F) \text{ where } F \equiv \sum_{i=1}^{A} F^i \qquad (7)$$

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). It lies below the reaction function except at the point E. At E secure property rights guarantee the exploitation of the plot of the forest area by a sole agent and so all receipts and costs are internalized.[5] For the other points, the optimal amount of deforestation is smaller than the level of deforestation in the Cournot Nash equilibrium. The level of overexploitation increases with the number of the players giving rise to a tragedy of the open access resources.[6]

(b) *The Von Stackelberg model*

Consider again the competition for land in Amazonia taking into account the temporal asymmetry between the landowner and the squatter. The squatter can invade the part of the landowner plot that is not cleared. The landowner reacts to this threat by choosing

[4] In the more general asymmetric case, the Cournot-Nash equilibrium is located on the reaction function $G(\tilde{F})$ where it intersects the reaction function of the other player.

[5] Under the assumption that all externalities are private and can be addressed through secure property rights.

[6] This expression is preferred to the so-called Tragedy of the Commons (Hardin, 1968). See for instance: Balland and Platteau (1996); Feeny, Berkes, McCay, and Acheson (1990) or Bruce (1998). The theory of optimal depletion of a natural resource establishes that overexploitation of an open access resource is exacerbated by the number of agents in competition (*e.g.*Cornes and Sandler, 2003).

preventively and strategically the level of deforestation.[7] The squatter has Cournot conjectures: she assumes that the landowner will not change her level of forest clearing in response to her own choice. The landowner makes rational conjectures: she anticipates the response of the squatter to her own deforestation level. Under these hypotheses, the game is sequential: at first, the landowner (the leader) maximizes her profit (*cf*. equation 2) and chooses a level of deforestation $F^l$, then the squatter (the follower) observes $F^l$ and chooses $F^s$. This framework constitutes a Von Stackelberg model.

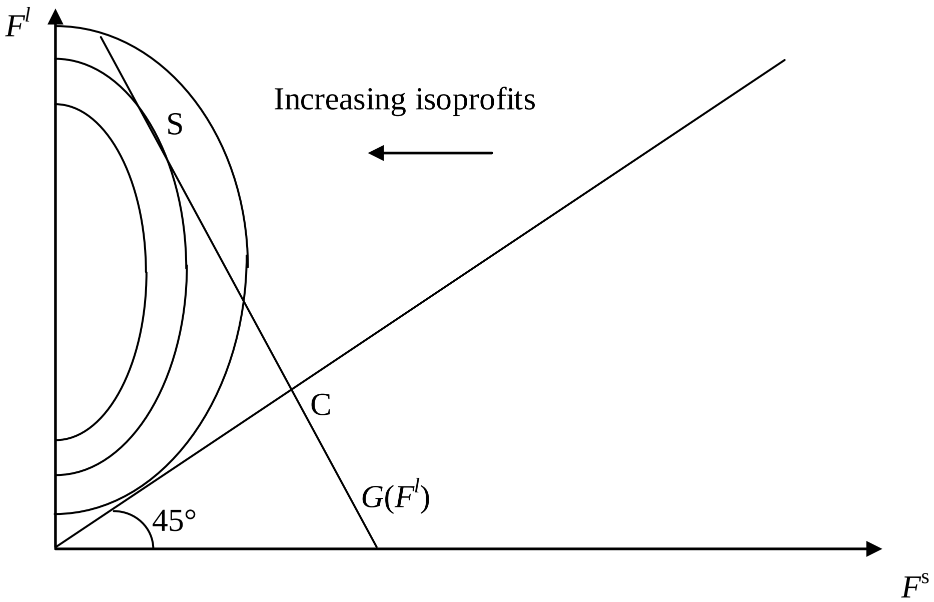
The threat of invasion in the natural forest urges the landowner to clear more forest. By this way, she generates negative externalities that reduce the squatter's forest clearing profitability. When the squatter clears less, the natural forest becomes more abundant and, its value or implicit price for the landowner ( $R_N^l$ ) decreases: the landowner clears more. The landowner deforestation can be interpreted as sunk costs that deter the squatter's entry. Indeed, their commitment value signals that the squatter's invasion will not be profitable. The landowner deforestation can even prevent invasion if the squatter supports a fixed entry cost in the plot of land. The landowner may choose $F^l$ that reduces the squatter's profit to zero.

