THE OPTION VALUE OF FOREST CONCESSIONS IN AMAZON RESERVES *

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Abstract

The Brazilian government is now planning to implement natural forest concessions for timber extraction. In addition to the legal requirements imposed on the management of concessions (minimum reserves, maximum extraction rates, etc.), the value of concessions is closely linked with uncertainties in estimates of the volume of commercial logs within the concession area and on future timber prices.

This paper proposes a method to appraise the value of forest concessions based on the real option theory (ROT). By combining the hypothesis of uncertainty in the volume of logs in a concession, logs prices modeled as a mean-reverting stochastic process, and applying inter-temporal maximization of profits, the method provides a more realistic estimate of the market value of concessions than does Net Present Value (NPV), which does not take these uncertainties into account.

Comparison between estimates using NPV and ROT shows that the latter are systematically higher. For the base case, the concession value using ROT is 153% higher. Since forest concessions are public resources, differences of that magnitude cannot be neglected. The paper also proposes methods to estimate the probability distribution of logging volumes in concession areas along with future prices. The volume distribution is specified in a spatial model as a function of geographic characteristics of the area as well of the neighboring areas.

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1 – Introduction

The Brazilian government has been developing a concession policy to exploit timber harvesting on Amazon forestry reserves (Flonas), located mainly in the Legal Amazon. As the concession right will be granted by auction, concession valuation is fundamental, and being a public resource, this valuation must be done as precisely as possible, 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), with high uncertainty 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 which deal with concession or asset valuation for privatization purposes use the Net Present Value (NPV) methodology, which relies basically on the expected free cash flow over the life of the undertaking, discounted by the proper interest rate. NPV does not consider such factors as the value aggregated by future efficient management of the asset, uncertainties over key variables or changes in regulatory policies. Real Option Theory (ROT) incorporates the effect of efficient management and other uncertainties, as well as changes in the 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 minimum value, 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 raising the cutting rate.

The greater flexibility of ROT adds value to the concession in comparison to NPV. It is well known the fact that for option without sufficiently moneyness the difference between the ROT and NPV can be very significant.

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

The option theory prices the concession in a way to maximize the revenues from the current cutting rate 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, or to a higher rate of return demanded by them to offset the investment risk. Nevertheless, the option value can be very useful and help government in setting for example a minimum bid price as a percentage of the option value.

Several papers examining the concession value of natural resources using option theory can be found in real options literature. Pindyck (1984) was the first to introduce real option theory to appraise a renewable resource with property rights. Morck, Schwartz and Stangeland (1989), the reference paper adopted in this work, apply the real option theory to value a white pine concession in Alberta, Canada using uncertainties and management flexibility to react to changes in the economy. Finally, Brennan and Schwartz (1985) apply the same methodology to value a non-renewable natural resource.

In this paper we use real option theory to appraise the concession value of a typical Amazon forestry reserve (Flona) in the Legal Amazon region of Brazil, and include the uncertainty effect of variables

[1] More comparisons between NPV and ROT can be found in Dixit and Pindyck (1994) or in Trigeorgis (1996).

and constraints from 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 chosen. These parameters are selected in a way to reflect a range of perspectives about productivity or market evolution. The numerical results will be the best estimation for the concession value conditioned on the set of parameters adopted[2], and therefore will mainly indicate how one can value a forest concession in an optimal way.

The main characteristic of the model is to consider uncertainty about the evolution of timber prices, timber inventories, as well as the uncertainty about initial quantity of biomass (timber inventory) in the lease area and its effect over time. The model also investigates how changes in regulatory policy, such as: changes in the minimum regulated inventory held in the lease area, the use of management techniques, the duration of the concession, affect the concession value. Because the concession value depends on the biomass density[3] in the concession area, which is not known[4], a methodological procedure has been proposed to estimate it. The biomass density data came from the RADAM project (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.

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). For an excellent application of ROT to value forest resources based on non-economic concepts see Conrad(1997). These environmental issues, however, are not considered in the analysis of this study, which is restricted to the question of determining the economic market value of concessions.[5]

The paper is organized as follows: the next section describes the Amazon forest-concession policy in Brazil; the third section presents the forest concession valuation methodology by Real Option Theory (ROT) and Net Present Value (NPV) models; and the fourth section presents the forest concession results and several sensitivity analyses and comparisons of ROT and NPV. The last section summarizes the results.

