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CASSANDRO MARIA DA VEIGA MENDES

ENSAIOS SOBRE O DESMATAMENTO:
CORRUPÇÃO, JOGOS DIFERENCIAIS, E EVIDÊNCIA EMPÍRICA

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Orientador: Sabino Porto Junior

Co-Orientador: Fabrício Tourrucôo

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RESUMO

O presente estudo tem como objetivo analisar o fenômeno do desmatamento no Brasil. Para este efeito, utilizou-se de instrumentais econométricos e matemáticos. O estudo se divide em três ensaios. No primeiro ensaio investigam-se os possíveis efeitos adversos da política governamental devido à existência de fracas instituições na maior parte da região da Amazônia legal. Neste primeiro ensaio também é analisado empiricamente a relação entre corrupção, desmatamento e Produto Interno Bruto (PIB) para os municípios de Mato Grosso. No segundo ensaio utiliza-se de jogos diferenciais para analisar teoricamente o efeito da corrupção no nível de desmatamento ilegal. Finalmente o terceiro ensaio, focalizando numa análise regional, faz-se uma análise empírica, através de modelos não paramétricos, para a relação entre corrupção, desmatamento, e PIB. No terceiro ensaio, também, utilizando-se de modelos não paramétricos, estima-se, numa análise internacional, a existência da curva de Kuznets.

Palavras-chave: Desmatamento. Corrupção. Teoria dos jogos. Estimação não paramétrica.

ABSTRACT

The present study aims to analyze the phenomenon of deforestation in Brazil. For this purpose, we used econometrics and mathematical tools. The study is divided into three essays. In the first essay, through the standard game theory, we investigated the adverse effects of the government policy due the existence of weak institutions in the Amazon region. In this first essay it is also studied empirically, for the municipalities of Mato-grosso, the relationship between corruption, deforestation and Gross Domestic Product (GDP). In the second essay we used differential game theory to analyze the effect of corruption on the level of illegal logging. Finally on the third essay, we focused on a regional and international analysis. For the regional analysis, we used nonparametric models to test the relationship between corruption, deforestation, and GDP. We used the same methods to perform an international analysis related with the Kuznets curve.

Keywords: Deforestation. Corruption. Game theory. Nonparametric regression.

SUMÁRIO

1 INTRODUÇÃO

O presente trabalho de tese tem como objetivo analisar a questão do desmatamento da floresta Amazônica no período recente sobre um prisma teórico e empírico não usual na literatura nacional. Investigações sobre o problema do desmatamento, normalmente, focam principalmente na análise das chamadas causas diretas do desmatamento, nomeadamente a agricultura (RIVERO et al., 2009), população (SILVA, 2009), e crescimento econômico. As causas indiretas do desmatamento, no entanto, tem recebido atenção na literatura internacional, por exemplo (LEITÃO, 2010). Assim, inovamos ao utilizarmos aspectos e modelos da teoria dos jogos (veja MAS-COLELL, 1995 para uma introdução à teoria dos jogos), assim como métodos não paramétricos na análise empírica do desmatamento.

Dessa forma, no primeiro ensaio, utilizamos jogos estáticos tradicionais para estimar o efeito da política de penalizações sobre o desmatamento. Considerando um jogo simultâneo entre o oficial do Instituto Brasileiro de Meio Ambiente (IBAMA) e o proprietário da terra, derivamos o equilíbrio de Nash em estratégias mistas. A partir deste equilíbrio derivam-se várias conclusões através da utilização da estática comparativa.

A principal intuição analítica que esses modelos introduzem, dizem respeito ao papel contra intuitivo das penalidades e das instituições no combate ao dano ambiental. Mostramos que devido à existência, no equilíbrio, de instituições fracas na região da Amazônia legal, a utilização de maiores recursos federais na penalização, na fiscalização de proprietários de terra, poderá resultar em maior nível de desmatamento.

Ainda no primeiro ensaio utilizamos a metodologia de econometria não paramétrica para estimar e avaliar, para os municípios de Mato-grosso, a relação empírica entre corrupção e o desmatamento. Nossos resultados mostram que existe uma relação estatisticamente significativa entre as duas variáveis. Para o cálculo do índice de corrupção utilizamos dados da Controladoria Geral da União (CGU).

No segundo ensaio, utilizamos a teoria de jogos diferencias para analisar como a presença de corrupção incentiva um maior nível de desmatamento (para maiores informações sobre jogos diferenciais ver Sethi et al. (2007). No modelo proposto o jogo é simulado entre o oficial do IBAMA e o proprietário de terra. Contudo, dada a estrutura do jogo, utilizamos a definição de equilíbrio de Stackelberg em jogos diferencias para derivar as consequencias da corrupção no nível de desmatamento. Os resultados apontam para um equilíbrio onde detecta-se como pode se organizar uma relação criminosa entre o funcionário do IBAMA e o proprietário de terra. Demonstramos, a seguir que o interesse individual do oficial do IBAMA, dado o esquema de salário aplicado pelo governo, acaba incentivando o aparecimento de um esquema de corrupção entre oficiais do IBAMA e o proprietário de terra. E essa corrupção tem um impacto negativo direto no nível de desmatamento.

No terceiro ensaio também utilizamos dos dados da Controladoria Geral da União (CGU) para estimar empiricamente o impacto da corrupção sobre o desmatamento. Utilizamos também os dados do Instituto Brasileiro de Pesquisa Espacial (INPE) para calcularmos as taxas de desmatamentos. Assim, a partir da aplicação de regressões não paramétricas (sobre regressões não paramétricas ver FOX, 2008; HAYFIELD; RACINE, 2008), estimamos os impactos da corrupção sobre o desmatamento.

Por fim usamos os mesmos dados, assim como dados do PIB, e testamos a existência ou não da curva da Kuznets ambiental para os municípios situados na região da Amazônia Legal. Os nossos resultados mostraram que para os estados de Mato Grosso e Pará, o nível de corrupção tem sim um impacto que provoca um aumento da área desmatada de florestas no Brasil. No entanto, assim como para a literatura internacional aquele impacto não é linear.

No terceiro ensaio também investigamos, através de regressões de Kernel, a existência da curva de Kuznets para 45 países. O nosso resultado confirma a existência da curva de Kuznets ambiental.

A tese foi construída, utilizando-se de três *softwares*, nomeadamente, R, disponível gratuitamente em *http://www.r-project.org*, que foi utilizado nas estimações não paramétricas, o *software* STATA (versão 10.1) que foi utilizado para tratamento de dados e outras regressões paramétricas. Finalmente o *software* MAPLE (versão 12.1) foi utilizado para simulações numéricas. No software R foram utilizados os seguintes *packages*: *BOOT* (para a rodar simulações *bootstrap*), *MGCV* (para estimação de modelos não paramétricos aditivos), *STATS* (para estimação não paramétrica), *NP* (para regressões não paramétricas (*Kernel*)).

2 WEAK INSTITUTIONS, CORRUPTION, AND DEFORESTATION: A THEORETICAL AND EMPIRICAL ESSAY ABOUT THE CASE OF THE AMAZON FOREST

2.1 INTRODUCTION

Deforestation is one of the main environmental problems in countries with great extensions of rainforest (CONTRERAS-HERMOSILLA, 2001). The economic aspect of the matter inspired endogenous policies that take into account the profit seeking behavior of the agents, e.g. the soil management, which has been considered an effective way of minimizing deforestation.

The current federal administration, through the Brazilian Institute of Environment (IBAMA), plans to decrease deforestation by introducing more severe penalties and more strict surveillances. However, this policy does not contemplate the possibility of corruption by the officials. According to Amacher (2006, 80% of the timber extracted from the Amazon forest is illegal.

There are substantial literatures on the economic causes of corruption. The subject is no longer ignored in the environmental field, and some research points to corruption as an important determinant of illegal deforestation. Amacher (2006) and Amacher, Koskela and Ollikainen (2006) assesses the importance of taking corruption into account when fighting illegal deforestation.

Some international studies on deforestation, for instance Pellegrini (2007), Palo (2002), and Amacher (2006), advises about corrupt practices in forest management and suggest tougher policies (heavier fines, more severe punishment for those who organize corruption schemes (i.e., landowners)), as a way of curtailing illegal deforestation. However, the information asymmetry, stimulates corrupt behavior (NAIR; KOWERO, 2004). The existence of collusion undermines the effectiveness of government policies (i.e., in the presence of information asymmetry corrupt practices cannot be stopped just by imposing harsher punishment for corruption).

Deforestation research in Brazil is mainly concerned with squatters and ranchers and with improving soil management techniques[1]. However, information asymmetry almost always breeds corruption and leads to results different from the ones intended. Thus, a policy of closer surveillance and harsher punishment to squatters and ranchers may not result in less deforestation because surveillance and dispensing fines are not directly controlled by the central government (i.e., the high rank officials), but by low ranked officials with low salaries. Therefore, if it's assume that there is an agency problem between the government and low ranked officials from IBAMA, fraud is a possible equilibrium outcome, and consequently more illegal deforestation.

This paper investigates the partial results of the government policies, which includes increased surveillance and heavier penalties for squatters, ranchers, and lumber producers. The central point of this paper highlights the possibility of corrupt behavior between the landowner and the IBAMA officials. This collusion[2] or corruption, besides eliminating the effects of penalties on the landowners, also guarantees that, under certain conditions, the penalties for corrupt officials (i.e., the ones with inspection duties) may not result in less illegal deforestation. This possibility is contrary to the *Beckerian* approach.

According with Becker (1968), the government to prevent the illicit acts, should impose high penalties. Becker and Stigler (1974) incorporate the possibility of corruption, and therefore argued for the existence of the private crime enforcement. Such private approach would enable bribes, and therefore corrupt behavior. Many earlier papers in this fields follows the *Beckerian* approach, that large fines decreases the quantity of crime or rate of violation, see for instance Bowles and Garoupa (1997) and Polinsky and Shavel (2000, 2001). We depart from the earlier works by constructing a simple game theoretic model. Our paper is closely related with Garoupa and Jellal (2007) which analyzes the same possibility, however through a different model setting. Their finding suggests that the optimal fine should not be maximal, because high fines would increase of corruption. Other paper that investigates a similar theoretic question to ours is Celik and Sayan (2008) they analyzed the effects of corruption on the composition of the group of potential offenders. Large fines, increases the likelihood that offenders will pay bribes, therefore the optimal fines (the one which guarantees the lower level of crime) should be less than the maximum. Another paper in the

[1] These matters are relevant in fighting illegal deforestation. Nevertheless, this paper intends to show that corruption is an issue that cannot be neglected.

[2] In the present paper we use the word collusion to reflect the behavior of a corrupt official and the landowner. Therefore, when we say collusion doesn't mean that these two individuals will play a coalition cooperative game. In fact, the results from the present work are derived by using the standard game theory (we applied the standard Nash equilibrium concept).

literature that deals with the same issue is Kugler, Verdier and Zenour (2005). They analyzed the effects of increasing policing on the rate of crime. They study how organized crime may increase their activity, given that the rents from the criminal activity are high. They found that increasing the sanctions may increase the crime rates.

Our work departs from these papers due the approach used here, and also given the direct application of the model in environmental issues. We used a simple game to show that even if the offenders and the official behave to maximize their own benefits, corruption is a natural outcome. We applied our model to the case of deforestation in Brazil and show that corruption between the government official and the landowner is a potential outcome. Earlier works on corruption usually advocates for the use of the bargaining game between the offender and the government official to solve the bribe equation and also the amount of the illicit act, see for instance Damania (2001), Celik and Sayan (2008) and Mookherjee and Png (1995). We reached our results by postulating a simple and a realistic assumption, that bribes are assumed to be directed linked with the amount of fines that the offender would pay to the government.

Even with different methodologies used, different assumption, and different applications, our main theoretical results are similar with the results from Celik and Sayan (2008), Garoupa and Jellal (2007) and Kugler, Verdier and Zenou (2005). However, the work of Garoupa and Jellal (2007) is the most similar.

Our theoretical finding adds more contribution when it is linked with the Brazilian literature on deforestation. The only theoretical papers found in the Brazilian literature that investigate the links between corruption and deforestation, are Sampaio, Mendes and Leite Filho (2008) and Mendes and Leite Filho (2009). As discussed earlier, the main research on deforestation focuses their attentions on the direct causes of deforestation. The present work extends the earlier work of Leite Filho and Mendes (2009). The extension happens in a several way. First the way we derived our conclusion from the model is altered (we defined the agents corruption space). Second we analyzed the case where initially there is no dominant pure strategy, and we derived the dynamic effects of the government policies by using static comparative. And finally we add an empirical section that investigates the relationship between corruption and the environmental Kuznets curve.

Imposing penalties is a necessary but not sufficient condition to eliminate corrupt behavior. The central theoretical result of this paper is that, when there is an information asymmetry or weak institutional enforcement, heavier penalties may result in more illegal deforestation.

Beyond the theoretical approach, we investigated the effect of corruption at the level of deforestation. Due to the nature of the data, we used non-parametric regressions. To create our corruption index, we used data from the Mato-grosso municipalities. Reports were delivered by the Controladoria Geral da União (CGU). The result shows that there is a positive relationship between corruption and deforestation. After controlling for gross domestic product (GDP), we found an inverted U-shape relationship between gross domestic product (GDP) and deforestation. Moreover, the results showed that higher corruption increases the turning point of the Kuznets curve[3]. Beyond this introduction, the paper is organized in the following way: in the section 2, we present some literature review about corruption at the forest sector, in the section 3 we introduce our model and many other theoretical results. In the section 4 we performed numerical simulation, and in the section 5 we present our empirical strategies. Empirical results are presented in the section 6, and concluding remarks are presented in the section7.

2.2 CORRUPTION AND THE FOREST SECTOR

The link between corruption and the forest sector is not a new issue. International researchers have claimed that the government have to incorporate such elements in any policy adopted e.g., see Amacher (2006), Damania (2002), Pellegrini and Gerlagh (2006a), Transparency International (2009). Despite knowing that corruption has an influence on the forest sector, little is known about how corruption and deforestation are co-related (TRANSPARENCY INTERNATIONAL, 2009). The existence of corruption can undermine all government policies (i.e., external policies, to avoid the illegal logging, DAMANIA, 2002[4]).

Pellegrini and Gerlagh (2006c), through a cross-section approach, found that between democracy and corruption, the latter is the most important variable to control forest damages. Moreover, democracy does not have statistical influence on environmental control. Welsch (2004) analyzed the influence of corruption and *per capita* GDP on the pollution. He found

[3] The same relation is found in Lopez and Mitra (2000), through a theoretic model.

[4] The problem of corruption in the forest sector is also responsible for a great tax evasion. The Liberian government loose each year millions of dollars due to this kind of problem (TRANSPARENCY INTERNATIONAL, 2009).

that there is a monotonic positive relationship between pollution and corruption, and a negative influence of the *per capita* GDP on pollution.

There is an international consensus that corruption has an important role in illegal logging. However, this reality has not been given much attention by the Brazilian researchers and the government. There are many works putting a great effort into analyzing empirical questions while theoretical questions are disregarded. The announced policies by the government only strikes those directly related with illegal logging, (i.e., farmers, etc. there are no internal mechanisms-designed to avoid the agency problem). Thus, given the private interest of the involved agents, the outcome of any policy may be totally different.

The inexistence of an internal mechanism of surveillance, allows the presence of an environment of corruption. At this point, it seems important to analyze such peculiarities of deforestation. In this context, game theory seems to be a powerful tool to model these interactions and incentives.

The influence of corruption on environmental policies (in a theoretical framework) has been given less attention, and within this group, deforestation is the less investigated, e.g., Polinsky (2004), Mookherjee and Png (1995), Fredicksson and Svenson (2003)[5], analyzed the problem of *ex-ante* collusion in the pollution. However, our work differs from their work in many aspects, namely: first – for different sectors in the economy, the corruption may have different rationality and consequences, Kolstad and Soreide (2009). Hence, the role of the corruption in the forest sector is somehow different from others sectors. Second – we use game theory to model the game between the IBAMA´s officials and the landowners, therefore the model is applied in the Brazilian context.

Our paper introduces several new contributions about how corruption may influence illegal deforestation in Brazil. The use of the game theory is not new, but its application in the case of Brazil, is. The present paper intends to fill some theoretical gaps left by previous studies, thus, we intend to make a *zoom in* about the illegal deforestation in the Amazon forest (focusing in the so called *indirect* causes of deforestation – weak institutions).

Beyond the theoretical contributions, our paper is the first, in the Brazilian literature, to investigate empirically the effects of corruption in the level of deforestation. For this purpose, we performed non-parametric regressions for 20 municipalities of Mato-grosso.

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[5] Fredrickson and Sevenson (2003) have a more general approach. They analyzed the influences of political instability, corruption and environmental policy.

2.3 GAME THEORETICAL MODELS AND ILLEGAL DEFORESTATION[6]

The game theory is widely used in many fields: economics, sociology, politics, etc. In the field of economics, there are a lot of applications in many areas: microeconomics, international trade, macroeconomics, experimental economy, etc. There are also many works that applies the game theory to corruption issues.

Mookherjee and Png (1995) analyzed, theoretically, the effect of collusion "*ex-ante corruption*" on the level of pollution. Corruption and illegal deforestation are mostly cited in an informal way, see Amacher (2006). Thus, this paper may represent one of the first attempts to model the relationship between corruption and illegal deforestation, especially in the Brazilian case. In the following sub-section we introduce a simple model to show the inter-dependence of the variables.

First we distinguish two players of the game, namely: the entrepreneur (landowner), the government official (IBAMA one). The incorruptible official (the Government) doesn't enter directly in the game. The government is responsible for establishing the role of the game: the salary schemes, the environmental laws, and consequently the fines and limits, i.e., the government he is responsible for the external incentives. Within the environmental incentive created by the Government, the two former players, the official and the entrepreneur, behave in a way to maximize their gain.

The entrepreneur has the possibility to cooperate with the law, i.e., to use just the limited areas or not. The official has the job of investigating the entrepreneur and if he finds any irregularity, he reports the illicit act to his superior, and thus, charges the fines. In this case, the entrepreneur will be forced by law to pay any kind of penalties, i.e., monetary fines[7]. However, the official may choose to be corrupt, and in this scenario, he wouldn´t inform the superior about the crime.

These are the scenarios that, we face in these days in the Brazilian case. As we will see in the following sub-section, the effectiveness of the governmental policies to control illegal deforestation depends on the assumptions about this relationship between the landowner and the government official.

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[6] All agents in this paper are risk-neutral.

[7] Using different types of penalties, like prison instead of fines, can lead to different outcomes, for example see Polinsky and Shavell (2001).

2.3.1 The Model

In the model, there are two players: the landowner, and the government official. A proportion Υ of the number of officials is composed of corrupt individuals[8]. In order to formalize the model, the behaviors of a representative landowner, a representative corrupt official and the government are analyzed. The main objective is to highlight how information asymmetry affects deforestation.

Let $\overline{T}$ be the size of the forest, which belongs to the representative landowner, where t^i is the lower bound is and t^s the upper bound. The landowner is allowed to clear the forest up to the limit t_m, which is a number between the lower and upper bounds. If the landowner surpasses the upper limit, he receives a fine (δ). Surveillance is not done directly by the government, but by a hired official, i.e., the official from IBAMA. After the area is inspected, the hired official reports to the government possible occurrences of illegal deforestation. At the end of the period, the official earns a salary (w), not contingent on his reports[9]. The landowner may choose whether to clear the forest up to the allowed limit or to go beyond the limit and risk being fined. That is, there are two states of nature: when the landowner clears more forest than he is allowed to $(t^i > t_m)$ and when the landowner respects the limit $(t^i \le t_m)$. The real state of nature is unknown to the government because the official may decide not to report illegal deforestation[10]. If all officials are honest $(\Upsilon = 0)$, then the reports received by the government informs them precisely whether or not the landowner cleared more forest than he was allowed to. If the honesty of officials is questionable, the government then just has a probable distribution over the real state of nature.

The actual relationship between the two players can be exposed in the following way: The landowner, L, can choose to illegally clear the forest, ID, or not NID. The landowner may be inspected, I, (or not *NI)*, by the official, F, with probability ζ. If an investigation takes place, the official finds out whether illegal deforestation occurred, $t^i > t_{\text{m}}$, or not, $t^i \le t_m$. The government, G, receives the report, but doesn't know, for sure, the actual state of

[8] Only the official belonging to this group has their behavior modeled.

[9] The salary of the official is not contingent on the government´s revenue from fines collected from the landowners.

[10] We assume that the official has the means to appraise the real state of nature when inspecting a landowner's lot.

nature. It just has a probable distribution of the real state of nature. Given the relationship involving the two players, it is possible to ascertain the effects of the corruption behavior between the landowner and the corrupt official on the illegal deforestation.

2.3.2 Type of Equilibriums

In the game between landowner and official, let the compact set $s_i = \{s_1, s_2\}$, be the actions space for each player. There is a pay-off function for each player, suitable for the strategy adopted in response to the one adopted by the other player. For clearer explanation, the game played is a simultaneous one. The strategies set for each player, are:

$$s_i = \begin{cases} s_1 = collude \\ s_2 = not\ collude \end{cases}$$

We follow the same approach of Leite Filho and Mendes (2008), thus, the landowner's profit, $\pi(p,v)$ is a function of the prices level p and of output v [11]. Sales depend directly on the deforested area t, where $t \in \{t_i, t_m\}$ and $v = \lambda(t)$. It is assumed that: $\lambda_t > 0 \wedge \lambda_{tt} = 0$. In the special case that the coefficient equals the unity, the landowner's profit is $\pi(p,t)$. The official's pay-off is given by the salary w earned at the end of the game.

To make feasible the game, it is necessary to analyze the case of illegal deforestation, that is, when $t^i > t_m$ [12]. When illegal deforestation takes place, the landowner can allure the official by proposing collusion. The official may agree to collude or not. If the official accepts, he has a pay-off given by $w + \Delta w(t > t_m)$, (Case **D** below) where $\Delta w(t > t_m)$ represents the bribe paid by the landowner. The landowner's pay-off, in this case, is given by $\pi(p,t) + \Delta\pi(p, t > t_m) - \varepsilon - \lambda$ (Case **A** below) where $\Delta\pi(p, t > t_m)$ represents the earnings from clearing the forest beyond the allowed area, ε represents the bribe due to the official, $\Delta\pi(p, t > t_m) \in \Re^+$ and $\varepsilon \in \Re^+$, it is easy to see that $\Delta w(.) = \varepsilon$ and finally λ represents the

[11] For example, the landowner who engages in logging has a profit that is a function of the price of the cubic meter and the quantity of timber extracted from the forest. For the sake of simplicity, production costs (capital and labor) are considered as zero.
[12] When there are no illegal deforestation, the landowner and the official has no reason to corrupt. So the situation of interest is the players' behavior in the case of illegal deforestation. Obviously, we suppose that there is no extortion.

transaction cost of the bribe. However, if the official choose to collude but the landowner not, his pay-off will be just his salary (Case **C** below). In this case the landowner's pay-off would be $\pi(p,t)+\Delta\pi(p,t>t_m)-\delta$ (Case **B** below) where δ is the fine imposed to the landowner by the government[13], $0<\varepsilon<\delta,\ \delta\in\Re^+\leq\infty$. We follow Mendes and Leite Filho (2009) and suppose that: $\delta := x+\varepsilon$, where x represent the part of fine (not paid) kept by the landowner, and ε represent the bribe paid for the official. In the event of illegal deforestation and the official is not willing to take the bribe, his pay-off depends of the strategies of the landowner: if the landowner decides to collude, he can receive $w+\alpha$ (Case **C´´** Below) where w represents the salary and α represents external or internal incentives received by the official, in this case the landowner would receive $\pi(p,t)+\Delta\pi(p,t>t_m)-\delta$ (case **B** below). However, if the landowner does not collude, he (the official), receives just $w-i+\theta$ (case **C´** below) where i represent the net cost of effort, and θ represent the internal gains due the decision for not colluding[14], in this case, the landowner would receive $\pi(p,t)+\Delta\pi(p,t>t_m)-\delta-\kappa$ where κ represents the landowner's social cost for the national media communication on the matter[15] (**case B´**). Given the pay-offs defined earlier, we used the concept of Nash equilibrium in static games with complete information to solve the game. The following figure summarizes the normal representation of the game.

The game in its normal form is:[16]

[13] Note that the penalty must be higher than zero, otherwise we wouldn't have a game between the official and the landowner.

[14] In the present model we suppose that when the landowner is available for colluding, and the official is not, the latter can receive an internal or external benefit for his behavior. The internal gain represents his moral wellbeing for not being caught in a corrupt process. The external incentives can represent promotion in his job.

[15] Is a fact that when IBAMA official found illegal deforestation related with any enterprise (landowner), there are, usually, media communication about the matter. These national communications impose a moral cost to the enterprise. In our model this cost are presented by *k*. Thus, there is a difference in this case with the one when the landowner opted to collude (Case B), in the latter, the landowner opted to collude and we suppose that in such case the landowner cannot be exposed to the media, thus he is just fined directly.

[16] The components of the pay-offs represented in the game are: the right side represents the official's pay-off and the left side represents the landowner's pay-off. Again, we should also highlight that we are not in the presence of a coalition game.

Official		*Landowner* *(Corrupt)* **Collude (q)**	*(Non-corrupt)* **Not collude (1-q)**
	Collude (corrupt) (p)	**D, A**	**C, B**
	Not collude (Non-corrupt) (1-p)	**C'', B**	**C', B'**

Where $A=\pi(p,t)+\Delta\pi(p,t>t_m)-\varepsilon-\lambda$ $B=\pi(\overline{p},t)+\Delta\pi(\overline{p},t>t_m)-\delta$ $C=w$

$C''=w+\alpha$ $D=w+\Delta w(t>t_m)$ $B'=\pi(\overline{p},t)+\Delta\pi(\overline{p},t>t_m)-\delta-\kappa$ $C'=w-i+\theta$.

The outcome of the game depends of some assumption about the parameters to ensure the uniqueness of the Nash equilibrium, however, as we know, the pure strategy equilibrium is just a degenerate case of mixed strategy equilibrium.

