Land inequality and deforestation in the Brazilian Amazon

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ABSTRACT

The aim of this paper is to demonstrate the relationship between land inequality and deforestation in the Brazilian Amazon. Therefore, it is developed an occupational choice model where an individual decides whether to become a farmer in an already established place or to move in search of economic opportunities and land to clear at the agricultural frontier. This model provides theoretical predictions that are tested empirically. Based on data from 515 municipalities, this paper estimates a Tobit model in order to test the theoretical predictions. Basically, it has been shown that there is little statistical evidence to support the existence of a direct relationship between land inequality and deforestation. Nevertheless, when one takes into account the effects of land inequality on deforestation through its interaction with credit and land reform policies, it can be shown that the pattern of land distribution, indeed, plays a role for deforestation. There is a positive relationship between credit and deforestation in more unequal places. Furthermore, this paper provides evidence that land reform in more unequal municipalities reduces deforestation. Hence, it is clear that there is a role for government to increase social welfare and reduce deforestation rates.

Keywords: deforestation, land inequality, Amazon
JEL Classification: Q15; Q23; Q24 ; Q38; P48

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[1] Brazilian Bank of Development (BNDES). The opinions expressed here are individual and do not represent the institution's view.

I. INTRODUCTION

The loss of large areas of Amazon forest has increasingly become a focus of national and international concern. Although this issue has previously been viewed as a threat to the overall mega-biodiversity of the planet, it is now assumed that the spreading problems associated with climate change will also serve to amplify the dramatic expected losses related to the destruction of native forests. After all, deforestation is the primary source of Brazil's contribution to net carbon emissions. Moreover, climate changes can lead to a higher frequency of extreme events, such as large floods, droughts or other climatic irregularities, and the impact of these events on the soil and water bodies will be accentuated without the protection of native vegetation. Events such as the great drought of 2005 and recent floods in 2009 highlight the vulnerability of the Amazon forest to the extreme events that are expected with global warming. Thus, problems associated with deforestation, which are simultaneously cause and consequence of climate change, are intensified and consequently garner the attention of various governments and of the public at large.

The literature on deforestation usually focuses on the economic causes of deforestation. On the one hand, there are perverse incentives caused by public policies aiming at the "development" of the region: fiscal incentives, credit subsidies, infrastructure investments, privatization "for free" of extensive public lands, etc. On the other hand, there are economic incentives provided by the increasing profitability of activities associated to deforestation (unsustainable logging, cattle ranching, cultivation), usually leading to land speculation processes that reinforce even further the process of land clearing (for example, Fearnside, 1992; Schneider, 1994; Ozorio de Almeida and Campari; 1995; Young, 1997; Margulis 2003, Angelsen, 1999).

Although the activity of deforestation is generally highly profitable, it is also associated to big risks. As usual in frontier areas, violence occurrence is very common. Disputes over land claims often end in death (Sant'Anna and Young, 2010a). This occurs because defining property rights is not an easy task in the frontier. Besides risks associated to violent conflicts, the mere fact of clearing a plot of land does not guarantee the acquisition of property rights. There is, then, a non negligible capital risk in the business. Finally, advancing into a tropical forest also provides health risks that arise from diseases like malaria and from the total lack of infrastructure like sanitation.

In this sense, it is not straightforward to assume that the risk-adjusted profitability in the frontier is bigger than in another agricultural activity (at least capital or land intensive crops, like soybean and sugar cane). In that sense, this paper assumes that the decision to clear land must be understood in a broader framework of occupational (or asset composition) choice (Takasaki *et al.*, 2000). In sum, the agent always decides whether to become a farmer in an already established place or to move to the frontier in search of economic opportunities and land to clear (Tole, 2004; Young, 1997). Therefore, it is assumed that deforestation results from an economic reasoning that compares payoffs from farming and from clearing land at the frontier. As such, the amount of land available for farming is a crucial element of the decision.

Therefore, the aim of this paper is to investigate the relationship between land inequality and deforestation in the Brazilian Amazon. Hence, this paper is organized in five sections, including this introduction. In section II, a brief revision of the related literature on land inequality and deforestation is presented. Section III develops a simple theoretical model that highlights how land inequality might affect decisions to clear land and possible policy responses and impacts. Based on predictions of the former section, empirical results, based on data from 515 municipalities of Brazilian Amazon, are shown on section IV. Finally, main conclusions are presented on section V.

II – RELATED LITERATURE

The literature on deforestation usually assigns a role for the exclusion to land as a motivation for deforestation (Becker, 1991; Fearnside, 1992; Sant'Anna and Young, 2010) Nevertheless, in general this process is indicated in a general discussion and it does not deserve a detailed observation. Few authors provide empirical analysis regarding the relationship between land inequality and deforestation, not many of them related to the Amazon[2,3].

As remarked by Tole (2004), the degree of land accessibility is a function of rural population density and land inequality, where unequal systems do worse in accommodating population pressures than more egalitarian systems. Thus, the pattern of land distribution shapes decisions regarding deforestation.