2 – Amazon Forest 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), in 1997 the region produced 25 million m³ of wood, 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.

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[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 informations. The rest of the biomass on the concession area is therefore estimated through econometric procedures.

[5] See Young and Fausto (1997). Valuation through the purely economic aspect has, however, some advantages: (i) easier understanding with less propensity to generate controversies; (ii) minimized value estimate for the natural resource; (iii) 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 A. and Ana C. Barros (1996) - Introduction

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. According to the Brazilian Forest Act (Law 4771 – September 15, 1965 – Art.5), the Flonas are 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 and 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 the 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 create 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 of 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 and providing for proper management.

Faced with the current political climate 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 (with the latter required to set up a Brazilian subsidiary to operate the concession).

The duration of the lease and the 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, selective cutting.

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[7] Additional information about existing Flonas, legislation, and management techniques can be found at www.ibama.gov.br

[8] See Ferraz C. and Ronaldo Seroa da Motta (1999)

3 – Forest Concession Valuation Methodology

Papers based on Real Option Theory (ROT) are becoming common in the economic literature on valuation of natural commercial resources. We mention three papers for their importance and relevance as the ROT pioneers relative to natural resource investment decision problems. Pindyck (1984), the first to introduce real option theory to appraisal a renewable resource with property rights. Morck, Schwartz and Stangeland (1989) apply ROT to value a white pine concession in Alberta, Canada, considering management flexibility to react due to changes in the economy. Brennan and Schwartz (1985) apply ROT to value a nonrenewable natural resource investment decision problem with uncertainty about future outcomes of a project to obtain optimal development, operation and abandonment policies. These papers apply ROT instead of the classic technique of predictable future cash flows, known as Net Present Value (NPV), and argue that ROT may be preferable to NPV. We follow the same approach for comparing ROT and NPV.

3.1 – The Real Option Model

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

The inventory of timber, I(m^3/ha), evolves as the following standard stochastic differential equation from the population ecology literature, with dw as the Wiener process, and where dz and dw are uncorrelated processes[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), [μ.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 growth rate of timber inventory (burning, discovery of new or valuable species, loss of market share).

The assumption for the logging company cost function, C(q), is very general. We adopt a linear cost function relative to timber cutting rate q. The linear function will lead to corner (*bang-bang*) solution relative to q, and was adopted due to the lack of available data.

$$C(q) = c_1\, q(P,I,t)$$

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

Letting F(P,I,t) denote the concession value[12] of the forestry resource given the current timber price P, the present timber inventory I, and time t until the end (t = T) of the lease. Letting π (q^*) represent

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[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 with 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 effect of the taxes on the cash flow. We can add this without any problem to the model.

the cash flows associated to the harvest. We adopted a dynamic programming analysis for evaluate the concession with an appropriated exogenous discount rate ρ. The stochastic optimization problem for 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) define the processes for the state variables P and I respectively.

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

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

Using Itô's Lema and dynamic programming valuation[13], one can demonstrate that the concession value, F(P,I,t), follows the optimality equation (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 condtions and constrains Eq.(5-10).

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

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

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

The boundary conditions guarantee that: Eq.(5) - at the end of the lease, the concession value is zero; Eq.(6) - if timber price drops to zero the lease value is nil; Eq.(7) - if the timber price becomes very large, changes in the lease due to changes in prices will be linearly 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 drops to zero. Eq.(10) - sets a minimum regulatory limit (I_{min}) to timber inventory, below which the extraction is no longer allowed.

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

Thus, given the set of parameters $\varphi = (c_1, \mu, r, \sigma_p, \sigma_I, q_{max}, I_{min}, P_0, T)$ and the current timber inventory (I_0), the concession value $F(\varphi, I_0, t=0)$ can be calculated.

We often do not have full information about the current level of timber (I_0) in the lease area. Instead, we have only a way to estimate its probability distribution function, $p(I_0)$, through sampling. Nevertheless, we can calculate the concession value $V(\varphi,t=0)$ in a Real Option approach, performing

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[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 traded on BMF, the Brazilian mercantile exchange market. Without any future market of timber we would have to use proxies coming from international timber market in order to use the contingent claims analysis.

