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Abstract:

This paper focuses on the impact of property rights insecurity on deforestation in the Brazilian Legal Amazon. Deforestation is considered as a risk management strategy: property rights insecurity reduces the present value of forests and fosters forest conversion into agricultural and pasture lands. Moreover, deforestation is the consequence of strategic interactions between landowners and squatters. Landowners clear the forest preventively in order to assert the productive use of land and to reduce the expropriation risk. Squatters invade land plots, clear the forest and may afterwards gain official recognition with formal property titles. A particular attention is paid to the measure of land property rights insecurity in the Brazilian context. It is assumed that property rights insecurity has a multidimensional character taken into account by the number of homicides related to land conflicts and expropriation procedures. Principal component analysis allows synthesising such information. An econometric model of deforestation is estimated on a panel dataset on the 1988-2000 period and the nine states of the Brazilian Legal Amazon. The hypothesis that insecure land property rights contribute to higher rates of deforestation is not rejected when the simultaneity bias between insecure property rights and deforestation is addressed. This result questions the modality of the Brazilian land reform that considers forested areas as unproductive and thus open for expropriation procedures.

Keywords
Deforestation, insecure property rights, Brazilian Legal Amazon

JEL Classification
O13, Q23

1 Introduction

According to the Brazilian National Institute of Space Research (INPE – Instituto Nacional de Pesquisas Espaciais) by August 2007, the deforested area in the Brazilian Legal Amazon (BLA) reached 700 thousand square km, which represent 14% of its geographic area.[1] Most of the deforestation, 570 thousand square km to be more precise, took place in the last three decades since 1977. During the 1988-2007 period the annual rate of deforestation (figure 1) fluctuates between 11000 square km in 1991 (0.2 % of the BLA geographic area) and 29000 square km in 1995 (0.6%) with an average value of 18000 square km (0.4%).

The deforestation process in tropical zones is highly complex and has been the subject of many theoretical and empirical studies mobilizing both social and natural sciences (e.g. Angelsen and Kaimowitz, 2000; Pfaff, 1999; van Kooten and Folmer, 2004, chapter 13). According to Geist and Lambin (2002), sources or proximate causes of deforestation relate mainly to investments in infrastructure and road networks (e.g. Andersen et al., 2002) and to economic activities such as cattle ranching (Kaimowitz, 1996; Caviglia-Harris, 2005), agricultural activities (Barbier, 2004) and commercial logging as well (Otsuki et al., 2002; van Kooten and Folmer, 2004). In the Brazilian Amazon, these activities supported by government policies through credit and tax policy, played intermingled roles in the process of deforestation (Binswanger, 1991; Margulis, 2003; Mertens et al., 2002; Walker et al., 2000). Geo-ecological factors such as soil quality, rainfall and temperature conditions (Chomitz and Thomas, 2003) are considered as predisposing factors of deforestation which condition the links between proximate and underlying causes. The latter operate mainly at the macro level and are related to social processes and economic policies such as population pressure

[1] Legal Amazon is a 5 millions square km administrative area defined for regional planning purposes comprehending 4 millions square km of tropical forests as well as the savanna (cerradão) and transitional vegetation in the southeast areas of the region.

(Cropper and Griffiths, 1994), landownership and income distributions, national and regional development strategies (Koop and Tole, 2001), agricultural research and technological change as well (Southgate et al., 1990).

Particular attention has been paid to the environmental Kuznets curve for deforestation in econometric studies based upon international datasets (e.g. Bhattarai and Hammig, 2004; Culas, 2007; Cropper and Griffiths, 1994). Other studies have highlighted the role played by macroeconomic - fiscal, exchange rate and / or sectoral policies - in the deforestation process (e.g. Anderson, 1990; Arcand et al., 2007). In studies dedicated to tropical deforestation, institutional factors have received special attention. Forest is considered as a natural capital that will generate future streams of output and income (Angelsen, 2007; Solow, 1992). Incentives to accumulate long term assets including natural ones thus depend on the quality of legal institutions and more specifically on the enforcement of rules that protect property rights. The poor quality of institutions enforcing property rights in developing countries - De Soto (2000) claims that western property law transplanted from colonial countries does not fit the context of developing countries - may thus constitute a major impediment to investment in forest conservation.

Numerous empirical studies point out that the weakness of institutions in developing countries favours forest and other natural resources depletion. Deacon (1999) and Mendelsohn (1994), working on a cross-country dataset, evidence a detrimental effect of insecure ownership on deforestation. In both studies, property rights insecurity arises from the lack of government accountability and the political instability as measured by the type of government, constitutional changes, revolutions, political assassinations, purges, as well as guerrilla warfare. Bhattarai and Hammig (2001) highlight also the positive effects of an improvement in political institutions and governance for forest preservation while measuring institutional quality with indices of political rights and civil liberty. Culas (2007) uses the

Knack and Keefer's (1995) indicators of contract enforceability and bureaucracy efficiency to demonstrate the positive impact of institutional arrangements for secure property rights on forest preservation.