Assunção and Ghatak (2003) explain the documented inverse relationship between farm size and productivity with heterogeneity in farming skills. According to them, the average farm size of skilled farmers is smaller than that of unskilled farmers. Additionally, Assunção (2008) shows that unproductive farms are larger than agricultural farms on average. This provides a useful insight to understand why land inequality leads to less land accessibility in the absence of rental and credit markets.

In such a framework, an increase in land inequality jointly decreases agricultural production and also drives deforestation up. If this is correct, there is clearly much room for policy intervention that would increase social welfare. Young and Neves (2009), for instance, provide evidence from an analysis of municipalities in Southeast and South Brazilian Mata Atlantica that there is no consistent correlation between deforestation and development, as measured by the Human Development Index.

Although Young and Neves (2009) do not propose a causal relation, it can be argued that if deforestation decreases development, it is just another form of resource curse, where overexploitation of natural resources does not lead to development. Frankel (2010), in a survey of the literature on natural resource curse, points to six possible channels for the existence of the phenomenon. One of these channels is through poor institutions that arise in rent-seeking and extractive states. So, probably, municipalities that have better governance schemes will show better results for deforestation and development.

Poor institutions, as advanced by Engerman and Sokoloff (1997), may be an outcome of factor endowments. Briefly, according to the authors, factor endowments are central to structural inequality (usually associated to land inequality), which is, in turn, a determinant of bad institutions, low human capital investment and, therefore, underdevelopment[4]. Naritomi et al. (2009) present evidence that brazilian municipalities that are associated to colonial rent-

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[2] Tole (2004) analyzes explicitly the relationship between land distribution and deforestation, but in a cross-country perspective. The author also provides an extensive review of the literature on this subject.

[3] Caldas et al. (2005), Simmons (2005), Alston et al. (1999) analyze related issues as the role of land reform, violence and wealth for deforestation. Nonetheless, the authors do not provide a specific variable related to land inequality.

[4] There is a vast literature that builds on the Engerman and Sokoloff hypothesis. See, for instance, Easterly (2007) for a revision of the literature and for empirical results that confirm the hypothesis mentioned above.

seeking episodes (sugar-cane and gold colonial cycles) display lower provision of public goods and lower income per capita[5].

Although this paper focuses only on the relationship between land inequality and deforestation, it is arguable that land inequality affects development under different forms, including through deforestation. Nonetheless, in this paper, it is explored only the link between land inequality and deforestation, as proposed by Tole (2004).

III – A SIMPLE MODEL OF LAND DISTRIBUTION AND DEFORESTATION

The key characteristic of this model is to address the effect of less land accessibility, through an increase in inequality, to deforestation. As remarked before, when someone is about to decide whether to move into the frontier to clear land, this possibility is confronted against an opportunity cost of farming elsewhere. It is, then, developed an occupational choice model, where the individual maximizes her expected utility by choosing what her occupation will be: a worker, a farmer or a settler[6]. The main point is that what matters for an economic analysis of deforestation is the relative risk-adjusted payoff. This point is also put forward by Tole (2004).

III.1 Setup

Consider an economy with infinite periods, overlapping generations and where individuals live for two periods. In each period, population with mass normalized to one is born and has a given wealth distribution $G_t(W)$. Initial wealth is received as a bequest.

In period t, individuals decide what to do with their wealth. That is to say, they may buy a plot of land L at a price p, they may clear land – D - at the frontier at a cost c, with $c<p$, or they may decide to enter the labor market and receive a wage - w. At the following period, agents receive their revenues (wages and profits) and sell their land to the new generation that is born, in order to consume. Agents are risk neutral and preferences are given by its consumption and the bequest for next generation.

As shown by Assunção (2008), under such a framework, expected utility can be a function of profits and the value of land sold. It is further assumed that there are no credit and land rental markets. So, individuals can only go as far as their initial wealth allows. That means that $cD<W$ and $pL<W$. An important assumption to be made, following Tole (2004), is that accessible land is a function of land inequality[7].

If an individual decides to become a farmer, her profit will be revenues received from the sell of agricultural products – q – less the wage paid to employee. It is assumed, therefore, a production function with fixed technology in labor and land. In this case, there are no capital gains after land is sold. If the decision is to clear land, it is assumed that the individual does not need to employ labor[8] and receives a profit – b. As everyone is price taker in land, there is a possibility of capital gains – p-c. This point is crucial, since it is well known that deforestation follows a speculative motive that is linked with the “creation of property rights” (Sant’Anna & Young, 2010b).

[5] An interesting point made by the authors is that, as the analysis is within Brazil, a country that shares a single colonizer, a single language and is highly centralized, they are able to identify different *de facto* institutional arrangements that are associated with different factor endowments.

[6] As it will be made clear later, initial wealth is crucial for the decision.

[7] Nonetheless, instead of assuming L = L(i), it will be assumed later that there is a threshold, L^F that depends on the degree of land inequality.

[8] Usually, early settlers clear land and establish extensive cattle production that does not require much labor.

