THE OPTION VALUE OF FOREST CONCESSIONS IN BRAZILIAN AMAZON

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Summary

The Brazilian government currently implements concession policy to exploit timber harvesting on national forestry reserves in the Amazon region. This paper proposes methods to appraise the value of the forest concessions based upon option theory. Timber price is modeled as a mean-reverting stochastic process while the biomass volume follows the standard stochastic differential equation from the population ecology literature. Spatial regression estimates the probability distribution of biomass volumes in concession areas.

The concession value under option theory is 153% higher than the Net Present Value methodology. Since forest concessions are public resources, differences of that magnitude are not negligible.

Key Words: Brazil, Amazonia, Forest Reserves, Forest Concessions, Real Option Theory, Spatial Correlation.

1 – INTRODUCTION

The Brazilian government currently implements concession policy to exploit timber harvesting on national forestry reserves (Flonas) in the Amazon region. Concession rights will be granted by auctions. Since national forests reserves are public resources, the right appraisal is required to avoid undervaluation (potentially resulting in windfall profits for private groups and also wasting of scarce natural forestry resources) or overvaluation (discouraging bidding and/or making sustainable exploitation unprofitable).

Forest lease is a capital investment opportunity with a long time horizon (usually thirty years), high uncertainties about timber price and inventory. Due to the fact that harvest decision is an instantaneous irreversible decision, and the leaseholder has the right but not the obligation to proceed the harvest, it seems naturally to use the option theory to appraise the concession value.

In Brazil, most studies dealing with concession or asset pricing valuation for privatization purposes use the Net Present Value (NPV) methodology, which relies basically on the expected free cash flow over the lifetime of the undertaking, discounted by the risk-adjusted discount rate. NPV does not consider such factors as the value aggregated by future efficient management of the asset, uncertainties over economical variables or the regulatory policy effect. The Real Option Theory (ROT) incorporates the effect of efficient management and economical uncertainties, as well as the effect of possible changes over regulatory regime. Particularly in the concession of Flonas, management involves the number of trees being felled in each period. For instance, if timber prices fall under some threshold level, the manager has the option of suspending production, waiting for a more advantageous moment; or if an unexpected amount of timber inventory is encountered, the concessionaire (leaseholder) has the option of increasing the harvest rate.

The flexibility of ROT increases the concession value in comparison to NPV. It is a well-known fact that the difference between ROT and NPV can be very significant, especially for out-of-the-money options.

From this perspective, in many cases NPV undervalues the concession and leads to mistaken decisions about the investment decision problem[1].

The option theory prices the concession in a way to maximize the expected cash flows coming from the current harvest policy and subsequent decisions about it. Therefore, it calculates the concession value assuming an optimal cutting rate policy adopted by the leaseholder. This concession value is higher than any figure coming from a non-optimal cutting policy. Obviously, the concession value paid at auction will not necessarily be the same as that calculated from the maximization problem, due to different knowledge or expertise of the bidders. Nevertheless, the option value can be very useful and help government decisions on setting a minimum bid price as a percentage of the estimated option value.

Several papers using ROT on concession valuation of natural resources can be found in literature. Pindyck (1984) was the first to introduce option theory to appraise a renewable resource with property rights. Brennan and Schwartz (1985) apply the same methodology to estimate a value for a non-renewable natural resource. Morck, Schwartz and Stangeland (1989), MSS (1989) hereafter, show how option theory can be used to value a white pine concession considering economical uncertainties and management flexibility to react to changes in the economy.

This study employs ROT to appraise the concession value of a typical Amazon forestry reserve (Flona) in the Legal Amazon region of Brazil, including economical uncertainties and analyze the effect of the government regulatory policy.

As a methodological paper, our goal is to present and calculate the optimal concession value. This optimal value depends on the set of parameters adopted. These parameters are selected in a way to reflect a range of perspectives about productivity or market economy. The results will be the best estimate for the concession value conditioned on the set of parameters adopted[2], and therefore will mainly indicate how to appraise a forest concession in an optimal way.

The main characteristic of this paper is to extend the MSS (1989) model by considering that timber price follows a mean-reverting stochastic process which is a more appropriated feature for commodities. We also deal with the realistic assumption about uncertainty over the current timber volume (biomass) in the lease area and how this volume evolves over time. Because concession value depends on the biomass density[3] in the lease area, a methodological procedure has been proposed to estimate it by applying spatial econometric models[4]. The biomass density data came from the RADAM database (Brazilian natural resources statistics). This methodology has been used to estimate the biomass density function in any Legal Amazon municipality and therefore can be employed to calculate the concession value for any specific area. Appendix A presents the estimates for timber price stochastic process and for the current timber biomass in the concession area and its stochastic evolution over time.

The model also investigates how the regulatory policy, such as changes over the minimum inventory required to be held in the lease area, the management techniques utilization and the duration of the concession, affects the concession value.

It is useful to mention that the use of purely economic concepts in the valuation of natural resources is overly simplified. For a broader valuation of the costs and social benefits, it requires an appraisal of the environmental benefits of the forest areas, which are not reflected in the market price of the concession (such as retention of carbon and its contribution to global, regional and local climatic stability; biodiversity preservation; water balance maintenance). These environmental issues, however, are not considered in this study, which is restricted to the question of determining the economic market value of concessions[5]. For an application of ROT to value forest resources based on non-economical concepts see Conrad (1997).

The paper is organized as follows: the next section is an overview of the Amazon forest-concession policy in Brazil; the third section describes the Real Option Theory (ROT) and Net Present Value (NPV) methodologies employed to appraise the Amazon-forest concessions; the fourth section shows the results and comparisons between ROT and NPV are performed; and the last section presents our main conclusions.