Typology of the Equilibrium: ***Mixed Strategies Equilibrium***

The engagement of the individuals in "active" corruption demands several worries about the behavior of the other player, i.e., nobody have the conviction about the strategy that the other player will adopt. So, the best way to analyze this kind of situation is to analyze *the mixed strategies*. In such way, the static form is presented in the Figure 1. Where *p* represents the probability that the official will opt to collude, in the same sense, *q* represents the probability that the landowner will collude. Given the structure we can define *p=p** , such that the landowner is indifferent between the both choices, or *q=q*,* such that the official in indifferent between both choices. To calculate such probabilities we may analyze, in each case, the expected gain for each player.

The Problem for the Official

The expected gain for the colluding or not, for the official, depends of the strategies adopted by the landowner. The expected gain for colluding is:

$$\left(w+\Delta w(.)\right)q+w\left(1-q\right):=E\left[C\right] \tag{1}$$

And for not colluding, is:

$$\left(w+\alpha\right)q+\left(w-i+\theta\right)\left(1-q\right):=E\left[NC\right] \tag{2}$$

However, we can describe the decision rule (reaction correspondence) of the official as follow:

$$\begin{cases} E\left[C\right]>E\left[NC\right]\Rightarrow collude & \text{(I)} \\ E\left[C\right]<E\left[NC\right]\Rightarrow dont\ collude & \text{(II)} \\ E\left[C\right]=E\left[NC\right]\Rightarrow indiferent & \text{(III)} \end{cases}$$

From condition (I) we derive the following theorem;

THEOREM-1: The Official will collude, that is p=1, if and only if,

$$q>\frac{\theta-i}{\left[\left(\Delta w(.)+\theta\right)-\left(i+\alpha\right)\right]}$$

Proof:

The choice between one strategy from another is based on the expectancy of the pay-offs. Hence, the expected gain for the official is

$$E\left[G(p)\right]=p\bullet\left(\left(w+\alpha\right)q+\left(w-i+\theta\right)\left(1-q\right)\right)+\left(1-p\right)\bullet\left(\left(w+\Delta w(.)\right)q+w\left(1-q\right)\right)$$

The strategy from the official (p, 1-p), will depend of his prior believes about the strategy adopted by the landowner (q, 1-q). Simplifying the expected gain, we find that

$$E\left[G(p)\right]=\Phi+p\left(\Delta w(.)q-q\alpha+i-\theta-iq+\theta q\right)$$

Where $\Phi=q\alpha+w-i+\theta+iq-\theta q$

Hence, the expected gain increases with p, if and only if:

$$q\left(\left(\Delta w(.)+\theta\right)-\left(\alpha+i\right)\right)+i-\theta>0$$

Solving it, the result follows.

COROLLARY-1: The official will not collude, (p=0), if and only if

$$q < \frac{\theta - i}{\left[\left(\Delta w(.) + \theta\right) - \left(i + \alpha\right)\right]} \in \left[0,1\right]$$

COROLLARY-2 The official is indifferent between colluding or not, $p \in \left[0,1\right]$, if and only if;

$$q^* = \frac{\theta - i}{\left[\left(\Delta w(.) + \theta\right) - \left(i + \alpha\right)\right]} \in \left[0,1\right]$$

Proof;

Substituting q* in the of the expected gain, E[G(.)], we find that

$$E\left[G(p)\right] = \Phi$$

Because $\Delta w(.)q - q\alpha + i - \theta - iq + \theta q = 0$

Hence, the expected gain is the same give any $p \in \left[0,1\right]$ chosen.

DEFINITION-1*:* We define *q** as the probability value that makes the official indifferent between colluding or not colluding.

Not that to have a meaningful probability, it is necessary to have $q^* \in \left[0,1\right]$

Therefore, two conditions must be satisfied, namely:

$$\theta - i \leq \left[\left(\Delta w(.) + \theta\right) - \left(i + \alpha\right)\right] \qquad \text{(I)}$$

$$\theta \geq i, \left(\Delta w(.) + \theta\right) > \left(i + \alpha\right) \qquad \text{(II)}$$

So far, we have analyzed the conditions under which, the official would opt to be corrupt. In the later section we will see how this option for being corrupt increases when the higher is the penalty for the environmental crime.

The Problem for the Landowner

The expected gain for the colluding or not, for the landowner, depends of the strategies adopted by the official (p, 1-p).

$$\left(\pi(.)+\Delta\pi(.)-\varepsilon-\lambda\right)p+\left(\pi(.)+\Delta\pi(.)-\delta\right)\left(1-p\right):=E\left[C\right] \tag{3}$$

And for not colluding, is:

$$\left(\pi(.)+\Delta\pi(.)-\delta\right)p+\left(\pi(.)+\Delta\pi(.)-\delta-\kappa\right)\left(1-p\right):=E\left[NC\right] \tag{4}$$

Therefore, we describe the decision rule of the landowner as follow:

$$\begin{cases} E\left[C\right]>E\left[NC\right]\Rightarrow collude & \text{(I)} \\ E\left[C\right]<E\left[NC\right]\Rightarrow dont\ collude & \text{(II)} \\ E\left[C\right]=E\left[NC\right]\Rightarrow indiferent & \text{(III)} \end{cases}$$

THEOREM-2: The landowner will collude, q=1, if and only if[17]:

$$p<\frac{\kappa}{\left((\varepsilon+\lambda+\kappa)-\delta\right)}\in\left[0,1\right]$$

Proof:

The choice between one strategy from another is based on the expectancy of the pay-offs. Hence, the expected gain for the landowner is

$$E\left[G(q)\right]=q\bullet\begin{pmatrix}\left(\pi(.)+\Delta\pi(.)-\varepsilon-\lambda\right)p+\\+(1-p)\left(\pi(.)+\Delta\pi(.)-\delta\right)\end{pmatrix}+\left(1-q\right)\bullet\begin{pmatrix}\left(\pi(.)-\Delta\pi(.)-\delta\right)p+\\+\left(\pi(.)-\Delta\pi(.)-\delta-\kappa\right)\left(1-p\right)\end{pmatrix}$$

After some algebraic manipulations we find

$$E\left[G(q)\right]=\Theta+q\left(\kappa-p(\kappa+\varepsilon+\lambda-\delta)\right)$$

Where

$$\Theta=\pi(.)+\Delta\pi(.)-\delta-\kappa+p\kappa$$

Hence, the expected gain is positively related with q if, and only if

[17] Note that to have a equilibrium in mixed strategies (with $0<p<1, 0<q<1$), we cannot have a player with dominant strategy. Therefore, clearly for the case of the landowner this condition implies that $\varepsilon+\lambda>\delta$, that is the financial cost of collusion in high enough and the bribe is high enough. Otherwise, the landowner would have a dominant strategy in colluding. For official, the sufficient condition to not have an dominant strategy is that $\theta>i, \Delta w(.)>\alpha$. The main objective here is to show how, due the information asymmetry, a game with only mixed equilibrium (with $0<p<1, 0<q<1$) will turn in a game with unique pure equilibrium in dominant strategies (with $p=1, q=1$).

$$\left(\kappa - p(\kappa + \varepsilon + \lambda - \delta)\right) > 0$$

Solving this condition, the proof follows[18].

CORROLARY-3: The landowner is indifferent between colluding or not, $q \in [0,1]$, if and only if;

$$p^* = \frac{\kappa}{\left[(\kappa + \varepsilon + \lambda) - \delta\right]} \in [0,1]$$

Proof;

Substituting q* in the of the expected gain, E[G(.)], we find that

$$E\left[G(p)\right] = \Phi$$

Because $\Delta w(.)q - q\alpha + i - \theta - iq + \theta q = 0$

Hence, the expected gain is the same given any $q \in [0,1]$ chosen, therefore any q is optimum.

DEFINITION-2: We define p* as the value of probability that leaves the landowner indifferent between colluding or not colluding.

So far, we have analyzed the conditions for the set of values under which the landowner will opt to corrupt or not. In the next section we make a more formal exposition of these finding. We introduce the concept of collusion space, and its amplitude. These concepts will allow us, later on, to investigate the effects of the government policies in the strategies used by the agents, namely the official and the landowner.

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[18] Note that we suppose that Landowner would penalized after he reached the market and sell his product. Hence, in both case he would have the profit from the illicit act. However, if it is supposed that in case of illicit act he is caught before taking is product to the market, is straightforward to show, that in such case we would have:

$$p^* = \frac{k}{\left(\varepsilon + \lambda + k\right) - \left(\Delta\pi(.) + \delta\right)}$$

2.3.3 *Mixed Strategies Equilibrium* and "ex-post" corruption

In the present section we make an introduction to important concepts that we will use to derive important results from our model.

The result of the game played between the landowner and the official can be represented in the following decision's diagram;

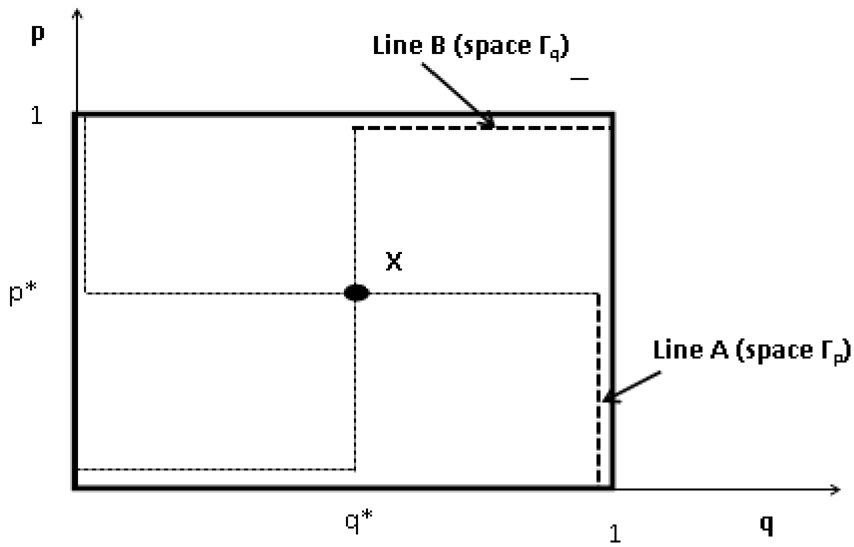

Figure 1 - Mixed-Nash static equilibrium

Source: Author's elaboration.

Solving the game above, we can see that there is no equilibrium in pure strategies. The only result of the game is a mixed strategy equilibrium. This equilibrium is presented as the interception of the reaction correspondence in *X*.

The strategies to be used by each player will depend on ones' believes about the other's strategy. The explanation of the Figure 1, is straightforward. The official will choose which strategy to use, i.e., which value of *p* to use, based in his believes about the strategy that would be used by the landowner. If he believes that the landowner will collude with a probability higher than, say *q**, he will opt to collude (*p=1*), and he will not collude otherwise (*p=0*). Finally, if his believes is equal to *q** he is indifferent, and any value of *p* is optimal.

The same analysis may be done in the case of landowner. His strategy, that is which *q* to use, depends of his believes about the strategies to be used by the official *p*.

DEFINITION-3: We call *Γ* s the collusion space, which represents the set of values *q* and *p*, for which the official and the landowner will opt to collude, that is p=1,q=1.

Hence, the set *Γ* is defined as a two compact sets, namely,

$$\Gamma_p \subseteq [0,1] \qquad \Gamma_q \subseteq [0,1]$$

The Γ_p set and Γ_q are represented by the thicker dashed-line in the Figure 1.

DEFINITION-4: Inside the collusion space for each player, we defined, between any points, the following metrics.

$$d_p = d_p(p_i, p_j) \qquad d_q = d_q(q_i, q_j) \qquad \forall i \neq j$$

Where d_p represent the metric defined in the landowner collusion space, and d_q represents the metric in the official collusion space.

DEFINITION-5: *We define as one collusion space's amplitude, the metric defined at the supremum and infimum of the collusion metric set*.

$$d_i = d_i(\sup_i, \inf_i) \qquad i = p, q$$

Note that for the official the maximum amplitude (length) of the collusion space is given *by*

$$d_q = d_q(1, q^*) \in [0,1]$$

And

$$d_p = d_p(p^*, 0) \in [0,1]$$

For the landowner.

Clearly larger amplitude represents the existence of higher incentives of colluding.

DEFINITION-6: *We define the level of corruption in the forest sector as function of the length of the collusion space.*

To analyze the effect of the policies adopted by the government, we can use the static comparative. Through static comparative, we can see the effect of the government policies in the players willing to engage in corrupt behavior.

THEOREM-3: The amplitude of the collusion space for the official is higher when the amount of bribes increases.

As defined earlier the indifference point for the official is given by

$$q^* = \frac{\theta - i}{\left[\left(\Delta w(.) + \theta\right) - \left(i + \alpha\right)\right]}$$

Hence,

$$\frac{\partial q^*}{\partial \Delta w(.)} = \frac{-1(\theta - i)}{\left[\left(\Delta w(.) + \theta\right) - \left(i + \alpha\right)\right]^2} < 0$$

Therefore**,** the collusion metric space, which is represented by the dashed line in the Figure 1, has more elements, and given that the collusion space is a ordered one, the difference of the *supremum* and the *infimum* (amplitude of the collusion space) is larger, which means, following the definition 6 that the level of corruption will be higher.

This analysis can be made by analyzing the refinement of the Figure 1. The Figure 2 represents the new equilibrium in mixed strategies.

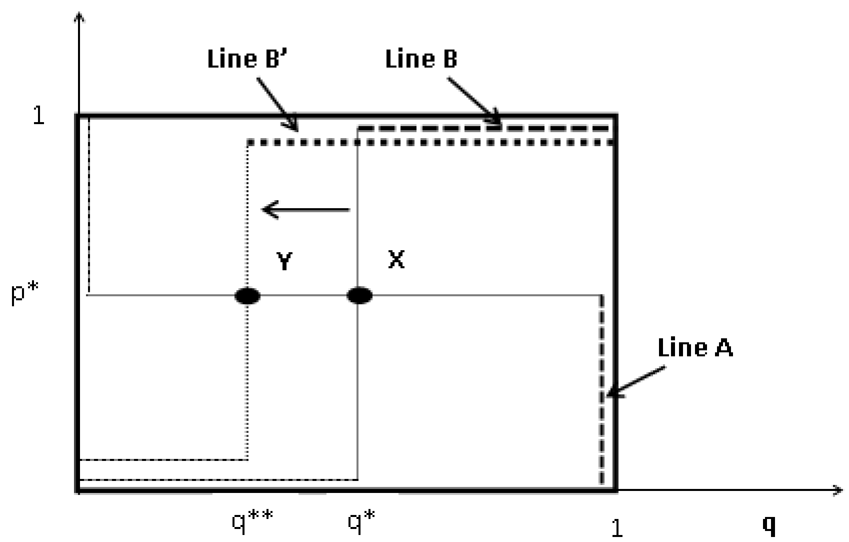

Figure 2 - Mixed-Nash static equilibrium

Source: Author's elaboration.

The increase of the bribes, will decrease q*, which implies that the official's indifference point is lower, and therefore more likely he will opt to collude. This measure of incentive to collude is reflected by the metric defined in the *d (B')*. Given that the metric in *d (B')* is larger than in *d (B)*, we conclude, by using the definition 6, that the level of corruption, in the forest sector, is higher.

THEOREM-4: The impact of the penalties in the incentives to collude, from the official point of view, is positive since the impact of the penalties in the bribes is positive.

Proof: the bribes are a linear function of the penalties, that is

$$\Delta w = f(\delta)$$

Where

$$\frac{\partial f(\delta)}{\partial \delta} > 0$$

Hence, the indifference condition for the landowner is given by

$$q^* = \frac{\theta - i}{\left[\left(f(\delta) + \theta\right) - \left(i + \alpha\right)\right]}$$

Therefore,

$$\frac{\partial q^*}{\partial \delta} = \frac{-f_{\delta}(.)(\theta - i)}{\left[\left(f(\delta) + \theta\right) - \left(i + \alpha\right)\right]^2} < 0$$

This concludes the proof.

The result of the theorem-4 implies that there is a positive impact of the penalties in the amount of bribes. Clearly this is not a strong assumption given that we are in presence of complete information games. Hence, the official knows the amount that the landowner would pay, therefore if the official is rational, he would demand more bribes when the penalties are higher.

We can also use the static comparative to analyze the effect some variables have on the probability of being corrupt, from the landowner's point of view.

In the mixed equilibrium, the probability that the official will be collude is given by:

$$p^* = \frac{\kappa}{\left[(\varepsilon+\kappa+\lambda)-\delta\right]}$$

Earlier we defined that the landowner would opt to collude, if and only if

$$p < \frac{\kappa}{\left((\varepsilon+\lambda+\kappa)-\delta\right)} = p^*$$

Hence, any change in the indifference point will induce a change in the metric defined in the landowner's collusion space.

THEOREM-5*:* The increase of the penalties will increase the landowner's incentives to collude.

Proof:

Since

$$\frac{\partial p^*}{\partial \delta} = \frac{(1-\tau)k}{\left[(\varepsilon+\kappa+\lambda)-\delta\right]^2} > 0$$

Where τ is the defined through the following relationship: $\varepsilon = \tau\delta, \forall \tau < 1$

We can see that, as the penalties increases the indifference point also increases, meaning more likely the landowner will be available to collude. In other words, this means that the amplitude of the collusion space is larger. This result can be demonstrated in following Figure 3:

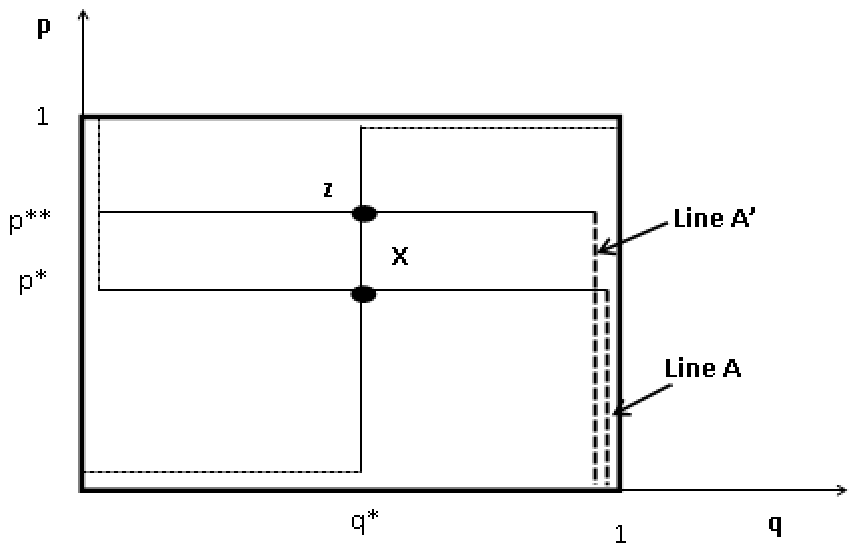

Figure 3 - The impact of penalty in the landowner strategy

Source: Author's elaboration.

As represented in the Figure 3, the increase in the indifferent point makes the line **A** to become larger, **A'**. Larger Lines (inside the natural limits [0,1]) represent in fact larger amplitude of the collusion space. Therefore, the increase of penalties increases the landowner incentives to collude.

The results show that the policy of more penalties will increase the incentive of the landowner to corrupt the official. More penalties mean more bribes to be paid by the landowner, however, given that the bribe he would be paying is lower than the penalty, he will have the incentive to give the bribes (opt to collude).

As we stressed earlier, $\varepsilon = f(\delta)$ and so, $\delta = f^{-1}(\varepsilon)$, really speaking we get $\delta = \mu\varepsilon$, where $\mu \in (1, \forall \Re < \infty)$, so we have (don´t forget that $\varepsilon = \Delta w(.)$):

$$p^* = \frac{k}{\left[(\varepsilon + \kappa + \lambda) - \delta^{-1}(\varepsilon)\right]}$$

Such that: $$\frac{\partial p^*}{\partial \varepsilon} = \frac{-\kappa(1-\mu)}{\left[(1-\mu)\varepsilon + \kappa + \lambda\right]^2} > 0$$

Or $$\frac{\partial p^*}{\partial \Delta w(.)} = \frac{-\kappa(1-\mu)}{\left[(1-\mu)\Delta w(.) + \kappa + \lambda\right]^2} > 0$$

Thus, the probability to collude increases as increase the bribe paid, given that $\mu > 1$. *Ceteris paribus* an increase of the fine just modifies the bribes to be paid by the landowner. This result, again, shows that the policies adopted by the governments may back-fire the *ex-ante* expected outcome.

THEOREM -6: The increases of the penalty, in the environment of weak institutions, will incentive Nash equilibrium in dominant strategies. In this Nash equilibrium every player will have a dominant strategy in playing collude given any believes about the other player's strategy.

Proof: The proof comes from the analysis of the previous theorems. We have shown that

$$\frac{\partial p^*}{\partial \delta} = \frac{(1-\tau)k}{\left[(\varepsilon+\kappa+\lambda)-\delta\right]^2} > 0$$

$$\frac{\partial q^*}{\partial \delta} = \frac{-f_\delta(.)(\theta-i)}{\left[(f(\delta)+\theta)-(i+\alpha)\right]^2} < 0$$

And we have shown that given such relationship, there is an increase of the collusion space amplitude, hence the level of corruption in the forest sector is higher. Since we are supposing the collusion space as a compact set, in this case a K-cell, the larger amplitude is reached when the metric is equal a unity. Hence, increasing the penalties will increase the amplitude, and this increase will force a unique Nash equilibrium with both players opting to collude, ever (p=1, q=1).

$$d_i = d_i(\sup_i, \inf_i) = 1, \qquad i = p, q$$

Therefore, the proof is concluded.

The following figure summarizes the Nash equilibrium in dominant strategies.

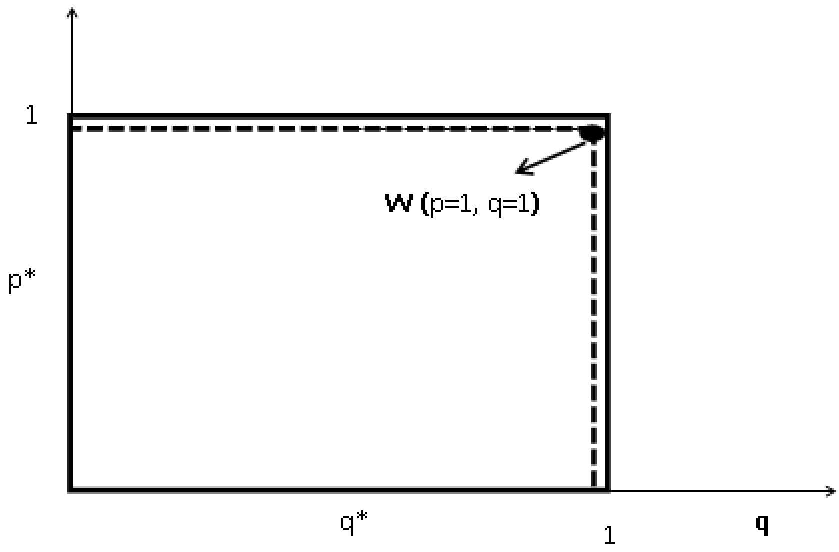

Figure 4 - Equilibrium in dominant strategies

Source: Author's elaboration.

The above theorem shows, through the static comparative, that the increase of penalties would turn the collusion strategy the best one (equilibrium in W). This results show that the use of penalties (fines) in a situation of weak institutions, would worse the problem of corruption in the forest sector, and therefore the level of illegal deforestation.

So far our main findings are based in the assumption that there is no internal auditing on the official´s reports. The based model developed can be expanded to include effects of the internal auditing in the strategies used by the players.

2.3.4 Equilibrium Strategies and the Influences of Surveillance by the Government

The internal surveillance that may be used by the government to avoid the problems of corrupt behavior, can be an important tool to prevent corrupt behavior. We can use the same approach to analyze the effect of such policy. For the official we have the following expected gains:

$$\big((w+\Delta w(.))(1-\beta)+(w+\Delta w(.)-F)\beta\big)q+w(1-q):=E[C] \qquad (5)$$

$$\left(w+\alpha\right)q+\left(w-i+\theta\right)\left(1-q\right):=E\left[NC\right] \tag{6}$$

We departed from the earlier case by adding the term F that represents the fines for corrupt behavior, and the term β , that represent the probability that the official will be investigated. Solving for the indifference level we obtain the following outcome decision rule for the Official:

$$\begin{cases} \textit{collude} & \text{if } q > \dfrac{\theta - i}{\left[\left(\Delta w(.)+\theta\right)-\left(i+\alpha+\beta F\right)\right]} \in \left[0,1\right] \\ \textit{not collude} & \text{if } q < \dfrac{\theta - i}{\left[\left(\Delta w(.)+\theta\right)-\left(i+\alpha+\beta F\right)\right]} \in \left[0,1\right] \\ \textit{indifferent} & \text{if } q = \dfrac{\theta - i}{\left[\left(\Delta w(.)+\theta\right)-\left(i+\alpha+\beta F\right)\right]} \in \left[0,1\right] \end{cases}$$

For the landowner the problem will be:

$$\left(\left(\pi(.)+\Delta\pi(.)-\varepsilon-\phi-\lambda\right)\beta+\left(\pi(.)+\Delta\pi(.)-\varepsilon-\lambda\right)\left(1-\beta\right)\right)p+\left(\pi(.)+\Delta\pi(.)-\delta\right)\left(1-p\right):=E\left[C\right] \tag{7}$$

When he opts to collude, and:

$$\left(\pi(.)+\Delta\pi(.)-\delta\right)p+\left(\pi(.)+\Delta\pi(.)-\delta-\kappa\right)\left(1-p\right):=E\left[NC\right]$$

Otherwise.