III.2 – Occupational Choices

Summing up, individuals can invest in a farm, engage in deforestation or become an agricultural worker. Given the structure described above, expected final wealth will be:

$$E(W_{t+1}) = \begin{Bmatrix} W_t + w \\ (p+b)D \\ (p+q-w)L \end{Bmatrix} \tag{1}$$

The occupational choice results from the comparison of the expected final wealth paths in (1). At this point, it assumed that there land distribution is not binding on the size of *L*. Hence, individuals will choose to become farmers if final wealth from farming is higher than from clearing land and being a worker:

$$r_L > g_D + r_D and W > \frac{w}{r_L} \equiv W_0 \tag{2}$$

Where r_L is the return on farming - $(q\text{-}w)/p$ – g_D is the capital gain from selling deforested area – $(p\text{-}c)/c$ – and r_D is the return on activity after the land is cleared – b/c. Thus, in order to become a farmer it is necessary that the return from this activity is larger than that from clearing land and initial wealth must be larger than w/r_L.

In order to clear land at the frontier, comparing with becoming a worker, initial wealth must be larger than:

$$W > \frac{w}{g_D + r_D} \equiv W_1 \tag{3}$$

Assuming that there is not yet any constraint on the size of *L*, we have the following Lemma:

Lemma 1. If $r_L > g_D + r_D$, *occupational choices will be restricted to become a farmer or a worker, depending on initial wealth. There is no room for deforestation.*

Proof: If $r_L > g_D + r_D$, it is easy to see that $W_0 < W_1$. *Therefore, if an individual has enough wealth for clearing land, she also has wealth for being a farmer at the old frontier.*

Thus, occupational choices are fully described by initial wealth and by the relationship between returns from farming and at the frontier.

III.3 – Introducing land inequality

Now, suppose accessibility to land is completely related to land inequality[9]. We will represent this by assuming there is a limit on the size of land available to be used – $L^F(i) < L$. Besides, when an individual receives her initial wealth, if her option is to keep farming, a portion of his/her wealth will be allocated to an asset that does not provide any interest payment – *m*. That is to say: $W_t = pL^F + m$. Thus, occupational choices in that case become:

[9] In order to assume this, we follow Assunção (2008), that states that unproductive farms are (weakly) larger than agricultural farms on average. If larger farms are kept idle, we assume land inequality is positively related to accessibility to land.

$$E(W_{t+1}) = \begin{Bmatrix} W_t + w \\ (p+b)D \\ (p+q-w)L^F + m \end{Bmatrix} \tag{4}$$

Comparing final expected wealth, the occupational choice pro clearing as compared to working and to farming land will occur if:

$$W > \frac{w}{g_D + r_D} \equiv W_1; W > \frac{r_L pL^F}{r_D + g_D} \equiv W_2 \tag{5}$$

It is clear, from (5), that the extend of land inequality, as $L^F = L^F(i)$, is a major determinant of the occupational choice. Again, comparing payoffs between been a farmer and a worker, we have the following condition:

$$L^F > \frac{w}{q-w} \tag{6}$$

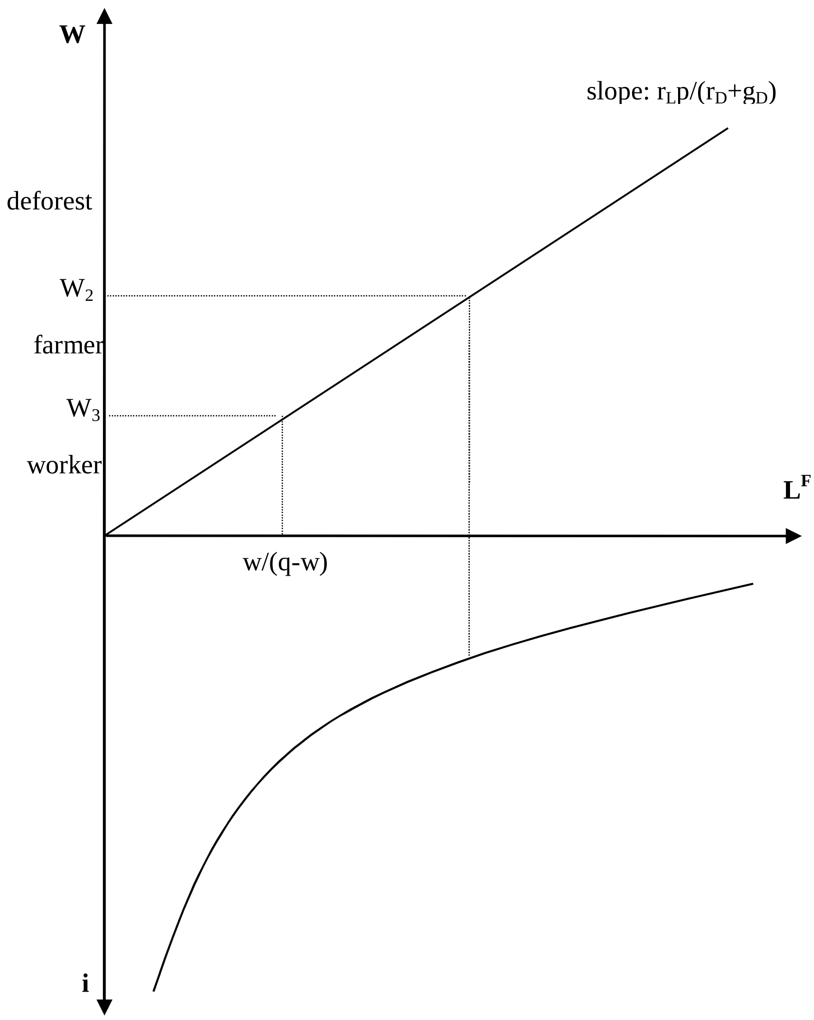
Substituting (6) into farmer's expected final wealth given by (4), we have:

$$W > \left(1 + \frac{1}{r_L}\right)w + m \equiv W_3 \tag{7}$$

Thus W_3 is the threshold that determines the minimum wealth level in order to be a farmer.