2 – AMAZON RESERVES CONCESSION POLICY

Containing some one-third of the world's tropical forests, the Brazilian Amazon has an estimated 60 billion cubic meters of wood[6]. According to Veríssimo and Júnior (1997), the region produced 25 million cubic meters of wood in 1997 - 80% of the country's total output.

In the international market for tropical wood, Brazil still has a small participation, producing only four percent of world exports. However, significant expansion of this share is expected over the next decade, due to the gradual exhaustion of Asian forestry resources.

One recent instrument for forest regulation in Brazil is the National Forest Program, created in 1998, allowing concession of national forest areas (Flonas) for public use. The Brazilian Forest Act (Law 4771 – September 15, 1965 – Art.5), defines Flonas as public domain areas, endowed with native or planted vegetal coverage, established for the purposes of: promoting the management of natural resources (with emphasis on the production of timber and other plant products); guaranteeing the protection of water resources, landscapes, historic and archaeological grounds; and stimulating the development of scientific research, environmental education, recreation and tourism activities.

According to Barreto and Veríssimo (1999), currently, there are 46 legally demarcated Flonas, adding up to 152,000 km^2, with 99.5 percent located in Legal Amazon[7]. No Flonas have been used yet for legal timber production.

The current area for logging corresponds to three percent from the total Legal Amazon area. There have been several debates in Brazilian congress in order to increase this amount up to twelve percent and also to establish a financial market associated to environmental commodities (forest products, pollution or harvest allowances, etc).

The extraction of wood in the Brazilian Amazon is not carried out in a sustainable way due to the low market prices of native wood. The causes are the abundance and the ease of access to the forestry resources. This situation is aggravated by a lack of adequate public policies. Among these, mention can be made on the construction of public infrastructure projects, especially highways, which facilitate access to forestry resources; the inadequate vigilance in the region, together with disregard for sustainable management techniques; and last but not least, the inefficient regulation of wood extraction.

Due to a poor inspection system and the huge expanses of wooded areas involved, the current legislation has not been efficient in controlling deforestation or providing the proper forest management.

Faced with the current political situation and the lack of public resources, the implementation of a public concession policy for natural forest exploitation comes naturally as an institutional solution for forest management. The main benefit is to grant public responsibilities to private leaseholders, thus achieving the future sustainability of logging and reducing government costs for management and control. The basic tenet is to conciliate private self-interest and the good of society by making sustainable exploitation economically attractive and penalizing irresponsible destruction of ecosystems.

The delegation of public responsibilities to the private sector along with the rights and obligations related to commercial exploitation of natural forests would be established through forest legislation and concession contracts. Disobedience with any of the conditions established would result in penalties or even the termination of the concession[8]. The concessions would be granted to the leaseholders by public auction or some similar mechanism, and would be open to both national and international companies.

The duration of the lease and the size of concession area are critical to ensure the sustainability of any undertaking. Too short a period would tend to encourage maximum cutting to get a quick return. Too small an area would have the same effect, by not allowing a leaseholder to make a profit through sustainable and selective cutting.

3 – FOREST CONCESSION APPRAISAL

In order to determine the stochastic differential equation that conducts the concession value we follow the same methodology of MSS (1989) with some extensions. The procedure is described in the following sections.

3.1 – THE REAL OPTION APPROACH

Timber price, P ($/m^3), evolves according to the following stochastic differential equation[9], with dz as a Wiener process.

$$dP = \eta \cdot \left(\overline{P} - P\right) dt + \sigma_P dz \qquad dz = \varepsilon \sqrt{dt}\,,\ \ \varepsilon \sim N(0,1) \tag{1}$$

Eq.(1) implies that the timber price follows a mean-reverting process, which is the natural choice for commodities, with long-run equilibrium mean $\overline{P}$, reversion speed η, and volatility σ_P.

Timber inventory, I (m^3/ha), evolves as the following standard stochastic differential equation from the population ecology literature, with dw as a Wiener process uncorrelated to dz[10].

$$dI = \left[\mu \cdot I - q(P, I, t)\right] dt + \sigma_I\ I\ dw \tag{2}$$

The inventory growth rate in Eq.(2), $[\mu . I - q(P,I,t)]$ allows negative values. The parameter μ corresponds to the timber inventory growth rate as a percentage of the residual inventory; q(P,I,t) is the control variable representing the optimal cutting rate policy in a short period dt; σ_I is the uncertainty about the growth rate of timber inventory (burning and discovery of new or valuable species). The assumption for the logging company cost function, C(q), is very general. We adopt a linear cost function relative to the timber cutting rate q. Linear cost function leads to a corner (*bang-bang*) solution relative to q.

$$C(q) = c_1\, q$$

We further assume that production can be suspended or restarted at any time without additional costs[11].