The response function $G(F^l)$ of the squatter and the landowner's isoprofit curves are depicted in Figure 3. The symmetric Cournot-Nash (with two agents) and Von Stackelberg equilibria are respectively $C$ (intersection between $G(F^l)$ and the first bisecting line) and $S$ (the landowner chooses the point on the squatter's response function that maximizes her own profit). When compared to the Cournot-Nash equilibrium, the landowner clears more whereas the squatter clears less. This result is supported by descriptive statistics that show higher deforestation rates by landowners (Figure 1). The landowner's profit is greater in the Von Stackelberg case. Moreover, in this model where the response functions are downward sloping, the landowner's profit is always greater than the squatter's profit. Indeed, the leader can make a preventive move that reduces the follower's entry profitability (Gal-Or, 1985).

The slope of the squatter's response function being less – 1 (stability condition of the Cournot Nash symmetric equilibrium), an increase in the landowner's deforestation yields an increase in total deforestation even if the squatter reduces his own deforestation. Hence the threat of the squatter's invasion induces an overexploitation of the forest because of the defensive strategy of the landowner. Moreover, it is straightforward that an exogenous shift in the squatters' response function, for example a modification in the socio-economic environment that facilitates the squatter's entry, yields an increase in landowners and total deforestation rates (Figure 3).

[7] The temporal asymmetric between agents is predetermined. Hence, the question of choosing roles is ignored See for an endogenous assignment of roles of the players: Dowrick (1986).

**Figure 3.** Von Stackelberg equilibrium with dominant negative externalities




## 4. ASSESSING THE INFLUENCE OF SQUATTERS ON DEFORESTATION: ECONOMETRIC ANALYSIS

(*a*) *The data set*

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 Legal Amazonia.[8] 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, Granger, Reis, Weinhold, and Wunder (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.

[8] Legal Amazonia includes 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).

**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 |
| Amapá | 0 | 1 | 1 | 2 | 1 |
| Goiás | 21 | 35 | 46 | 48 | 54 |
| Maranhão | 16 | 19 | 26 | 29 | 21 |
| Mato Grosso | 3 | 6 | 10 | 13 | 22 |
| Pará | 3 | 3 | 6 | 7 | 7 |
| Rondônia | 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

The most deforested areas are located in the states of Goiás, Tocantins, Maranhão and Mato Grosso which cover the "arc of deforestation" along the southern and eastern edges of Legal Amazonia.

Only 79% of Legal Amazonia is naturally forested (*cf*. Andersen, Granger, Reis, Weinhold, and Wunder (2002, chapter 2)). For instance, in the southern and eastern parts of Legal Amazonia, 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.[9] The econometric results obtained with this variable are shown in appendix II for robustness tests.

(*b*) *Econometric modeling approach and econometric findings*

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

The econometric estimation is driven in three steps:

- Ordinary Least Squares estimation (OLS) where all observations are pooled;
- Panel Least Squares estimation (PLS) with double fixed effects that control for municipal and temporal heterogeneities;
- Panel Two-Stage Least Squares estimation (PTSLS) with double fixed effects and a control for the endogeneity of *Squatters*

[9] The naturally forest cover data come from IBGE. We consider as naturally forested land, the areas of low density forest, seasonal forest, dense forest, river bank, mangrove and swamp forest.

**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 $R^2$ | 0.17 | 0.91 | 0.85 | 0.78 | 0.91 |
| Fixed effects | | Yes | Yes | Yes | Yes |
| (Cross-section/Period F *p-value*) | | (0.00)*** | (0.00)*** | (0.00)*** | (0.00)*** |
| Instrument list | | | Log(Nbets)<br>Log(Gdpp)<br>$Log(Gdpp)^2$<br>Church | Log(Nbets)<br>Log(Gdpp)<br>$Log(Gdpp)^2$<br>Log(cattle price)<br>Church | Log(Nbets)<br>Log(Gdpp)<br>$Log(Gdpp)^2$<br>Church<br>Public |
| Exogeneity test (*p-value*) | | | 0.0001 *** | 0.00 *** | 0.06 * |
| Suridentification 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

The OLS estimation (Table 3: 1) displays a negative and significant correlation between *Cleared land* and *Squatters*. Obviously, this result does not allow concluding that squatters have a negative impact on deforestation. Indeed, two sorts of biases can 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, Libecap, and Schneider, 1996).

The PLS estimation does not support the theoretical restriction that *Squatters* have a positive and significant impact on *Cleared land*. However, this result could be the consequence of the simultaneity bias between *Cleared land* and *Squatters*. Indeed, according to the theoretical model, deforestation is a defensive strategy of landowners against squatters' settlements. In order to correct this bias,[10] *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). Moreover, the Church has sometimes distributed lands to the poorest (Rodriguez, 2004).