Solving for the indifference level we obtain the following outcome decision rule for the landowner;

$$\begin{cases} \textit{collude} & \text{if } p < \dfrac{k}{\left(k+\varepsilon+\lambda+\phi\beta\right)-\delta} \in \left[0,1\right] \\ \textit{notcollude} & \text{if } p > \dfrac{k}{\left(k+\varepsilon+\lambda+\phi\beta\right)-\delta} \in \left[0,1\right] \\ \textit{indifferent} & \text{if } p = \dfrac{k}{\left(k+\varepsilon+\lambda+\phi\beta\right)-\delta} \in \left[0,1\right] \end{cases}$$

Where ϕ represents the fine paid by the landowner when the official is investigated. Note that we are supposing that when the government does the surveillance, he discovers the real state of nature (the auditing is perfect). In this case he will penalize both i.e., the official and the landowner. That is, in this case the landowner receives two penalizations.

With these two results, we can analyze the static comparative when changes the parameters of the government policies, namely: $\beta,\ \phi, F$.

$$\frac{\partial q^*}{\partial \beta} = \frac{-F\left(i-\theta\right)}{\left[\left(\Delta w(.)+\theta\right)-\left(i+\alpha+\beta F\right)\right]^2} > 0$$

$$\frac{\partial q^*}{\partial F} = \frac{-\beta\left(i-\theta\right)}{\left[\left(\Delta w(.)+\theta\right)-\left(i+\alpha+F\beta\right)\right]^2} > 0$$

The results show that, there is a positive effect of the policy of surveillance in the indifference point. Increasing q* will decrease the amplitude of the collusion space (as defined earlier). More surveillance will increase the expected loss for engaging in the illegal activity, and this new environment will lower the incentives for colluding (from the official's point of view).

The condition of indifference from the landowner implies that:

$$p^* = \frac{k}{\left(k+\varepsilon+\phi\beta+\lambda\right)-\delta} \in \left[0,1\right]$$

Thus,

$$\frac{\partial p^*}{\partial \phi} = \frac{-k\beta}{\left[\left(k+\varepsilon+\phi\beta+\lambda\right)-\delta\right]^2} < 0$$

Increasing the penalties for corrupt behavior will decrease the amplitude of the collusion space of the landowner, which means that less likely the landowner will opt to collude (corrupt). This result means that the policy of surveillance can be an important tool to avoid the problem of corruption. Using the same approach, we can see the influence of the probability of surveillance. Results show that:

$$\frac{\partial p^*}{\partial \beta} = \frac{-k\phi}{\left[\left(k+\varepsilon+\phi\beta+\lambda\right)-\delta\right]^2} < 0$$

Thus, the policy of surveillance and fines can an important tool to avoid the problem of illegal deforestation. However, as expressed in Gneezy and Rustichini (2000), the fines can be adopted as price. Therefore, more fines from engaging in illegal behavior will be incorporated in the pay-off of the agents. Thus, the effectiveness of such policies can be mined if we have a *wealth effect* bigger than the price *or substitution effect*.

2.3.5 The Substitution Effect and the Crowding out Effect

The important issue to answer is the effect of both policies, i.e., fines from engaging in illegal deforestation, surveillance and fines from engaging in corrupt behavior. A naive analysis would defend that these policies, jointly, could mitigate the problem of illegal deforestation. Using simple calculus and the previous results we can demonstrate that the results are not so trivial. Ceteris paribus, we can define collusion space for the official as

$$\Gamma = f(q^*) = f\left(F\beta, \delta\right)$$

Where, *f*(q)* is the reaction function of the official, given his believes (*q*).

As showed, earlier, in our discussion,

$$\frac{\partial f(.)}{\partial (F\beta)} < 0, \frac{\partial f(.)}{\partial \delta} > 0$$

Thus, using the derivate approximation, around any initial point in the domain, $\left(F\beta^*, \delta^*\right)$, we find that:

$$\Delta\Gamma \approx \underbrace{\underbrace{\frac{\partial f\left((F\beta^*), \delta^*\right)}{\partial (F\beta)}}_{-} \underset{+}{\Delta F\beta}}_{-} + \underbrace{\underbrace{\frac{\partial f\left((F\beta^*), \delta^*\right)}{\partial \delta}}_{+} \underset{+}{\Delta\delta}}_{+}$$

$$\text{If, } \Delta\left(F\beta^*\right) = \left(F\beta - F\beta^*\right) > 0 \text{ and } \Delta\delta = \left(\delta - \delta^*\right) > 0$$

We can define the first part as a *substitution effect* and the second part as a wealth effect or *crowding out effect*. As we can see, increasing the fines to the environment crime would increase the likelihood of corrupt behavior (from the official point of view). Hence, in such scenario, the government should expend more resources in auditing, as a way to compensate the increase in the fines. Moreover, as auditing requires financial resources, the government should increase the fine for corrupt behavior (*F*), decrease the auditing (β) (or should be set constant) and decrease the fines for the environmental crime.

To derive the linear approximation, some notes must be made. We define

$$\Gamma\left(F\beta^*, \delta^*\right) + \begin{pmatrix} \frac{\partial f\left((F\beta^*), \delta^*\right)}{\partial (F\beta)} & \frac{\partial f\left((F\beta^*), \delta^*\right)}{\partial \delta} \end{pmatrix} \begin{pmatrix} \Delta F\beta \\ \Delta\delta \end{pmatrix}$$

As a parametric representation of the plane, tangent of the 2-dimensional graph in $\Re^3$, (in this case $\Gamma(.)$), and $\left(\frac{\partial f\left((F\beta^*),\delta^*\right)}{\partial(F\beta)} \quad \frac{\partial f\left((F\beta^*),\delta^*\right)}{\partial\delta} \right)$ is known as a Jacobin matrix, J , of $\Gamma(.)$ at the initial points, i.e., $\left(F\beta^*,\delta^*\right)$. Therefore, for the use of linear approximation, we are supposing that the surface, in the relevant domain, is sufficiently smooth.

For the rest of the paper we suppose that the conditions expressed above, of the smoothness, holds even for higher dimension. Therefore, we can apply linear approximation through the equations of hyperplanes.

The substitution effect represents the change in the official behavior due the existence of internal surveillance in IBAMA. Thus, more surveillance (for corrupt behavior) represents more expected cost. This *substitution effect* increases the cost of a corrupt behavior (from the official's point of view). The first effect would attract fewer officials for corrupt behavior, therefore would imply in less illegal deforestation.

However, the policies adopted by the government uses the fines, δ , and as we showed earlier, in presence of such policies, the landowner can offer a bribe to the official, i.e., by increasing the fines, the government allows more available bribes in the game between official and landowner. Consequently, in this framework, the official is more likely to have a corrupt behavior, i.e., $\Delta w(.) = \varepsilon = \frac{1}{\mu}\delta$. Thus, increasing the fines would increase his will to be corrupted. We call this result as the *crowding-out effect or wealth effect*.

This effect can undermine all the policies adopted by the government. The net out effect of the policies depends of the weight of each effect, i.e., the *crowding-out effect* (Negative effect) and the *substitution effect* (positive effect)[19].

The interesting outcome, in this framework is that decreasing the penalties for environmental crime (illegal deforestation), δ , and increasing the expected cost for corrupt behavior, *F*, would decrease the incentive for colluding behavior (in other words, the amplitude of the official's collusion space is lower). Using derivate approximation we find that:

$$\Delta\Gamma \approx \underbrace{\underbrace{\frac{\partial f(F,\delta)}{\partial F}}_{-}\underset{+}{\Delta F}}_{-} + \underbrace{\underbrace{\frac{\partial f(F,\delta)}{\partial \delta}}_{+}\underset{-}{\Delta\delta}}_{-}$$

[19] Positive effect means that the illegal deforestation is reduced by that effect. Otherwise we defined it as a negative effect.

If $$\Delta\delta = (\delta - \delta^*) < 0$$

In both case, the *substitution* and *crowding out effect* have negative signal, meaning that the incentive to collude is lower, therefore, reducing the effect of corruption on illegal deforestation.

Using the same approach we can test the separate effect of surveillance, penalty, and the bribe amount.

$$\Gamma = f(F, \Delta w, \beta)$$

Thus, $$\Delta\Gamma \approx \underbrace{\underbrace{\frac{\partial f(F,\Delta w,\beta)}{\partial F}}_{-}\underset{+}{\Delta F}}_{-} + \underbrace{\underbrace{\frac{\partial f(F,\Delta w,\beta)}{\partial \Delta w}}_{+}\underbrace{\Delta(\Delta w)}_{+}}_{+} + \underbrace{\underbrace{\frac{\partial f(F,\varepsilon,\beta)}{\partial \beta}}_{-}\underset{+}{\Delta\beta}}_{-}$$

Again, we cannot see the net out effects of such policies because they have different signals. In the present case, the middle part represents the *wealth effect* and the other two components represent, jointly, the *substitution effect*.

The situation investigated in this paper shows that the interactions between the players may create an incentive to perpetrate frauds, thus, rendering ineffective government policies directed on fighting illegal deforestation. Consequently, a new framework must be implemented in order to dissuade officials and landowner from colluding.

In the following section is presented some numerical simulations to summarize, our mains theoretical findings in this paper.

2.4 NUMERICAL SIMULATIONS: EFFECTS OF THE POLICIES[20]

We analyzed two types of simulation. First, we analyzed the influences of the auditing by the government in the collusion space. Second, we analyzed the effects on the collusion space.

For our first simulation we use the following values:

$i = 50$ $\alpha = 60$ $\theta = 100$ $\Delta w(.) = 110$

$\mu = 2$ $k = 10$ $\lambda + \varepsilon = 120$ $\delta = 120$

[20] Estimations made through the software MAPLE (12.0).

$\phi = 150$ $F = 50$

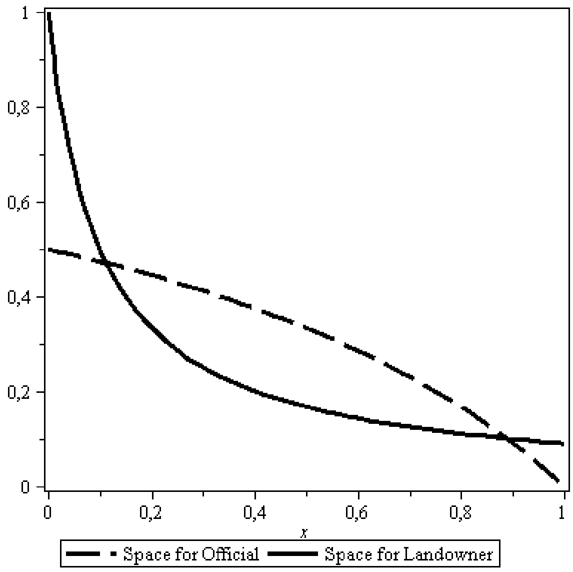

Figure 5 - The effects of internal Auditing (β) on the collusion Space

Source: Author's elaboration.

Results in this simulation fit perfectly the results mentioned earlier. The increase of the auditing from the government will decrease, jointly, the corruption space, that is the incentive to collude is lower.

The explanation is straightforward, given that we are supposing that these internal auditing are hundred percent efficient, more auditing means more expected cost, and therefore they (the agent and the landowner) will have more to lose in case of illegal deforestation.

In the second analysis we assume, for the official collusion space, that:

$$\alpha = 10 \quad \theta = 100 \quad \mu = 2 \quad i = 50 \quad F = 150 \; \beta = 0.5$$

And

$$\mu = 2 \quad k = 10 \; \lambda = 10 \; \beta = 0.5 \quad \phi = 100$$

For the landowner collusion space. .

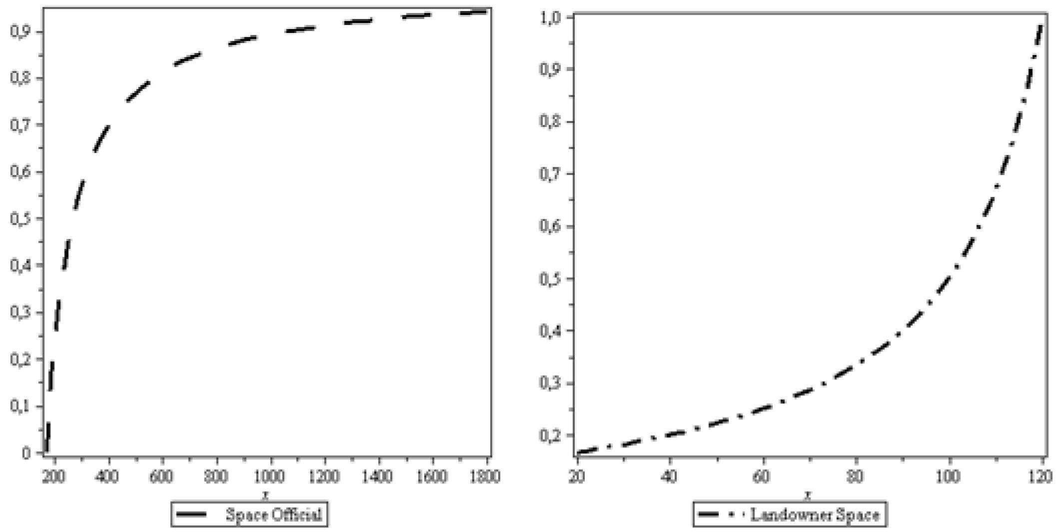

Figure 6 - The effects of Penalty in the collusion Space

Source: Author’s elaboration.

As we can verify by the numerical simulation, results are robust in terms of our theoretical findings. The Figure 6 shows that as the government increases the penalty, the incentive from the landowner for corruption behavior increases. The same happens to the official’s incentive.

So far our main findings are the relationship between the weak institutions and collaterals effects of government policies. We found that due the lack of solids institutions, the policy of penalties for environmental crime may incentive corruption between the officials of IBAMA and the landowner. More penalties may increase corruption in the forest sector. And given the international evidence, the level of corruption and deforestation seem to be positively correlated. Thus, weak institutions mean more corruption and consequently more deforestation. To search for a deeper analysis about this relationship, we proceed through our own empirical analysis. We performed non-parametric analysis, using the municipalities of Mato-grosso.

2.5 CORRUPTION, GROSS DOMESTIC INCOME (GDP) AND DEFORESTATION: NON-PARAMETRIC ANALYSIS

The measurement of corruption is something that’s difficult to be done, because, it represents illicit acts, and therefore, quite impossible to be analyzed in a solid bases. In this section we want to test some evidence from the impact of corruption in deforestation. We also included the GDP to test for the existence of the environment Kuznets curve (for a review in the environment Kuznets curve see CULAS, 2007).

To proceed to the analysis between the deforestation we used the data from *Controladoria Geral da União* (CGU) to construct indexes of corruption. Since 2003, the federal government implemented the CGU as a tool to investigate the ways that the money transferred from the federal government was used within the municipalities and states. The municipalities are taken from a random sample calculated through the methodologies used in the lotteries produced by the federal bank *Caixa Económica*. The municipalities included in the sample have at most 500 thousand habitants. In recent years, many empirical study on corruption (at regional level: municipalities and states), have used these data to construct index of corruption at municipal or regional level, see for instance Sodré and Alves (2010), and Ramos, Souza and Fernandes (2008)[21].

2.5.1 Empirical Strategy

To analyze the relationship between corruption, GDP and deforestation we choose non-parametric models. We choose this methodology because of the data limitation. Given the structure of the data available from the CGU's reports, we are not able to track the same municipality over the years. Therefore, it is impossible to use panel data models (about panel models see for instance WOOLDRIDGE, 2000). Therefore, we preceded using non-parametric regression (for a survey and an introduction about the non-parametric regressions see FOX 2002; PAGAN; ULLAH, 1999; RACINE, 2008; WOOD, 2007).

There is an expanding research in the nonparametric methods. Hence, there is today a vast technical method to deal with non-parametric regressions. By using a parametric model one usually is interested in the parameters estimated. In the nonparametric regression there is no parameter to be estimated, the own function is estimated. One of the main advantage of the non-parametric analysis is that we don't have to restrict the functional form for the regression to be estimated.

The simplest case between corruption and deforestation can be stated as: $Defo_i = f(Corrup_i) + \varepsilon_i$ where *Def* represents the deforestation arte and *Corrup* represents the corruption index calculated, and finally, ε_i represents the error term which is supposed to

[21] We constructed our corruption index by investigating the irregularities in the ministry of education. The reason to choose such ministry is because it is one of the few ministry investigated that appears in all reports.

be $\varepsilon \sim N(0,\sigma^2)$. The function $f(.)$ refers to the functional form of the relationship between the deforestation and corruption. Note that there is some refinements of the model to be estimate if we want to include others covariates. For instance we should have

$$Defo_i = f(Corrup_i, GDP_i) + \varepsilon_i$$

Or

$$Defo_i = f_1(Corrup_i) + f_2(GDP_i) + \varepsilon_i$$

The first one is called the multiple regression model and the second one the additive model (FOX, 2002). For the present study we focus our analysis in the first model. Wood (2000, 2004, 2006, 2007) presents detailed information on the additive models. To perform the multiple regression we use method called of *local linear regression*. Also called of LOESS (KELLE, 2008) this method has been widely used in applied set. The LOESS method is based in the locally regression for each data point in the data set. The variant of the LOESS is LOWESS, which is short for *local weighted regression*. Both methods were initially defined by the seminal work of Cleveland (1979). He proposed a polynomial regression within the bin, however in applied setting the linear regression is mostly used.

Suppose that one wants to estimate the following model through nonparametric methods

$$y_i = f(x_i) + \varepsilon_i$$

Where y is the dependent variable e x the independent one.

The LOESS method is built by connection for each point x_i, of the result linear regression. This regression are constructed through the use of some data around x_i. Here we call x_i as the focal point, and around this focal point we choose several points to include in the regression. The quantity of points to be included in the each regression, depends of the *span* chosen. Span represents in a percentage terms, the quantity of data to be included in each bin. The definition of *span* is the same of the *bandwidth* when we are talking directly of the kernel regression. Given the different distance of the points around the focal point, we may want to use to adjust for different distance. This is the essence for the difference between LOESS and LOWESS. For the first case we don’t use weight. To perform LOWESS, a kernel function is used. Therefore, for each focal point we have a weight regression, where points are given less weight when they are from the focal point.

There is a lot of different form for the kernel functions. However in applied setting, the tricube kernel is the most used (KELLE, 2008)

$$K_T = \begin{cases} (1-|z|^3)^3 & for\,|z|<1 \\ 0 & for\,|z|>1 \end{cases}$$

Note that the local linear regression, LOESS (or more general local polynomial regression, for degrees higher than one) is general case of the called local averaging, where all the observation in the bin has the same weight.

For the present case, that we have just one covariate, for a polynomial of degrees p, the local polynomial would be

$$y_i = \alpha + b_1(x_i - x_0) + b_2(x_i - x_0)^2 + b_3(x_i - x_0)^3 ......b_p(x_i - x_0)^p + \varepsilon_i$$

For technical issues, usually the degree of the polynomial is set as unity, that´s why the model is called local linear regression. As stressed in Kelle (2008) and Fox (2002), the choices of the kernel function don’t have important impact in the shape of the smooth. The key variable that impact in this shape is the *bandwidth* or the *span* chosen. The most used data to choose the *span* is the cross validation (CV), however this method is very sensitive for small sample (FOX, 2002). Therefore, we proceed as suggested by Fox (2002), and we made such choice manually.

When one is working with nonparametric application, there are no estimated parameters see for instance (FOX, 2002). Hence, we are not able to perform test hypotheses for the parameters. However, we can perform statistical inference by using standard tests used in the parametric estimations. We can use for instance F-test or likelihood-ratio (LR)-test to test the performance of different estimated functions. The typical test used in the one between a parametric model and nonparametric models (for nested models). In such case we would have

$$F = \frac{RSSP - RSSNP / w}{RSSNP / df}$$

Where RSSP is the residual sum of squares of the parametric model (null hypotheses) and RSSNP is the sum of squares of the nonparametric model (alternative hypotheses). *w* is the difference of the parameters from the two models, and *df* is the degrees of freedom. This statistic has *F*- distribution. (more details about these tests can be found in Kelle, 2008).

2.5.2 The Data

As highlighted earlier, to perform the empirical analysis, we constructed the corruption based in the CGU's reports (published on line). The deforestation was obtained through the National Institute for Spatial Research (INPE) web site. We used data from 20 municipalities.

2.5.2.1 Regional delimitation

We choose to analyze the municipalities from Mato-grosso. We have two reasons to choose these municipalities: first, between 2003 and 2005, the state presented one of the highest rates of deforestation in the history. Hence, it is a good region to test our theoretical insight about the corruption's effects on the illegal deforestation. Second, the analysis within states, gives us great advantage, because some characteristic are *naturally* controlled, e.g., timber price, meat price, cultural issues, legal issues, etc. Given the lack of credible data to measure all these variables, this seems to be the best approach.

2.5.2.2 Corruption index

To analyze the effects of corruption we construct the index of corruption, based on the reports from the CGU delivered between 2003, and 2005. The index is constructed in the following way: first, we made a deep analysis of the reports, and analyzed the number of irregularities for each state and municipalities. The reports from CGU refer to the irregularities found in different Ministries, e.g., Ministry of Education, Ministry of Environment, Ministry of Justice, etc. To construct our corruption index, we focused in the regularities found in the Ministry of Education[22]. However, to control the overrepresentation of bigger municipalities, we used the number of auditing as a weight, and we create in this fashion, a corruption index for each municipality in the state of Mato grosso.

2.5.2.3 Deforestation

We used the data delivered by the Brazilian institute of spatial research (INPE). It provides annual data for each state and municipalities of the legal Amazon. To see the

[22] We decided to use the irregularities found in the Ministry of education, because is one of the few ministries that appear in all the reports from the CGU.

relationship between corruption and deforestation, we used the data from 2004, because there was a peak of deforestation is this year.

2.5.2.4 Gross domestic production

We also used data from GDP to test the existence of the Kuznets curve for Mato-grosso. Data are at constant price of 2000, and were collected at Ipeadata website.

2.6 RESULTS

As argued earlier the nonparametric regression estimates the function itself, rather than the parameters of the function. Hence, the results should be interpreted in the resulting plot. The following figures present the results for ours estimations.

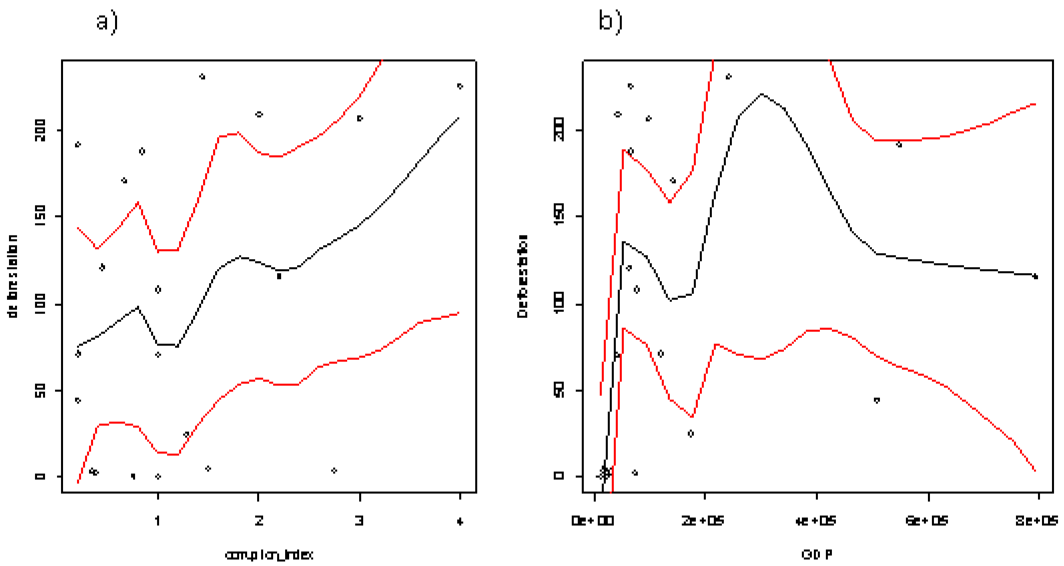

Figure 7 – Corruption, GDP and deforestation

Source: Author's elaboration.
Note: The left panel (A) shows the effects of corruption in the deforestation. The right panel (B) shows the effects of GDP in the deforestation. The black curve is the estimations by LOESS. The red lines represent the 95% bootstrap percentile interval. It was used 1000 resample. The span used was 0.5.

As we can see the partial estimations, shows that there is a positive relationship between corruption and deforestation. Our results also argues the existence of an inverted U-shaped between deforestation and GDP.

In the Figure 7 (a), we can see that, for some range, there is an inverted U-shape relationship between corruption and the level of deforestation. For other range, this relationship seems to be almost linear. However, the general idea that we get from this analysis is that there is a positive relationship between corruption and deforestation.

In the Figure 7 (b) we see that there an inverted U-shaped relationship between deforestation and GDP. The explanation is straightforward: as the GDP increase, at first stages of development, there is higher pressure over the natural resources. However, over certain turning point this relationship turns to be downward slopping. This change happens because at higher stage of development, variable as the public concern imposes more constrain in the use of natural resources.

The combination between GDP and corruption leads to higher level of deforestation. This result can be shown to exist, when we plot three-dimensional impact of both variables in the deforestation. The Figure 8 presents these results.

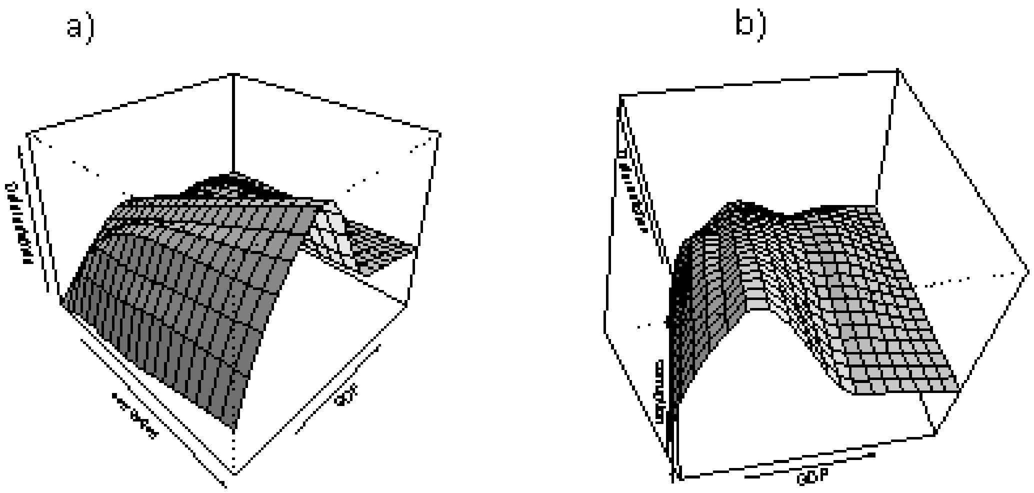

Figure 8 - LOESS estimates of the effect of the GDP (x) and the Corruption (y) in the deforestation (z).