[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).

an integration among all the option value $F(\varphi, I_0, t=0)$ to consider the probability distribution of initial inventory. Eq. (11) shows how this integration is performed.

$$V(\varphi, t=0) = \int F(\varphi, I_0, t=0).p(I_0)dI_0 \qquad \textbf{(11)}$$

3.2 – The Net Present Value Model

We adopt a probabilistic NPV model in order to compare the results with ROT methodology. Without using a probabilistic NPV model, the comparison between NPV and ROT is not straightforward. Probabilistic NPV means that the free-cash flows coming from harvest are also uncertain.

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

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

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

3.3 – The Model Parameters

The parameters assumed in this paper come from selected papers about timber industry in Amazon and international market; and estimations presented in Appendix A.

The following parameters come from timber industry in Amazon[16]: 1) concession time: 30 years; 2) total area: 120×10^3 ha; 3) effective density of extraction: $25 m^3/ha$[17]; 4) maximum annual cutting rate: 16×10^3 m^3; 5) variable cost with (without) management techniques[18] $\$40/m^3$ ($\$42/m^3$); 6) minimum timber inventory imposed by regulatory policy: 12.50 m^3/ha[19]; 7) annual discount rate of timber industry[20]: 15%.

The parameters estimated in Appendix A are: 1) probability density function for current timber inventory: lognormal with mean $25 m^3/ha$ and standard deviation of 0.41 for the corresponding associated normal; 2) annual timber price volatility[21]: 13.436; 3) reversion speed parameter for timber price: 0.473.

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[16] In particular Barreto (1999), Veríssimo et al (1992); and Stone(1997).

[17] This paper uses for extraction purposes the effective wood density per hectare, which 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 $100 m^3/ha$ was divided by four to take into account these aspects. The estimates will be presented in Appendix A.

[18] Variable costs are extraction costs plus costs of transportation.

[19] We assume that 50% of the effective lease area cannot be harvested.

[20] Due to the lack of data available in Amazon timber industry, we arbitrarily set the discount rate. This rate is not derived from CAPM, since we adopt a dynamic programming methodology instead of the contingent claims analysis. Nevertheless, sensitivity analysis will be made relative to this parameter.

[21] Since we use for the base case estimates coming from Malaysian Hardwood data, it is necessary to adjust the estimates to Amazon timber data, because the level of both data is quite different (while Malaysian price is around $\$180/m^3$, Amazon price is around $\$50/m^3$). The adjustment for the volatility is made by multiplying the Malaysian

The parameters from international timber industry include[22] 1) annual inventory volatility: 10%; 2) inventory growth rate as a percentage of the residual inventory held: 1% (0%) with (without) management techniques.

For the base case we set the current timber price in the Amazon lease 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$). We further assume that the long-run average price is equal to the current price[23]. Due to the lack of available data of Amazon timber price, the reversion speed and price volatility parameters were estimated from International Hardwood Prices and adopted as a proxy to Amazon timber price parameters.

4 – Amazon Forest Concession Results

We assume the typical values for the base case as shown in Table 1:

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$)	P_0	50
Standard deviation of P (year)	σ_P	13.436
Standard deviation of timber inventory (year)	σ_I	0.1
Production cost without management techniques ($/$m^3$)	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 imposed by regulation (m^3/ha)	I_{min}	12.50

The concession value was calculated using Traditional (NPV) and Real Option Theory (ROT) approaches. The concession value was appraised by assuming that: 1) the current timber inventory in known, and 2) the current timber inventory is given by the probability distribution estimated in Appendix A. In the latter case the concession is given by $V(\varphi)$, and in the former by $F(\varphi,I_0)$.

Table 2 presents the Concession Value for the base case, considering the management effect. Table 3 presents the Concession Value for three combinations (NPV, $F(\varphi,I_0)$, $V(\varphi)$) considering disturbances in the initial conditions of timber inventory and price, for no management. Table 4 presents the sensitivity analysis of the results relative to price and inventory uncertainties.

Table 2: Concession Value ($/ha): management Hypothesis

Conditions	NPV	$F(\varphi,I_0)$	$V(\varphi)$
Management	3.9	9.9	8.8
No Management	2.8	8.7	7.9

volatility estimated in Appendix A (52.751) by the ratio between the Amazon and Malaysian long-run average of timber price (0.254). This leads to a 13.436 volatility. 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.

[22] In particular, Morck, Schwartz and Stangeland (1989)

[23] To better reproduce the current international market position. The current Malaysian Hardwood price is $180/$m^3$ (in US$1995); roughly similar to the long-run average estimated from Malaysian date by our procedures ($196/$m^3$). Therefore, we set the Amazon long-run average price at its local average current price ($50/$m^3$). One reason that explains why current Amazon timber price is bellow the international Hardwood market level is the fact that the available data of timber price in Amazon as well as the extraction and transportation costs were collected just after the harvest, and for sales address to local market.