Econometric studies of the impact of ownership risk on deforestation have also been carried out on South and Central American countries but the results are far from conclusive. Godoy et al. (1998), working on a panel of eighteen Bolivian villages in the rainforest, show that conflicts between cattle ranchers, loggers and smallholders boost deforestation. Otsuki et al. (2002), using a municipal panel dataset on the Brazilian Amazon, conclude that holding a land title improves the technical efficiency and thus reduces deforestation. Nelson et al. (2001) indicate that removing property rights in indigenous reserves is likely to foster deforestation in Panama. However Deininger and Minten (2002) working on two poor Mexican states, show that property rights do not have any impact on deforestation once physiogeographic factors and population density are controlled for. Wood and Walker (2001) find ambiguous results when they compare the behaviour of titled and untitled small farmers in the Brazilian Amazon: possession of title discourages exploitation of timber and promotes reforestation but encourages expansion of cultivated areas to the detriment of forest.

This paper focuses on the consequences of ownership insecurity on deforestation in the Brazilian Amazon proposing an original measure of property rights insecurity. The Brazilian legal system does not provide a complete bundle of rights to land as defined by the property rights paradigm (Alchian, 1965; Alchian and Demsetz, 1973).[2] As a consequence, insecure land property rights prevail resulting in violent land conflicts and expropriation procedures. These variables - land conflicts and expropriation processes - are used to measure land property rights insecurity in the econometric analysis. The rest of the paper proceeds as

[2] A property right is said complete when three elements are warranted by the legal system: (i) exclusivity of rights of use of a resource (usus); (ii) exclusivity of rights to the services provided by a resource (fructus) and (iii) right to transfer a resource (abusus) (Furubotn and Pejovich, 1974; Libecap, 1999).

follows. Section two discusses the links between property rights insecurity and deforestation. Section three presents the econometric model and the panel dataset, which includes annual observations from 1988 to 2000 on the nine states of the Brazilian Legal Amazon. Section four concludes.

2 The effects of insecure land property rights on deforestation

According to de Soto (2000), economic history offers striking examples of how squatters have organized themselves through individual and collective actions to get informal or extralegal ownership and legitimate land occupations. The North American experience in the 19th century illustrates how laws have evolved to grant the recognition of squatters' rights on land settlements and thus allowing them to be incorporated into the market economy. In developing countries however, the historical trajectory was quite different. In most of them a large part of the land settled is not legally owned. The legal requirements to get a formal title are often onerous and the legal system does not protect landholders against expropriation from government and eviction from other individuals.[3]

The Brazilian legal framework illustrates this kind of institutional failures since it does not provide adequate protection to landholders' rights: a large number of landholders do not have legal titles and enforcing property rights is costly especially in remote areas. Moreover, title holders face a risk of loosing their rights to the land as a result of land reform policies (section 2.1). In such a risky environment, deforestation becomes a rational choice. As part of a risk management strategy, agents convert forests into pasture or agricultural lands (section 2.2). At the same time, deforestation can also be analysed as the result of strategic interactions between landowners and squatters who compete for land access and attempt to legitimate

[3] See for example the case of Peru in de Soto (2000).

their ownership (section 2.3). In both cases, insecure property rights are expected to favour forest clearing.

2.1 The weaknesses of the institutional framework for secure property rights in the Brazilian Amazon

2.1.1 Numerous landholders do not have legal titles

The vast majority of small and large farmers' settlements in the Amazon occurred spontaneously outside the official colonization areas, taking place on public lands or unused private lands along the Belém-Brasilia, Cuiabá-Porto Velho and Cuiaba-Santarém axial roads. Large scale government settlements in the Brazilian Amazon started in the early seventies with the federal programs of colonization associated with the construction of the Transamazonic highway. Though there were occasional sales of large plots of public lands, most of the colonization programs took place by sales of smaller plots to colonists within official projects managed by the INCRA.[4] These opportunities of legal access to public lands were practically halted by the end of the eighties (Fearnside, 2001).

A large part of the territory of the Brazilian Amazon, however, remained under public domain, lacking any kind of government titling and thereby open for private claiming. On top of that, the Brazilian legal framework provides a strong stimulus for moving from informal land occupation to full property rights (Cleary, 1993). According to the Statute of the Land of 1964, later incorporated in the 1988 Brazilian Constitution as the legal basis of land reform, squatters have the right to settle on undeveloped public lands and to make private use of them. If they exploit land for at least one year, they can receive a right of usufruct and, after five years of continuing occupation and development they are able to get full property rights. The Constitution also recognizes the squatters' right to claim for private land that is not in

[4] INCRA (Instituto Nacional de Colonização e Reforma Agrária) is the National Institute for Colonization and Land Reform, a federal agency created in 1971.

productive use. If squatters exploit private lands during five consecutive years without legal opposition from landowners, they are able to obtain formal property titles.[5]

INCRA is the government agency responsible for the supervision and distribution of land titles in public lands. Its prerogatives also include the expropriation of unproductive land from private landowners to be redistributed among squatters. The titling process however tends to be costly and long, requiring two to five years for completion. Furthermore, budget constraints limit the actions of INCRA, as well as its ability to process title applications (Alston et al., 1996).

As a consequence a large fraction of landholdings are not legally registered or remain untitled. Agricultural Censuses show that at least 50% of landholdings in the Legal Amazon during the seventies were exploited by squatters or farmers without a legal title of land property (posseiros). During the following decades, the share of posseiros decreased but, up to 1995 they still represented about 30% of landholdings according to the last published Agricultural Census (Araujo et al., 2006). This large fraction of illegal agricultural establishments results from the complexity and inefficiency of the system of land registration which tends to foster land grabbing (grilagem da terra). Land grabbers (grileiros) constitute large illegal holdings resorting to the falsification of documents, corruption of INCRA's agents or notaries (cartorios), threats and violence against small landowners. Their activities are often financed by large scale logging and landowning companies (Fearnside, 2001; Margulis, 2003).