As figure 1 depicts, land inequality determines the amount of accessible land. The maximum of land that can be used for farming - L^F -, in its turn, is determinant of the wealth threshold – W_2. Above that threshold, the individual will decide to clear land and not to farm.

Figure 1



As can be seen on Figure 1, if land inequality increases, the wealth threshold W_2 moves down and, *ceteris paribus*, there is an increase in deforestation. If the relative return of deforestation increases, the slope of the curve will decrease, leading again to an increase in deforestation. Next, these main results are presented in a more formal treatment.

Equilibrium

An equilibrium in the market for cleared land must equalize the aggregate demand and the supply of deforested land. Condition (5) determine that every individual with wealth greater than W_3 demand W/c units of cleared land. Therefore, the equilibrium condition can be arranged as

$$\int_{W_2}^{\infty} W dg(W) = cD \tag{8}$$

Thus, the amount of cleared land under a world with land inequality is given by:

$$D = \frac{\int_{W_2}^{\infty} W dG(W)}{c} \tag{9}$$

The result above leads us to the following proposition:

Proposition 1: Deforestation is positively related to land inequality (i); land prices (p); cattle ranching profits (b); and negatively related to cost of deforestation (c); and agricultural prices and yields (q). As for wages, the effect is ambiguous.

Proof: The effects on deforestation are driven by the effects on the wealth threshold – W_2. A higher W_2 implies less demand for deforestation. Thus, it is sufficient to analyze the determinants of W_2. Record that

$$W_2 = \frac{r_L p L^F}{r_d + g_d} = \frac{c(q-w)L^F}{p-c+b}$$

It is straightforward that

$$\frac{\partial W_2}{\partial L^F} > 0; \frac{\partial W_2}{\partial q} > 0; \frac{\partial W_2}{\partial c} > 0; \frac{\partial W_2}{\partial p} < 0; \frac{\partial W_2}{\partial b} < 0; \frac{\partial W_2}{\partial w} < 0$$

On the other hand,

$$W_1 = \frac{w}{g_D + r_D}$$

As wage increases, there will be a point where $w > r_L p L^F$. If such a situation occurs, the relevant wealth threshold becomes W_1. At that point, the effect of wages on deforestation is negative.

From the definition of W_2, it is expected that land inequality, land prices and profitability at the frontier should exert a positive influence on deforestation. On the other hand, profitability of farming and the cost of deforestation should decrease incentives to clearing land. Regarding wages, there are mixed signals: since it reduces the incentive to farming it should have a positive influence on deforestation, by reducing W_2. Nevertheless, wages also represent an opportunity cost and as it increases W_2, incentives to clearing land are also reduced. Thus its influence on deforestation cannot be defined *a priori*.

The equilibrium in the labor market is defined by aggregate demand for labor that results from farming decisions and supply of labor:

$$\int_{W_3}^{W_2} W dG(W) = wG(W_3) \tag{10}$$

The equilibrium wage rate is determined by the endowments of the economy and the wealth distribution.

In the following, we evaluate the role of public policies, more specifically, land reform and credit.

III.4 - Introducing governmental policies

Land Reform

Assuming that $r_L > g_D + r_D$, the emergence of land inequality will result in a loss of welfare, irrespective of the decision to engage in deforestation or in becoming a constrained farmer. This loss of welfare can be represented by:

$$S_1 = (q-w)(L^F - L); \quad (11)$$
$$S_2 = (p-c+b)D-(q-w)L-\alpha D;$$

In the first case, the loss of welfare is just the difference between the land constrained production and the unconstrained one. In the second case, the loss of welfare is the difference between private gains from deforestation, the loss of unconstrained production and a parameter α that is related to negative externalities related to deforestation as loss of biodiversity and CO_2 emissions.

Now suppose two different policies are available for the government. The first one is land reform, in order to increase access to land. That is to say, government can act to increase L^F, at a cost $\lambda(L-L^F)$[10]. The second policy, assuming deforestation occurs all in public land, is just to "let it go", making a "fake" land reform. In that case, there is no additional cost for the government. Thus, government payoff function is

$$G = \min\{(q-w)(L-L^F)+ \lambda(L-L^F); (q-w)L-(p-c+b)D+\alpha D\} \quad (12)$$

Now, assume that $W=W_2$. An individual will be indifferent between clearing land or becoming a farmer. In that case, government decision is based exclusively on the analysis of $\lambda(L-L^F)$and αD. If the political cost is larger than the environmental cost, the option is to let individuals expand the frontier. Otherwise, government will engage in land reform. Thus, it can be expected that where land reform occurs in more unequal places, there will be a reduction in deforestation.