Source: Author’s elaboration.
Note: First perspective in (a), and another perspective in (b).

The Figure 8, presents the jointly effects of corruption and GDP in the level of deforestation. As we can see, the partial effects are similar to the previous analysis. However, analyzing the superficies, we see that the turning point at Kuznets curve happens at higher level when there and increase of the corruption. Our results argue that corruption leads to higher level of deforestation for a given level of development (measure here as GDP).

These results from applying the LOESS suggest that the relationship between deforestation, corruption and GDP, are nonlinear. To test also the robustness of our finding, we also used pooled cross-section (POOLED) to verify our results (about POOLED see Wooldridge, 2001). The results are presented in the following table.

Model-1 $Defo_i = \beta_0 Corrup_i + \beta_1 GDP_i + \varepsilon_i$

Model -2 $Defo_i = \beta_0 Corrup_i + \beta_1 GDP_i + \beta_2 \left(GDP_i\right)^2 + \varepsilon_i$

Model-3 $Defo_i = \beta_0 + \beta_1 \log(Corrup_i) + \beta_2 \log(GDP_i) + \varepsilon_i$

Model-4 $Defo_i = \beta_0 + \beta_1 \log(Corrup_i) + \beta_2 \log(GDP_i) + \beta_3 \left(\log(GDP_i)\right)^2 + \varepsilon_i$

Table 1 - Pooled OLS estimations

Model	**Model1**	**Model2**	**Model3**	**Model4**
constant	43.8 (1.30)	-16.6 (-0.41)	-359.4** (-1.85)	-3545,2* (-2.75)
Corruption	31.96** (1.74)	43.62* (2.53)		
Gdp	9.88E-05 (1.09)	0.000812* (2.49)		
$(Gdp)^2$		-9.9 E-10* (2.25)		
Log(corruption)			40.56** (2.10)	41.69* (2.60)
Log(GDP)			41.08* (2.69)	599.3* (2.67)
$(Log(GDP))^2$				-24.21* (-2.46)
Concave		Yes		Yes
Sample (n)	20	20	20	20
R^2-adjusted	0.093	0.27	0.28	0.42

Source: Author's elaboration.

Note: For the models 3 and 4 we used White standard robust error. * Significant at 5% and ** significant at10%.

Our parametric analysis also confirms the earlier findings in the nonparametric estimation. Corruption is significant covariate in the model. However, given the sample size (n=20), the classical assumption should not be applied, therefore to give more robustness to our parametric model, we should proceed with nonparametric bootstrapping estimations of the confidence interval. For such purpose we constructed nonparametric percentile confidence interval. To construct our confidence interval, we used the bootstrapping methodology. The bootstrap is an empirical way to derive the distribution of any specific statistic. We used nonparametric bootstrap, which is not based in any defined parametric distribution.

The procedure the bootstrap is, in essence, the same of an Monte Carlo simulation. Suppose that we are interested of any statistic *T*, however, the sample is too small, therefore the classical assumption are not respected here. In such case one can use nonparametric bootstrap to derive the empirical distribution. The idea of bootstrap is to use the sample as the population. We can choose from sample B- sample, which the elements of the each sample are chosen with replacement. Usually B (number of replication) is preferred to be high, say 1000 replication. From each of the bootstrap sample we calculate our T* statistic from each sample. Given the statistic for each sample, T^*_b, we can obtain any bootstrap estimates on the statistic, as mean or variance. More details about application of the bootstrap methods can be found in Efron and Tibshirani (1993), Fox (2002), Schmidheiny (2010), Cameron and Trivedi (2005), and Kelle (2008).

For present purpose, we used the BOOT package in the R-software (bootstrap can be also performed, easily, in STATA[23]).

Table 2 - Bootstrap percentile interval (Parametric Model)

	Estimated Coefficients	Percentile Bootstrap C.I (95%)	Percentile Bootstrap C.I. (90%)
Model-1	Corruption	(1.28 – 71.46)	
	GDP	(0.0001 – 0.0021)	
Model-4	Log (corruption)		(14.27 – 71.67)
	Log(GDP)		(143.6 – 1031.5)
	$(\text{Log(GDP)})^2$		(-43.11 – -3.67)

Source: Author’s elaborations.

23 Schmidheiny (2010) presents a simple guide for the implementation in STATA.

Note: Bootstrap sampling was repeated 2000 times. The intervals are presented in following way: (lower bound – upper bound). For the model-4 we presented here the 90% C.I. because at 95% the interval on $(\log(gdp))^2$ includes zero.

This result confirms the robustness of our findings. These results should be treated as a pioneering exercise to explore empirically the effects of the corruption in the deforestation (for the case of Amazon forest).

2.7 CONCLUSION

Even thought, many cases of corruption of IBAMA official has been denounced in the media, we did not find many works on the matter. Thus, this is one of the first papers, in the Brazilian literatures that focus on the problem of corruption as a leading variable for illegal deforestation.

Using a theoretical approach, static game, we analyzed how the actual relationship between the IBAMA official and the government can play an important role. Due to the static approach, our model have some limitation on capturing the dynamic relationship between the landowner and the official, however, it fulfills, perfectly, the aims of the paper, that is, it highlights perfectly how the problem of corruption, due the lack of good institutions, may backfire all the policies adopted by the government. Even though the model was built in static approach, the structure used here allows, given the assumptions considered, to use static comparative to derive important results.

Generally speaking, our theoretical model suggests that the actual relationship between the official and the landowner may motivate the corruption strategy for both players. The gain is bigger when they are corrupt than otherwise. In the present context, the external policies adopted by the government are useless, that is, corruption may back-fire all the efforts from the government to avoid the problem of illegal deforestation. The main theoretical result seems to be paradoxical when the government uses the policy of heavier fines. In the present context, more fines may encourage more illegal deforestation.

Our main results argue that, if the institutions are weak, higher penalties rates for the environmental crime would increase the likelihood of corrupt behavior. Therefore, in this scenario increasing penalties for environmental crime would increase the corruption in the forest sector. As we know from international evidence, more corruption means more deforestation; therefore the policy adopted by the government would increase the rate of deforestation. This results seems to be senseless, however it is very intuitive. Given that there no internal auditing from the report delivered by the official, his discretionary power will induce him to request for bribe. This insight means that a higher fines means that higher level of bribes is required by the official. In the case of illicit act, the landowner willingness to pay bribe to the official is higher when the penalty increases. Given that the bribes are always lower than the fine to be paid, the landowner will always prefer to pay the bribes. Given this scenario, the environmental crime is never discovered (at least from the point of view of a corrupt official).

We generalized our model and we introduced the probability that when the official makes a report he will be investigated (this would mean an internal auditing policy in the IBAMA). In this scenario, the auditing policy from the government would increase the expected cost of corrupt behavior and therefore would decrease the level of corruption.

Finally our results argue that given, the existence of cost of internal auditing, this policy should be followed with an increase of the penalties for corrupt behavior. Together with this policy, a policy of lower penalties for environmental crime would decrease the probability of bribe. However, we should highlight that the penalties should never be zero, otherwise every landowner would commit crime. Hence, the optimal penalty for the environmental crime should be fixed between the maximum and the minimum.

Beyond the theoretical contributions, this paper is the first to analyze empirically, in Brazil, the effects of corruption in the deforestation. For such analysis we focused in the municipalities from Mato-grosso, and we used non-parametric estimations.

The empirical analysis showed that there is positive impact of corruption on the level of deforestation. Higher level of corruption is related with higher level of deforestation. We tested the existence of Kuznets curve for the municipalities. We found that there is an inverted U-shaped relationship between GDP and deforestation. Moreover, due the existence of corruption, the turning point of the *Kuznets curve* happens in a higher level of deforestation.

Finally we would like to highlight that this work is an important beginning for those with special interest in environmental issues. However, as highlighted earlier, the static approach leaves a gap for further research on more sophisticate models. The introduction of dynamic programming seems to be a perfect tool for such approach. In terms of empirical research, further research is needed. Others type of corruption index should be tested.

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3 CORRUPTION AND TROPICAL DEFORESTATION IN AMAZON FOREST: A DIFFERENTIAL GAME MODEL

3.1 INTRODUCTION

Deforestation is an environmental problem especially for countries with large areas of tropical forests, such as, among others, Thailand, Malaysia, Indonesia, Congo, Ghana and Brazil. Studies have analyzed the various facets of the process of deforestation, and usually they highlight the importance of the economic decisions involved, as one of the major cause, as, for instance, in Pellegrini and Gerlagh (2006a, 2006b).

In China, according to Liu (2005), the Government provides educational programs through funds to support environmental programs, and the main purpose is to alert people about the adverse results caused by the loss of forests. A study by Liu et al. (2007) indicates that the exploitation of rubber has been the main cause of deforestation seen in the region of Xishuangbanna, China.

In the study by Ichikawa (2007), for Malaysia, a systematic loss of large forests was identified as mainly the result of cultivation of tradable goods, specially palm oil. In fact, many empirical research at national or international level, found that variables as the price of meat, timber, beans, have a great impact in the level of deforestation, as, for example, in Young (1997) and Margulus (2003).

Recently, together with the variables cited above, the inexistence of solid institutions has been considered the major factor responsible for deforestation (WORLD BANK, 2008; GREENPEACE-BRASIL, 2010). Weak institutions always encourage corruption, and they are included in the so-called indirect causes of deforestation.

The corruption in the forest sector may take many forms, and it is not related just with the low rank government officials. The government official may take bribes to illegal exportation of protect species of wood, also the Ministers may take timber resources for political purposes (KISHOR; DAMANIA, 2007). Therefore, corruption in forest sector may be very persistent. Beyond the direct impact of the corruption in the deforestation, it increases the loss in the government revenue from exportation. For instance, in Indonesia the total value added related with logging is estimated to be US$ 6.6 billion per year, however the contribution of the legal logging is just US$ 1.5 billion (KISHOR; DAMANIA, 2007).

Empirical evidences have shown that corruption has a great impact on deforestation see for instance, Pellegrini and Gerlagh (2006a). Despite the empirical researches on the causes of deforestation, we didn't find any theoretical work that shows how works this relationship between corruption and deforestation. Hence, this is the first to show how several variables, e.g., the salary paid by the government may contribute to more or less deforestation.

We developed two dynamic models. In the first one, we suppose the existence of two markets, namely the legal and illegal market. We showed how the wood's price in these market impacts in the quantity of wood logged and divided between both markets. We modeled the environment benefits from the forest as a linear function of stock of forest, and demonstrated the negative impact of the market price in the amount of benefits received by the society.

In the second model, we used differential game to explore the effects of corruption on the stock of forest. We suppose a game with two direct players, namely the government official and the landowner. The government enters in the game indirectly by defining the rules, namely the penalties scheme and also the salary received by the official. Our results argues that the salary paid by the government have a positive impact in the bargaining power of official. Hence, with low salary more increases the likelihood that the official will be corrupted. We analyzed the direct effects of these salary schemes in the final stock of forest.

Besides this short introduction, the paper is structured in the following way: in the second section some evidences of the deforestation in Amazon forest are presented; in the third section some international evidences on the effect of corruption in deforestation are analyzed. In the fourth section, we make a short survey about the literature in differential games, and we also introduce the basic Stackelberg game. In the fifth section we introduce a basic model with two different markets: illegal and legal market. In the sixth section we introduce the second model, where it is included the corruption in the first model. Final remarks are given in the seventh section.

3.2 DEFORESTATION IN AMAZON FOREST

The Amazon forest cover an area of nine Brazilian states, namely Acre, Amazonas, Rondônia, Roraima, Pará, Tocantins, Amapá, Mato Grosso and part of Maranhão. Due its extensive area and biodiversity, its considered one of the great human wealth, and its great loss in the last two decade has promoted an increasing worldwide (including at national level) concern about its future (ALSTON; MULLER, 2007).

The main government policy used by the government has been the coercive delimitation of the area that can be deforested and the application of penalties for those directly engaged in illegal deforestation. The governmental organization for the ministry of environment, IBAMA, has been the main instrument for such policies. These policies are part of the government's plan for the avoidance and control of deforestation in the Amazon forest, which seeks to reduce it immediately. However, every year the forest loses its size, and direct variables, as international price of meat, soy, etc, are highlighted as the main causes of deforestation (KEOHANE; OLMSTEAD, 2008; MARGULIS, 2003).

The increasing demand for commercial products have increased the occupation of virgin areas, which, due the great investment from government in social capital, induces more deforestation in the Amazon forest (CALDAS et al., 2003. Recently satellite images have shown that Mato Grosso is the first state in deforestation in Brazil– in 2008 about 1,120 km^2 have been deforested in Amazon, and 70% was in Mato Grosso (GREENPEACE BRASIL, 2010).

There are a lot of empirical papers analyzing the causes of deforestation, however, they are mainly concerned with the direct causes of deforestation. Corruption undermines all the government's effort to control or stop deforestation. The result of using coercive policies are not so trivial. Applying such policies in the field is a crucial part of all the policy, therefore, government policies may show innocuous under the assumption of existence of corruption (WORLD BANK, 2008).

According with Amacher (2006), 80% of all products are illegally collected. Hence, in this environment, corruption appears to be an important issue that needs to be investigated.

In this scenario, the paper adds new insight on how government policies may mitigate the illegal exploration of Amazon resources. We used our model to analyze how low salaries in the public sector and high market price contribute to lower stock of forest. Our model argues that, the low salary (and constant salary) received by the government official, and the inexistence of internal auditing, allows a quicker depletion of the forest. In this scenario, on the one hand, the corrupt official increases his gain (which includes the salary received and the bribe paid by the landowner) over the period. In the other hand the quantity of wood extracted by the landowner increases over time. Hence, we show, through our model, which are the conditions that encourages the presence of criminal group (corrupted officials and landowner (enterprises)), and their direct implication on the deforestation.

3.3 CORRUPTION AND THE FOREST SECTOR

The connection between corruption and the forest sector is not a new issue; researchers claim that the governments shall incorporate such phenomenon in their policies (AMACHER, 2006; DAMANIA, 2002; KOYUNEN; YILMAZ, 2009; PELLEGRINI; GERLAGH, 2006a; TRANSPARENCY INTERNATIONAL, 2009). For instance, Pellegrini e Gerlagh (2006a) analyzed the impact of the entrance of new countries of the Europe Union in the environment policies. Using cross-section estimation, they found that corruption is the main responsible for the effectiveness of the environment policies in these countries. Koyunen e Yilmaz (2009) analyzed through the cross-section data the impact of corruption in the deforestation level, in 100 countries. They used many corruption indexes in their estimation, e.g., corruption perception index (CPI), International country risk, etc. They found a strong correlation between corruption and deforestation.

Despite knowing the impact of corruption in the deforestation phenomenon, the way they are correlated is little known (TRANSPARENCY INTERNATIONAL, 2009). Pellegrini and Gerlagh (2006b), through the cross-section methodologies, have analyzed the effects of corruption and democracy on deforestation. He found that democracy have non statistical significance in the model. In the other hand, corruption proved to be an important variable to explain the difference in deforestation rates around the world.

Welsch (2004) analyzed the impact of corruption and GDP in the level of pollution. He found a positive and monotonic relationship between corruption and pollution, and a negative relationship between GDP and pollution.

As cited mentioned above, there is an international consensus about the impact of corruption on deforestation. However, in the case of Brazil, little attention has been given by the Brazilian researchers. There are a lot of empirical works that focus their attention on the so called direct cause of deforestation, for instance Silva (2009) and Young (1998). However, the weak institutions in several regions of Brazil and the low salaries paid by the government may increase corruption in the forest sector. Many cases of corruption have been showed in the Brazilian media in the last years: cases of collusion between IBAMA officials and enterprise/landowners have been showed to co-exist since a long time.

The present work helps to understand how corruption may directly affect the deforestation. Due the dynamic structure, our results help the understanding how incentives play an important role in the deforestation issue. We derived important results showing how indirect factor, e.g. corruption, may increase the rate of illegal exploration of the Amazon resources (our model focus in the case of forest, however the model can be adapted to any renewable resource). Hence, this is the first theoretical work on this field, which allows for a theoretical understanding of the empirical results archived by the cited papers.

3.4 DIFFERENTIAL GAMES AND DEFORESTATION

Since Hoteling (1931), the economic analysis entered a new area – the economics of natural resources. The increasing study of natural resources issues began in the first oil crisis in the 70's. From then, a lot of theoretical work has been done, incorporating many different types of resources and environment. They usually use optimal control theory and dynamic programing to analyze the effects of human activity on natural resources. Others authors, like Amacher (2006) and Amacher, Koskela and Ollikainen (2006), Hamilton and Zilberman (2006) change the focus of the analysis and highlight that the direct owner of the property are not the only agent responsible for deforestation. The existence of corrupted governments usually encourages more deforestation.

The present paper work follows the same framework of the earlier ones, that is, it aims to use the optimization by a "*representative*" agent to show the effects of his activity in the deforestation. However, we use differential game to model the impact of corruption in the rate of deforestation. Hence, our work adds two important points in the literature of Brazilian deforestation: we use differential game and analyze the *open-loop stackelberg equilibrium*, and finally we introduce a new variable in the analysis – corruption[1].

The use of the differential game to model deforestation in tropical forest is not new . Fredj et al. (2006) analyzed, by applying differential game, the impact of subsidies from rich

[1] We define the *stackelberg open-loop equilibrium* when the strategies of the players are simply time dependent.

countries (north) to poor countries (the south). They followed some assumptions from earlier works, namely, Ehui, Hertel anda Preckel (1990) and Van Soest e Lensink (2000).

Using differential games in the current case is not senseless. Given the structure of the relationship between those engaged in collusion behavior (landowner and officials of government), and supposing that there is a state variable involved, the differential game is a perfect tool for this case[2].

3.4.1 A Stackelberg Differential Game: A Basic Introduction

In this subsection we present the basic approach of a Stackelberg differential game. Suppose that we have two players, namely the leader and the follower. Following the traditional approach of standard games, the follower chooses after the leader choice. However, the game is solved by backward induction. The Stackelberg equilibrium in the differential game is obtained in the same way. The only difference between the differential game and the standard game, is that now we are dealing with dynamic games which incorporates a state variable. Therefore, we should apply the optimal control or the dynamic programing to solve this type of game. The choice between these two methods depends on the information structure chosen for the game. For the present work we choose the *open-loop equilibrium*. Hence, we applied the optimal control conditions. Markovian games are usually solved by dynamic programing.

As defined earlier we have two players, the leader and the follower. The utility of the leader is $u^l(v^l(t), x(t), v^f(t), t)$ and the follower's utility is $u^f(v^f(t), x(t), v^l(t), t)$. Where $x(t)$ represents the state variable of model. v^f is the control variable of the follower and v^l is the control variable of the leader. Note that we suppose that there is just one control variable and one state variable, however, we could easily generalize this structure by imposing matrix representation. We suppose an problem with finite time, i.e., $\forall T < \infty$.

[2] The differential game was first introduced by Isaacs (1965). These games consider the existence of constrains on the strategies used by players; these constrains are in fact, the first order differential equation for the state variable or the so called "*kinematic equations*". The equilibrium definition used in differential games depends on the structure of information under which the game is played (BASAR; OLSTER, 1999). Under In the case of perfect state information, we may have *closed-loop no memory, feedback, and open-loop*. In our case, we used the notion of *open loop equilibrium à la* stackelberg. The name stackelberg comes from the "traditional" view of stackelberg games, that is, there is a leader and followers in the game, and the equilibrium solution is obtained by using backward induction. For a simple survey about stackelberg equilibrium, see Sethi et al., (2007), or for introduction to differential games, see Feichtinger and Jorgehnen (1983).

The state variable, *x(t)*, changes according to the following *kinematic* equation,

$$\dot{x} = f(v^l(t), x(t), v^f(t), t)$$

Using the backward induction, we know that the leaders incorporate the decision of the follower in his optimization. The follower solve is problem given the strategy used by the leader. Hence, by applying the backward induction we solve the problem of the follower first. The follower choose the optimal path for his control variable as a way to maximize the stream of benefits over the defined period, $\forall T < \infty$.

$$J_f = \int_0^T u_f\left(v^f(t), x(t), v^l(t)\right)dt$$

By applying the maximum principle we construct the follower Hamiltonian

$$H(.)_f = u_f\left(v^f(t), x(t), v^l(t)\right) + \pi_f \bullet f(v^l(t), x(t), v^f(t), t)$$

Where π_f is the follower co-state variable. To find the optimal path for the control variable, we should apply the necessary and sufficient conditions (see LEONARD; LONG, 1992), namely

$$\frac{\partial H(.)}{\partial v^f} = 0 \qquad \text{(I)}$$

$$-\frac{\partial H(.)}{\partial x} = \dot{\pi}_f \qquad \text{(II)}$$

$$\frac{\partial H(.)}{\partial \pi_f} = \dot{x} \qquad \text{(III)}$$

Solving condition (I)-(III) we find the optimal path for the control and co-state variable. Obviously, the follower optimal control variable, in general, depends directly of the control variable of the leader. Hence, the solution of the follower optimization may be reported as

$$v^f*(t) = g(x(t), v^l(t), \pi*(t))$$

$$\dot{\pi}_f*(t) = g(x(t), v^l(t), t)$$

Given the reaction function for the follower, the leader incorporates these variables in his optimization problem. The objective of the leader is to maximize the stream of benefits over the defined period.

$$J_l = \int_0^T u_l \left(v^l(t), x(t), v^f *(t), t \right) dt$$

His Hamiltonian is

$$H(.)_l = u_l \left(v^f(t), x(t), v^l(t) \right) + \pi_l \bullet f(v^l(t), x(t), v^f *(t), t) + \lambda \bullet g(x(t), v^l(t), t)$$

Note that we introduce a new state variable. We treat the follower co-state variable as a state variable in the leader problem. Hence, we add another co-state variable (in some cases we don't need to do so, see LONG et al. (2000) for further discussion)).

By applying the maximum principle as in the case of the follower, we find the optimal path for the leader problem. Since we know the solution for the leader, is straightforward to obtain the solution for the follower problem. At this stage, the model is solved and we get the stackelberg *open-loop equilibrium*. Note that this equilibrium will be time-dependent.

In the following sections, we apply such dynamic approach to solve our corruption model.

3.5 THE BASIC MODEL – MODEL 1

Our first model wants to analyze the effect of the existence of a market of illegal selling of timber or related products. In many countries, e.g., Brazil, one of the many ways to guarantee the provenience of the timber is the certification of the wood. In Brazil this certification is made by IBAMA.

In the current model, there are two markets: a "legal" one, for selling the forest product (related to deforestation) and an "illegal" (or "black market") one. In the first one, the accreditation works perfectly. However, the landowner may choose to target his production to the "black" market or "illegal" market, in which he can sell his timber without a certification. These two markets may have different characteristics: different demands, selling related costs, price, etc. Given that there is no audition for landowners by IBAMA officials (in this first case we are not including the potential corruption behavior), the landowner can choose spontaneously how much quantity to target to both market[3]. Therefore, in our model the landowner may choose how much of forest to cut down, but also how to split this amount between the legal and the illegal market.

Assuming a finite horizon optimization problem, the landowner may choose at each point of time and the quantity of his product to maximize his net revenue[4]. We define his revenue, R(t), as:

$$R(t) = p(t) * Q(t)$$

Where p(t) represents the price of the product and Q(t), the quantity of timber. In fact, we can define Q(t) as[5]:

$$Q(t) = Q^{L}(t) + Q^{IL}(t)$$

Therefore $Q^{IL}(t) = \alpha Q(t)$ and $Q^{L}(t) = (1-\alpha)Q(t)$, so, by choosing $q^{j}(t),\ j = L, IL$, the landowner is automatically choosing the proportion and the quantity of timber to be harvested. Following the international literature and using the inverse demand, the total revenue of the landowner can be written as:

$$R(t) = p^{L}(t).Q^{L}(t) + p^{IL}(t).Q^{IL}(t)$$

or

$$R(t) = \left(\overline{p^{L}} - \lambda q^{L}(t)\right).q^{L}(t) + \left(\overline{p^{IL}} - \theta q^{IL}(t)\right).q^{IL}(t) \qquad (1)$$

Where $\overline{p^{j}},\ j = IL, L$ represent the highest price to be paid when the quantity is zero, i.e., $\lim_{q^{j} \to 0} p^{j} = \overline{p^{j}},\ j = IL, L$. θ, λ represents positive parameters. Note that, increasing θ or λ means that lower will be market price in both market, or higher, otherwise.

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[3] This assumption will be relaxed later.

[4] For the sake of simplicity, we suppose that the capital cost or labor cost in the production is zero.

[5] As discussed in Ehui et al. (1990), Van Soest and Lensink (2000) and Fredj (2006), the timber can be extracted in general form or selective logging's methods; however, for sake of simplicity we ignore these differences and suppose that there is a non-selective logging. Another note that we must bear in mind is: following Fredj (2006), $Q^{j},\ j = I, IL$ is the rate of deforestation, therefore, if we suppose that there *n* valuables stems per unit of land, the quantity of wood/timber produced is equal to *n* times $q^{j},\ j = I, IL$. Therefore, if we normalized *n* to unity, we have that: $q^{j}(t) = Q^{j}(t),\ j = I, IL$, that is, the quantity of timber is the same of the rate of deforestation.