Farmers who do not have legal land titles cannot successfully prosecute to enforce their rights. Furthermore, in case of land disputes, their claims are hardly considered by courts. Legal titles are difficult to enforce as well since the presence of judiciary institutions is

[5] If landowners evict squatters, the latter can obtain compensation on behalf of the owners for all improvements made to the land (Alston et al., 2000).

scanty. It is often the case that property rights are secured through occupation of the land, resorting to violence (Margulis, 2003).

2.1.2 Land titles do not provide protection against encroachment or expropriation

Though, in principle, land title possession should give the holder the right for legal enforcement of his property right, the Brazilian Constitution allows invasion of private lands that are not used for productive purposes. This concept is not clearly defined, but the Constitution authorises the reassignment of private lands to squatters if the land is not placed into productive use. In practice, forestlands are considered as unproductive areas (e.g. Margulis, 2003). Consequently, forested lands in Amazon are more vulnerable to invasions by squatters and redistribution by the INCRA, than pasture and agricultural lands (Alston et al., 2000; Fearnside, 2001).

Since the end of the eighties, land redistribution actions consisted mainly of ex-post regularization of landholdings which are the outcome of invasions of private lands (Alston et al., 2000; Fearnside, 2001). Squatters' organizations such as the Landless Peasant Movement (Movimento dos Trabalhadores Rurais Sem Terra)[6] developed strategies for selecting and invading farms and then obtaining expropriation by the INCRA. In order to draw the attention of the INCRA, squatters are prompted to engage in conflict with landowners who try to evict them by all means including violence. Landowners can also appeal to courts to obtain the recognition of their rights and recover their plots, but the INCRA can expropriate farms even if courts have ordered eviction of squatters.

The phenomenon of land invasions by squatters led to the so called industry of invasion. Migrants receive land from the INCRA, sell it through informal arrangements and manage to

[6] This movement is rooted in the civil society and was structured in the 1980s by the Catholic Pastoral Land Commission in order to promote land reform.

get land through another INCRA settlement (Fearnside, 2001). This industry is favoured by the lack of a national registry of settlements.

2.2 Deforestation as a risk management strategy

As emphasized by the property rights paradigm, any legal or extralegal system shapes economic incentives and risks which condition agents' behaviours. When property rights are insecure, agents face a risk of expropriation or eviction and may lose their lands and capital, including natural assets. As a consequence, they try to reduce their risk exposure by choosing activities that generate immediate returns. This choice is usually detrimental to forest stocks which require long periods to accumulate.

Farmers choose between alternative land uses – forest exploitation, cattle ranching or agriculture - comparing their relative risk adjusted profitabilities. Forest is a natural asset which generates inter-temporal flows of incomes that arise from timber (wood, fuel wood, etc.) and in a smaller amount from non-timber forest products (fruits, oils, medicinal plants, latex, ecological services, etc.)[7]. A sustainable forest management consists in harvesting a given amount of wood every *t* years or in a sustainable exploitation of non timber products that generates annual returns.[8] The risk of losing property rights in land affects landowners' choices. It increases the discount rate in present value calculations and depreciates future incomes from land. Mendelsohn (1994) shows that the value of sustainable forest uses, falls more rapidly than the value of forest mining activities. Agents who face a risk of confiscation favour clear-cutting, agricultural land conversion and cattle ranching that yield immediate

[7] The 1995 – 96 census data show that extraction of non-timber forest products generated approximately 25% of the total value of forest extraction activities (Andersen et al. 2002, p. 107).

[8] Defining and identifying a sustainable forest management is a complex question. According to the conservationist point of view any exploitation of primary forests is non sustainable. A less stringent approach allows selective clearings which do not definitely compromise the fundamental functions of forest ecosystems. For instance, ITTO (2005) defines criterions for a sustainable management of forests.

profits. Moreover, the mobility of livestock makes it easier to protect than fixed assets such as standing forests in case of confiscation episodes.

Put differently, ownership insecurity promotes activities and production technologies that are less capital intensive (Deacon, 1994). Land users are incited to substitute less capital intensive activities such as traditional agriculture and cattle ranching, to a sustainable forest management that is natural capital intensive and has a longer production process. Deforestation is then a kind of disinvestment that reduces exposure to eviction risk. Moreover, Bohn and Deacon (2000) establish that the effect of ownership risk depends critically on the capital intensity of resource extraction technologies. If the latter are capital intensive (e.g. oil extraction), eviction risk favours resource conservation; it is not the case of wood extraction in the Brazilian Amazon.

2.3 Deforestation as the result of strategic interactions

In order to strengthen their rights, landowners have an incentive to clear the forest thus proving their productive use of land. Clearing forest also signals the landowners' willingness to keep squatters away (Libecap, 1999). Landowners will react more firmly when cultivated or pasture plots are threatened by invasions. Moreover, deforestation may help to enforce property rights: it may be easier and less costly to protect property rights on cultivated areas than on forest lands. Farm boundaries may be purposely marked with trees, irrigation systems, etc. that are easier to monitor or that help detect intrusions.