F(P,I,t) denotes the concession value given the current timber price P, current timber inventory I, and time t until the end of the lease at t = T. Let $\pi\,(q^*)$ represent the cash flows associated to the harvest. We adopt the dynamic programming approach for evaluating the concession and use an appropriated exogenous inter-temporal discount rate ρ. The stochastic optimization problem that leads to the option pricing can be summarized by the Bellman´s equation Eq.(3) where q_{max} represents the maximum annual cutting rate allowed by regulation policy, and Eq.(1) and Eq.(2) represent the processes for the state variables P and I respectively[12].

$$F(P,I,t) \equiv \max_{q^*(P,I,t) \in [0,q_{max}]} E_t\left\{ \left[\int_0^T \pi(q^*) \cdot e^{-\rho . t} dt \right] + F(P,I,T) \right\} \qquad \textbf{(3)}$$

$$\pi(q^*) = P.q^* - c_1.q^*$$

Using Ito’s Lemma and dynamic programming valuation[13], one can demonstrate that the concession value, F(P,I,t), follows the optimality Eq.(4)[14]. The right hand side of Eq. (4) is a partial differential equation (PDE) of parabolic type in two dimensions with the appropriated boundary conditions Eq.(5-10).

$$0 = \underset{q^*(P,I,t) \in [0,q_{max}]}{\text{máx}} \left\{ \frac{1}{2}\sigma_P^2 F_{PP} + \left[\eta \cdot \left(\bar{P} - P\right) \right] \cdot F_P + \frac{1}{2}\sigma_I^2 I^2 F_{II} + \left[\mu \cdot I - q^* \right] \cdot F_I + F_t - \rho F + \pi(q^*) \right\} \qquad \textbf{(4)}$$

$$F(P,I,T) = 0 \quad \textbf{(5)}; \qquad F(0,I,t) = 0 \quad \textbf{(6)}; \qquad \lim_{P \to \infty} F_P = I \quad \textbf{(7)}$$

$$\left.\frac{\partial F}{\partial I}\right|_{I = Imax} = 0 \quad \textbf{(8)}; \qquad F(P,0,t) = 0 \quad \textbf{(9)}; \qquad q(P, I \le I_{min}, t) = 0 \quad \textbf{(10)}$$

The boundary conditions guarantee that: Eq.(5) - at the end of the lease, the concession value is zero; Eq.(6) - if timber price falls to zero the lease value is null; Eq.(7) - if the timber price becomes very large, changes in the lease due to changes in price will be proportional to the inventory held; Eq.(8) - there is a reflector barrier due to maximum timber inventory density (I_{max}), leading to a constant concession value above that barrier. Eq.(9) - sets a zero concession value if timber inventory falls to zero. Eq.(10) - imposes the minimum regulatory level (I_{min}) to timber inventory, where the harvest is no longer allowed below that level.

Eq.(4), as well as the appropriated boundary conditions, was numerically solved by the finite difference method (FDM) in explicit form[15].

For each current level of timber inventory (I_0) and timber price (P_0), $F(P_0,I_0,t_0)$ defines the concession value for any period of time t_0. Actually, there is an uncertainty associated to the current level of timber inventory and sometimes we only have a way of estimating its probability distribution function, $p(I_0)$, through sampling. Let $V(P_0,t_0)$ be the concession value relating to this uncertainty. Eq.(12) shows how $V(P_0,t_0)$ can be calculated based on integration over the option value $F(P_0,I_0,t_0)$.

$$V(P_0, t_0) = \int F(P_0, I_0, t_0).\, p(I_0) dI_0 \quad \textbf{(11)}$$

3.2 – THE NET PRESENT VALUE APPROACH

We adopt a probabilistic NPV model in order to compare the results with ROT methodology. Probabilistic NPV means that the free-cash flows coming from harvest are also uncertain.

For negative free cash flows or for inventories below the minimum level (I_{min}) imposed by regulation the concession value is zero, because no harvest is allowed. For positive cash flows and inventories above that minimum level the concession value follows Eq.(4) with the cutting rate policy settled as its maximum level q^*_{max}.

Eq.(12) summarizes the NPV model subject to same boundary conditions Eq.(5-10): described earlier.

$$\begin{cases} \left\{ \frac{1}{2}\sigma_P^2 F_{PP} + \left[\eta \cdot \left(\bar{P} - P \right) \right] \cdot F_P + \frac{1}{2}\sigma_I^2 I^2 F_{II} + \left[\mu \cdot I - q \right] \cdot F_I + F_t - \rho F + \pi(q) \right\}, \text{ for } I(t) \geq I_{min} \text{ and } \pi(q) > 0 \\ 0 \text{ ,otherwise} \end{cases} \quad \textbf{(12)}$$

4 – RESULTS

Table 1 presents the parameters adopted for the concession pricing. The parameters are consistent with Barreto (1999); Veríssimo et al (1992); Stone (1997); Morck, Schwartz and Stangeland (1989); and our estimates presented in Appendix A. Due to the lack of available Amazon timber price data, the reversion speed, price volatility and long-run price parameters were estimated from Malaysian Hardwood data and adopted as a proxy for Amazon timber price estimates after some adjustments explained in Appendix A. For the base case we set the current timber price in the Amazon area as $50/m^3 (according to Stone (1997) the prices in US$ 1995 varied in a range from $27/m^3 to $82/m^3).

[Table 1 here]

The concession value was calculated using Traditional Methodology (NPV) and Real Option Theory (ROT) approaches. The concession value was appraised by assuming that: 1) the current timber inventory -$V(P_0,t_0)$- is known and 2) the current timber inventory -$F(P_0,I_0,t_0)$- follows a probability distribution estimated in Appendix A.

Table 2 shows the concession value for the base case and table 3 shows the concession value considering disturbances in the initial conditions. Table 4 shows the sensitivity analyses relative to price and inventory uncertainties. Table 3 and 4 suppose no use of management technique.

[Table 2 here]

[Table 3 here]

[Table 4 here]

The results show that:

- The NPV technique undervalues the concession. For the base case, the ROT model computes a 153% higher result.
- The current timber inventory uncertainty in the lease area depresses the concession value $V(P_0,t_0) < F(P_0,I_0,t_0)$.
- Management reduces the concession value roughly by 10%. Therefore management should be determined by concession contracts, rather than for economical proposals.

Next we present some further graphs organized in a way to explore the effects of the application of option pricing methodology and its application comparing to the NPV technique.