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

[10] The instrumentation also protects against the consequence of omitted pertinent variables which are correlated with the relative number of squatters. For instance, squatters may be characterized by a high time preference that could fuel deforestation. Hence, the instrumental variable must be uncorrelated with squatters' characteristics

[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.

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' invasion. The introduction of *Public* is also motivated by the possibility to test the overidentification hypothesis.

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

| | PLS | PLS |
|---|---|---|
| Constant | -0.13 | 0.00 |
| | (-0.67) | (0.02) |
| Log(Nbets) | 0.06** | 0.03 |
| | (2.21) | (1.53) |
| Log(Gdpp) | -0.04 | -0.03 |
| | (-1.59) | (-1.43) |
| $Log(Gdpp)^2$ | 0.00 | 0.00 |
| | (0.40) | (0.02) |
| Church | 2.63*** | 2.28*** |
| | (4.39) | (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).

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 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. According to the PTSLS estimations there exists a positive causal influence of squatters on deforestation. Table 5 below shows that deforestation responds strongly to a decrease in the relative importance of the squatter ratio.

**Table 5.** Predicted effect of a reduction in *Squatters* on *Cleared land*

| Squatters | Cleared land | |
|---|---|---|
| Absolute difference | Absolute difference | Elasticity |
| - 0.10 | - 0.07 | 0.82 |

To calculate the effect of an increase in the ratio of squatters on deforestation, the explanatory variable is set to its mean value in 1985 (0.35) and reduced to its mean value in 1995 (0.25). The explained variable is set to its mean value in 1985 (0.29). This prediction is valid other things held equal.

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 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 higher. This result does not differ from existing empirical literature which generally refers turning point estimates that are significantly higher than average income levels (Barbier and 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. Infrastructure is a major source of deforestation as shown by numerous studies (*e.g.* Andersen, Granger, Reis, Weinhold, and Wunder, 2002).[12]

In Amazonia, 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.

The results are also robust to a more restrictive definition of deforestation that drops out municipalities that are not naturally forested (*Corrected cleared land*). The results remain qualitatively unchanged (see appendix II).

## 5. Conclusion

In this paper, land reform is put forward as a driving force of deforestation in the Brazilian Amazonia. In Brazil, state-led land reform mainly consisted in redistributing unused privately owned plots to farmers without titles. Land reform thus creates property rights insecurity on naturally forested lands that are considered as unused.

A game theoretical model stresses the indirect influence of land reform on deforestation through strategic interactions between landowners and squatters. In this framework, landowners clear the forest to prevent squatters' settlements and squatters clear the forest to gain formal property rights. Econometric findings exhibit a positive causal relationship of the number of squatters towards deforestation. Squatters not only directly contribute to deforestation but also indirectly: the threat of squatters' invasions incites landowners to clear more.

[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.

This model 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. Land reform may be promoted on equity and efficiency grounds. But, 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.

These results may also support a market-based approach to land reform, which relies on negotiations between willing buyers and sellers. Beneficiaries choose the land that best suit their needs and negotiate its price. Such an experiment was conducted in 1997 in five Northeast states but was severely criticized by landless peasants movements. Although this mechanism has the advantage of not fueling deforestation process, MST put forward the high cost to land access borne by the beneficiaries in this system..

## Appendix I

*(a) The Cournot-Nash model*

*(i) The private 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:[13]

FONC: $R_F^i\left(F^i, N\right) - R_N^i\left(F^i, N\right) - C_F^i\left(F^i, \tilde{F}\right) = 0$ (8)

SOSC: $R_{FF}^i\left(F^i, N\right) + R_{NN}^i\left(F^i, N\right) - C_{FF}^i\left(F^i, \tilde{F}\right) < 0$ (9)

The first two terms of the first order condition (equation 8) give the receipt of an extra unit of forest clearing. It is equal to the difference between the marginal receipt of agricultural land (or pasture land) and the marginal receipt of natural forest. This difference is assumed to be positive. The third term is the marginal cost of forest clearing.[14]

The FONC shows that there exists an implicit relationship between the deforestation of agent *i* and the deforestation of other agents written: $F^i = G^i\left(\tilde{F}\right)$. $G^i$ is the response function of the agent *i*. The existence of $G^i$ is guaranteed by the implicit function theorem and the SOSC (equation 9). The slope of $G^i$ is obtained by the total differentiation of the FONC:

$$\left.\frac{dF^i}{d\tilde{F}}\right|_i = \frac{C_{F\tilde{F}}^i\left(F^i, \tilde{F}\right) - R_{NN}^i\left(F^i, N\right)}{R_{FF}^i\left(F^i, N\right) + R_{NN}^i\left(F^i, N\right) - C_{FF}^i\left(F^i, \tilde{F}\right)} \quad (10)$$

---

[13] If $F^i$ maximises $\pi^i$, then a global and unique maximum is reached provided that the objective function is strictly concave.