In this situation where property rights are insecure, forestlands can be considered as open access resources and deforestation as ownership establishment strategies. These strategies can be compared to those of the colonists in the 18th and 19th centuries in the United States who

gained extralegal land titles resorting to the so-called tomahawk right.[9] These extralegal titles have been legalized years later by occupancy laws and pre-emption (De Soto, 2000).

Angelsen (2001) establishes that strategic interactions between landowners and squatters who compete for open access forestlands result in excess deforestation, i.e. higher than it would be with secure property rights. Strategic behaviours may explain why farmers clear the forest even though net profit might be negative in the first years. Farmers anticipating positive future returns after the expansion of roads or the adoption of technological change, clear the forest now in order to prevent others from claiming the land. Alston et al. (2001) also model interactions between squatters and landowners leading to violent conflicts. In this framework, landowners clear the forest to prevent squatters' settlements and squatters clear the forest to gain formal property rights. Conflicts arise from invasions by squatters and efforts to evict by owners. Expropriations by the INCRA generate incentives for squatters' encroachments and violent conflicts with landowners.

3 The econometric model

The discussion above has underscored positive effects of insecure property rights on deforestation. An econometric approach relying on a model of deforestation is now developed to formally test this hypothesis. The model includes usual economic determinants of deforestation (control variables) and a measure of land property rights insecurity which constitutes the test variable. Dataset heterogeneity and a potential endogeneity bias of the insecure property rights measure are taken into account through adequate econometric modelling. The econometric specification and dataset description are followed by the discussion of econometric results.

[9] The tomahawk right is implemented by marking trees, planting trees near springs etc.

3.1 Model specification and data

We test the impact of property rights insecurity on deforestation with the following equation:

$$deforestation_{i,t} = \alpha_i + \alpha_t + \beta\, insecurity_{i,t} + \sum_{k=1}^{K} \gamma^k X_{i,t}^k + \varepsilon_{i,t}$$

Where subscripts *i* denote the nine states which encompass the Brazilian Legal Amazon,[10] and subscripts *t* denote the 13 years between 1988 and 2000.[11] The dependent variable, (deforestation), is the annual rate of deforestation in square km; insecurity proxies for property rights insecurity; X^k is a control variable; $k = 1,\ldots, K$; α, β, γ^k are unknown parameters to be estimated. The fixed state effect is a specific constant term α_i catching unobserved time invariant state heterogeneity due to differences in their geographical and environmental characteristics; the time or period fixed effect α_t catches unobserved annual heterogeneity generated by federal policies and international environment modifications that may impact deforestation; $\varepsilon_{i,t}$ is the disturbance term independently and normally distributed.

3.1.1 Deforestation

INPE provides annual deforestation data for each state of the Legal Amazon since 1988 (Figure 1). Deforestation measures are based upon Landsat satellite images interpreted by project PRODES (Monitoramento da Floresta Amazônica Brasileira por Satélite). Deforestation is a gross measure since interpretation of satellite image counts as permanently deforested any geographic area that was cleared once. Secondary forests are thus counted as deforested areas (Andersen et al., 2002).

[Insert Figure 1] Annual deforestation in the Brazilian Legal Amazon

[10] The states are the following: Rondônia, Acre, Amazonas, Roraima, Pará, Amapá, Tocantins, Mato Grosso and part of Maranhão.

[11] The sample size is limited by the availability of data on property rights insecurity.

The geographic distribution of deforestation among the Legal Amazon states is unequal. From 1988 to 2007, deforestation is concentrated in the so-called arc of deforestation i.e. the northern areas of the state of Mato Grosso and the southern areas of Pará and Rondônia. These three states are respectively responsible for 36%, 32 % and 14% of total deforestation in the Legal Amazon. As a percentage of geographic area, cumulative deforestation for the 1988-2007 period represents 21%, 14% and 9% respectively of the states of Rondônia, Mato Grosso and Para.

Time trends in deforestation are similar within the nine BLA states. Two major peaks took place in 1995 and 2004. Apart from the high growth record of the Brazilian economy, no specific reasons have been identified to explain the large jump in deforestation in 1995 (Andersen et al., 2002). The recorded high levels of deforestation in 2004 however, are clearly related to the booming agricultural prospects brought by the coupling of continuous exchange rate depreciation and improvement of international prices of agricultural commodities, soybean in particular.

3.1.2 Property rights insecurity

Property rights insecurity has a multidimensional character and is measured crossing different indicators. It is assumed that proxies for insecure property rights are the number of homicides related to land conflicts (homicides)[12] measured by the Catholic Pastoral Commission[13] and expropriations initiatives undertaken by the INCRA. The latter are measured by expropriated areas (expropriated areas) and the number of families settled in agrarian reform projects (expropriation number).[14]

[12] The number of homicides related to land conflicts can be compared to overall homicides rates provided by the IPEA. These two measures are positively and significantly correlated. The former is preferred since the latter encompasses urban violence which is not directly related to land property rights insecurity.

[13] They are reported by the Landless Workers' Movement (MST).

[14] Descriptive statistics on the sample are reported in Table 6 in the appendix.