Credit

It is well known that credit subsidies are also an important driver of deforestation. Based on that, let us analyze how credit can affect occupational choices. Suppose credit is only directed to machines, equipment and fertilizers[11]. Hence, credit, here represented by δ, affects only q and c, with

$$\frac{\partial q}{\partial \delta} > 0; \frac{\partial c}{\partial \delta} < 0$$

Thus, an increase in credit availability increases profitability for farming and for clearing land. The final effect of credit depends on its relative effects over deforestation and farming. That is to say:

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[10] It can be seen as a political cost the government faces if it is to challenge a powerful landowner elite. Conning & Robinson (2007) model the probability of land reform depending on a game between landlords and peasants trying to influence political parties.

[11] It is assumed that credit is earmarked for machines, equipment and fertilizers. Thus, credit constraints still hold for the purchase of land.

$$\frac{\partial E(W^{D}{}_{t+1})}{\partial \delta} > \frac{\partial E(W^{F}{}_{t+1})}{\partial \delta} \rightarrow \frac{\partial D}{\partial \delta} > 0 \tag{13}$$

Hence, credit will expand deforestation if

$$\frac{(p+b)D}{qL^{F}} > \frac{\varepsilon_{qy}}{\left|\varepsilon_{cy}\right|} \tag{14}$$

An increase in credit will result in more cleared land if inequality in equation (13) holds. Another interpretation for equation (14) is that, given the credit elasticities of q and c, an increase in land inequality will result, assuming $W=W_2$, in an increase in deforestation, for the same level of credit.

IV. ECONOMETRIC RESULTS

In accordance with the previous section, as inequality reduces access to land, given a low opportunity cost[12], individuals become more prone to clear land at the frontier. If this assumption is correct, deforestation will be a function of previous land inequality in the municipality. In addition, the previous section, as it analyzes the role of different policies, provides a framework for understanding the effects of land reform on deforestation and of credit on deforestation. The literature usually associates land reform and credit availability with an increase in deforestation. In accordance with the predictions of the model, land reform and credit effects on deforestation might depend on the actual degree of inequality in the municipality. These predictions will also be tested in this empirical section.

III.1. Database

The data used in this article are from 515 municipalities in eight Amazonian states, namely Acre, Amapá, Amazonas, Mato Grosso, Pará, Rondônia, Roraima and Tocantins.[13] The data on deforestation were extracted from the PRODES database, which was provided by the National Institute of Space Research (INPE). The pattern of land distribution as measured by gini index, was constructed with data from the 1996 Brazilian Agricultural Census. A measure of land reform policies was constructed considering the percentage of expropriated areas within each municipality from 1998 to 2001. IPEADATA, a database powered by the Applied Economic Research Institute (IPEA) was the source for these data. The mean value of rural credit between 2000 and 2004 was utilized as measure of credit[14]. These data were also extracted from IPEADATA

Other data were used in the regressions as control variables: an index that measures transport cost from the municipality to São Paulo, the population density and the increase in heads of cattle per km^2 from 2000 to 2007. These data were extracted from the IPEADATA[15].

[12] In recent years, the deforestation rate has significantly decreased. This fact may be related to real minimum wage gains and, generally, improvements in the labor market conditions in recent years. As such, this is as an interesting hypothesis to be explored in later studies.

[13] Maranhão is also considered part of Legal Amazon, but it was not included in the sample because there was incompatibility between data from different sources at the municipal level.

[14] This is the last year of available information.

[15] In the appendix, there is a description of the variables and data sources used.

The table below presents the principal descriptive statistical values of the data used.

Table 1: Descriptive statistics

	DEFOR_07_02	LAND_GINI	EXPROP	DIST_SP	DENSITY	CRED	CATTLE_07_00
Mean	2.537	0.799	0.975	3327.544	15.905	4053713.	9.266
Median	0.865	0.813	0.000	2922.740	3.182	1237239.	3.446
Maximum	23.568	0.940	38.700	10511.92	2127.400	1.14E+08	107.912
Minimum	0.000	0.500	0.000	1188.000	0.125	0.000000	-66.994
Std. Dev.	3.597	0.066	2.970	1603.701	107.196	10226691	16.933
Observations	588	515	588	575	575	588	588

As indicated above, there was significant heterogeneity in the municipal data. Other than the distance to São Paulo and Gini index, the coefficients of variation were all greater than 1. For the increase in deforested area between 2002 and 2007, for example, there were municipalities with values between zero and almost a quarter of the total area (one municipalty). Heterogeneity in data also occurs heavily with expropriation rates and the increase in the number of cattle heads. Land inequality on the other hand has a very coefficient of variation. This has an implication on the results achieved, as it will be explored later on.

IV.2 The econometric model

In accordance with the predictions of the theoretical framework presented above, the magnitude of land inequality should be able to explain the deforestation rate. Thus, the model can be described by the following equation.