The forest size develops according with following dynamic equation (we omit from now on the time argument for the sake of simplicity of writing):

$$\dot{X} = -\left(q^{L} + q^{IL}\right) + rX \tag{2}$$

Where *X* represents the stock of forest owned by the landowner, and *r* represent the rate of natural growth of forest. Thus, the net growth of the forest at each point in time will depend of the weight of each component – more logging will decrease the stock of forest and higher *natural* rate of growth, *r*, will increase the stock of forest.

Note that we used a linear case of growth equation, this is different of the logistic function usually used in these studies – in the present paper we supposed that the forest would increase indefinitely over time, that is, without the loggings from the landowner, the forest would increase - there is no *natural* steady state in the future for the stock of forest. This assumption is not far from reality, because we are talking about rain forest in the tropics, hence, the natural causes for deforestation, as fire, etc. do not exist. In the present case, it is the human activity, rather than the natural causes, the key elements in constraining the growth of the natural resource (see LONG, 2011, for the case of linearity of the kinematic function for the case of fish biomass).

Given the control variables and the kinematic equation, we define that the landowner wants the maximize the streams of revenue over an finite horizon, $t \in \left[0, T\right]$, therefore his optimization problem is[6]:

$$Z = \underset{\{q^{L}, q^{IL}\}}{MAX} \int_{0}^{T} R(t)dt + \phi X(T) \tag{3}$$

Where $\phi X(T)$ represents the “scrap” value function for the final period, and *Z* the optimum value found. Following Fredj (2006), we suppose that the scrap value is linear in its arguments, even though it is usually a non-linear function[7]. The use of the scrap value is optional, however given that we suppose a short period of time it is more appealing to make such assumption.

The landowner optimization depends on the following constrains:

$$\dot{X} = -\left(q^{L} + q^{IL}\right) + rX$$

[6] We do not incorporate the discount factor because we suppose that the *T* is not so large. Therefore, the loss in terms of analysis is minimum. However, further explanation can be found in Freyd (2006).
[7] About these issues see Freyd (2006).

And the transversality condition (see Leonard and Long (1992) about this condition):

$$\frac{\partial}{\partial X}(\phi X(T)) = \phi = \pi(T) \qquad (4a)$$

And the boundary constrain

$$X(0) = x_0 \qquad (4b)$$

Where $\pi(T)$ is the co-state variable at terminal date.

The optimal solution for the landowner is found through the application of Pontryagin's maximum principle. In such way, we organize the following Hamiltonian:

$$H(t, q^j, \pi, X) = \overline{p^L}.q^L - \lambda\left(q^L\right)^2 + \overline{p^{IL}}.q^{IL} - \theta\left(q^{IL}\right)^2 + \pi\left[-\left(q^L + q^{IL}\right) + rX\right] \qquad (5)$$

Solving the Hamiltonian and assuming an interior will provide the optimal path for the control variables and the state variable.

Even though we did not use a logistic function for the state variable, the second order differentiation guarantees that the controls found are optimal, given that the first principal minor is negative, i.e., $\frac{\partial^2 H(.)}{\partial^2 q^j} < 0,\ j = IL, L$ [8].

Theorem-1: The stock of forest will decline in $t \in [0, T]$, and this decline depends on the amount of the logging and the natural growth rate. Given that the logging rate will depend on the parameters of the inverse demand, these will indirectly determinate the stock of forest in the final period (please, see Figures 2 and 3 for numerical illustration)[9].

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[8] In the present case, following Leonard and Long (1992) to analyze the sufficient condition for a maximum, we must see if the Hamiltonian is concave. Hence, it is straightforward to show that the Hessian associate to the Hamiltonian is negative definite, and it is given by

$$H = \begin{bmatrix} -2\theta & 0 \\ 0 & -2\lambda \end{bmatrix} = H_2$$

Hence, given that $\theta > 0, \lambda > 0$ by definition, we have that the determinant of the second principal minor is positive, i.e., $|H_2| > 0$. Therefore, the optimal solution found is a maximum.

[9] The numerical simulations in this section follow, for some parameters, the same values found in Freyd (2006) and Van Soest and Lensink (2000). The parameters used are

$T \geq 5 \quad \theta = 20 \quad \lambda = 20 \quad \overline{p}^{IL} + \overline{p}^{IL} = 95000 \quad r = 0.2 \quad X(0) = 2000 \ \phi = 9000 \quad \overline{p}^{IL} = 50000$

To simulate the quantity of loggings (figure-1) we used:

$$\overline{p}^{IL} + \overline{p}^{IL} = 150000$$

Proof: see Appendix A

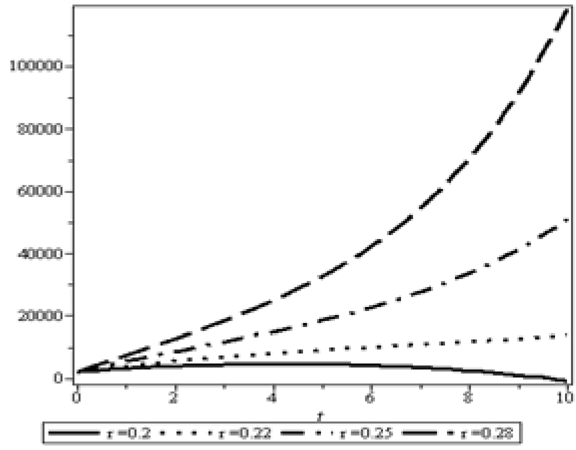

Figure 2 - Stock of Forest over period: the effect of different rate of natural growth.

Source: Author's elaboration.

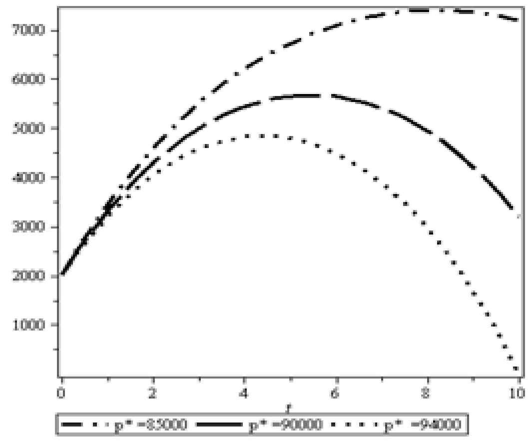

Figure 3 - Stock of Forest over period: the effect of higher price in both markets.

Source: Author's elaboration.

As we can see in the Figures 2 and 3, an increase in the natural rate of growth will increase the amount in the forest at final stage (Figure 2). This result is intuitive, given that, through the kinematic equation, we can see that the natural rate have a positive impact on the growth rate of the forest. For the same reason, as expected theoretically, the increased price at market (Figure 3) will increase the logging level, and therefore, decreasing the amount of forest in the final period.

As we can see in both figures, for short horizon, the stock of forest is increasing and after some point it will decrease. The reason for this is the different weight of the impact of the natural rate of growth and the quantity logged over the period. As we can see, for a shorter period, the impact of the natural rate of growth is higher than the quantity of timber logged, and this explains why the amount of forest is growing up. However, for a larger period the quantity logged will overcome the weight of the impact of natural growth and therefore the size of the forest will decrease after some turning point.

Therefore, the quantity logged, in both markets (see figure-1 for numerical simulation), in any $t \in [0,T]$ will depend on the inverse demand parameters and the natural growth rate of the forest. In the present case the total logged quantity will be (considering that $\lambda = \theta$)

$$Q(t) = \frac{\left(\overline{p}^{L} + \overline{p}^{L}\right) - 2\phi e^{r(T-t)}}{2\lambda} \qquad (6)$$

According to optimal path of the quantity for both markets, we see (please, see Figure 1 for numerical simulation) that the logged quantity will increase over time, for $t \in [0,T]$. Given the constant rate of growth, we find that, in the finite horizon specified, the stock of forest will decrease over the time.

Definition-1: The environmental benefits from the forest at any *t*, are function of the stock of forest at any $t \in [0,T]$.

The benefits from the environment depend on the stock of the forest (for instance, see AMACHER; KOSKELA; OLLIKAINEN, 2006; GREENPEACE, 2010), hence, it is intuitively appealing to assume that during all $t \in [0,T]$, the magnitude of the benefits of the forest will fluctuate according to the stock of forest at each time, and not only in $t = T$. The explanation is straightforward – the forest stock can be high for any $t \in [0,T)$ and rapidly become low in the neighborhood of $t = T$. In this case, if we analyze just the final stock we could underestimate the real benefits of the forest over the time. Hence, not to engage in such problem of underestimation or overestimation of the real "*environmental*" benefits of the forest, the best way is to calculate the total area of the forest over the period.

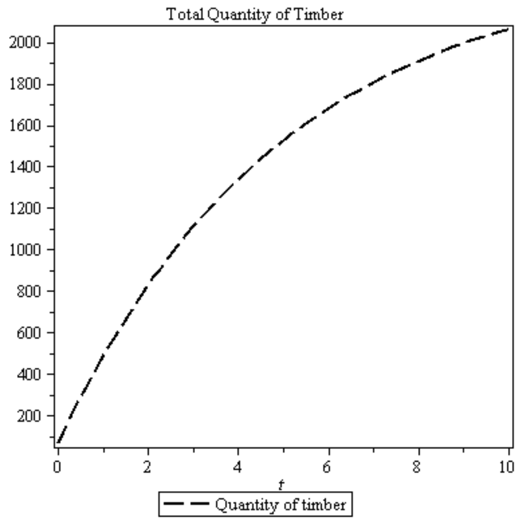

Figure 1 - Total Quantity of timber logged in both markets.

Source: Author's elaboration.

Theorem-2: The "*environmental*" benefits received from the forest, for all $t \in [0, T]$, is higher when the price is lower[10] (see also Figure 3).

Proof: see Appendix A.

Theorem-3: The split of the logged quantity of timber between the "legal" and "illegal" market will depend on the difference of price in these two markets.

Proof: see Appendix A.

This results show that if it is more profitable for the landowner to shift from the market with accreditation "legal" market to the "illegal" market, due to the higher price paid, he will do so. If $\lambda > \theta$, that means that the price in the legal market, *ceteris paribus,* is lower than in the illegal market, then the landowner will shift the production from the legal market to the illegal market.

In this simple model, we introduce the effect of "illegal" timber market in the strategies used by the landowner to maximize his profit. However, we know that in fact there may be audition for these individuals and that usually this auditing is made by internal

[10] This proof supposes that $\lambda = \theta$.

institutions of government that are responsible for environmental issues (in the case of Brazil, this auditing is made by IBAMA).

The existence of auditing by the government and the profitability of the logging activity, mainly due to the “illegal” market, may contribute to the “active” corruption. In such framework, it is important to see how corruption may influence the optimal path of deforestation over time.

In the following section we use a modified model of the earlier one to analyze this new issue: corruption.

3.6 THE EFFECTS OF CORRUPTION ON DEFORESTATION – MODEL 2[11]

To model this new scenario, we suppose, first of all, that there are three elements in the game: two active players – the landowner and the governmental official – and one passive: the government itself. The passive one is responsible for defining the roles of the game, in the present case; the government is responsible for the salary scheme, penalty function, and for the surveillance of the land; however, there is no auditing in the field of the official work. The official of the government income is only his constant salary, in each $t \in [0, T]$. Besides the official of the government, in the active side, there is the landowner, whose objective is to find the optimal way for the profit.

To model this section, we suppose that the differential game (there is just one state variable represented by a single kinematic equation) between the landowner and the official follows this structure: first, in the last stage, the official choose his control variable as way to maximize his net gain, given the strategies used by the landowner. Given the strategies used by the official, the landowner will incorporate this optimal path in his problem and choose his best strategy, i.e., amount of timber to be logged.

The information structure of the differential game used to solve this model is open-loop (or degenerate Markov equilibrium, LONG et al., 2000) equilibrium *à la* stackelberg. We suppose that the leader in this game would be the landowner and the follower would be the official of government. It is plausible to suppose this structure, considering that in this kind of

---

[11] The numerical simulations in this section follows, for some parameters, the same values found in Freyd. (2006) and Van Soest and Lensink (2000). The parameters used are

$\varphi = 5000$ $T = 5$ $\bar{p} = 50000$ $\theta = 20$ $r = 0.2$ $f_0 = 2$ $X(0) = 2000$

illegal behavior we expect that the landowner will interact with the official to see the amount of bribe to give; therefore he is the leader.

3.6.1 The Government Role

As discussed, the government is responsible for the penalty function that the landowner will face.

We assumed that the penalty function is given by

$$F(t) = f(t)Q(t)E(t) \tag{7}$$

Where $f(t)$ represents the penalty rate defined by the government (the variable of control for the government) for each $t \in [0,T]$. If we suppose that the government is a passive agent in this relationship, therefore, we must also suppose that in fact the penalty rate is constant over time. $E(t)$ represents the effort that comes from the official. Note that we suppose a linear function of the penalties and the efforts, i.e., when effort is zero the penalty to be paid by the landowner will be zero.

We supposed that there is a direct link between the effort applied by the official and the amount of penalties, because, if he (the official) does not apply effort it means that the landowner is not audited and therefore no illicit act is found. Thus, for any possible collusion between the landowner and the official, the latter must find some illicit act, and this can only be done according to the effort applied.

$$F(t) = \overline{f}Q(t)E(t) \tag{8}$$

We suppose that the penalty rate is constant over time, i.e., $f(t) = f_0$: initially the government announces its penalty policy, and this policy will remain until the final period[12]. For simplicity, we supposed that the penalty is a linear function of the quantity of timber.

Usually in many countries, as in Brazil, there is a legal limit volume for the level of depletion on state variable. For Mathematic simplicity, in the present model, we suppose that

[12] In a good sense, this is the situation in most part of the countries. For example, in Brazil each new government usually begins announcing new environment policies (and also others policies) for all legal period (five years until the next elections).

these legal limits are actually physically archived by the landowner, but he has the free will to choose to illegally deforest or not. In this case, the control variable of the landowner will be just the quantity for the illegal market, i.e., $Q(t) = q^{IL}(t)$.

3.6.2 The Role of the Governmental Official (IBAMA)

To make it simple, we supposed that the official from IBAMA wants to maximize his utility over a finite period. His utility is disjointedly given by the consumption and the cost of his work (effort).

$$U(c(t), E(t)) = c(t) - v(E(t))$$

We suppose that the consumption is linear in its arguments. We define the consumption at each $t \in [0, T]$, as $c(t) = w_0 + B(t)$, Therefore, the official from IBAMA objective is to maximize the following function

$$V^1 = \int_0^T \left[\left(w_0 + B(t) \right) - v(E) \right] dt \tag{9}$$

Where w_0 indicates the salary paid for $t \in [0, T]$, and it is constant (this assumption is true for most part of the world – public officials received a constant salary per period). However, in case of illegal deforestation, he can be bribed by the landowner and receive a non-negative amount, $B(t)$. We define the bribe paid as function of the penalty function adopted by the government.

We could make the bribe paid as function of the profit, however we are supposing that the official does not know the amount of the profit of the landowner. On the other hand, he knows the amount of fine that would be paid by the landowner, given the quantity of wood arrested/logged.

Given the discussion above, the bribe function is defined as

$$B(t) = b(t) F(t)$$

Where $b(t)$ represents the bargaining power of the official. For sake of simplicity, we suppose that the bargaining power is constant over the specified period, hence $b(t) = b_0$. Therefore, the bribe function can be stressed in the following way

$$B(t) = b_0 f_0 QE \tag{10}$$

To make feasible the game played between the landowner and the official, we defined $b_0 \in [0,1)$, that is, the bargaining power need to be less than one unity. If we had $b_0 = 1$, that would mean that the landowner would pay all the penalties to the official. Therefore, is this case it is better for him not to engage in any collusion with the official, because he would not have anything to gain. In this case, it would be rationally better for him to pay directly the penalties to the government. Given this explanation, we suppose that when $b_0 = 1$, we have "optimum state", for there is no corruption is this case.

3.6.3 Determination of the Stackelberg equilibrium[13]

To derive the equilibrium in this model, we must bear in mind that the open-loop equilibrium will in fact result in optimal time-dependent controls. Hence, the use of optimal controls is critical. First we derive the strategy for the official and after the one of the landowner. Given these strategies, the model can be solved. Given the strategy used by the leader (the landowner), and the path of his co-state variable, we can derive jointly the path of the effort chosen by the official, and the path of the forest.

The purpose of the official is to choose the level of effort to maximize his gain over a finite period of time[14].

$$\max_{\{E\}} \int_0^T \left[\left(w_0 + f_0 b_0 EQ \right) - v(E) \right] dt$$

We suppose a quadratic form for the cost function, that is $v'(.) > 0, v''(.) > 0$.

To obtain the optimal path for his control, we applied the maximum principle. Hence, for the official we have the following reduced Hamiltonian[15].

[13] Using an open-loop structure for the game demands some explanation: usually as stressed by Sethi et al. (2007) the open-loop equilibrium is time inconsistent given the interest of the leader to change his strategies at any time $t \in (0,T]$, (that is, the commitments of the players, in these games, have the same importance as in traditional static games of incomplete information). However, we suppose that the leader (landowner) can credibly pre-commit to his strategies at the beginning of the game. This approach has been applied for many works in the literature (SETHI et al., 2007).

[14] Note that if we had no bribe for the official, the maximum principle would imply that

$$2E = 0$$

Therefore, the equilibrium would be trivial, and the optimal effort chosen by the official would be zero for any $t \in [0,T]$.

$$H(.) = w_0 + f_0 b_0 QE - E^2 \tag{11}$$

From the Hamiltonian, we know that the optimal path for the official control will be

$$E = \frac{b_0 f_0 Q}{2} \tag{12}$$

Theorem-4: The effort applied by the governmental official depends, essentially, of the quantity of timber, his bargaining power, and the penalty rate applied by the government.

This result is intuitive, given that the bribe the official will receive will depend on the amount of penalties, and the latter will depend on the amount logged, the agent will apply more effort to discover the illicit act. The same analogy can be applied to the bargaining power and the rate of penalties.

As a leader the landowner will incorporate this result in his optimization problem. The purpose of landowner is to choose the quantity of timber to maximize his profit over the defined time horizon. Given the kinematic equation showed in the earlier section, we have

$$Z = \underset{\{Q(t)\}}{MAX} \int_0^T \left[R(t) - b_0 F(t)\right] dt + \varphi X(T)$$

s.a.

$$\dot{X} = -Q + rX \tag{13}$$

$$\mu(t) = \mu_0 e^{-rt} \tag{14}$$

$$\pi(T) = \frac{\partial\left[\varphi X(T)\right]}{\partial X} = \varphi \tag{15}$$

Where $\varphi X(T)$ represents our scrap value function.

The short Hamiltonian for the landowner is (see Appendix C for more information about this Hamiltonian)

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[15] We refer this Hamiltonian as a reduced form, because we did not include the co-state variable for the official. In fact, given that the state variable, from the perspective of the official, is not influenced directly by the official controls; this simplicity will not change the main results in this section. If we had added the co-state equation in his Hamiltonian, we would have

$$H(.) = w_0 + f_0 b_0 QE - E^2 + \mu(-Q + rX)$$

Applying the maximum principle, we would find that the optimal path of the co-state variable-time dependent is

$$\mu(t) = \mu_0 e^{-rt}$$

where μ_0 is the initial value of the co-state variable.

$$H(t,Q,\pi,X)=\overline{p}Q-\theta Q^2-\frac{f_0^2 b_0^2 Q^2}{2}+\pi\left[-Q+rX\right]$$

Assuming an interior and applying the maximum principles we find that

$$\overline{p}-2\theta Q-f_0^2 b_0^2 Q-\pi=0 \tag{16}$$

$$H_\pi=\dot{X}\Rightarrow\dot{X}=-Q+rX \tag{17}$$

$$\dot{\pi}=-H_X\Rightarrow\dot{\pi}+\pi r=0 \tag{18}$$

$$\mu(t)=\mu_0 e^{-rt} \tag{19}$$

From the conditions stated above, we find that

$$Q=\frac{\overline{p}-\pi}{2\theta+f_0^2 b_0^2} \tag{20}$$

The results, which are similar to other works in the field (see, for instance, FREDJ, 2006), show that the quantity of timber logged will depend positively of the market price and negatively with the shadow price of each unity of forest. For the present model, we also find that it also depends negatively of the bargaining power of the official and the penalty rate.

Theorem-5: The open-loop Stackelberg equilibrium is given by the pair of time-depend strategies.

$$Q(t)=\frac{\overline{p}-\varphi e^{r(T-t)}}{2\theta+f_0^2 b_0^2} \tag{21}$$

$$E=\frac{b_0 f_0\left[\overline{p}-\varphi e^{r(T-t)}\right]}{4\theta+2f_0^2 b_0^2} \tag{22}$$

And the optimal paths for the co-state variables are

$$\pi(t)=\varphi e^{r(T-t)}$$

$$\mu(t)=\mu_0 e^{-rt}$$

Proof: see Appendix A.

As we can see, the deforestation rate is negatively influenced by scrap value. The deforestation rate is positively influenced by the price in the timber market. However, in this new environment (the potential existence of corruption), the quantity of timber will be affected by the penalty rate and the official bargaining power. Increasing the penalty rate or the bargaining power of the official will decrease the quantity logged. These results are intuitive, given that the official have a real appraisal of the illicit act, increasing the bargaining power will increase the landowner cost, hence lowering the profit. The same analogy can be made in terms of the penalty rate – increasing the penalty rate will increase the potential cost of timber activity and therefore lower the profit of the landowner.

The penalty rate and the bargaining power affect the effort by two channels: the first one is through the direct impact on the penalties and the second channel is due the effects of these parameters in the quantity of timber. Therefore, increasing these variables has a double impact. However, if $b_0 < 1$, $f_0 < 1$ we may have an increase in the effort when these parameters are increased. However, if $f_0 > 1$ the increase of the penalty rate decreases the effort chosen, the explanation is straightforward – in this case, the negative effect of this penalty rate in the quantity of timber is bigger than the direct, positive effect, of this rate on the level of effort chosen. In our numerical simulations, we supposed that $f_0 > 1$.

Theorem-6: The presence of corruption, i.e., $b_0 < 1$, will decrease the stock of forest in the final period.

Proof: see Appendix A.

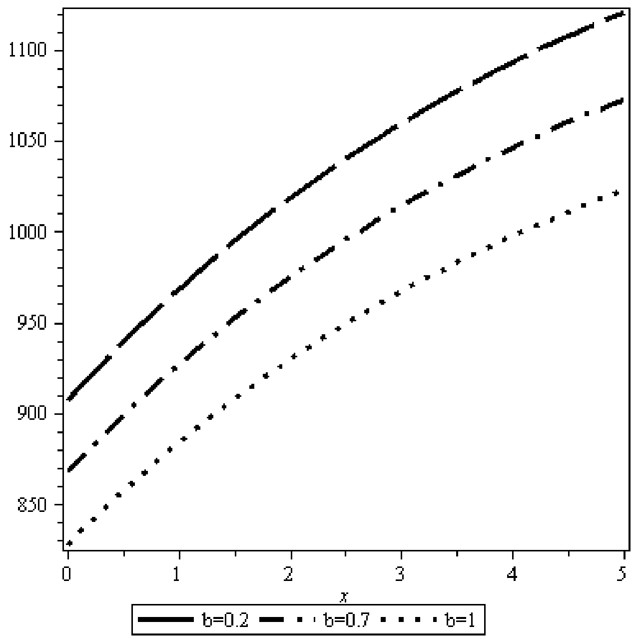

Figure 4 - Quantity of Forest Logged over period: the effect of different salary scheme

Source: Author's elaboration

As we can see, the decrease of the bargaining power of the official will increase the quantity of timber logged, and this will lead to a higher level of deforestation, i.e., the stock of forest will tend to zero in a shorter period of time.

If the bargaining power of the official is important for the final stock of forest, it will be interesting to check which variables can influence the bargaining power of the official. It is theoretically appealing to assume that one of the variables that may influence the bargaining power of the official is the salary received by the agent. Intuitively we can expect that the lower the salary received, the lower is the bargaining power of the official. The explanation is very intuitive: when the official has a low salary and finds an illicit act, the landowner can easily convince him to receive any small amount of bribe, given his salary situation – in this case, he has relatively more to lose if he does not accept the bribe. However, if we suppose that the salary is high, he has relatively little to lose by not accepting the bribe.

Theorem-7: In the presence of potential corruption, the static comparative shows that the salary scheme played by the government will determinate positively the bargaining power of the official, and indirectly (positively) the stock of forest in final period (see figure-4 for numerical simulation).

Proof: see Appendix A.

The results above show that the strategy of the government to use independent salary scheme, i.e., salary independent of output or effort, can increase the possibility of bribes, and lower salaries will decrease the bargaining game of the official, and therefore the bribes, to be paid by landowner, are less, and all this will increase the rate of deforestation. Given the increase of the rate of deforestation, the stock of forest in the terminal date will be lower.

Our results are similar to the corruption literature, in the sense that the salary scheme is a good policy that can be used to avoid the problem of corruption, and in this particular case to fight illegal deforestation.

3.7 CONCLUDING REMARKS

The existence of countries with huge forest areas and a high level of corruption seem to be the perfect environment to promote non-sustainable deforestation. Empirical evidence, in a national level, shows that countries with higher level of corruption, on average, have higher rates of deforestation. In Brazil, the attention is concentrated in the so called direct causes of deforestation, however, the Amazon forest covers the poorest regions or states in Brazil. Generally, in these states the institutions are weaker, which encourages the existence of potential corruption. Recently, through the media, it has been shown more and more cases of corruption, in which officials of IBAMA are involved.

Despite the international evidence (and the national cases of corruption) of the effect of weak institutions in the rate of deforestation, researches in Brazil did not give the proper importance to the matter. Thus, this paper is the first attempt to show how the corruption may have a positive effect in the rate of deforestation and therefore in decreasing the stock of forest.

The use of differential game is not new, however, to our best knowledge, this is the first work that tries to model it (the effect of corruption), using the methodology of differential games.