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

Alternatives	(I_0,P_0,I_{min})	NPV	$F(\varphi,I_0)$	$V(\varphi)$
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): no management

Alternatives		$F(\varphi,I_0)$	$V(\varphi)$
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

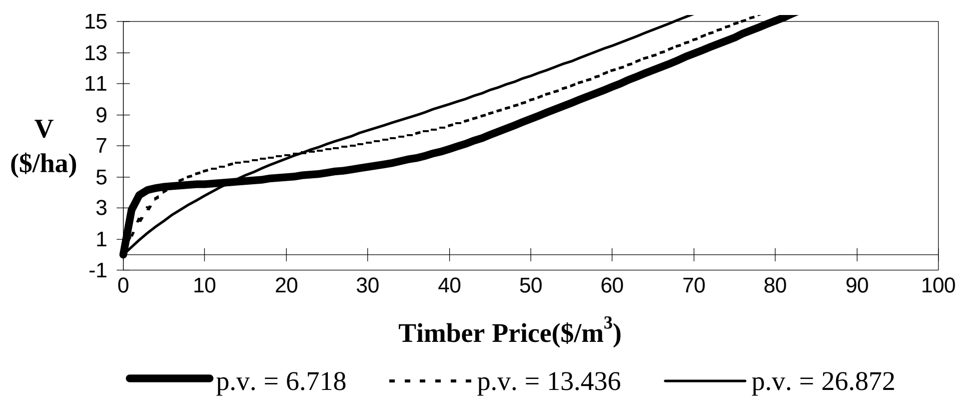
The results show that:

- The NPV technique undervalues the concession value. For the base case, the ROT model computes a 153% higher result.
- The concession value decreases by assuming that the current timber inventory is unknown, $V(\varphi) < F(\varphi,I_0)$. Therefore, the uncertainty about the current amount of timber in the lease area decreases the value of the concession.
- 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 option pricing methodology (ROT) to value the concession in Amazon Reserves.

Figure 1 shows the sensitivity analysis for the concession value V ($/ha), 30 years to maturity, relative to price volatility (standard deviation per year). The option presents the typical shape relative to the mean-reverting process[24]. Due to the change in concavity, the volatility has two different effects on the option value. For the region of positive second derivative relative to prices (F_{PP}), price volatility increases the option value. For the others cases we found the opposite effect. One can inspect the signal of the term F_{PP} in Eq.(4) to verify this effect.

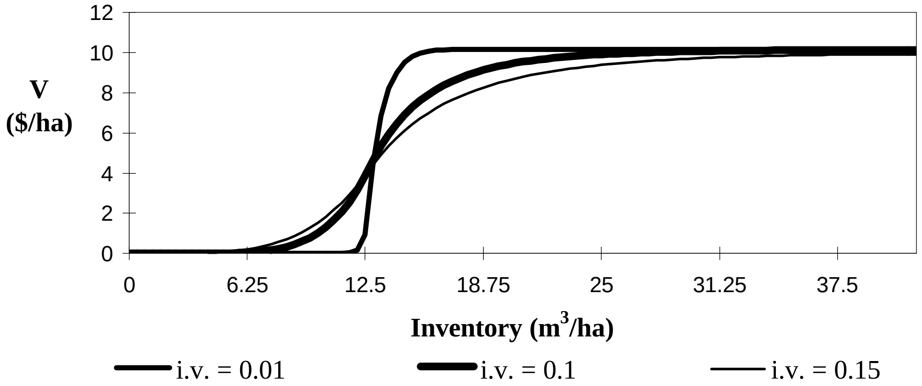
Figure 1: Concession Value V ($/ha) X Timber Price Volatility (p.v.) – 30 yrs to maturity



[24] See Dixit and Pindyck (1994) chapter 5.

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

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



Note that for inventories beyond the regulatory minimum limit (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 the regulatory minimum limit), the concession still has a positive value, contrary to the NPV technique, which gives a nil concession value.

For inventories above the regulatory minimum limit, 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 limit (12.5 m^3/ha), and a negative value for inventories above that limit. It explains the unusual effect of decreasing the option value due to an increasing of the volatility parameter. In Morck, Schwartz and Stangeland (1989) it is not possible to observe this fact because there was no regulatory minimum limit for the harvest. Therefore only the right side of figure (2) was shown.