(1)

$$Defores02\_07 = C + \beta_1 Land\_gini\_01 + \alpha_i X + \varepsilon$$

In this equation, Defores02_07 is the deforestation that occurred between 2002 and 2007 in relation to the total municipal area, Land_Gini is measure of inequality in land distribution in 1996, X is a vector of the control variables by municipality, based on the theoretical predictions of the previous section and ε is the model error term. It is important to note that the period used for the dependent variable is different and later than the period used for the independent variable, to address the temporal effect of land inequality on frontier expansion.

Based on the above description of the land occupation process within the Amazon agricultural frontier, it is expected that both the distance to the markets and the livestock activity exert an impact on the level of deforestation in the municipalities of the region. In this context, the following were used as control variables: the costs of transport from the municipality to São Paulo as a *proxy* for the distance to markets; this same variable squared; the variation in the livestock industry between 2000 and 2007; the population density.

The distance variable appeared in linear and quadratic form to capture the non-linear effects discussed in the literature. The goal was to test the U-inverted form proposed by Hotte (2001) and Alston *et al.* (1996). Besides that, distance is used as a *proxy* for the cost of deforestation – *c*. The variation in the livestock business from 2000 to 2007 captures the effect of the incentives (relative to the profitability of the cattle - *b*) on deforestation, as proposed by

Margulis (2003)[16]. The population density controls for urban municipalities and is related to returns on farming – q – as more dense places should have less productivity.

Credit and expropriation measures are introduced to capture other effects inferred from the model. Later, interaction terms between land inequality, credit and expropriation are introduced in order to understand how credit and land reform on more unequal municipalities affect deforestation. In that case, the model can be represented by

$$Defores02\_07 = C + \beta_1 Land\_gini\_01 + \beta_2 Z + \alpha_i X + \varepsilon$$

Where Z represents a vector with other variables of interest as credit, expropriation and interaction terms between those two variables and land inequality.

IV.3. Results

There were a significant number of observations (100 out of 515, or 19.4%) with a zero value in the dependent variable. Thus, at first, four regressions were estimated using OLS and Tobit methods. These four regressions present results without interaction terms. Table 2 presents the results of the model specified above.

Table 2: First Estimations results

Dependent variable: Deforest_2007_2002	**(1) OLS**	**(2) Tobit**	**(3) OLS**	**(4) Tobit**
C	**-1.454**	**-4.491** ^{b}	**-3.097**	**-7.124** ^{a}
	(1.904)	(2.243)	(1.913)	(2.251)
LAND_GINI	**0.487**	**1.707**	**1.011**	**2.615**
	(2.144)	(2.511)	(2.114)	(2.461)
DIST_SP	**0.001** ^{a}	**0.002** ^{a}	**0.002** ^{a}	**0.003** ^{a}
	(0.000)	(0.000)	(0.000)	(0.000)
DIST_SP^2	**-1.37E-07** ^{a}	**-1.95E-07** ^{a}	**-1.63E-07**	**-2.36E-07** ^{a}
	(2.79E-08)	(3.25E-08)	(2.78E-08)	(3.25E-08)
DENSITY	**-0.002**	**-0.039** ^{a}	**-0.001**	**-0.039** ^{a}
	(0.001)	(0.010)	(0.001)	(0.010)
CATTLE_07_00	**0.088** ^{a}	**0.100** ^{a}	**0.099** ^{a}	**0.099** ^{a}
	(0.009)	(0.010)	(0.010)	(0.010)
EXPROP			**0.135** ^{a}	**0.175** ^{a}
			(0.043)	(0.049)
CRED			**5.23E-08** ^{a}	**7.83E-08** ^{a}
			(1.31E-08)	(1.51E-08)
OBS	**515**	**515**	**515**	**515**
Adj R2	**0.21**		**0.25**	
F-Stat	**28.989**		**25.311**	
LR chi2		**148.98**		**193.76**
Prob>chi2		**0.000**		**0.000**

a significant at the 1% level, **b** significant at the 5% level, **c** significant at the 10% level. The values in parentheses are the standard errors. In Regressions (1) to (4), 111 of the 588 observations have values equal to zero.

16 In the model presented in section III, this can be translated as a proxy for an increase in *b*.

The first remarking feature of the results is that land inequality cannot significantly be associated with deforestation in the Brazilian Amazon. In every equation, land inequality presents positive coefficients, in accordance with theory, but without statistical significance. This might be related to the low variability in the land inequality data that does not allow to give significance to the results.

The amount of credit and expropriated area, as measure of land reform, on the other hand present statistical and economic significance. Both have positive coefficients. These results are in line with many authors' findings and signal that there are strong economic incentives for deforestation in the Brazilian Amazon region. (Alston et. al, 1999; Silva, 2010, Roebeling and Hendrix, 2010). In fact, as observed in Section II, deforestation confers to the occupant greater capitalization (because deforested land is more valued) and provides benefits through the sale of wood and the development of cattle activities.[17]

Control variables present expected signs and are statistically significant for the whole range of equations. Moreover, coefficients are highly stable. Distance to markets corresponds to the behavior predicted by the theory; the positive and negative coefficients for the linear and quadratic variables respectively provide evidence that the thesis that distance to markets affects the deforestation in the form of a U-inverted curve. The observed result corroborates the hypothesis that there are two factors that link deforestation to the distance from markets. On one hand, land close to markets tends to enjoy a better definition of property rights. This factor creates an incentive for frontier expansion into more distant regions. On the other hand, the transport costs grow with distance. It is the interaction between these two factors that causes the effect of distance on deforestation. Thus, one can understand the relationship between deforestation and distance from markets using a Ricardian land model by introducing a restriction that is associated with an increased cost of transport.[18]

The variable that measures the increase in the livestock industry from 2000 to 2007, CATTLE07_00, presents positive coefficients in all specifications. This result corroborates the theory of Margulis (2003) that livestock is a major cause of deforestation in the region. Population density shows a negative sign, which might be related to urban areas, where pressure over deforestation is no longer a big issue.