The model developed here is based on some critical assumptions used for mathematic simplicity. First, we suppose a control problem defined in a finite period of time. We suppose that the time range is relatively small, and in such case there is no need to use discounted values. Secondly, we suppose that kinematic equation is linear, therefore; without any quantity logged by the landowner, the forest would grow without limits over the years. Regarding forest stock, this approach seems to be real given that in tropical forests the possibility for natural degradation of the natural forest is very limited.

The model that we use is based on the “representative agent” fashion. However, the results are important if we suppose that a big number of similar agents may exist. Our models focus mainly on the case of Brazil; however, given that many other countries, with huge tropical forests, shares the same institutional problems, the findings in this paper can be considered for such countries.

The results from our model are consistent with the main empirical evidence that corruption increases the rate of deforestation over a certain period of time. The model shows that the salary scheme can be an important tool, for the government, to control for the potential illegal behavior.

When the governmental official receive a low salary and this salary is constant over time, independently of his effort, his bargaining power in the collusion game is lower and therefore he is more likely to receive a small amount of bribe – because in this case his potential loss, in case he rejects the bribe, is higher. Note that our models consider that the landowner knows he will be fined, however he knows he can bribe the official (given that the bribes is, generally, lower than the penalties, this ensure that he (the landowner) will always opt to bribe the government official.

Our model suggests that “*bad*” salary schemes controlled by the government and high international price for timber will constitute the worst possible scenario – in this case corruption is more likely to happen and the deforestation rate will be in the highest level. These findings help us understand why and how the salary scheme paid by the governments and the international price of timber jointly promotes higher levels of deforestation around the world. Hence, with these findings, we must advocate that the policies adopted by the governments must internally solve the agency problem, which creates a potential environment for corruption.

Finally, our model suggests that any policy adopted by the governments must include two main approaches – dealing with the “direct” and “indirect” causes of deforestation.

3.8 APPENDIX

A) Proof of the Theorems

Proof of theorem-1: supposing an interior solution, the first order condition (FOC) for this problem is:

$$\overline{p}^{IL} - 2\theta q^{IL} - \pi = 0 \quad (23)$$

$$\overline{p}^{L} - 2\lambda q^{L} - \pi = 0 \quad (24)$$

$$\dot{\pi} = -r\pi \quad (25)$$

$$\dot{X} = -\left(q^{IL} + q^{L}\right) + rX \quad (26)$$

From the co-state differential equation, and using the condition (4 a), we find that:

$$\pi(t) = \phi e^{r(T-t)} \quad (27)$$

For the first condition in q^{IL}, q^{L}, we know that the quantity of timber logged depends on the co-state variable or the shadow price of unity of forest. Substituting the co-state equation in the quantity, we find that

$$q^{IL} = \frac{\overline{p}^{IL} - \phi e^{r(T-t)}}{2\theta} \quad (28)$$

$$q^{L} = \frac{\overline{p}^{L} - \phi e^{r(T-t)}}{2\lambda} \quad (29)$$

Substituting these equations in the kinematic equation, and supposing that $\lambda = \theta$, we can obtain the time-dependent equation for the stock of forest given by

$$X(t) = \frac{4\lambda r x_0 e^{rt} + 2\left(\overline{p}^{L} + \overline{p}^{L}\right)\left(1 - e^{rt}\right) + 2\phi\left(e^{r(T+t)} - e^{r(T-t)}\right)}{4\lambda r}$$

As we can see at $t = T$, we have

$$X(T)=\frac{4\lambda r x_0 e^{rT}+2\left(\overline{p}^{L}+\overline{p}^{L}\right)\left(1-e^{rT}\right)+2\phi\left(e^{2rT}-1\right)}{4\lambda r}$$

Easily, by using static comparative, we see, by using linear approximation, that the stock of forest in the final period will depend, ceteris paribus, on price parameters and the natural rate growth of the forest.

$$\Delta X(T)\approx \Delta r\frac{\partial X(T)}{\partial r}+\Delta p^{j}\frac{\partial X(T)}{\partial p^{j}},\ j=IL,L$$

Using calculus, we can see that

$$\frac{\partial X(T)}{\partial r}=\frac{16\left(\lambda r\right)^{2}Tx_0e^{rT}+8e^{2rT}\phi\lambda\left(Tr-1\right)+8e^{rT}\lambda\left(p^{IL}+p^{L}\right)\left(Tr-1\right)+8\lambda\left(\phi-\left(p^{IL}+p^{L}\right)\right)}{16\left(\lambda r\right)^{2}}>0$$

And

$$\frac{\partial X(T)}{\partial p*}=\frac{\left(1-e^{rT}\right)}{2\lambda r}<0$$ [16]

Where $p*=p^{IL}+p^{L}$.

Hence, everything constant, the net effect in the final stock of forest will depend on the weight of each effect. That is, we have:

$$\begin{cases}\dfrac{\partial X(T)}{\partial r}\Delta r>\dfrac{\partial X(T)}{\partial p^{j}}\Delta p^{j}\rightarrow \Delta X(T)>0,\ j=IL,L\\ \dfrac{\partial X(T)}{\partial r}\Delta r<\dfrac{\partial X(T)}{\partial p^{j}}\Delta p^{j}\rightarrow \Delta X(T)<0,\ j=IL,L\end{cases}$$

Where we suppose $\Delta r>0,\Delta p*>0$.

This concludes the proof. ■

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[16] We have defined the inverse demand as $p^{IL}(t)=\overline{p^{IL}}-\theta Q(t)$ for the illegal market, and as $p^{L}(t)=\overline{p^{L}}-\lambda Q(t)$ for the legal market; therefore, the price will be affected jointly by $\overline{p^{j}}$ or the parameters λ and θ. Hence, to see the effects of price in the stock forest, we can do it by supposing the change in one of this parameters. In the present case, we are supposing the change in the intercept of the inverse demand function.

Proof of theorem-2:

By using the definition-1, and using a linear function for the benefits, $BEN(t) = X(t)$, we must derive the respective area of the forest for all period, i.e., $t \in [0, T]$.

First step: As demonstrated earlier, substituting the optimal for the controls in the kinematic equation, and integrating them, we can find the optimal path for the state variable (after some algebraic manipulation) is given by

$$X(t) = \frac{4\lambda r x_0 e^{rt} + 2\left(\overline{p}^{L} + \overline{p}^{L}\right)\left(1 - e^{rt}\right) + 2\phi\left(e^{r(T+t)} - e^{r(T-t)}\right)}{4\lambda r} \tag{30}$$

Considering that $\lambda = \theta$.

Second step[17]**:**

Let's define the following two areas in the Cartesian plan $[X \times [0, T]]$

$$d^1 = \int_0^T X(t, \overline{p^{IL}}^1, \overline{p^L}^1) dt \qquad d^2 = \int_0^T X(t, \overline{p^{IL}}^2, \overline{p^L}^2) dt \tag{31}$$

Where $\overline{p^{IL}}^1 > \overline{p^{IL}}^2$ and $\overline{p^L}^1 > \overline{p^L}^2$. That is, we suppose that the price would change to a higher level, given that the intercept will change from $\left(\overline{p^{IL}}^2, \overline{p^L}^2\right) to \left(\overline{p^{IL}}^1, \overline{p^L}^1\right)$.

Therefore, it is straightforward to show that

$$\int_0^T X(t, \overline{p^{IL}}, \overline{p^L}) dt = \frac{4x_0\lambda r(e^{rT} - 1) + \left(2rT - 2e^{rT} + 2\right)\left(\overline{p}^{IL} + \overline{p}^{L}\right) + 2\phi\left(e^{2rT} - 2e^{rT} + 1\right)}{4\lambda r^2} = \int_0^T BEN(t, \overline{p^{IL}}, \overline{p^L}) dt$$

(32)

Thus, given that $2rT + 2 < 2e^{rT}$ (defined for all $t \in [0, T]$)

We have that

[17] In this analysis, we suppose that the price in both markets will change, but this is not necessary to show the aimed results. That is, we would have the same results if we supposed that just the price of one market has changed, while the price of the other one remained constant.

$$d^2 - d^1 = \int_0^T X(t, \overline{p^{IL}}^2, \overline{p^L}^2)dt - \int_0^T X(t, \overline{p^{IL}}^1, \overline{p^L}^1)dt \tag{33}$$

$$d^2 - d^1 = \left(2rT - 2e^{rT} + 2\right)\left(\overline{p^{IL}}^2 + \overline{p^L}^2 - \overline{p^{IL}}^1 - \overline{p^L}^1\right) \tag{34}$$

Thus,

$$d^2 - d^1 > 0 \tag{35}$$

That is, an increase in the price in both markets will decrease the stock of forest for all specified time horizon. Therefore, given that the benefits at any $t \in [0,T]$ are a linear function of the stock of forest for any $t \in [0,T]$, we conclude that a lower level of price means a higher stock of forest at any $t \in [0,T]$, and consequently a higher level of "environmental" benefits at any $t \in [0,T]$. This concludes the proof. ■

Proof of Theorem-3: This can be obtained easily by computing the differences between the obtained logging function, that is $q(t)^{IL} - q(t)^L$, we find that

$$q(t)^{IL} - q(t)^L = \frac{\left(\overline{p}* - \Omega\right)(\lambda - \theta)}{2\lambda\theta} \begin{matrix} < \\ - \\ > \end{matrix} 0 \tag{36}$$

Where $\overline{p}^{IL} = \overline{p}^L$, $\Omega = \phi e^{r(T-t)}$.

The results will depend on the signal of the numerator, and therefore of the signal of $(\lambda - \theta)$. If $\left(\overline{p}* - \Omega\right) > 0$ (this is satisfied for small $t \in [0,T]$ or large $\overline{p}*$ and small ϕ hence the signal of $q(t)^{IL} - q(t)^L$ will the signal of $(\lambda - \theta)$, thus we have the following cases

$$\begin{cases} q(t)^{IL} - q(t)^L > 0 & if\, \lambda > \theta \\ q(t)^{IL} - q(t)^L < 0 & if\, \lambda < \theta \end{cases} \tag{37}$$

Hence, the proof is completed. ■

Proof of Theorem-5: using condition (18) and integrating it, we find $\pi(t)$, and replacing it in the condition (16) we find $Q(t)$. Finally, we can obtain $E(t)$ by substituting the last one in equation (12). ■

Proof of Theorem-6:

From the results of the co-state variable from the landowner, the optimal path for the quantity of timber, we can derive the forest stock equation

$$X(t)=\frac{2r\Delta x_0 e^{rt}+2\overline{p}\left(1-e^{rt}\right)+\varphi\left(e^{r(T+t)}-e^{r(T-t)}\right)}{2r\Delta} \quad (38)$$

Where $\Delta=2\theta+f_0^2 b_0^2$

In the final period, $t=T$, we find that

$$X(T)=\frac{2r\Delta x_0 e^{rT}+2\overline{p}\left(1-e^{rT}\right)+\varphi\left(e^{2rT}-1\right)}{2r\Delta} \quad (39)$$

Hence, after some algebraic manipulation, we have that

$$\frac{\partial X(T)}{\partial b_0}=\frac{-\left[2\overline{p}\left(1-e^{rT}\right)+\varphi\left(e^{2rT}-1\right)\right]\bullet 4rf_0^2 b_0}{\left[2r\Delta\right]^2}$$

Since we must have $Q(t)\geq 0, \forall t\in\left[0,T\right]$

The condition that guarantees this is $\frac{\overline{p}}{\varphi}>e^{rT}$

Therefore,

$$2\overline{p}\left(1-e^{rT}\right)+\varphi\left(e^{2rT}-1\right)<0, \forall t\in\left[0,T\right]$$

Thus,

$$\frac{\partial X(T)}{\partial b_0}>0$$

Hence, for two cases, namely $b_0<1$, and $b_0=1$, we have

$$X(T,b_0<1)-X(T,b_0=1)=\frac{\chi\left(f_0^2-f_0^2 b_0^2\right)}{\Gamma}<0 \quad (40)$$

Where $\Gamma=2r\Delta\left(2\theta+f_0^2\right)$ and $\chi=2\overline{p}\left(1-e^{rT}\right)+\varphi\left(e^{2rT}-1\right)$.

This concludes the demonstrations. ■

Proof of Theorem-7 (see Figure 4 for numerical simulation):

The current case is a subcase of the previous one; therefore, the proof follows the previous one. We investigate the forest stock in two different salary schemes: w_1 and w_2, where $w_1 > w_2$; hence $b_1(w_1) > b_2(w_2)$ because we are supposing a linear bargaining function, i.e., $b_i = \sigma(w), and \sigma_w > 0, \sigma_{ww} = 0$.

By using calculus, we generically can derive the impact. We would have

$$\frac{\partial X(T)}{\partial w} = \frac{\partial X(T)}{\partial b} \bullet \frac{\partial b}{\partial w} = \frac{-2\left[\overline{p}\left(1-e^{rT}\right)+\varphi\left(e^{2rT}-1\right)\right] \bullet 4rf_0^2 b_0)\sigma_w(.)}{\left[2r\Delta\right]^2} > 0$$

For the two cases above, we would have

$$X(T,b_1) - X(T,b_2) = \frac{\Upsilon\left(f_0^2 b_2^2 - f_0^2 b_1^2\right)}{\Psi} > 0 \tag{41}$$

Where $\Psi = 2r\Delta_1\Delta_2$ and $\Upsilon = 2\overline{p}\left(1-e^{rT}\right)+\varphi\left(e^{2rT}-1\right)$, $\Delta_1 = 2\theta + f_0^2 b_1^2$ $\Delta_1 = 2\theta + f_0^2 b_2^2$.

Since $2\overline{p}\left(1-e^{rT}\right)+\varphi\left(e^{2rT}-1\right) < 0$. Hence, the proof is completed. ■

B) Deriving the stock forest equation

To derive the equation, first of all we investigate the kinematic equation, which is given by

$$\dot{X} = -\left(\overline{q}^{L} + \overline{q}^{IL}\right) + rX$$

Where $\overline{q}^{IL} = \dfrac{\overline{p}^{IL} - \phi e^{r(T-t)}}{2\theta}$ and $\overline{q}^{L} = \dfrac{\overline{p}^{L} - \phi e^{r(T-t)}}{2\lambda}$

Note that $\phi e^{r(T-t)}$ represents the solution for the co-state variable in the equation (25) we may see that

$$\dot{\pi} + r\pi = 0$$

Hence, the solution to this first order differential equation is given by

$$\pi(t) = e^{-\int rdt}\left[A\right] \tag{42}$$

Where A is a constant. Using the condition (4 a), we can easily find the solution expressed in equation (27).

Using (28) and (29), and replacing them in the kinematic equation (26), we obtain

$$\dot{X} - rX = -\left(\frac{\overline{p}^{IL} - \phi e^{r(T-t)}}{2\theta} + \frac{\overline{p}^{L} - \phi e^{r(T-t)}}{2\lambda}\right) \tag{43}$$

Hence, the solution for the stock of forest is given by

$$X(t) = e^{\int rdt}\left[B - \int\left(\frac{\overline{p}^{IL} - \phi e^{r(T-t)}}{2\theta} + \frac{\overline{p}^{L} - \phi e^{r(T-t)}}{2\lambda}\right)e^{-\int rdt}dt\right] \tag{44}$$

Using the method of integral by substitution and the condition (4 b), and supposing that $\lambda = \theta$, after some algebraic manipulation, we obtain the equation (30).

Note that to obtain the equation (38) we used the same methodologies, given that they are similar, there is no need to present it here.

C) Deriving the conditions for landowner Hamiltonian

In the text we present a short version of the Hamiltonian when we analyzed the optimal problem for the landowner. However, the open-loop Stackelberg equilibrium requires us to introduce, in the leader problem, a co-state variable for the co-state variable of the follower, thus, in this case, the landowner Hamiltonian should be

$$H(t, Q, \pi, X) = \overline{p}Q - \theta Q^2 - \frac{f_0^2 b_0^2 Q^2}{2} + \pi\left[-Q + rX\right] + \gamma\left[-\mu r\right] \tag{45}$$

Where γ represents the co-state variable of the landowner related to the co-state variable of the follower. Given this expanded Hamiltonian, the maximum principles are

$$\bar{p} - 2\theta Q - f_0^2 b_0^2 Q - \pi = 0 \tag{46}$$

$$H_\pi = \dot{X} \Rightarrow \dot{X} = -Q + rX \tag{47}$$

$$\dot{\pi} = -H_X \Rightarrow \dot{\pi} + \pi r = 0 \tag{48}$$

$$H_\gamma = \dot{\mu} \Rightarrow \dot{\mu} = -r\mu \tag{49}$$

$$\dot{\gamma} = -H_\mu \Rightarrow \dot{\gamma} - r\gamma = 0 \tag{50}$$

Note that for the current model, since there are no direct effects of the optimal response of the follower in the forest kinematic equation, the inclusion of the condition (49) and (50) has no effects on the optimal path for the quantity of timber or the co-state variable of the forest landowner. Hence, we omitted in the text.

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4 DEFORESTATION, ECONOMIC GROWTH AND CORRUPTION AT REGIONAL AND INTERNATIONAL LEVEL: AN EMPIRICAL ANALYSIS THROUGH NON-PARAMETRIC MODELS

4.1 INTRODUCTION

Recently, the global warming has been a discussed issue in the international scenario. Between the discussed issues, the necessary policies to control the problem have been the focus of such discussion. According to data, one of the main cause of the global warming is pollution and the fire caused by deforestation (FOOD AND AGRICULTURE ORGANIZATION, 2008).

The deforestation is the main cause for the losses of the forest around the world. According to Food and Agriculture Organization (2008) until the twenty century the world had lost 40% percentage of its size (FOOD AND AGRICULTURE ORGANIZATION[1] (2001); BRYANT et al.,[2] 1997 apud KOYUNEN; YILMAZ, 2009). The international focus in the matter has provided a great field of investigations. In the last two decade a lot of empirical and theoretical works has been developed by researchers in this area.

As a consequence of the worldwide concerns, there is a lot of work that analyzes the causes and consequences of deforestation. Usually there are two groups of causes, namely, the direct causes and the indirect ones. Related with the direct causes generally are included wood's price (YOUNG, 1998), economic growth (KOYUNEN; YILMAZ, 2009), population growth (CROPPER; GRIFFITHS, 1994), construction of social infrastructure, e.g., roads, bridge, (YOUNG, 1998) etc. However, one of the principal causes of deforestation is the agriculture activities (DAMANIA et al., 2005; RIVERO et al., 2009).

Despite the great research related with the direct causes, less attention has been given to the indirect causes of deforestation. The group of indirect causes includes weak institutions, democracy, political instability, corruption, etc. Empirical evidence has shown that there is a huge impact of these variables in the level of deforestation; see for instance Leitão (2010).

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[1] FOOD AND AGRICULTURE ORGANIZATION. **Global forest resources assessment**. Rome: FAO, 2001. (FAO Forestry Paper, n. 140).

[2] BRYANT, D. et al. **The last frontier forests: ecosystems and economies on the edge**. Washington D.C.: World Resource Institute, 1997.

The existence of higher level of corruption and/or weak institutions constitutes a good environment for higher level of deforestation. There are a lot of cases around the world that shows the effect of the corruption or lack of governance in the deforestation. Damania et al. (2007) presents some of these cases in many countries. For instance the case of Indonesia seems to be a typical case. Given the structure organized by the last government of Suharto, the country lost a huge part of their tropical forest. Studies have shown that corruption was the main cause of such environmental disaster (PALMER, 2003).

Aside from Indonesia, Brazil is another country that has been suffering with high level of deforestation. The Amazon region has lost several amount of forest during the years. Within the Brazilian states Mato-grosso, is the one with the highest deforestation rate (National institute of spatial research (INSTITUTO NACIONAL DE PESQUISA ESPACIAL, 2010). On this concern, many empirical works has been developed in Brazil in recent decades. However, these studies have focused their analysis in the direct causes of deforestation. Rivero et al. (2009) used data from the National Institute for Spatial Research (INPE), and analyzed the effects of direct variables. They used a sample of 782 municipalities and performed a panel data estimations for the period 2000-2006 and found out that agriculture is the principal cause for deforestation.

Prates and Serra (2009) analyzed the effects of the government policies in the state of Pará. Using a panel of 211 municipalities, they applied panel fixed effects estimations for the period 2002-2004. They found the some direct causes of deforestation were not statistically significant, namely GDP and agriculture. However, some variables were significant, such as rural credit, population, etc. Diniz et al. (2009) analyzed through a dynamic panel, the causality between the deforestation and agriculture. They found a bi-directional relationship between deforestation and these variables. Silva (2009) analyzed, through the methodology of panel data, the impact of many direct causes in the deforestation. He used data from 783 municipalities from the period 2002-2007. He found a great correlation between deforestation and wood’s price, rural credit, meat price, etc. He tested the influence of the quantity of IBAMA officials and the level of penalties. He found a statistical significance for these variables.

Beyond the Brazilian research of the deforestation, there is a lot of international empirical study on environmental quality. Pollution is the variable that has been receiving an extensive analysis, see for instance Leitão (2010) and Pellegrini and Gerlaghe (2006a).

The present paper aims to analyze the indirect cause of deforestation. We suppose that despite the direct impact of the variables cited above, there is an important indirect cause of deforestation that leads to higher rate of deforestation. This variable is corruption. The link between corruption and deforestation is already investigated in the international scenario, but there are no such empirical studies in the Brazilian literature. Given that the Amazon forest is one of the most important natural resource in the world, it seems important to study such potential relationship. Hence, the present work aims to partly fulfill this gap.

Beyond testing the effectiveness of the impact of the corruption in the level, we tested the existence of the Kuznets curve for the Brazilian municipalities. We analyzed what we call modified Kuznets curve. We call it modified Kuznets curve, because we used for such model the economic growth rate as the independent variable, instead of using the gross domestic product (GDP) *per capita* which is commonly used in the literature, see for instance Silva (2009). The Kuznets environment curve is based in the original idea from the work of Kuznets (1955) which argued that the inequality is related with economic growth in a nonlinear way: for initial stage of development, higher economic growth leads to the increase inequality, but after some turning point this relationship changes. After this turning point, in a higher level of development the inequality should decrease with economic growth.

The environmental Kuznets curve is based in the original inequality Kuznets curve. For initial level of development or economic growth, there is a big pressure on the natural resource, and this pressure imposes several environmental losses. However after some turning point, at a higher development level, the pressure in the natural resource becomes lower and the relationship between economic growth and the deforestation changes. There is a lot of empirical work which analyses the existence or not of the environmental Kuznets curve, see for instance Ehrhardt-Martinez et al (2002), Millimet, List and Stengos (2003), Taskin and Zaim (2000), Zapata, Paudel and Moss (2008), and others. Our aim here limits our analysis in the empirical test for the Kuznets curve. Hence, for more theoretical analysis on the environment Kuznets curve readers are encouraged to read Barbier (1997). Dinda (2004) also introduce an excellent survey on the issue.

Another difference between this paper and the Brazilian literature on the matter, is the empirical methodology used. At best of our knowledge this is the first study in the referred literature that uses nonparametric methods to study such issue. Normally parametric approach is used in these empirical studies. However, the parametric approach is weak when the real relationship is not known. In such situation, nonparametric approach is the best approach (HAYFIELD; RACINE, 2007).

Beyond the regional analysis, this work also aims to perform an international analysis. The main contribution to the current international literature is focused on the use of nonparametric estimations to test for the impact of economic development in the deforestation rate (Kuznets curve) with more recent data (2004-2008).

The results from this empirical study can be grouped in two different sets: first for the regional analysis and second the international findings. For regional analysis we used a polled cross-section of 538 municipalities over the nine Amazon states in 2004. We found no evidence for the Kuznets curve (i.e., in an original sense), however there is evidence of the existence of the modified Kuznets curve (the one which uses the economic growth rate as an independent variable), using the corruption as independent variable, our estimates shows no evidence of the impact of the corruption in the deforestation rate.

Given the natural difference in these states, we must control for others differences. therefore, we decided to look at the two states with the highest deforestation for the period 2003-2005 - Mato-grosso and Pará. We decreased our sample from 45 to 25 municipalities given the restriction in the reports from CGU. Our results argued for a zero impact of the corruption in the deforestation rate, however, we tested the level of deforestation as a dependent variable, and we found a nonzero impact of the corruption in the deforestation (measured in km2).

For the international analysis we used for the years 2004 and 2008, a panel of 45 countries. We tested through kernel estimators the existence of the Kuznets curve. Our findings based in our data, argued for the existence of the Kuznets curve. Beyond this introduction, the present work is organized as follows: in the second section we present a literature that deals with the impact of the corruption in the environment degradation. In the third and fourth section, we present the empirical strategies and the strategy for the regional analysis. The section 5 presents the results for the regional analysis. In the sixth section is presented the general overview on the international analysis. The section 7 presents the results for the international analysis. Finally, final remarks are presented in the section 8.

4.2 BRIEF REVIEW OF THE LITERATURE: The Corruption Effects

The studies on the effects of corruption on the deforestation are not new, even though, their relationship is complex (SHANDRA et al., 2011).

Corruption may affect the level of corruption in several ways, for instance, due the weak institutions, entrepreneurs and companies may bribe the government officials to disregard the environmental crimes (FREDRIKSSON; SVENSSON, 2002; KOYUNEN; YILMAZ, 2009). Therefore, corruption seems to be one of the primaries component causes of the so called resource curse (DAMETTE; DELACOTE, 2009).

The existence of countries with higher stock of natural resources and weak institutions, increases corruption and decreases the economic growth. In these cases, the corruption may take two form, patronage and rent-seeking (KOLSTAD; SOREIDE, 2009). It is important to note that corruption, as a general definition of an illicit act or the use of the public source for private gain - may have different origins, which depends of the sector being investigated. Thus, it is important to know that, the factor that leads to the existence of corruption in the forest sector is, in general, different from others sectors (KISHOR; DAMANIA, 2007).

A number of empirical studies were done in recent years analyzing the effects of the corruption in the deforestation. In general, these works highlights the positive effects of corruption in the deforestation. In the following lines we briefly summarized some of these works; Umemiya et al. (2010) made a simply analysis about the effects of good governance in the deforestation. They found that increased quality of governance is related with lower level of deforestation.