First we check the positive correlation between these three indicators coming from two independent sources (Table 1). Second, a principal component analysis is conducted in order to derive an aggregate measure of insecure property rights as a weighted sum of the three indicators. The resulting insecurity variable is the first principal component calculated as a linear combination of the homicides, expropriated areas and expropriation number variables; their weights are given by the first eigenvector (Table 7 in the appendix). This procedure reduces the dimension of the insecurity variable while minimising the loss of information. It then saves instruments[15] in the econometric estimation.

[Insert Table 1] Correlation matrix of insecurity indicators

The insecurity values computed annually for each state should be exclusively read as relative indices of property rights insecurity.[16] The states of Parà, Maranhão and Mato Grosso exhibit insecurity indices that are higher than the median value of the pooled sample of states in the 1988-2000 period (Table 2).[17] It is striking that these three states together with Rondônia also show annual deforestation rates higher than the median value of the sample; this correlation holds when deforestation rate is calculated as a percentage of geographic area. Data also highlight a spectacular jump in ownership insecurity in 1995/1996 echoed in deforestation data (Table 3). These findings suggest a potential relationship between property rights insecurity and deforestation that requires more rigorous econometric tests to be confirmed.

[Insert Table 2] State level of property rights insecurity and deforestation

[Insert Table 3] Annual level of property rights insecurity and deforestation

[15] Principal component analysis allows neutralising a potential multicollinearity problem as well. The latter can however hardly be rigorously tested because of missing instruments.

[16] The sign of the insecurity measure should not be given a particular interpretation. Measures should solely be taken relatively, for instance: property right insecurity is higher in Rondonia (-.56) than in Acre (-.77); and Rondonia insecurity is smaller than in Mato Grosso (0.08). In short, an increase in the measure depicts an increase in insecurity.

[17] The state of Para is often quoted as an example of struggle for land (Luta pela terra).

3.1.3 Controls

Several control variables (X^k) are introduced in the estimations in order to replicate usual drivers of deforestation considered in the literature. An environmental Kuznets curve for deforestation is specified to catch a non linear influence of income per capita (GDPC and $GDPC^2$) on deforestation (e.g. Angelsen and Kaimowitz, 2000; Barbier, 2004; Bhattarai and Hammig, 2004; Culas, 2007; Koop and Tole, 2001). One would expect an increase in deforestation due to agricultural expansion and demand for fuelwood in first stages of development (e.g. Anderson, 1990 for Brazil). The relation may be reversed in later stages. First, diversification of the economy increases the share of non agricultural activities. Second, there is an energy ladder that exhibits energy substitutions from biomass to fossil or hydroelectric energy accordingly with the level of development. Third, environment tends to be a luxury good and thus development induces a demand for natural forest preservation.

Other control variables are related to development policies and to the profitability of alternative activities in the Brazilian Amazon. Road network (Roads)[18] is introduced as proxy of transportation costs which are usually considered as a major factor of deforestation in the region (Pfaff, 1999; Weinhold and Reis, 2007). Cattle prices (Cattle prices) capture profitability of cattle ranching which is often blamed to be the main cause of deforestation in the Brazilian Amazon (Walker et al., 2000). Forest area (Forest area) and population density (Density) are also usual control variables. Forest area captures the saturation effect or forest scarcity effect associated with deforestation: deforestation decreases as forest areas become scarcer.[19] Population density may have a positive effect on deforestation by increasing food

[18] Road network is measured by kilometers of federal and state paved roads reported by the Ministry of infrastructures and the Brazilian Institute of Geography and Statistics (IBGE). Unpaved roads data appeared to be too unreliable to be considered (Andersen et al., 2002, chapter 3). Since data do not exist for 1994, 1996, and 1998; the missing values are interpolated.

[19] The IBGE gives an evaluation of forest areas for 1991 of which accuracy may be questioned. Yearly forest coverage on the 1988-2000 period were reconstituted for the econometric analysis. The Forest area variable should only be considered as a rough approximation of forest areas.

demand, but this effect may be partially compensated by an increase in the demand for forest products and forest surfaces (Foster and Rosenzweig, 2003). Increased population density may also promote the adoption of more intensive agricultural techniques (Pfaff, 1999).

3.1.4 Endogeneity bias

An endogeneity bias is suspected as deforestation may reduce ownership insecurity: landowners are prompted to clear preventively in order to discourage squatters from invading their lands and to prevent expropriation processes. The variable measuring property rights insecurity must therefore be instrumented. The restriction implied by instrumental variables is that, conditional on the control variables, they do not have any effect on deforestation, other than their effects through insecure property rights. State expenditure for judiciary functions (Justice) is used as an instrument.[20] Supposedly, this variable captures the ability of the judiciary system to secure property rights and thus to prevent land conflicts. However, judiciary spending could be the mechanical consequence of insecure property rights: to repress land conflicts, judiciary spending ought to increase with property insecurity. It is assumed however that this is unlikely to be the case. Land procedures represent only a tiny part of judiciary procedures that are mainly concerned with criminal and civil procedures in urban areas. Moreover instrumental equations exhibit negative and highly significant marginal impacts of judiciary spending on property rights insecurity (Table 4). Thus, judiciary spending seems to prevent land insecurity rather than to be the mechanical result of legal procedures generated by land conflicts.

[Insert Table 4] Instrumental equations

[20] State judiciary spending comes from the IPEA (Instituto de Pesquisa Economica Applicada) database and is deflated by consumer price indices calculated by the Fondaçao Getulio Vargas.