Figure 1 shows the sensitivity analysis for the concession value V($/ha), 30 years to maturity, relative to price volatility (p.v. - standard deviation per year). The option presents the typical shape relative to the mean-reverting process[16]. Due to the change in concavity, the volatility has two different effects on the option value. For the region of positive second derivative (F_{PP}), price volatility increases the option value. For the others cases we see the opposite effect. One can inspect the signal of the term F_{PP} in Eq. (4) to verify this effect.

[Figure 1 here]

Figure 2 shows the sensitivity analysis for the concession value V($/ha), relative to inventory volatility (i.v. - standard deviation per year).

Note that for inventories beyond the regulatory minimum level (12.5 m^3/ha), i.v. increases the concession value. Even though the profit is zero in this region (it is not allowed to the leaseholder proceed the harvest when the inventory is bellow that level), the concession still has a positive value, contrary to the NPV technique, which gives a null concession value.

For inventories above the regulatory minimum level, i.v. reduces the concession value.

One can inspect the signal of the term F_{II} in Eq. (4). It has a positive value for inventories bellow the regulatory minimum level (12.5 m^3/ha), and a negative value for inventories above that level. It explains the unusual effect of decreasing the option value due to an increasing of the volatility parameter.

[Figure 2 here]

Figures 3 shows the concession value V($/ha) comparison between the NPV and ROT. Note that for out-of-the-money options the difference between the two approaches is higher comparing to deep-in-the-money options.

[Figure 3 here]

Figure 4 shows how the concession value V($/ha) calculated by ROT changes relative to time to maturity (t) in years. Note that for time to maturity superior than 15 years, there is no significant increase in the option value.

[Figure 4 here]

Figures 5 shows the differences for the concession value V($/ha) relative to changes in the risk-adjusted discount rate. The concession value is very sensitive to changes in the discount rate. As expected a higher discount rate decreases the concession value and vice-versa. For the base case the concession changes by 40% due to changes of 0.05 points in the discount rate.

[Figure 5 here]

5 – CONCLUSIONS

This paper proposes a Real Option Theory (ROT) methodology to estimate the concession value of a typical Amazon natural forest for harvesting of commercial wood. The proposed method is superior to the traditional approach of Net Present Value (NPV) leading to a higher concession value. ROT allows quantifying the gains from management decisions due to unpredictable changes in the economy.

For the base case, the concession value calculated by ROT is 153% higher than the one calculated by NPV.

Our results concerning the regulatory policy shows that: (i) there is no need for a reduction on the minimum inventory level imposed by regulation; (ii) 15 years appears as an ideal concession time since no significant improvements on the concession value can be obtained by applying longer duration; (iii) management should be established as an obligation on concession contracts since it reduces concession value; and (iv) as the concession value is very sensitive to changes on risk-adjusted discount rate, the latter should be estimated very carefully.

The paper also proposes methods to estimate the probability distribution of log volumes in concession areas as well as future timber prices. The volume distribution is specified in a spatial model as a function of geographic characteristics of the area as well as the neighboring areas.

The data available about forestry resources are scarce and often in disagreement. Therefore, the numerical results must be seen as merely indicative of the concession value. However, we believe that the results are quite revealing and can motivate the use of this methodology with any set of parameters.

NOTES

1. More comparisons between NPV and ROT can be found in Dixit and Pindyck (1994) or in Trigeorgis (1996).
2. Note that the set of parameters is often controversial.
3. For a given soil quality, climate and other characteristics not observable but spatially related of a specific area, the amount of biomass determines the number of trees with a minimum diameter that can be harvested.
4. Just few points of biomass in the total area of concession are actually inspected either by collecting sample data at the local or by satellite information. The rest of the biomass on the concession area is therefore estimated through econometric procedures.
5. Valuation based on economic aspect has, however, some advantages: (i) easier understanding with less propensity to generate controversies; (ii) results that are easily grasped by central planners, with penalties imposed for any harmful effects through taxes or royalties, generating financial income aimed at the future sustainability of logging.
6. See Veríssimo and Barros (1996)
7. Additional information about existing Flonas, legislation, and management techniques can be found at www.ibama.gov.br
8. See Ferraz and Seroa (1999)
9. Eq.(1) implies that prices can even become negative. In order to avoid this, we use a truncated distribution for the numerical calculations on option value. Since Eq.(1) represents a stationary process, for a relative high long-run equilibrium mean and current timber price level, the probability of negative values becomes unlikely.
10. We assume that the logging company is a small firm in comparison to the whole industry (the international market). Therefore, changes in forest inventory of a single concession do not affect the market price of timber.
11. Brennan and Schwartz (1985) and Dixit and Pindyck (1994)-chapters 6 and 7, relax this assumption.
12. The model does not consider the tax effect over the cash flows. We can add taxes with no additional problems.

13. We adopt a dynamic programming methodology instead of the contingent claims analysis, due to the lack of available data of Amazon timber industry, as well as the nonexistence of an environmental products on any Brazilian trading floor.
14. See Dixit and Pindyck (1994) chapter 5, equation 28, for a contingent claims equivalent approach when the underlying follows a mean-reverting geometric process.
15. More about FDM can be found in Ames (1977) or Smith (1971), and the employed methodology is available from authors upon request.
16. See Dixit and Pindyck (1994) chapter 5.

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APPENDIX A

A.1 – Timber Volume (Biomass) Estimates

The amount of biomass in a region is one of the value determinants of the concession of a forest reserve. It depends basically on the soil quality, the climate and other characteristics that are not directly observable but are spatially related.