Damania et al. (2005) analyzed the effects of corruption and the terms of trade in the land's conversion (deforestation). Using the panel methodology for the period of 1960-1999, they found a positive relationship between deforestation and these variables.

Leitão (2010) analyzed the effects of corruption in the Kuznets curve. She used as dependent variable the quantity of Sulfur. It was used a panel for the period of 1981-2000. Using the International Country Risk Guide (ICRG) as proxy for the measure of corruption, she tested the effect of corruption in the turning point of the Kuznets curve. Her results showed the existence of the Kuznets curve for Sulfur, and also the turning point of the Kuznets curve is positively impacted by the index of corruption.

Koyunen and Yilmaz (2009) analyzed, through a sample of 100 countries, the effects of many different index of corruption, namely: corruption perception index (CPI), international country risk guide, etc, on the level of deforestation. Their results showed that this impact has a statistically significance, and it is robust for several others controls.

Pellegrini and Gerlagh (2006b) analyzed the effects of the entrance of new countries from the Eastern part of Europe, in the environmental control. Using cross-section data, they found a positive impact of corruption in the environmental policies control. These impacts are statistically robust even with introduction of others covariates.

The impact of corruption in the environmental quality is well known. However, this international evidence is based on international data. This approach, have two drawbacks. First, these data are not necessarily homogenous, since they are based in subjective measures. Second, these international perspectives don't allow for regional analysis. Given that it's based in aggregated corruption index for each country, it is impossible to have, through these data, a more realistic and detailed overview of its impact at micro level. This is especially true when we take a look at bigger countries such as Brazil or Indonesia. Hence, jointly with the international approach, it is important to analyze the heterogeneity of the effect of corruption at lower level and if possible to use a non-subjective measure of corruption.

In the next section we present a detailed script about our strategy to perform such analysis on the impact of corruption in the deforestation. Also, we outline the strategy for the international analysis.

4.3 THE EMPIRICAL STRATEGY: AN OVERVIEW

In the empirical literature on corruption normally it is used international measure of corruption. The measurement of corruption is something that's difficult to be done, because it represents illicit acts, and therefore, quite impossible to be analyzed in a solid bases. To overcome these problems, many corruption indexes have been developed by many international institutions around the world, namely: Business Intelligence (BI), Corruption Perception Index (CI), and International Country Risky Guide (ICRG).

These indexes have been widely used in the international research on corruption (see for instance KOYUNEN; YILMAZ, 2009). However, they represent national estimation of corruption, and in general, subjective measure of corruption, and therefore useless for a regional analysis for any country.

To proceed to the analysis between the deforestation in the Brazilian municipalities and corruption, we needed go deeper in the corruption analysis. Thus, for the present paper, we developed our own corruption index based in an objective measure.

In Brazil, literature on corruption has been focused in the use of data from *Controladoria Geral da União* (CGU) to construct indexes of corruption. Since 2003, the federal government implemented the CGU as a tool to investigate the ways that the money transferred from the federal government is used within the municipalities and states.

Each year various municipalities in each state are taken from a random sample calculated through the methodologies used in the lotteries produced by the federal bank *Caixa Económica*. The municipalities included in the sample have at most 500 thousand habitants. For those municipalities with no more than 20 thousand habitants, the investigation includes all the resources transferred, and for those between 20 and 500 thousand, the resources investigated are linked with education, social assistance, and health sector (SODRÉ; ALVES, 2010).

In recent years, many empirical studies on corruption (at regional level: municipalities and states), have used these data to construct index of corruption at municipal or regional level: Sodré and Alves (2010) analyzed the effect of the relationship between corruption and the amendments to the Brazilian Federal Budget. Ramos, Souza and Fernandes (2008) analyzed, through a *Poisson* regression, the causes of corruption at municipal level using data from CGU. They used the number of irregularities as a proxy to the level of corruption. Peixoto et al. (2009) analyzed the effects of decentralization on corruption. They used data from CGU, at the municipal level, to test their hypotheses. Mendes (2004) analyzed, using data from CGU, the irregularities related with the grants released by the federal government.

As claimed earlier in this manuscript, different sectors in the economy may have different source for the corruption, i.e., they may provide different incentive for corruption. However, given the inexistence of any available data about corruption for each sector, we were forced to follow others work in the area, that is, we used the data from CGU to construct our corruption index.

The data used in this study is divided in two parts: first, for the regional analysis, and second for the international analysis.

4.4 REGIONAL ANALYSIS

As highlighted earlier, to perform the regional empirical analysis, we constructed the corruption based in the CGU’s reports (published on-line). The deforestation rate was obtained through the National Institute for Spatial Research (INPE) web site. Some extra explanation about the data used, are detailed in the next sub-section.

Regional Delimitation

First, in our empirical model, we used data from municipalities from all the states in the legal Amazon. However, to incorporate the corruption in the empirical model, we choose to analyze the municipalities from Mato-grosso and Pará. The reason for choosing the Mato-grosso and Pará municipalities, are in twofold. First, in the period 2003-2005, these two states presented one of the highest rates of deforestation in the history of Brazil, therefore, it is a good region to test our theoretical insight about the effects of corruption on deforestation. Second, the analysis within states, gives us great advantage, because some characteristic are naturally controlled, e.g., timber price, meat price, cultural issues, legal issues, etc. That is, we are supposing that if we control these variables we can perform an empirical analysis only about the effects of corruption, GDP, and GDP rate on the deforestation. Given the lack of credible data to measure all these variables, we opted to use this approach.

Corruption Index

To analyze the effects of corruption we construct the index of corruption, based on the reports from the CGU delivered in 2004. The index is constructed as follow: first, we made a deep analysis of the reports, and analyzed the number of irregularities for each state and municipalities. The reports from CGU refer to the irregularities found in different Ministries, e.g., Ministry of Education, Ministry of Environment, Ministry of Justice, etc. To construct our corruption index, we focused in the regularities found in the Ministry of Education. However, to control the over-representation of bigger municipalities, we used the number of auditing as a weight[3].

The reports have information about irregularities and a percentage of these irregularities, in fact, are administrative problems. Hence, the construction of the corruption index is sensible to the definition of what constitutes corruption and what is considered just administrative failures. However, based in international evidence, one of the main consequences of the corruption, in regions with weak institutions, is the loss of the government's efficiency. Therefore, empirical results have shown that there is a huge and positive relationship between corruption and government's inefficiency, see for instance Yeh and Vaughn Jr. (2007), and Kumar (2009). Following these results and some others work in

[3] We used the data from the Ministry of education, because it was one of the few ministries that appear in all the CGU's reports.

the field (see for instance RAMOS; SOUZA; FERNANDES, 2008), we defined corruption as any irregularities found in the reports, regardless of its provenience.

Gross Domestic Income (GDP)

The data on the GDP for each municipality were collected in the Ipeadata. The values are adjusted at the 2000's price. To obtain the GDP per capita we used the information about the resident population. All these information were collected in the Ipeadata.

Deforestation

We used the data delivered by INPE. It provides annual data for each state and municipalities of the legal Amazon. To see the relationship between corruption and deforestation, we used the pooling of data from 2004 for different municipalities. We performed this analysis in such way because the limitation of the reports delivered by CGU, and also, because of the peak of deforestation in these years. It is important to note that we used both: deforestation rate and deforestation level (measured in km^2).

The Empirical strategy

To perform our empirical analysis, we used smoothing spline, and for multivariate model we used additive model. The use of additive model is based in the use of penalized spline regression. Spline constitutes a polynomial function that is calculated by at different ranges for a given covariate. Suppose that we want to estimate nonparametricaly the following relationship

$$y = f(x) + \varepsilon_i \tag{1}$$

Where we suppose that $\varepsilon_i \sim N(0, \sigma^2)$ and *f(x)* is the function to be estimated. Let´s suppose that the covariate *x* is continuous and belong to some compact metric set in the real line. Therefore we can split the components of the covariate x in different subsets of data (or bins). The maximum value assumed by the covariate x in each subset is called knot. spline regression uses these data to perform in each subset polynomial or linear regression.

Suppose the function in equation (1), and that there is just one knot at c_0. The representation for a linear basis would be (see KELLE, 2008).

$$B_L(X) = \begin{cases} c_0 - x & \text{if } x \le c_0 \\ 0 & \text{otherwise} \end{cases}$$

and

$$B_R(X) = \begin{cases} x - c_0 & \text{if } x \ge c_0 \\ 0 & \text{otherwise} \end{cases}$$

Given those new rows, a new matrix of covariates X is created with new dimension. Given that the splines are fitted by least square, by using this new matrix is easy to find the fitted spline (see WOOD, 2007), which predict values are given by

$$\hat{y} = Hy$$

Where H is the *hat* matrix given by

$$H = \left(X^T X \right)^{-1} X^T$$

Note that given that to join the regression in each note would imply in many kinks in the fitted spline. Therefore, the estimations (which the least square is used) of the spline should be made under some conditions. The continuity and differentiability in the knots are two special conditions that must be fulfilled. That’s why, instead of using linear regression, the cubic spline is the most used in applied setting.

Even though the use of the spline regression is based in the application of ordinary least square, there is many criticism because we can have an overfitting given an excess of parameters. This is the same problem that we have in parametric modeling when we use R^2 (increasing the number of parameters, i.e, number of variables, increases R^2). This is the reason that the R^2-ajdusted is the better to be used. The same problem we can have when we use the regression spline, and the result should induce a wrong local non-linear relationship between the variables. Given the criticism about the overfitting obtained by the standard splines, it was developed the penalized regression spline or smoothing spline (SS) (see WOOD, 2006). The spline regression is constructed by the minimizing of the following expression

$$SS(\lambda) = \min \left\{ \left\| y - f(x) \right\| + \lambda \int_{\min_x}^{\max_x} \left[f''(x) \right]^2 dx \right\} \tag{2}$$

In this approach the fitted model is less sensible to the choice of the number of the knots and how they are distributed (WOOD, 2006). In the present case the key variable to control the smoothness of the fit is the parameter λ. This spline is called penalized regression spline (or *smoothing spline*), because of the second term in the equation above. The second derivation of the function measure how smooth is the curve or in other words the curvature of any function (larger value means high curvature). The integral sign represents the sum of such measure in all domains.

The penalty parameter controls the shape of the smoothness of the curve. Hence, in the present approach there is tradeoff between the good fit and the smoothness of the estimates. Therefore, there a is tradeoff between the bias of the fitted model, and the variance. Hence, the choice of this parameter is crucial for the estimates. For standard spline or smoothing spline we can use the same procedure used for local linear model for inference statistics. Hence, we can we use F-test or LR-test to perform hypotheses test. Also we can use standard errors to construct confidence interval for the estimated function.

The choice of the parameters to be used can be manually. In this case we could choose the one that better fits the model. However, in the literature, the choice of the parameter is closely related with the choice of the *bandwidth* in the Kernel regression. Hence, the use of general cross-validation (GCV) is normally used for such choice. Note that the GCV is a refinement of the ordinary cross validation. The cross validation mark results from leaving out one data each time, and fitting the model. This procedure should be performed considering all the data. Each time is calculated the squared difference between the fitting and y_i. Hence we have

$$CV(\lambda) = \frac{\sum_{i=1}^{n} \left[y_i - \hat{f}_\lambda(x_{-1}) \right]^2}{n}$$

One also can used the GCV, in such case we would have.

$$GCV(\lambda) = \frac{\sum_{i=1}^{n} \left[y_i - \hat{f}_\lambda(x_i) \right]^2}{\left[1 - n^{-1} tr(S) \right]^2} \tag{3}$$

Where S is the generalized *hat* matrix (see Ruppert, Wand and Carrol, 2003, apud Kelle (2008) for more details), given by.

$$S_\lambda = X \left(X^T X + \lambda^{2p} D \right)^{-1} X^T \tag{4}$$

Where the matrix D have the following form Kelle (2008):

$$D = \begin{bmatrix} 0_{2\times 2} & 0_{2\times k} \\ 0_{k\times 2} & I_{k\times k} \end{bmatrix}$$

Where k denotes the number of knots used.

Given the fitted spline, hypotheses test can be constructed to compare different types of spline basis or between a penalized spline regression and any other estimation method. The usual test used to compare smoothing spline and others type of fits is the F-test or the use of the AIC criterion (see WOOD, 2006; KELLE, 2008). Given the great use of the smoothing spline in the applied setting, a lot of software's package has been developed to cover such nonparametric methods. The package developed by Wood (2006), *mgcv*, is an example of such resources. The great advantage of such package is that confidence interval (CI) can be plotted together with the fitted model. However, other type proceeding can be chosen, namely, the standard CI or bootstrap percentile CI (FOX, 2002).[4]

So far we have analyzed methods to deal with simple regression, i.e., just one independent covariate. However, given the *dimensional curse*, is quite complicated to run jointly regression with more than two covariate (we lose a lot of interpretability of the result of the fitting). That would demand large sample (see WOOD, 2006; KELLE, 2008). One of the ways to solve this problem is to use the additive assumption. Suppose the case of two covariates, the additive assumption requires that instead of fitting the following model

$$y = f(x_1, x_2) + \varepsilon \tag{5}$$

We should estimate

$$y = f_1(x_1) + f_2(x_2) + \varepsilon \tag{6}$$

This approach solves the problem of *dimensional curse*, because we transformed the problem of multiple regressions in a case of estimation of many uni-dimensional functions.

Given that each function is estimated considering the covariance of the others covariates in the model, the function may be seen as the partial effects of each variable in the dependent variable holding the others covariates constant. Therefore, the interpretation follows the common one in parametric models.

Despite the great advantage of the additive models, they are not able to estimate when there is a discrete covariate. The natural generalization of the additive model is the

[4] Some software don't have such procedure, therefore, in that case some programming is required.

semiparametric regression (see YATCHEW, 2003 for general analysis). There is a list of different methods to fit these models. The most famous and used is the *backfiting* first introduced by Hastie and Tibshirani (1990). A detailed description about this method can also be found in Yatchew (2003). We used the iterated reweighted least square algorithm developed by Wood (2006). One of the main advantage of this method is that one can incorporate the automatic smoothing technics in the algorithm. A detailed analysis about this algorithm can be found in Wood (2006).

For the present paper, to investigate the existence of the Kuznet curve in the Amazon forest, we used spline by applying the package developed by Wood (2006), namely the package MGCV. The results are presented in the following figures.

4.5 RESULTS

The first results from our study rely on the existence or not of the environmental Kuznets curve. We used data from 538 municipalities in the Amazon region.

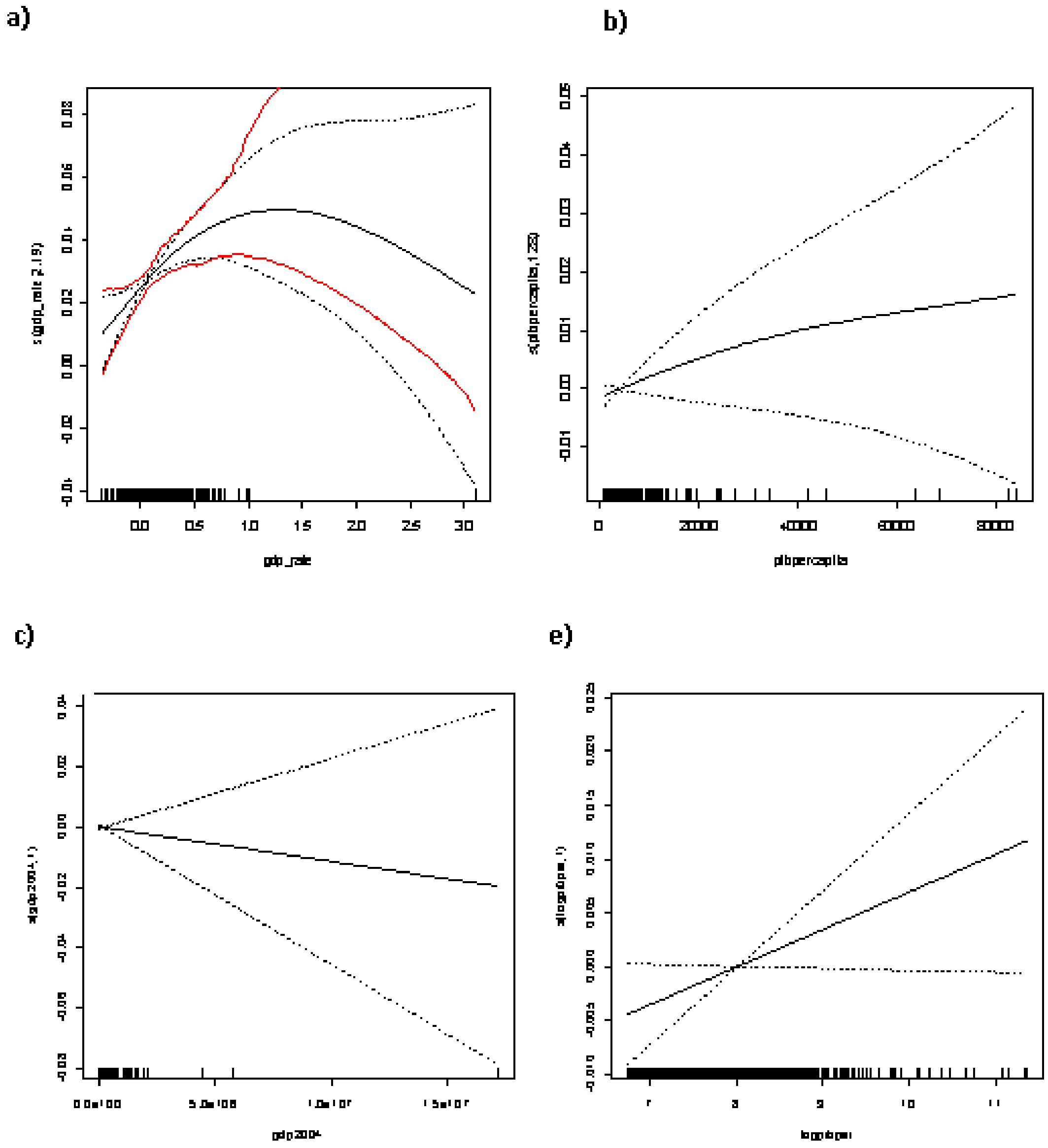

Figure 1 – Kuznets Curve

Source: Author's elaboration.

Note: Estimated effects on the deforestation rate given: (a) the GDP growth rate, (b) GDP per capita, (c) GDP at 2004, and (c) log of GDP per capita. The solid curve represents the estimated nonparametric functions and 95% pointwise confidence intervals respectively. Each model was estimated by using singular covariate. We added 95% bootstrap percentile confidence interval for the first covariate (we used 1000 bootstrap's replication (red curves)). We used, for each estimation penalized cubic splines.

The estimations above shows the only variable with statistically significant effects on the deforestation rate is the GDP growth rate. The estimated confidence intervals shows that in the case (a) the zero line is not included in the all range meaning that there is statistically effect on the deforestation rate. However, analyzing the others figures, we realized that the zero line is all included in the confidence interval, which shows the zero effects of these variables in the deforestation rate. The following table summarizes the approximated significance test for each model.

Table 1 - Statistic significance of the estimated functions

Estimated function	F-statistic	p-value
$f(GDPRate)$	5.466	0.0016***
$f(GDP2004)$	1.066	0.302
$f(GDPpercapita)$	0.287	0.592
$f(\log GDPpercapita)$	0.573	0.445

Source: Author's calculations.

Note:*** Significant at 1%. n=538.

Given the results above, if the Kuznets curve is tested by using the either GDP, log GDP per capita, or GDP per capita we would say that, with this sample of municipalities in 2004, there was no evidence for Kuznets curve. The use of GDP per capita (and its refinements, e.g., growth rate of GDP per capita, log of GDP per capita) as a proxy for the level of the development is normally argued in studies of Kuznets curve (even in the literature on the inequality Kuznets curve). However, given the results above we argued that, explaining the deforestation, not only the level of GDP may be important but the intensity of such growth may have a deeper effect on the deforestation level.

After the testing for the Kuznets curve to the municipalities, we proceed to test the effects of corruption in the deforestation rate. We used data from the nine states, namely, Pará, Mato grosso, Acre, Amapá, Amazonas, Tocantins, Maranhão, Roraima, and Rondônia. With all these states we got a sample of 42 data point in our sample.

The results of our smoothing spline model are presented below.

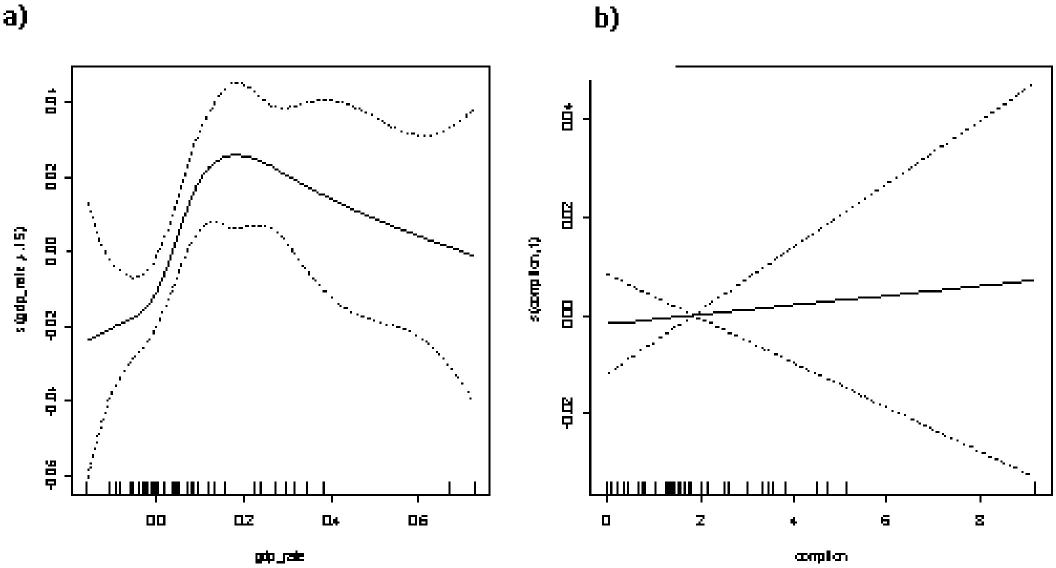

Figure 2 – GDP, corruption, and deforestation rate.

Source: Auhor’s elaboration.
Note: Penalized cubic Estimates on the deforestation rate given, (a) the GDP growth rate, (b) corruption index. The solid curves and the dashed one, represents the estimated nonparametric functions and 95% pointwise confidence intervals respectively. We used penalized cubic spline. We supposed also that there is non-zero covariance between corruption and GDP rate. In such case we performed an additive estimations, however the only significant variable still the GDP rate (p=0.0087 – significant at 1%). Corruption is not significant at any standard significance level (p=0.331).

The results show that, for the present sample, we have an inverted U-shaped curve which measures the impact of the GDP growth rate and the level of deforestation. The zero line is not included in the entire interval showing that the impact of the growth rate is statistically different from zero. The analysis of the impact of the corruption index in the deforestation rate is not statistically valid. The zero line is included in all the intervals, which shows the existence of zero impact of the corruption. The second result deserves a better discussion. As argued earlier, the level of corruption has been calculated as irregularities found in the CGU reports, and these reports don’t necessarily measure the level of corruption in the forest sector. We used data from the education ministry’s reports, but others information from others ministries could be used.

Table 2 - Statistic significance of the estimated functions

Estimated function	F-statistic	p-value
$f(GDPRate)$	3.5	0.013*
$f(corruption)$	0.124	0.727

Source: Author’s calculations.
Note:* significant at of 5%. n=42.

One of the possible problems in our estimations is the existence of controls between the municipalities from different states. One possible way to do so is to group municipalities from each state and perform nine different analyses. To proceed our testing, we decided to look just for the municipalities from the state of Mato-grosso and Pará. Given that together these municipalities are those with higher historical deforestation rate, we used 25 municipalities from these two states to check for the Kuznets curve and the impact of the corruption in the shape of this relationship. Note that given the restriction in the reports from the CGU we decrease our sample size from 42 to 25 municipalities. Our nonparametric results are represented in the following figure.

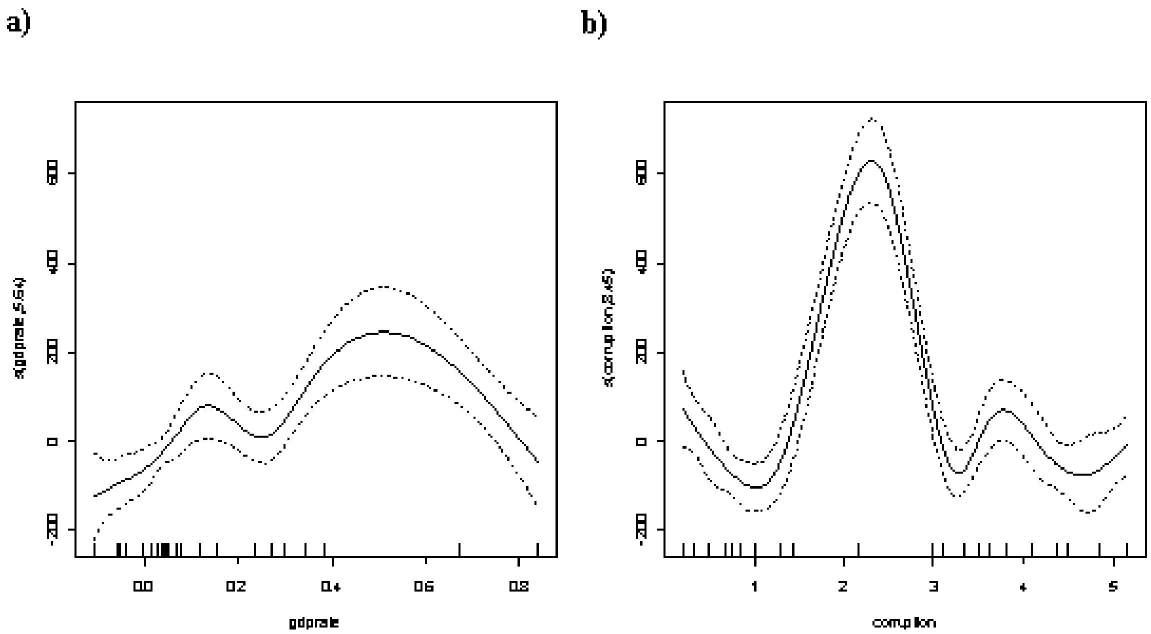

Figure 3 – GDP, Corruption, and Deforestation (measured in Km^2)

Source: Author’s elaboration.
Note: Penalized cubic Estimates of the deforestation level given, (a) the GDP growth rate, (b) corruption index. The solid curves represent the estimated nonparametric functions and 95% pointwise confidence intervals respectively. Given the potential non-zero covariance between the two covariates we used additive estimations.