Figures 3 shows the differences for concession value V ($/ha) calculated by NPV and ROT versus price. Even adopting a probabilistic NPV, we can still verify that NPV and ROT converges for infinite prices.

As expected, note that for out-of-the-money options the difference between the two methodologies is higher than for options deep-in-the-money.

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

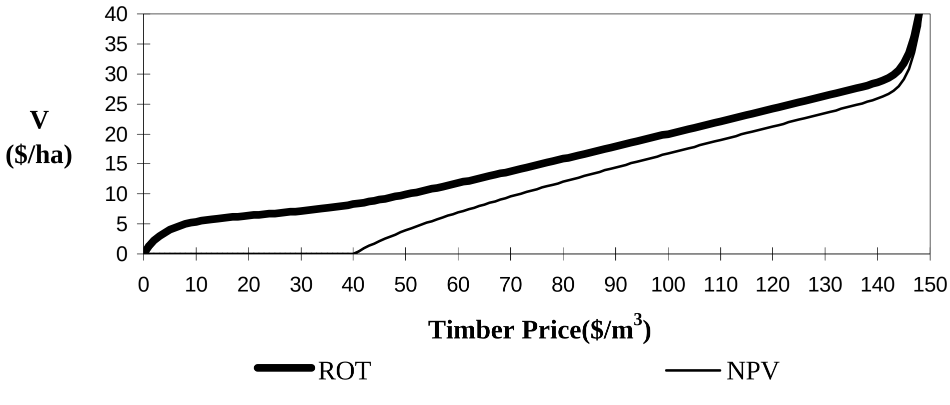
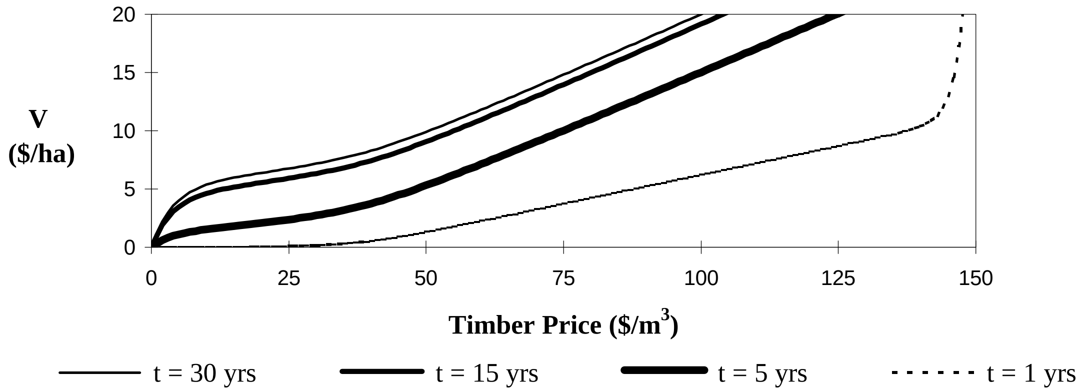


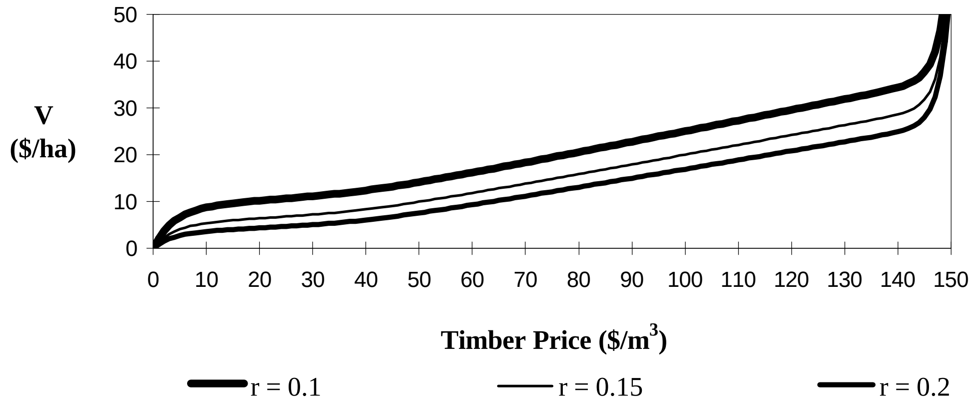
Figure 4 shows the how the concession value V ($/ha) calculated by ROT changes relative to time to maturity (t) in years. Note that for time to maturity superior to 15 years, there is no increase in the option value.