The present work proposes that a mapping be carried out of the Legal Amazon in order to verify which regions have highest potential for economic activities related to wood extraction. The qualities of the data used and methodological limitations recommend that the results must be seen as a first step. The biomass density data came from the RADAM database project, which in 1991 measured the density of wood for 2400 localities. The time elapsed since this measurement was done and the spatial dispersion of the sample indicates the fragility of the results. Considering the methodological aspect, it was only possible to construct biomass estimates down to the level of a single municipality (corresponding roughly to a county), which implies excessive aggregation in most of the cases.

The measures obtained from the RADAM project correspond to particular points and do not cover the entire area of a potential concession, making it necessary to extrapolate or predict these measures for the whole area. Table 5 shows that 300 municipalities were not considered and that 31 had less than 3 hits.

[Table 5 here]

The prediction will be carried with a model that relates the density of biomass (b) with the density of neighboring regions, and explanatory variables (x) which are measured for the whole area.

The explanatory variables considered are geological and ecological factors such as the kind of soil, vegetal cover, altitude, distance from the sea; and climatic factors, including in this category rainfall and mean temperature per quarter of the year. Besides these factors related to measurable characteristics of each region, we considered the influence of neighboring regions. That is, it will be assumed that biomass density varies uniformly over the space, which implies that the biomass density of a region is an estimator of biomass density of neighboring regions.

The research (IBGE – The Brazilian Institute of Geography and Statistics) identified for the Legal Amazon homogeneous regions according to the kind of soil (S) and the kind of vegetal coverage (V), uses the same classification adopted by RADAM. Besides these characteristics, this research also measured the mean temperature (T) and the mean precipitation per quarter for each municipality. The mean altitude and distance from the sea may be obtained from other sources. All these latter variables will be denoted by (C). The variables (S,V) are known for each point of the RADAM sample, as well as means for municipalities. The variables (T,C) are known only as means at the municipal level.

The RADAM sample refers to places – identified as points since they are small areas (1 ha) – and the results are related to areas. In order to make the data compatible with the level of aggregation of the results, the model was estimated with the RADAM sample, and predicted on an aggregate basis. It has two versions, one including the density effect of neighboring regions, and the other ignoring it. Naturally, the first one is an unrestricted form of the second and, in that way, the models will be presented in the desegregated form.

$$b_i = \rho W_i b + \sum a^j s_i^j + \sum c^j g_i^j + \sum d^j v_i^j + e_i \quad e_i \sim (0,\sigma^2) \qquad \textbf{(13)}$$

where:

b_i : density of biomass for $i \in R$

M(m) : set of the points in municipality m

W : neighborhood matrix between the RADAM points

j : altitude and distance from the sea, mean temperature and rainfall in each quarter

s_i^j : variable indicating the kind of soil (j) at point i

g_i^j : variable indicating the kind of vegetal cover (j) at point i

v_i^j : logarithm of variable (j) at point (i), with $v_i^j = v_m^j \;\; i \in M(m)$.

ρ : spatial correlation coefficient.

After the model's estimation, it is necessary to obtain the aggregate result per municipality, $E(\hat{b}_m) = \int_{x \in M(m)} b_x$. Hence, it is necessary to integrate each part of equation (13), where (p(x)=k) is the probability of (x). Except for the neighbor effect part, the integrals are exact.

$$\int_{x \in M(m)} a^j s_x^j \; p(x)\partial x = a^j \int_{x \in M(m)} s_x^j \; p(x)\partial x = a^j x_m^j$$

$$\int_{x \in M(m)} c^j g_x^j \; p(x)\partial x = c^j \int_{x \in M(m)} g_x^j \; p(x)\partial x = c^j y_m^j$$

$$\int_{x \in M(m)} d^j v_x^j \; p(x)\partial x = c^j \; v_m^j \int_{x \in M(m)} p(x)\partial x = d^j v_m^j$$

where:

x_m^j : proportion of municipality (m) that has soil type (j)

y_m^j : proportion of municipality (m) that has vegetal cover (j)

Empirical Results

The regressors of the model were grouped in the vectors: (S) indicating the kind of soil; (V) the kind of vegetation; (T) the temperature per quarter; (C) the rainfall, altitude and distance from the sea; and (W) the neighbor effect. The model represented by Eq.(13) is specified in general form and the best transformation must be chosen for b_i. To keep the results interpretable we will choose only between the identity transformations, which correspond to ($e \sim N(0,\sigma^2)$) or ($e \sim LN(0,\sigma^2)$). We estimated the model with desegregated data and all the explanatory variables, considering these two transformations. Than we choose the one which maximized the likelihood. The results indicated the logarithmic transformation, as can be seen in Table 6.

[Table 6 here]

The total number of regressors is 22 and the sample has 1968 points. Although the degrees of freedom are more than sufficient, the objective of extrapolating the results outside the sample recommends avoiding redundant variables in trying to reach a "structural" model. We therefore tested different selections within the set {S,V,C,T} and chose the one which minimized the standard error and the Akaike information criteria (AIC). The likelihood of the model with spatial correlation cannot be computed since It depends on |I-W|, a matrix whose dimension equals the number of observations (N), which is 2400. However, as long as the element omitted is the same for all models with spatial effects, the selection criteria were not affected.

The results in Table 7 show that the best model is (C,V,W) which includes the neighbors effect. Although being the best model, it relies on the homogeneity hypothesis and can be used to predict a smaller number of municipalities since we do not have neighborhood information for many of then. For this model we obtained a biomass lognormal distribution with mean 100 m^3/ha and standard deviation of 0.40 from the associated normal distribution. However, the effective wood density per hectare corresponds only to a fraction of the actual wood density per hectare. The rest of the density value includes damage from extraction procedures and area for natural preservation. The estimated value with mean 100m^3/ha was divided by four to take these aspects into account, leading to a biomass mean of 25m^3/ha an estimate consistent with Barreto (1999).