3.2 Econometric Results

[Insert Table 5] Econometric results

The deforestation equation is estimated using the panel two-stage least squares (TSLS) estimator with time and state fixed effects (Table 5). The instrumental variables are the contemporaneous (Justice, equations 1, 2, 3, 4) and lagged (Justice(-1), equation 4) judiciary spending. The latter attempts to take into account delayed preventive effects. As the model is over identified, it is possible to test the accuracy of instruments, i.e. their orthogonal character with respect to the residuals from TSLS estimation (equation 4). The relevance of instrumental variables in first stage equations (Table 4), i.e. the null hypothesis of weak instruments, is tested in two ways. Firstly, coefficients' significance of instrumental variables is tested with F tests of which p values are reported in Table 5. Secondly, the adjusted R^2 statistic from instrumental (first stage) equations is reported in Table 4. The results show that instruments are not weak; the TSLS inference is thus reliable. In addition, the Nakamura and Nakamura (1981) exogeneity and Sargan (1988) overidentification tests are presented. The Nakamura and Nakamura test rejects the exogeneity of property rights insecurity (null hypothesis) at the 1% level whereas the Sargan test cannot reject the null hypothesis of instrumental variables orthogonality (with respect to the residual) at the 1% level.

The existence of a deforestation Kuznets curve is weakly confirmed (equations 1, 2, 3).[21] Suggested explanations for the weak significance of GDPC coefficients are: first, the variance of development levels of Brazilian Amazonian states is insufficient to capture the Kuznets curve; second, part of the impact of GDPC and $GDPC^2$ is caught by state and period fixed effects. Third, Brazil is an important ethanol sugarcane producer. At advanced stages of development, an increase in GDPC can lead to an expansion of ethanol demand which can promote deforestation and thus may displace the turning point of the curve. Cattle prices are

[21] The GDP coefficients should be cautiously interpreted; they may be affected by an endogeneity bias.

not significant (equation 1). This result may be the consequence of integrated cattle markets: cattle prices follow a common trend that is caught by time fixed effects. Nevertheless, we can assume that cattle ranching is driven by other factors than cattle prices such as securing property right. Forest area is also insignificant while Roads and Density (in logarithms) have a positive and significant effect on deforestation (equations 1 and 2).[22] Since the Roads variable is weakly reliable (due to missing data, see footnote 18) estimation results are given with (equations 1 and 2) and without (equations 3 and 4) this variable: the effect of Insecurity on deforestation remains unchanged.

Whatever the specification, insecure property rights have a positive impact on deforestation.[23] This impact is significant at the 1% level when Justice is the sole instrument (equations 1, 2, and 3); it is significant at the 5% level when both Justice and Justice(-1) are used as instruments (equation 4). The instrumentation procedure allows interpreting the effect of insecure property rights as a causal relationship. Consequently, policy measures aiming at reducing property rights insecurity should allow reducing deforestation rates in the Brazilian Amazon. A simulation exercise is provided to estimate an elasticity of deforestation with respect to insecurity taking its lowest estimated coefficient (equation 3) in order not to overestimate the effect of insecurity on deforestation. The elasticity evaluated at median values of insecurity and deforestation shows that a 10% decrease in insecurity induces a 7% decrease in annual deforestation rates.[24]

[22] Roads are considered as an exogenous variable since the location of federal and state roads is independent from forest clearing (Andersen et al. 2002). When Roads and Density are introduced separately, these two variables are not significant.

[23] OLS estimates (not presented in the paper but available from the authors) underestimate the impact of insecure property rights on deforestation when compared to TSLS estimates. Unobserved determinants of deforestation are thus negatively correlated with insecure property rights. This result strengthens the assumption according to which deforestation is a mean of securing land property rights.

[24] The functional form does not allow directly inferring elasticities; a log-log specification is not relevant.

4 Concluding remarks

The main outcome of this paper is that insecure property rights in land drive deforestation in the Brazilian Amazon. This result should not be interpreted as a simple positive correlation between deforestation and property rights insecurity. A causal relationship is provided by a theoretical analysis and econometric estimations on the Brazilian Amazonian states in the 1988-2000 period, that rely on instrumental variables. Thus an exogenous escalation in property rights insecurity brings a significant increase in the rate of deforestation.

Two main aspects of property rights insecurity have been considered: occurrence of violent conflicts for land access and scale of expropriation procedures for land reform purposes. It is argued that the way land reform is implemented has a detrimental impact on deforestation: untenured deforesters claim property rights that are gained after expropriation procedures. Indeed, according to the Brazilian rule of law, forested lands, even privately owned, are often classified as unproductive and hence eligible to expropriation.

This paper does not intend to assess the relevance of the Brazilian land reform. Land reform is a potential source of equity benefits, production and productivity gains, investment incentives, better access to credit for the poor. Moreover, tenure security favours sustainable uses of natural resources (e.g. Cattaneo, 2001) and allows payments for natural services provision (e.g. Fearnside, 2003; Grieg-Gran et al., 2005). However, it may be desirable to accommodate land reform purposes and environmental concerns.

It is suggested here that modifying the incentive framework could help reducing deforestation. Sustainable forest management should be regarded as a productive use of land in the Brazilian law. Beyond the scope of this paper is the definition of operational measures of sustainable tropical forest management, which should in fact resolve the conflicts related to the secure property rights between the landowners and the squatters in the Brazilian Legal Amazon.