[14] In other words the marginal profit of clearing is equal to the natural forest's implicit price ( $R_N^i$ ). This is a well known result in the theory of optimal depletion of natural resources.

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

$$sign \left.\frac{dF^i}{d\tilde{F}}\right|_i = -sign\left(C^i_{F\tilde{F}}\left(F^i, \tilde{F}\right) - R^i_{NN}\left(F^i, N\right)\right)$$

The numerator is positive when there is an "agricultural land scarcity effect" ( $C^i_{F\tilde{F}} > 0$ ) and a "natural forest scarcity effect" $-R^i_{NN} \geq 0$. In that case, the response function is downward sloping: the more the other agents clear the forest, the less agent *i* clears. Forest clearing decisions are then strategic substitutes. When the "frontier effect" ( $C^i_{F\tilde{F}} < 0$ ) dominates the two scarcity effects, the numerator is negative and the response function is upward sloping. An increase in forest clearing by other agents implies that clearing the remaining forest becomes more profitable for *i* (in other words, forest clearing decisions are strategic complements).

(*ii*) *Pareto optimal solution*

Let us consider the first-order necessary (FONC) and the second order sufficient (SOSC) assuming that there exists a unique interior solution:

FONC: $R_F(F,N) - R_N(F,N) - C_F(F) = 0$ (11)

SOSC: $R_{FF}(F,N) + R_{NN}(F,N) - C_{FF}(F) < 0$ (12)

(*b*) *The Von Stackelberg model*

The FONC for the landowner is:

$$R^l_F\left(F^l, N\right) - R^l_N\left(F^l, N\right) - C^l_F\left(F^l, F^s\right) - R^l_N\left(F^l, N\right)\frac{dF^s}{dF^l} = 0 \quad (13)$$

$\frac{dF^s}{dF^l}$ is the slope of the response function of the squatter. If local negative externalities predominate, the slope is negative. Compared with equation (8), the first order condition in the Cournot-Nash model, the positive term $-R^l_N\left(F^l, N\right)\frac{dF^s}{dF^l}$ is added.[15] The receipt of an extra unit of forest clearing increases.

[15] In the FONC derivation, it is assumed that the squatters' deforestation in period 2 does not influence the landowner's cost in the first period: $C^l_{F^s}\left(F^l, F^s\right) = 0$

## Appendix II

**Table 6.** Estimation results on reduced sample (explained variable: Log[*Corrected cleared land*])

| | OLS | PLS | PTSLS |
|---|---|---|---|
| Constant | -8.05*** | -7.21*** | -8.21*** |
| | (-7.33) | (-5.18) | (-4.89) |
| Log(Nbets) | 0.60*** | 0.31 | 0.35** |
| | (4.58) | (1.67) | (1.84) |
| Squatters | -2.71*** | 1.23*** | 2.83*** |
| | (-5.33) | (5.86) | (3.82) |
| Log(Gdpp) | 0.39 | 1.44*** | 1.51*** |
| | (0.85) | (5.28) | (6.30) |
| $Log(Gdpp)^2$ | -0.17 | -0.88*** | -0.80*** |
| | (-0.73) | (-6.86) | (-4.92) |
| Number of observations | 191 | 191 | 191 |
| Adjusted $R^2$ | 0.21 | 0.92 | 0.88 |
| Fixed effects | | yes | Yes |
| (Cross-section/Period F P-value) | | (0.00)*** | (0.00)*** |
| Instrument list | | | Log(NBETS), Log(GDPP), $Log(GDPP)^2$, CHURCH |
| Exogeneity test (P-value) | | | 0.01*** |

t-statistics in parentheses; *: significant at 10 % level; **: significant at 5 % level; ***: significant at 1% level

**Table 7.** Instrumental equations on the reduced sample (explained variable: *Squatters)*

| | OLS |
|---|---|
| Constant | 0.39 |
| | (0.55) |
| Log(Nbets) | 0.00 |
| | (0.00) |
| Log(Gdpp) | -0.03 |
| | (-0.27) |
| $Log(Gdpp)^2$ | -0.05 |
| | (-0.65) |
| Church | 11.50*** |
| | (3.28) |
| Number of observations | 191 |
| $R^2$ | 0.82 |

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

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