[Table 7 here]

A.2 – Timber Price Estimates

Figure 6 shows the monthly time series data of timber price for Brazilian Mahogany exporting data, Malaysian Hardwood logs and USA Softwood logs, those two latter were collected from IFS (International Finance Statistics) database. For comparison proposes, Mahogany data were adjusted to the same level of Malaysian and USA timber.

[Figure 6 here]

It is not straightforward which data to use. The wood produced by the concession is not yet traded on international market, making difficult the estimation procedure.

The model for timber price should attend to some conditions. Real options model needs a model as simple as possible to avoid complex solution methods. Since timber is a commodity, its price should be stationary following a mean-reverting process with long-run equilibrium mean. Both conditions suggest an AR(1) process Eq. (14)

$$\Delta P_t = a + bP_t + e_t \qquad e_t \sim N(0,\sigma_e^2) \tag{14}$$

For monthly data we get models with two or three lag variables, implying in an autoregressive process with order greater than one. However using annual data we obtain an AR(1) process for all timber prices. Therefore we choose the latter. Table 8 shows the results for each timber price data.

Mahogany and USA Softwood logs present unit root processes (b=0) which is not reasonable. Therefore we consider Malaysian data the one that better describes timber prices process. Calculations of (η) and (σ) parameters for the continuos time models are based on Pindyck and Dixit (1994) chapter 3 equation (19).

Since we use for the base case estimates coming from Malaysian Hardwood data, it is necessary to make some adjustments on the estimates, in order to apply them to Amazon timber data.

The level of both data is quite different (while Malaysian price is around \$180/m^3, Amazon price is around \$50/m^3). Multiplying the Malaysian volatility (52.751) by the ratio between the Amazon and Malaysian long-run average of timber price (0.248) makes the adjustment for the volatility (13.082). For the reversion speed parameter there is no need of adjustments, since we assume the same degree of speed reversion for both Malaysian and Amazon timber prices.

The current Malaysian Hardwood price (\$180/m^3 in US\$1995) is roughly similar to the long-run average estimated from Malaysian Hardwood data (\$202/m^3). Therefore, we set the Amazon long-run average price at its current price (\$50/m^3). One reason that explains that price difference is the fact that the available data of Amazon timber price as well as the extraction and transportation costs were collected just after the harvest, and for sales address to local market.

[Table 8 here]

TABLES

Table 1: Parameters for the base case

Variable		Value
Current timber inventory (m^3/ha)	I_0	25
Standard deviation of the current timber inventory I_0	S	0.41
Current timber price (\$/m^3)	P_0	50
Standard deviation of P (year)	σ_P	13.082
Standard deviation of timber inventory (year)	σ_I	0.1
Production cost without management techniques (\$/m^3)	c_1	40
Production cost with management techniques (\$/m^3)	c_1'	42
Timber inventory growth rate as % of residual inventory with/without management (year)	μ	0.01 / 0
Long-run equilibrium mean	$\overline{P}$	50
Discount rate (year)	ρ	0.15
Reversion speed	η	0.473
Maximum cutting rate (m^3/year)	q_{max}	16.10^3
Minimum timber inventory for preservation purposes imposed by regulation (m^3/ha) (50% of the current timber inventory)	I_{min}	12.50
Concession Time (years)	T	30

Table 2: Concession Value (\$/ha)

	NPV	$F(P_0,I_0,t_0)$	$V(P_0,t_0)$
Management	3.9	9.9	8.8
No Management	2.8	8.7	7.9

Table 3: Concession Value ($/ha) Relative to Disturbances in the Initial Conditions

Alternatives	(I_0,P_0,I_{min})	NPV	$F(P_0,I_0,t_0)$	$V(P_0,t_0)$
Base Case	(25,50,12.5)	3.9	9.9	8.8
(-10) Inventory	(15,50,12.5)	2.9	7.3	5.3
(+10) Inventory	(35,50,12.5)	3.9	10.1	9.7
(x 0.5) Price	(25,25,12.5)	0	6.8	5.9
(x 2.0) Price	(25,100,12.5)	16.7	20	17.9
(x 0.5) I_{min}	(25,50,6.25)	3.9	10.2	10

Table 4: Concession Value ($/ha) Relative to Uncertainties ($/ha)

Alternatives		$F(P_0,I_0,t_0)$	$V(P_0,t_0)$
Base Case	$\sigma_P = 13.436$, $\sigma_I = 0.1$	9.9	8.8
(x 0.5) Price Uncertainty	$\sigma_P = 6.718$	8.7	7.7
(x 1.5) Price Uncertainty	$\sigma_P = 26.872$	11.5	10.2
(-)Inventory Uncertainty	$\sigma_I = 0.01$	10.2	9.3
(+)Inventory Uncertainty	$\sigma_I = 0.15$	9.4	8.3

Table 5: Distribution of Municipalities over the RADAM sample

Class	0	1-3	4-5	6-10	11-15	16-20	21-40	40-60	>60	Total
Municipalities	300	31	18	17	25	12	12	10	7	442

Table 6: Choice of the Transformation:

Model	(level)	(logarithm)
LVM	-7514.34	-7140.36

Table 7: Model with 1968 RADAM points

Variables	Std. Dev.	Number of Regressors	Spatial Correlation (ρ)	AIC
C,T	.4253	10	-	-1.700
S,V	.4313	12	-	-1.670
S,C,T	.4247	17	-	-1.695
V,C,T	.4224	15	-	-1.708
S,V,C,T	.4217	22	-	-1.705
C	.4254	6	-	-1.703
C,V	.4223	11	-	-1.713
C,T,W	.4024	11	.45	-1.809
S,V,W	.4138	13	.43	-1.752
S,C,W	-	-	-	-
S,V,C,T,W	.4008	23	.45	-1.805
C,W	.4021	7	.47	-1.815
C,V,W	.4021	12	.43	-1.810

Table 8: Timber Price Estimates

	b (t-test)	a	σ_e	d.w	η	σ	H (half-life) ln(2)/η	Long-run average
Brazilian Mahogany	-0.11(0.8)	24.5	20.0	1.82	0.117	13.082	6 years	US$ 50/m^3
Malaysian Hardwood logs	-0.37(2.0)	74.9	60.0	2.2	0.473	52.751	2 years	US$ 202/m^3
USA Softwood logs	-0.17(1.1)	27.7	21.0	2.00	0.186	18.463	4 years	US$ 163/m^3

FIGURES

Figure 1: Concession Value V ($/ha) X Timber Price Volatility (p.v.) – 30 yrs to maturity

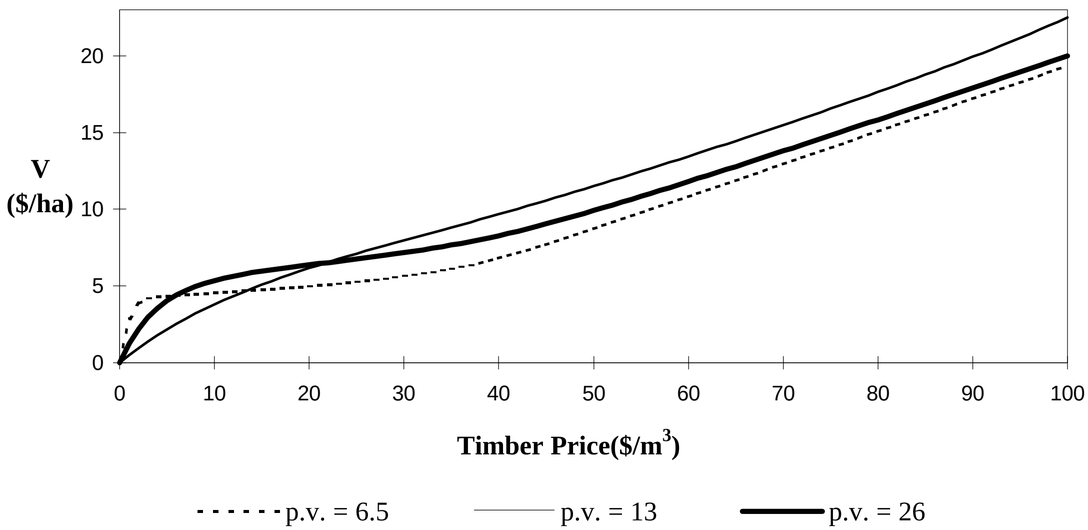

Figure 2: Concession Value V ($/ha) X Inventory Volatility (i.v.) – 30 yrs to maturity