Appendix

[Insert Table 6] Descriptive statistics

[Insert Table 7] Property rights insecurity measure: principal component analysis on pooled sample

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Table 1. Correlation matrix of insecurity indicators

	Homicides	Expropriation number	Expropriated areas
Homicides	1.00		
Expropriation number	0.18 **	1.00	
Expropriated areas	0.38 ***	0.68 ***	1.00

Source : Authors' calculations. Number of observations : 113, Period : 1988-2000. * : significant at 10% level ; ** : significant at 5% level ; *** : significant at 1% level

Table 2. State level of property rights insecurity and deforestation

States (Number of obs)	Median values of Insecurity	Deforestation (annual, km²)	Deforestation (annual, percentage of state area)
Rondônia (13)	-0.56	2340	0.98
Acre (13)	-0.77	482	0.31
Amazonas (10)	-0.91	33	< 0.01
Roraima (13)	-1.06	240	0.11
Pará (13)	1.75	5111	0.41
Amapá (13)	-0.95	720	0.50
Tocantins (12)	-0.49	371	0.13
Maranhão (13)	0.20	1065	0.32
Mato Grosso (13)	0.08	6220	0.69
Pooled sample (113)	-0.43	730	0.34

Source: Authors' calculations (Insecurity) and INPE (Deforestation).

Table 3. Annual level of property rights insecurity and deforestation

Years (Number of obs)	Median values of Insecurity	Deforestation (annual, km²)
1988 (8)	-0.33	1925
1989 (9)	-0.42	1180
1990 (9)	-0.94	580
1991 (9)	-0.86	670
1992 (9)	-0.23	799
1993 (9)	-0.97	372
1994 (9)	-0.82	372
1995 (9)	-0.16	1745
1996 (8)	-0.10	1042
1997 (9)	-0.02	409
1998(9)	-0.12	670
1999 (8)	-0.37	975
2000 (8)	-0.12	838
Pooled sample (113)	-0.43	730

Source: Authors' calculations (Insecurity) and INPE (Deforestation). The potential number of observations is 117 which is reduced to 113 because of missing values.

Table 4. Intrumental equations

	Explained variable: Insecurity		
Justice	-4.64 e-05	-6.07 e-05	-5.45 e-05
	(-2.26)**	(-2.06)**	(-2.66)***
Justice(-1)			-3.32 e-05
			(-1.72)*
GDPC	-1.18	-0.72	-0.65
	(-2.15)**	(-1.46)	(-1.03)
$GDPC^2$	0.10	0.07	0.05
	(2.32)**	(1.81) *	(0.90)
Roads	-0.23		
	(-2.34)**		
Density	-6.26		
	(-3.09)***		
Adjusted R^2	0.64	0.61	0.60
Obs	113	113	105

Estimation method: panel least squares. White period standard errors and covariance. t statistics are in parentheses. *: significant at 10% level; **: significant at 5% level; ***: significant at 1% level

Table 5. Econometric results

	Explained variable: Deforestation			
Equations	1	2	3	4
Insecurity	1840.58	1756.68	1270.95	1335.49
	(2.67)***	(2.70)***	(2.43) ***	(1.95)**
GDPC	2884.76	2478.13	1133.00	974.53
	(1.87)*	(1.73)*	(1.52) *	(1.14)
$GDPC^2$	-232.15	-194.92	-104.89	-69.68
	(-1.78)*	(-1.76)*	(-1.70) *	(-0.86)
Roads	563.08	428.54		
	(1.94)*	(1.98)**		
Density	16174.56	12608.03		
	(1.91)*	(1.81)*		
Forest area	2.77 e-03			
	(0.31)			
Cattle prices	8140.66			
	(0.67)			
Obs	111	113	113	105
Adjusted R^2	0.53	0.57	0.71	0.69
Cross-section/period F (P-value)	(0.00)	(0.00)	(0.00)	(0.00)
Instrument list	Justice	Justice	Justice	Justice, Justice(-1)
First stage (significance of instruments): p value	0.31	0.03	0.004	0.03
Exogeneity test: p-value	0.04	0.00	0.00	0.00
Suridentification test: p value				0.57

Estimation method: panel two-stage least squares. White period standard errors and covariance correction. *: significant at 10% level; **: significant at 5% level; ***: significant at 1% level. Unless otherwise specified, t statistics are in parentheses. The equations 1 to 4 differ by the control variables and by the instrumental variables.

Table 6. Pooled sample: Descriptive statistics (1988 2000)