Effects of land inequality, credit and land reform

Although the results related to land inequality do not show statistical significance, it is interesting to analyze what happens when interaction terms are introduced (Table 3).

Still, there is little evidence that land inequality is directly related to deforestation. There are, indeed, signal changes depending on the regressions' specifications. Thus, a first conclusion is that there is no evidence of a positive relationship between land inequality and deforestation.

[17] For a description of this process, see Castro (2005).
[18] It should be noted that the opening of highways relaxes this restriction and consequently permits the expansion of the deforestation frontier.

Table 3: Estimations results with interaction terms

Dependent variable: Deforest_2007_2002	(5) OLS	(6) Tobit	(6) OLS	(7) Tobit	(8) OLS	(9) Tobit
C	**-4.589** [b]	**-8.526** [a]	**-1.922**	**-5.307** [a]	**-3.409** [c]	**-6.733** [a]
	(1.959)	(2.308)	(1.957)	(2.285)	(1.995)	(2.335)
LAND_GINI	**2.800**	**4.289**[c]	**-0.759**	**-0.135**	**1.010**	**1.556**
	(2.176)	(2.534)	(2.212)	(2.561)	(2.262)	(2.621)
EXPROP	**2.050** [a]	**1.948** [a]	**0.139** [a]	**0.182** [a]	**2.111**[a]	**2.023** [a]
	(0.625)	(0.711)	(0.043)	(0.049)	(0.622)	(0.704)
CRED	**5.07E-08** [a]	**7.68E-08** [a]	**-2.95E-07** [b]	**-4.51E-07** [a]	**-3.11E-07** [b]	**-4.62E-07** [a]
	(1.30E-08)	(1.50E-08)	(1.36E-07)	(1.53E-07)	(1.35E-07)	(1.52E-07)
DIST_SP	**0.002** [a]	**0.003** [a]	**0.002** [a]	**0.003** [a]	**0.002** [a]	**0.003** [a]
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
DIST_SP^2	**-1.60E-07** [a]	**-2.33E-07** [a]	**-1.69E-07** [a]	**-2.47E-07** [a]	**-1.67E-07** [a]	**-2.45E-07** [a]
	(2.76E-08)	(3.23E-08)	(2.78E-08)	(3.24E-08)	(2.76E-08)	(3.22E-08)
DENSITY	**-0.001**	**-0.037** [a]	**-0.002**	**-0.042** [a]	**-0.001**	**-0.039** [a]
	(0.001)	(0.010)	(0.001)	(0.010)	(0.001)	(0.010)
CATTLE_07_00	**0.087** [a]	**0.099** [a]	**0.087** [a]	**0.100** [a]	**0.087** [a]	**0.100** [a]
	(0.009)	(0.010)	(0.001)	(0.010)	(0.008)	(0.010)
EXPROP*LAND_GINI	**-2.311** [a]	**-2.141** [b]			**-2.379** [a]	**-2.223** [b]
	(0.753)	(0.856)			(0.749)	(0.847)
CRED*LAND_GINI			**4.60E-07** [b]	**7.01E-07** [a]	**4.79E-07** [a]	**7.13E-07** [a]
			(1.79E-07)	(2.03E-07)	(1.78E-07)	(2.01E-07)
OBS	**515**	**515**	**515**	**515**	**515**	**515**
Adj R2	**0.26**		**0.26**		**0.27**	
F-Stat	**23.692**		**23.219**		**22.133**	
LR chi2		**193.76**		**199.46**		**206.29**
Prob>chi2		**0.000**		**0.000**		**0.000**

[a] significant at the 1% level, [b] significant at the 5% level, [c] significant at the 10% level. The values in parentheses are the standard errors. In Regressions (1) to (4), 111 of the 588 observations have values equal to zero.

The interaction between inequality and land reform implies a negative and statistically significant coefficient. This means that when government expropriates land in more unequal municipalities, there is, actually, a decrease in deforestation. This result corroborates the model: if land reform is targeted to more unequal areas, deforestation shall be reduced. The overall effect of land reform is not different from zero as the coefficient of expropriation alone counteracts the interaction term. Thus, it can be said that, as it is designed today, land reform exerts little influence on deforestation.

Equations (6) and (7) that account for the interaction between credit and land inequality are also in accordance with theory. The availability of credit in more unequal regions increases deforestation. This is so because credit availability increases profitability from clearing land more than profitability from agricultural production, as land inequality reduces access to land for farming. Even accounting for credit individually, its overall influence is still positive. Probably, credit-elasticity for deforestation is larger than the credit-elasticity for farming.