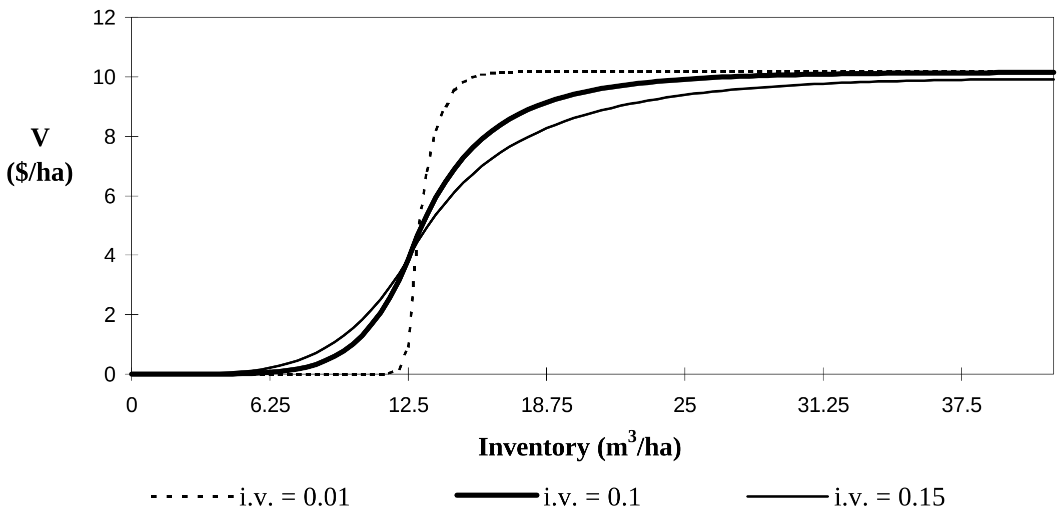

Figure 3: ROT X NPV - Concession Value V ($/ha) – 30 yrs to maturity

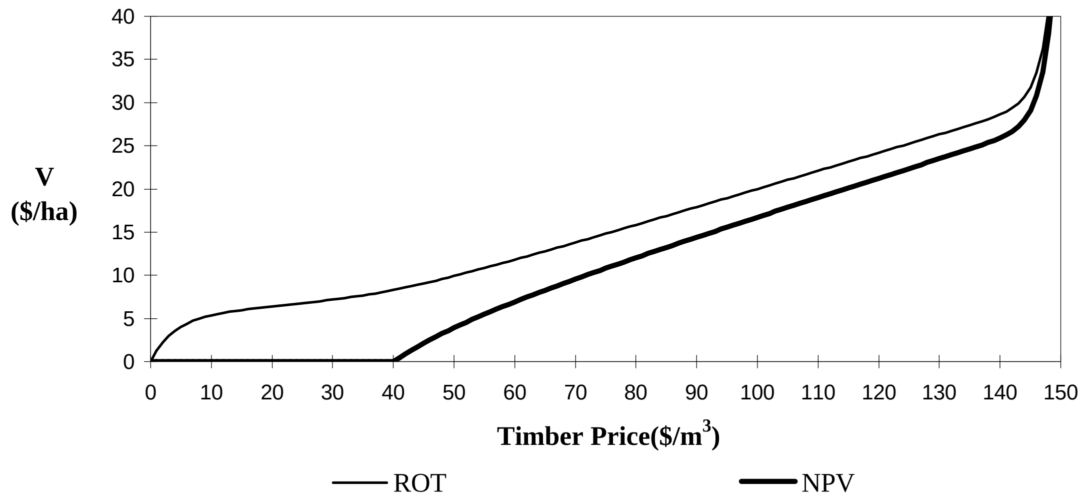

Figure 4: Concession Value V ($/ha) X Time to Maturity (t)

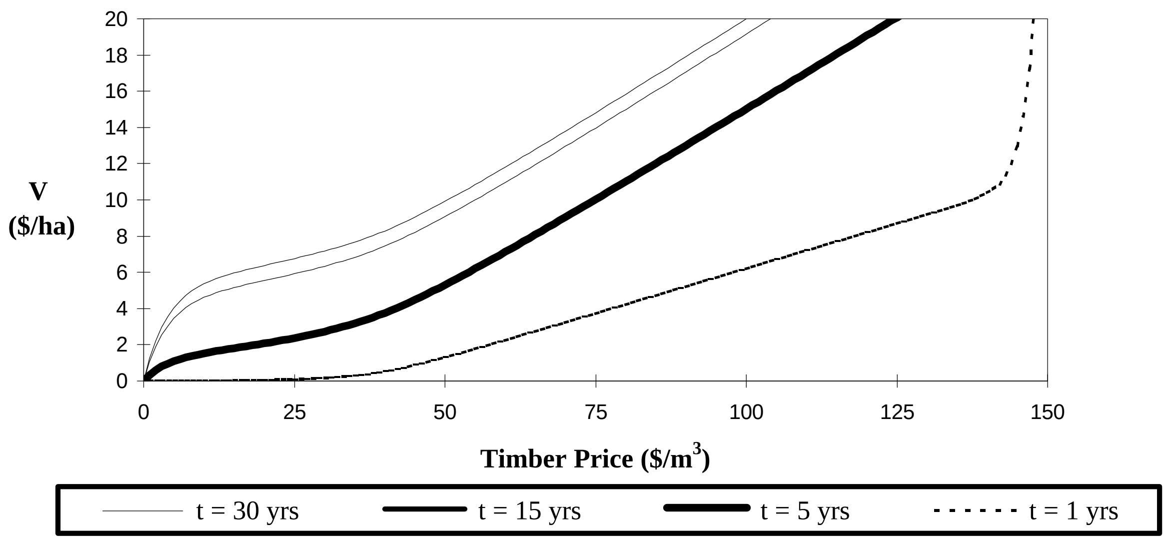

Figure 5: Concession Value V ($/ha) X Discount rate (r - %year) – 30 yrs to maturity

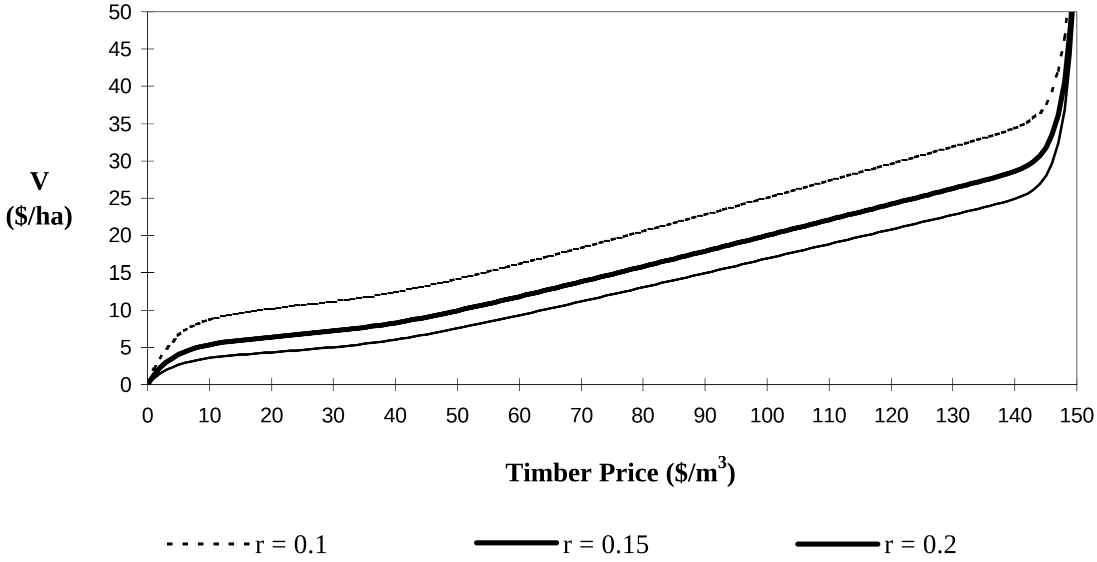

Figure 6: Timber Prices ($/m^3) in US$1995