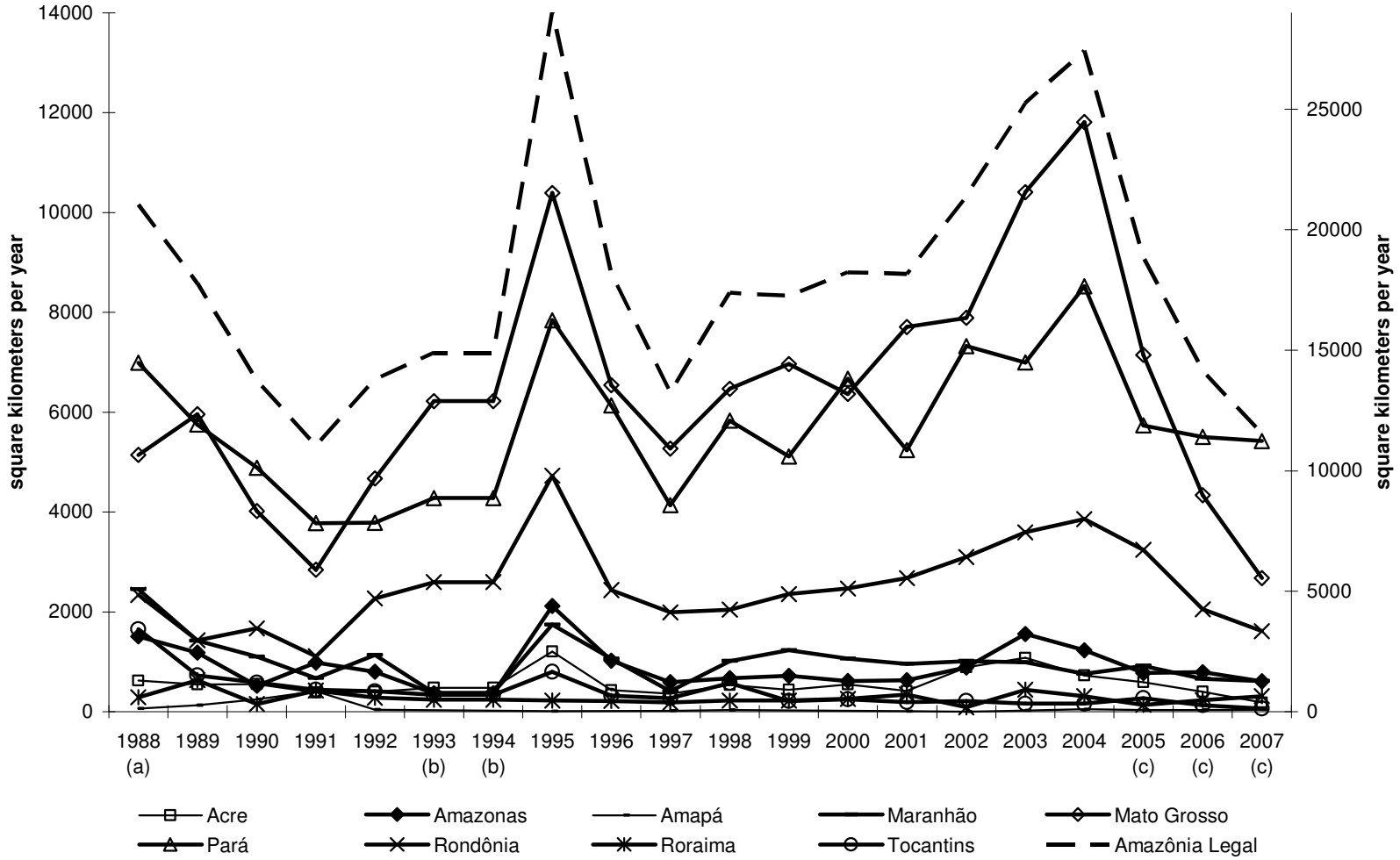
Variables		Mean	Median	Std. Dev.	Source :
Deforestation	State annual deforestation, km^2	1936.49	730.00	2280.61	www.obt.inpe.br/prodes/index.html
Homicides	Number of homicides related to land conflicts	2.97	1.00	5.25	www.mst.org.br www.cpt.org.br
Expropriated areas	Surfaces expropriated, km^2	1394.08	54000.0	2074.75	http://www.incra.gov.br/
Expropriation number	Number of expropriations procedures	10.32	2.00	18.57	http://www.incra.gov.br/
GDPC	Gross domestic product per capita, 10^3 real Reais per capita	3.51	3.31	1.35	http://www.ipeadata.gov.br
Justice	Judiciary expenses, 10^3 real Reais	3315.69	1114.97	5272.15	http://www.ipeadata.gov.br
Roads	Paved roads, km	1261.47	855.00	1224.65	Ministry of Infrastructures, Transportation department and http://www.ibge.gov.br
Density	Population density, habitants per km^2	4.36	3.17	4.22	http://www.ibge.gov.br

Table 7. Property rights insecurity measure: principal component analysis on pooled sample

	Principal Component 1	Principal Component 2	Principal Component 3
Eigenvalues	1.86	0.85	0.29
Variance Proportion	0.62	0.28	0.10
	Eigenvectors :		
Variable	Weights 1	Weights 2	Weights 3
Homicides	-0.42	-0.88	-0.22
Expropriated areas	-0.62	0.45	-0.64
Expropriation number	-0.67	0.14	0.73

The columns of the first part of the table refer to the principal components. The eigenvalues and the explained variance proportions are displayed. The variance proportion is calculated as the ratio of each eigenvalue to the sum of all eigenvalues. The columns of the second part of the table display the weights corresponding to each principal component (eigenvector corresponding to each principal component). In order to ease the interpretation, the opposite of the principal component 1 is introduced in the regressions.

Figure 1. Annual deforestation in the Brazilian Legal Amazon



Source: INPE (National Institute for Space Research), Project PRODES (Program for Deforestation Assessment in the Brazilian Legal Amazonia). (a) Average value between 1977 and 1988; (b) Average value between 1993 and 1994; (c) Consolidated deforestation rates. States values on the left axis; Total Brazilian Legal Amazon on the right axis.