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



Figures 5 shows the differences for the concession value V ($/ha) relative to changes in the 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 concession value changes by 40% due to changes of 0.05 points in the discount rate.

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



6 – 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 changes in the economy, and the uncertainty about the future behavior of critical variables.

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

ROT allows analyzing the regulatory policy effect. Related to regulatory policy our results for the base case show that the concession value increases only by 3% in response to a 50% reduction in the minimum regulated inventory; and for a lease time superior than 15 years of exploration the concession value remains roughly the same. Related to management, as there is no economical value coming from it, management should be determined as an obligation on concession contracts.

Our results for the base case show that: (i) there is no need for a reduction on the regulated minimum inventory; (ii) 15 years appears as an ideal concession time since no improvements can be obtained by applying longer duration; (iii) management should be obligated on concession contracts since it reduces concession value; and (iv) as the concession value is very sensitive to changes on discount rate, the latter should be settled in a very carefully way.

The paper also proposes methods to estimate the probability distribution of log volumes in concession areas as well as future log 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. These parameters can be chosen to reveal any other perspective about the Amazon Forest.

REFERENCES

1. Ames, William F.; *Numerical Methods for Partial Differential Equations*. Academic Press, 1977.
2. Anselin, Luc. *Spatial Econometrics: Methods and Models* (1987).
3. Barreto, Paulo; *Rentabilidade da Produção de Madeira em Terras Públicas e Privadas na Região de cinco Florestas Nacionais da Amazônia* - Relatório Técnico (1999).
4. Barreto P. and Adalberto Veríssimo; *Informações e Sugestões para a criação e gestão de florestas públicas na Amazônia* - Relatório Técnico, 1999.
5. Brennan M.J. and Eduardo Schwartz;. Evaluating Natural Resource Investments - Journal of Business, 58, April, 1985.
6. Conrad, Jon M; Analysis On the option value of old-growth forest. Ecological Economics 22. Elsevier.1997.
7. Dixit A. and Robert Pindyck; *Investment Under Uncertainty* - Princeton University Press, 1994.
8. Ferraz C. and Ronaldo Seroa da Motta; *Concessões Florestais e Exploração Madeireira no Brasil: Condicionantes para a Sustentabilidade* - PPP IPEA, Dec. 1998.
9. Lenos Trigeorgis; *Real Options*: Managerial Flexibility and Strategy in Resource Allocation - The MIT Press, 1996.
10. Morck R., Schwartz E. and David Stangeland; *The Valuation of Forest Resources under Stochastic Prices and Inventories* - Journal of Financial and Quantitative Analysis, vol. 24, no. 4, Dec. 1989.
11. Robert S. Pindyck. *Uncertainty in the Theory of Renewable Resource Markets.* – Review of Economic Studies, Vol. LI (2) No.165, april 1984.
12. Smith, G.D.; *Numerical Solution of Partial Differential Equations.* Oxford Mathematical Handbooks. Oxford University Press, 1971.
13. Stone, Steven W.; *Evolution of the Timber Industry Along an Aging Frontier: The Case of Paragominas (1990-95).* World development, vol 26, n3.1998 .
14. Veríssimo A. and Ana C. Barros; A Expansão da Atividade Madeireira na Amazônia - Impactos e Perspectivas para o desenvolvimento do setor florestal do Pará – IMAZON, 1996.
15. Veríssimo A., Barreto P., Mattos M., Tarifa R. and C. Uhl; *Logging Impacts and Prospects for Sustainable Forest Management in an old Amazonian Frontier: the Case of Paragominas* - Forest Ecology and Management, vol. 55, 1992.
16. Veríssimo A. and S. Júnior; *Política Florestal Coerente para Amazônia: Zoneamento Florestal, FLONAS e Monitoramento Florestal* IMAZON – July 1997.
17. Young C.E.F., Fausto J.R.B.; *Valoração de Recursos Naturais como Instrumento de Análise da Expansão da Fronteira Agrícola na Amazônia* - TDI 490 -IPEA - June 1997.
18. Relatório Técnico RADAM.

APPENDIX A

A.1 - 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 quality 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 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: 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

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 disaggregated 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

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)[25] at point (i), with $v_i^j = v_m^j \; i \in M(m)$.