These two results are striking as they show that, although land inequality does not influence deforestation directly, it can still have important effects as it affects the results of important policies like land reform and rural credit.

Endogeneity problems

It should be noted that there is a potential for endogeneity between deforestation and land inequality in the estimation. If deforestation is part of the process of occupying land that ultimately reproduces the current pattern of land distribution, it may occur an endogeneity problem.

In order to address this problem, we used the land inequality variable as of 1996 and deforestation data is from 2002 to 2007. Moreover, if the endogeneity above discussed were to exist, there should exist a strong correlation between the stock of deforestation (measured by total deforested area in 2001) and land inequality. Nonetheless, the correlation between land inequality in 1996 and total deforested area in 2001 is only 0.06 and is not robust[19].

V. CONCLUSION

This work aimed to address the impacts of land inequality on deforestation. Hence, it was presented a theoretical model that links the pattern of land distribution to individual decisions to clear land at the frontier. The empirical results, nonetheless, did not confirm the theoretical hypothesis. This might have happened because the model works with comparative statics and what actually happens is somewhat different. Thus, the parameters of the model could have changed evolving the model in a new dynamic. Some of the control variables were utilized in order to account for these parameter changes. Distance to markets, for instance, affects both land prices, costs of deforestation and agricultural returns. The increase in livestock measures the profitability in cleared land.

An additional feature of the model is to identify the impacts on deforestation of a credit expansion and land reform. Here lie the main results of this paper: usually, the literature imputes a positive relationship between land reform (and credit expansion) and deforestation. This paper suggests that this relationship must take in account the actual pattern of land distribution in the municipality. Thus, when one takes in account this relationship by introducing interaction terms, results become much more interesting.

When land reform occurs in more unequal places, there is a negative relationship between expropriated areas and deforestation. This means that if government chooses the correct municipalities to introduce land reforms there is a potential for substantial welfare gains. Moreover, as Assunção (2008) remarks on average unproductive farms are larger than productive farms. Thus, a reduction in land inequality can boost agricultural production without implying an increase in deforestation.

Regarding credit policies, there are a significant number of papers that link credit subsidies with deforestation. In this paper, it is argued that this relationship depends on credit elasticity of farming and credit elasticity of deforestation and also on the level of land inequality. Indeed, Assunção et al (2012) show that the rural credit policy change introduced in 2008 actually led to a reduction in deforestation, especially related to a decrease in livestock loans

[19] 2001 is the first year for the dataset on total deforested area.

and through large and medium contracts rather than small loans. The empirical analysis has shown that credit has, indeed, a positive coefficient on deforestation. Nevertheless, the introduction of the interaction term between credit and land inequality shows that this result exists through this relationship. In other words, where there is more land inequality, credit expansion leads to higher deforestation rates.

This paper has some results that can provide interesting references for governmental policies as regarding the relationship between land distribution and deforestation. When one takes into account the effects of land distribution on occupational choices and how they relate to credit and land reform, it is clear that there is substantial role for welfare improvements that can lead us to situation with less deforestation and better land use.

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Appendix 1 – Description of Variables and Correlation Matrix

Variable	Definition	Source
Deforest_2007_2002	Deforested area from 2007 to 2002 as a percentage of total municipality area	National Institute of Space Research - INPE
Gini_Land	Land inequality as measured by the gini index based on information of 1996 brazilian census	Naritomi et al (2009).
Dist_sp	Indexed cost of transportation from the municipal headquarters to São Paulo city	IPEADATA
Exprop	expropriated areas within the	IPEADATA

	municipality from 1998 to 2001 as a percentage of total municipality area	
Cattle07_00	Increase in heads of cattle per km^2 from 2007 to 2000	IBGE
Density	Population density: inhabitants per km^2	IPEADATA
Cred	Rural credit: average value from 2000 to 2004	IPEADATA

Correlation Matrix

Covariance Analysis: Ordinary
Date: 01/31/11 Time: 11:47
Sample (adjusted): 1 588
Included observations: 515 after adjustments
Balanced sample (listwise missing value deletion)

Correlation Probability	DEFOR_07_02	GINI_LAND	EXPROP	DIST_SP	DENSITY	CRED	CATTLE_07_00
DEFOR_07_02	1.000000 -----						
GINI_LAND	-0.015779 0.7209	1.000000 -----					
EXPROP	0.197587 0.0000	0.075147 0.0884	1.000000 -----				
DIST_SP	-0.059194 0.1798	-0.277208 0.0000	-0.126922 0.0039	1.000000 -----			
DENSITY	-0.061616 0.1626	-0.015072 0.7329	-0.015207 0.7306	-0.020311 0.6456	1.000000 -----		
CRED	0.073544 0.0955	-0.039563 0.3703	0.004981 0.9102	-0.204996 0.0000	-0.018943 0.6680	1.000000 -----	
CATTLE_07_00	0.427004 0.0000	-0.072809 0.0988	0.202705 0.0000	-0.131923 0.0027	-0.041002 0.3531	-0.075440 0.0872	1.000000 -----