The dependent variable in these estimations is the deforestation. The results by using the deforestation rate as the dependent variable were not statistically significant. The table below shows the statistic for this estimation.

Table 3 - Statistics from nonparametric estimations

Estimated function	F-statistic	p-value
$DEF(level) = \alpha_0 + f(GDPRate) + f(CORR) + \varepsilon_i$		
$f(GDP2004)$	25.8	9.93E-06***
$f(CORR)$	4.48	0.017*

Source: Author's elaboration.

Note: *** Significant at 0.1% level. and * significant at 5% level.

Given the results presented in the Figure 3, we see that the zero line is not in the entire confidence interval, which shows that there is a non-zero effect of the level of corruption in the level of deforestation.

So far we have analyzed the empirical existence of the Kuznets curve for the municipalities and analyzed the potential impact of the corruption in the level of corruption. Using our sample of 42 municipalities we found evidence for the existence of the Kuznets curve, however our sample does not support the existence of the impact of the corruption in the level of deforestation. In the second case by focusing just in the municipalities from the states of Pará and Mato-grosso, beyond the findings of the Kuznets curve, we found a nonzero impact of the corruption index in the level of deforestation.

The Table 3 presents the F-statistic that advocates that the relationship is statistically nonlinear. However, given the limited size of the sample, n=25, we should not use any parametric distribution assumptions, e.g., the normal assumption. Therefore, since the F-test is closely related with the standard normality assumption, the results from this test may not be completely robust. To have a robust inference, we performed nonparametric bootstrapping test, and we used, for such purpose, the algorithm presented in Kelle (2008). The test used is the difference of the deviance of the two models. The results are summarized in the following tables

Table 4 - Empirical significance test for nonparametric estimations

Estimated function	Bootstrap P-value	Standard χ^2 P-value
Restricted Model		
$DEF(level) = \alpha_0 + f(GDPRate) + \varepsilon_i$	0.05	<0.0001

Source: Author's elaboration.
Note: To test, empirically, the significance of corruption, we tested the restricted model against the full unrestricted model $DEF(level) = \alpha_0 + f_1(GDPRate) + f_2(CORR) + \varepsilon_i$. To perform the standard p-value calculation, likelihood ratio (LR) test is used. Bootstrap p-value is calculated by 999 replication.

Table 5 - Empirical Non-linearity test for nonparametric estimations

Estimated function	Bootstrap P-value	Standard value	χ^2	P-
Restricted Model				
$DEF(level) = \alpha_0 + f(GDPRate) + \beta_2 CORR + \varepsilon_i$	0.0349	<0.0001		

Source: Author's elaboration.
Note: To test, empirically, the potential non-linearity relationship between corruption and deforestation, we tested the restricted model against the full model, $DEF(level) = \alpha_0 + f_1(GDPRate) + f_2(CORR) + \varepsilon_i$.To perform the standard p-value calculation, likelihood ratio (LR) test is used. Bootstrap p-value is calculated by 999 replication.

Table 6 - Empirical Non-linearity test for nonparametric estimations

Estimated function	Bootstrap P-value	Standard value	χ^2	P-
Restricted Model				
$DEF(level) = \alpha_0 + \beta_1 GDPRate + \beta_2 CORR + \varepsilon_i$	0.032	<0.0001		

Source: Author's elaboration.
Note: To test, empirically, the potential non-linearity relationship between corruption and deforestation, we tested the restricted model against the full model, $DEF(level) = \alpha_0 + \beta_1 GDPRate + f(CORR) + \varepsilon_i$.To perform the standard p-value calculation, likelihood ratio (LR) test is used. Bootstrap p-value is calculated by 999 replication.

Following the results in the Table 4, Table 5, and Table 6, we must argued that there is a statistic evidence that there is a positive relationship between corruption and deforestation. Moreover, this relationship is not linear. This relationship is suggested even for the traditional Likelihood ratio (LR) test, or by nonparametric bootstrap analysis.

In the next section, we analyzed the existence of the environmental Kuznets curve, however we used a data panel for 46 countries for the years of 2004 and 2008.

4.6 INTERNATIONAL ANALYSIS

In this section we are interested to test the Kuznets curve. To proceed to international analysis, we followed the earlier work on the field, namely Taskin and Zaim (2000) and Bertinelli and Strobl (2005).

Regional Delimitation

To perform the regression, we used data for countries. We used data from 46 countries. Therefore we have for our analysis 92 data point.

Deforestation

To calculate the rate of the deforestation, we used data from FAO. In FAO database we found the size of forest areas, including various different types of vegetation and not only tropical forest. To calculate the rate of deforestation we used such data, and the deforestation rate is calculated as the difference between the forest's area (km^2) for two points in time. The following formula was used $DEF_{t=1} = \frac{F_{t=0} - F_{t=1}}{F_{t=0}}$.

Domestic Gross Product (GDP)

To test the existence, or not, of the traditional Kuznets curve, we used the GDP per capita at purchasing power parity (PPP). We used such variable as way for controlling for the differences in the cost of living in each country. Data were collected at International Monetary Fund (IMF).

Others Controls

To check the robustness of the estimation we introduced some other variables, as the population density (we used proportion of rural population as proxy). We introduced as proxy for the level of education and information, the number of internet users per 100 habitants. All these variables come from the World Bank. Some authors, for instance (BIMONTE, 2002) used number of newspaper for 1000 habitants as a proxy for the level of information. Van and Azomahou (2007) used the literary rate for such purpose. In the present work we used the number of internet user, which includes in the same direction the level of literacy and the level of information. We expect that the higher is the number of internet users the higher will be the amount of information available, which means that the higher is the literacy rate.

The idea behind this approach is that higher level of information and/or literacy rate, implies that people will have more information available about the environmental problems, and therefore more likely they will pressure their government about these problems. In our case, the higher the level of internet users means a higher level of environment's concerns, and therefore, more public awareness about the matter. Hence, countries with more educated population usually lead to lower level of deforestation.

The Econometric Model

In this section we are interested to test the existence of the Kuznets curve. To proceed in such investigation we used two different methodologies, namely a nonparametric specification test and also we performed nonparametric regression to test the existence of the Kuznets curve, namely, we used local constant regression, known as kernel Nadaraya-Watson estimation.

The kernel Nadaraya-Watson estimation for a given relationship,

$$y = g(x) + u \tag{7}$$

Is given by

$$\hat{g}_h(x) = \frac{\sum_{i=1}^{n} y_i K_h\left(\frac{X_i - x}{h_x}\right)}{\sum_{i=1}^{n} K_h\left(\frac{X_i - x}{h_x}\right)}$$

Where *K(.)* is the kernel function, and *h* represents the bandwidth. These results come from the application of kernel function to estimate the density function. For univariate case we that

$$Y = g(x) + u \Rightarrow g(x) = E\left[Y \mid X = x\right]$$

Hence, from the probability theory, we know that

$$E\left[Y \mid X = x\right] = \int_{-\infty}^{+\infty} y f_{Y|X}(y \mid x) dy = \int_{-\infty}^{+\infty} \frac{f_{X,Y}(x,y)}{f_X(x)} dy$$

Therefore, by using kernel methodology we can estimate each marginal density, hence the results follows.

For general description about this results see Hayfield and Racine, 2008. More technical details can be found in Racine and Liu, 2008.

The important variable in the kernel regression is the value for the *bandwidth*. The smoothness of any kernel nonparametric regression is directly linked with value of *bandwidth* chosen. Larger values of *h* produce smoother estimations, and rougher fits otherwise. The choice of the bandwidth can be subjective as argued by Kelle (2008), or one can use more sophisticate methods, i.e., cross validation (CV).

There is many data driven methodologies to estimate the optimal value for *h*. Two main methods are particularly famous, the cross validation (CV) method, and the AIC method (for instance see RACINE, 2008; RACINE; LI, 2008 for these methods).

The CV, as presented earlier in the case of penalized spline, is based in the optimal choose of *h* to minimize the following equation (further theoretical analysis can be found in PAGAN; ULLAH, 1999; RACINE, 2008), see Blundell and Duncan (1998) for practical implementation)

$$CV(h) = n^{-1}\sum_{i=1}^{n}\left(y_i - \hat{g}_{-1}(x_i) \right)^2$$

Where g_{-1} *(.)* is the estimator of *g(x)* when leaving out the *i-th* observation.

The cross-validation AIC method was introduce by Hurvich, Simonoff and Tsai[5] (1998 apud HAYFIELD; RACINE, 2008), and it is based on the minimizing of a modified Akaike information Criterion. The function to be minimized is

$$AIC = \ln(\sigma^2) + \frac{1 + tr(H)/n}{1 - \left[tr(H) + 2 \right]/n}$$

Where

$$\sigma^2 = \frac{1}{n}\sum_{i=1}^{n}\left(y - \hat{g}(x_i) \right)^2 = Y^T (I - H)^T (I - H) Y / n$$

Where **H** is the matrix of kernel weights. $\hat{g}(x_i)$ is the nonparametric estimator. More details can be found in Hayfield and Racine (2008) and Racine and Liu (2008).

The generalized product Kernel (GPK) is used (about GPK see HAYFELD; RACINE, 2008). Note that, as argued by Hayfield and Racine (2008) these two methods are

[5] HURVICH, C. M.; SIMONOFF, J. S.; TSAI, C. L. Smoothing parameter selection in nonparametric regression using an improved Akaike information criterion. **Journal of the Royal Statistical Society**, v. 60, p. 271–293, 1998. Series B.

asymptotically equal. In fact, in our empirical study we used both methods, however there is just a slight difference in the estimated function.

The results from our work are presented in the following section.

4.7 RESULTS

In this section we present the results. We tested the existence or not of the environmental Kuznets curve. First, we used a parametric estimation, namely we used pooled cross-section (POOLED), to test the original idea beyond the Kuznets curve, i.e., with GDP *per capita* as independent variable. We performed nonparametric specification developed by Hsiao, Li and Racine (2007). For such purpose we tested three different parametric models. Second given the results on the nonparametric specification test, we performed nonparametric Kernel regression to study the relationship between GDP and deforestation (the Kuznets curve).

Testing for the Original Kuznets Curve

In this subsection we follow the work of Liu and Stengos (1999) and Maasoumi, Racine and Stengos (2007), and we used pooled cross-section data to estimate the parametric model. We applied Hsiao, Li and Racine (2007) test in three different parametric models, namely

Model 1: $$DEF_i = \alpha_0 + Y_i + D_t + \varepsilon_i$$

Model 2: $$DEF_i = \alpha_0 + Y_i + Y_i^2 + D_t + \varepsilon_i$$

Model 3: $$DEF_i = \alpha_0 + Y_i + Y_i^2 + D_t + \beta Z + \varepsilon_i$$

Where Y represents the log of GDP *per capita*, D is a dummy for time (measuring the difference in the intercept), and finally Z a vector of controls. The following chart summarizes the estimation of pooled cross-section for each model.

Table 7 - Pooled cross-section Kuznets estimations

Estimated function (POLS)	**Model 1**	**Model 2**	**Model 3**
Intercept	0.02** (3.26)	-0.056 (-1.53)	-0.083 (-1.71)
Log(GDPperc)	-0.0013* (-1.77)	0.018* (1.93)	0.025** (-1.96)
Time Dummy	0.0002 (0.14)	0.0003 (0.21)	0.0002 (-0.17)
Log(GDPperc)(square)		-0.001** (-2.08)	-.0017** (2.00)
Rural			-6.2e-6 (-0.10)
internet			0.0002 (1.25)
Corru			0.0008 (0.72)
n	90	90	90
Concave	No	Yes	Yes
R-Adjusted	0.04	0.05	0.09
F-statistic (p-value)	1.54 (0.21)	2.51 (0.06)	1.37 (0.23)

Source: Author calculation.
Note: * significant at 10%, ** significant at 5%.

From the table above, we see that in general, after controlling for many others factors, just the level of development (measured here as the GDP per capita at PPP values) have an impact in the deforestation rate, all the others variables are insignificant at 10 % level. However, these t-values (based on the standard errors) calculates are based in the normal traditional assumptions about the normality of the population or errors. However, given the sample, we don’t know the real distribution in the population (it might be normal or not), therefore in such case empirical statistics can be archived by the bootstrap methodologies.

Given this restriction, and to avoid any constrains about the functional relationship between deforestation and per capita GDP, we performed non-parametric Kernel estimations on the relationship between GDP *per capita* at PPP values and deforestation rate. Before presenting the results from our estimation, the following chart summarizes the nonparametric specification test for the parametric Kuznets curve.

Table 8 - Nonparametric Specification test (see Appendix A)

Estimated function	Jn-statistic	P-values (Bootstrap)
$DEF_i = \alpha_0 + Y_i + D_t + \varepsilon_i$	0.072	0.041**
$DEF_i = \alpha_0 + Y_i + Y_i^2 + D_t + \varepsilon_i$	-0.884	0.328***
$DEF_i = \alpha_0 + Y_i + Y_i^2 + D_t + Z_i + \varepsilon_i$	2.29	<0.0001*

Source: Author's Elaboration.
Note: Null hypotheses refers to the parametric model being correct. * Reject the null at 0.1% level, ** Reject the Null at 1% level, *** Not reject the null at 10% level. We used 399 bootstrap replication. Note that we also performed wild bootstrap test, however the numerical p-values are just slightly different, and the qualitative decisions about the parametric model are the same.

As we can see the linear model and the general (with controls) model seems to suffer with misspecification. Hence, the nonparametric approach seems to be perfect tool in such case. We performed the nonparametric Kernel estimations on the effects of economic development in the deforestation rate. In fact, we estimated nonparametrically just the original idea beyond the environmental Kuznets curve. The results are presents in the following figure.

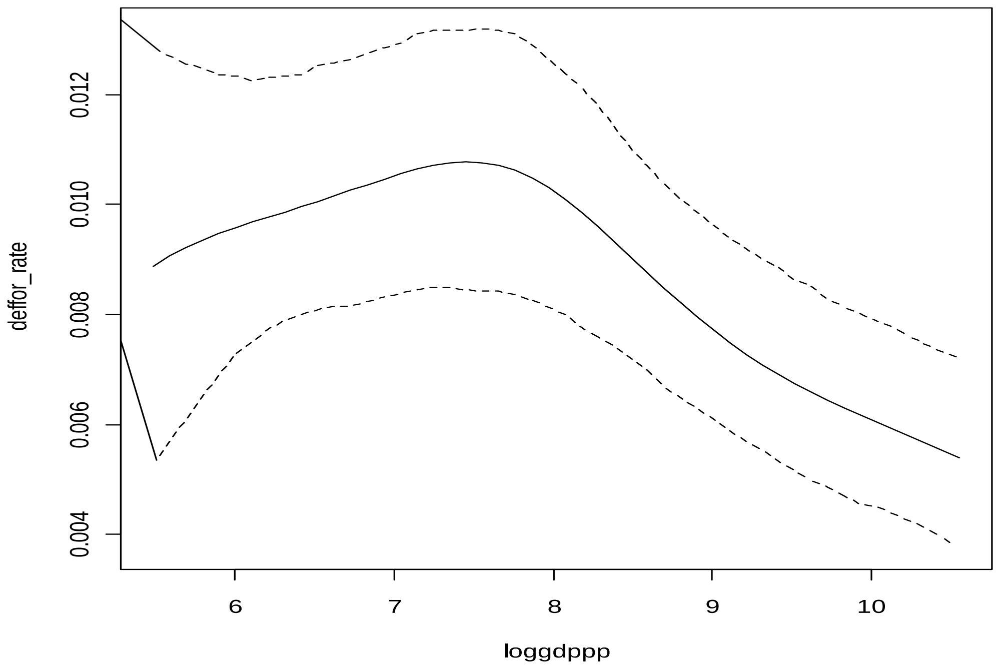

Figure 4 – Kuznets Curve

Source: Author's computation.
Note: Kernel nonparametric estimation (Gauss –Normal kernel was applied) - dashed lines represents confidence interval performed using the bootstrap empirical methodology. Percentile bootstrapped Confidence interval was created by 1000 bootstrap repetitions. Kernel regression was performed through the *Nadaraya-Watson* estimator.

And the selection data-driven method chosen was cross-validation. We used also the AIC criterion, however is tiny the difference between both method.

Our nonparametric estimations show evidence for the existence of the Kuznets curve. There is an increase in the deforestation rate when we have an increase in the GDP *per capita*, however beyond a certain turning point, for more developed economies, there is less pressure in the use of natural resources and therefore the curve is downward sloping.

To check our results we performed nonparametric significance test developed by Racine (1997) and Racine et al. (2006). The null hypothesis to be tested is that the covariate has no impact in the dependent variable (general description about this method can be found in Hayfield and Racine (2007) and Liu and Racine (2008)). For the present case, we would have

$$H_0 = E(def \mid GDP) = 0$$

Or

$$H_0 = \frac{\partial E(def \mid GDP)}{\partial (GDP)} = 0$$

The alternative hypothesis should be stated as

$$H_0 = \frac{\partial E(def \mid GDP)}{\partial (GDP)} \neq 0$$

The result from the test is summarized in the following table.

Table 9 - Nonparametric significance test

Estimated function	P-values (Bootstrap)
$DEF_i = f(Y) + \varepsilon_i$	0.035*

Source: Author's Elaboration.
Note: significance test are performed by using the package np (see HAYFIELD; RACINE, 2008). We used 399 bootstrap replication. * significant at 5%. We also performed wild bootstrap and we found p-value = 0.027 (significant at 5%). Therefore, is tiny the difference between both methods.

The results from the test argue that there is an inverted U-shaped relationship between deforestation rate and GDP per capita. The explanation for this relationship is straightforward. For low level of development there is a higher pressure for the natural resource, however after certain turning point, higher level of the development. Hence, our empirical findings is equivalent with many others empirical works in the literature.

4.8 FINAL REMARKS

The present work aimed to study empirically the deforestation phenomenon. For such way we used nonparametric models. We divided our study in two different regions, namely we performed a study on the Brazilian municipalities and the second study we focused in the international scenario.

This work in the first to use nonparametric methodologies to test the existence of Kuznets curve in the Amazon forest. Our result argues for the existence of the Kuznets curve. Also, this paper is the first analyzing the effects of corruption in the Amazon forest.

First we tested the impact of corruption by using all the municipalities in the legal Amazon (given the restriction of the quantity of the reports delivered by the CGU for 2004). In this first approach our results didn't argued for a statistical significance of the impact of corruption on deforestation. We decided therefore to take a look just for those municipalities from Mato-grosso and Pará. We decrease our sample from 42 to 25 municipalities. Our nonparametric results argued for a statistical significance of corruption on the deforestation. Given the sample size we decided to use bootstrapping nonparametric test between the models. Our robust empirical results also argue for the statistical significance of the effects of corruption on deforestation, even when we control for the GDP. Our results also argued that this relationship is not linear. In fact we found an inverted-U shaped relationship between corruption and deforestation. This result argues that for lower level of corruption, there is a positive relationship between corruption and deforestation, however after some turning point this relationship seems to be negative. The explanation for this relationship seems to be related with the great impact of the increased cases of corruption on the policies used by the government to prevent denounced cases of corruption. As increases the cases of corruption, increases the public pressure on the governments and this decrease the incentive for corruption.

The second objective of this empirical essay is to test the existence of the environmental Kuznets curve at international scenario. For such purpose we used kernel regression, namely we performed the so called local constant regression. Before the estimations, we also performed nonparametric specification test of the pooled cross-section model. We found that, for some models, the parametric modeling is incorrectly specified.

The empirical results from our international studies, argues for the existence of Kuznets curve. Therefore we archived similar results as others parametric and nonparametric works in the literature.

The main contribution of this essay relays on the estimation of the impact of corruption on the deforestation. Therefore, we should highlight that, as the first analysis in the Brazilian literature, further analysis may be performed in the future. For future research, it would important to use other type of objective measure of corruption. Also, further analysis may investigate the theory of the “natural resource curse” for the Brazilian municipalities by using nonparametric models as “count-data” models.

4.9 APPENDIX

A) Specification Test (Racine et al. (2007)).

One of the statistical test used to analyze the parametric specification, is the test developed by Racine et al. (2007). This test is one upgrade of the earlier test introduced for instance by Zheng (1996). The test developed by Racine et al. (2007) allows for the existence of both continuous and categorical data.

Let's assume that we want to test whether the parametric model is correctly specified or not. Hence, a traditional way to do that is to form a hypothesis analysis in such case the null hypotheses will be

H_0= Parametric model is correct

H_1= Other Approach (e.g., semi-parametric model)

Following Racine (2007) these two hypotheses could be written in the following way

$$H_0 = E(Y \mid x) = m(x, \beta), \quad \beta \in \mathrm{B} \subset \mathbb{R}^p$$

Where m(x,b) is a known function, which b represents a p x 1 vector of unknown parameters to be estimated. B is a compact subset of R. the H_1 is the negation of the above hypothesis, which is

$$H_1 = E(Y \mid x) \neq m(x, \beta), \quad \beta \in \mathrm{B} \subset \mathbb{R}^p$$

Appling nonparametric estimation on the null hypotheses, and using the method of iterated expectations, we obtain the test statistic purposed by Racine et al. (2007), which is given by

$$\hat{J}_n = n(h_1 ... h_2)^{1/2} \hat{I} / \sqrt{\hat{\Omega}}$$

Where

$$\hat{I}_n = n^{-2} \sum_i \sum_{i \neq j} \hat{\varepsilon}_i \hat{\varepsilon}_j K_{\gamma, ij}$$

Where $K_{\gamma,ij} = W_{h,ij} L_{\lambda,ij}, \gamma = h, \lambda$ is the bandwidth. *W* and *L* represents the multivariate kernels functions.

And

$$\Omega = \frac{2(h_1 \ldots h_q)}{n^2} \sum_i \sum_{i \neq j} \hat{\varepsilon}_i^2 \hat{\varepsilon}_j^2 \hat{W}_{h,ij}^2 L_{\lambda,ij}^2$$

Under the null hypotheses, bootstrap methods can be used to obtain the distribution of Jn. Further exposition of this method can be found in Liu and Racine (2008).

B) Descriptive Statistics

Chart.1 - Descriptive Statistics (International Data)

Statistics	GDP	CORRUPTIO N	DEFORESTATION RATE	INTERNE T	RURAL
Minimum	242.7	1.3	-0.00078	0.02	6.68
Maximum	38282.1	8.8	0.039	71.67	87.58
Mean	5317.6	3.1	0.0089	10.12	51.21
Median	3463.3	2.8	0.0071	5.47	52.54
3rd quartil	7697.9	3.5	0.01	11.33	65.89

Chart.2 - Descriptive Statistics (National Data)

Statistics	Deforestation Rate	GDP	GDP per Capita	GDP_Rate
Minimum	0.000000715	4312	856	-0.35
Maximum	0.263	17205511	84495	3.1
Mean	0.0276	149376	4577	0.096
Median	0.0157	37176	2972	0.058
3rd quartil	0.0415	80616	4791	0.14

Chart.3 - Descriptive Statistics (Mato-grosso Data)

Statistics	GDP	CORRUPTION_INDEX	DEFORESTATION (km^2)
Minimum	12997	0.2	0.3
Maximum	792591	4.0	230.9
Mean	158223	1.25	99.76
Median	70961	1.0	89.8
3rd quartil	150371	1.62	188.85

4.10 REFERENCES

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5 CONCLUSÃO

O presente trabalho buscou fazer uma investigação de caráter teórica e empírica sobre o fenômeno do desmatamento, mais concretamente para o caso da floresta Amazônica. O enfoque dado neste estudo é de todo muito diferente dos demais trabalhos na literatura nacional. Evidências mostram que na floresta Amazônica, grande parte das extrações, vegetal ou animal, é feita de forma ilegal (AMACHER, 2006). Assim, é de suma importância um estudo que investigue como um fator como a corrupção pode influenciar os desmatamentos na Amazônia. A novidade do presente estudo não reside somente no assunto analisado, mas também na ferramenta que é utilizado para este estudo. Na literatura nacional, não foi encontrado nenhum trabalho que utilize a ferramenta de jogos diferenciais. Desse modo este trabalho é o primeiro a fazer este uso.

Com relação á metodologia econométrica, não encontramos nenhum trabalho que tenha feito o uso desta ferramenta (econometria não paramétrica) no estudo do desmatamento na floresta Amazônica.

De forma geral podemos concluir, pelos modelos matemáticos aqui desenvolvidos e pelos resultados empiricos, que a corrupção (ou instituições em geral) é um elemento importante que de se deve levar em consideração se quisermos fazer uma análise robusta das causas do desmatamento. Elevados índices de corrupção está ligada a elevados níveis de desmatamento. Assim sendo, é de suma importância que as políticas do Governo Federal tenham em consideração os possíveis efeitos adversos dessas mesmas políticas.

Melhores salários, e políticas de auditoria interna no IBAMA, parecem ser, segundo os resultados dos modelos aqui analisados, duas das políticas que poderão ter efeitos reais sobre os niveis de desmatamento. Os resultados também demonstram que caso não for, ao menos parcialmente, eliminada a assimetria de informação entre o governo e o oficial do IBAMA, existe uma tendência clara para um equilíbrio em que o agente do governo optará em ser corrupto.

As simulações numéricas, assim como as estimações econométricas corroboram os nossos resultados, isto é, a corrupção é um fator importante na explicação do fenômeno do desmatamento.