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). 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 disaggregated 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: Choice of the Transformation:

Model	LVM| transformation	Adding log	LVM
(SVCT|level)	-7514.34	-	-7514.34
(SVCT|logaríthm)	1969.51	9109.87	-7140.36

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[26]. The results in Table 7[27] show that in both cases – considering or not the influence of neighbors – the model (C,V) is the best one. This model (C,V), which does not include the neighbor effect, despite the small explanatory capacity (<10%), does not rely on the density homogeneity hypothesis – adopted to estimate the neighbor effect – and allows prediction for a larger number of municipalities. Hence, it will be one of the selected models. The other models selected include all the

[25] Mean temperature in each quarter, rainfall in each quarter, altitude and distance from the sea.

[26] The likelihood of this model cannot be computed since It depends on |I-W| ,a matrix whose dimension equals the number of observations (N), which is 2400. Another consequence of the large number of observations is the irrelevance of the information criterion for model selection.

[27] ρ is the number of regressors.

regressors except the neighbor effect (S,C,V,T), and the best model (C,V,W) that includes the neighbors effect. This last one, although being the best model, 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.

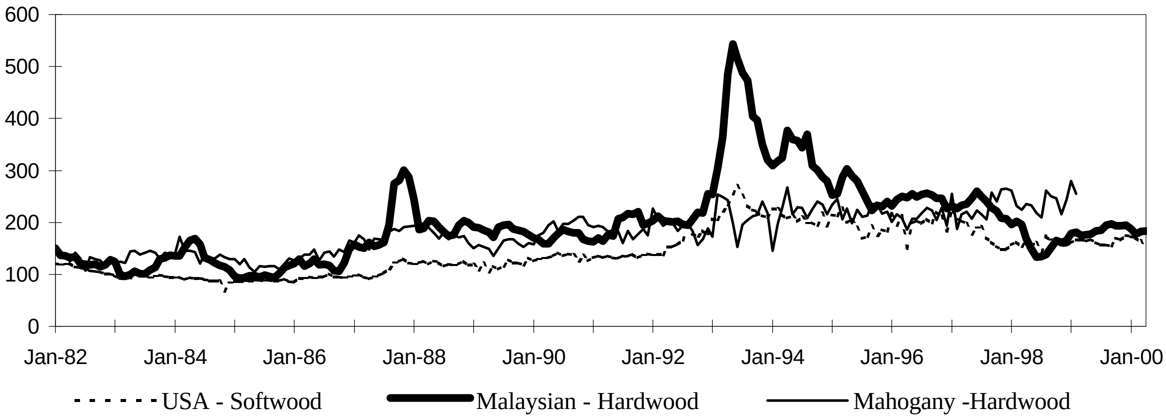
Table 7: Model with 1968 RADAM points

Variables	Std.Dev.	p	ρ
C,T	.4253	10	-
S,V	.4313	12	-
S,C,T	.4247	17	-
V,C,T	.4224	15	-
S,V,C,T	.4217	22	-
C	.4254	6	-
C,W	-	-	-
C,V	.4223	11	-
C,T,W	.4024	11	.45
S,V,W	.4138	13	.43
S,C,W	-	-	-
S,V,C,T,W	.4008	23	.45
C,W	.4021	7	.47
C,V,W	.4021	12	.43

A.2 – Timber Price Estimates

Figure 6 shows the monthly time series data of timber price for Brazilian Mahogany exporting data[28], Malaysian Hardwood logs and USA Softwood logs.

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



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)

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

[28] For comparison proposes, Mahogany data were adjusted to the same level of Malaysian and USA timber.

For monthly data we get models with 2 or 3 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. Mahogany and USA Softwood logs present unit root processes (b=0) which is not reasonable. Therefore we consider Malaysian data that better describes timber prices process. Calculations of (η) and (σ_e) parameters for the continuos time are based on Pindyck and Dixit (1994) chapter 3 equation (19).

Table 8: Wood Price Estimates

	b (t-test)	A	σ	d.w	η	σ_e
Brazilian Mahogany	-0.11(0.8)	24.5	20.0	1.82	0.117	17.584
Malaysian Hardwood logs	-0.37(2.0)	74.9	60.0	2.2	0.462	52.751
USA Softwood logs	-0.17(1.1)	27.7	21.0	2.00	0.186	18.463