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Estimating timber depreciation in the Brazilian Amazon

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DISCUSSION PAPER

Originally published by Ipea in July 1998 as
number 570 of the series Texto para Discussão.

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Brasília, January 2015

ESTIMATING TIMBER DEPRECIATION IN THE BRAZILIAN AMAZON[1]

Ronaldo Seroa da Motta[2]
Claudio Ferraz[3]

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RESUMO

O objetivo principal deste estudo é estimar o valor de depreciação de florestas da produção madeireira na região amazônica. Utilizam-se três principais metodologias recomendadas na literatura para analisar-lhes a capacidade em capturar esses valores de depreciação na região, graças às suas características de livre acesso que fragilizam a definição de direitos de propriedades. Identifica, ainda, diferenças metodológicas associadas a alguns fatores teóricos como taxas de desconto apropriadas e comportamento dinâmico ótimo que também têm um papel fundamental no caso da Amazônia. Conclui-se que a valoração das perdas de outros serviços relacionados à deterioração de capital natural na Amazônia será necessária para viabilizar o instrumental de contabilidade ambiental como instrumento de planejamento ambiental na região.

ABSTRACT

This study applies distinct methodological forest accounting approaches, following Vincent and Hartwick (1997) lines, to estimate economic depreciation of timber exploitation in the Brazilian Amazon region. Although our results may be not definitive ones due to data availability problems, this exercise has proved to bring about issues which, though are theoretical and methodologically fully recognised, are not always revealed in other regional studies. High timber stocks, lack of well defined property rights and informal economic relations are issues related to the Amazonian case that require great deal of caution when one is applying economic depreciation methodologies, as will be addressed on the basis of our results.

1 - INTRODUCTION

This study is part of an international project undertaken by the Forestry Department at the Food and Agriculture Organization (FAO) of the United Nations and The World Bank. It aims at the application of forestry accounting in distinct regional scenarios. Apart from Brazil, studies were also performed in Australia, Chile, Philippines and Zimbabwe.

To do so, methodological lines were set up in a background paper by Vincent and Hartwick (1997), carefully briefed and commented by distinguish experts and here denominated as V&H (1997).

The Brazilian case was selected to be applied in the Amazonian context. That choice was justified on the basis of the wide recognised importance of the region in ecological terms as well as its increasing economic relevance since it currently generates more than 70% of the total round wood produced in Brazil.

That choice was not taken however without considering the data availability problems since it will be requiring information which is usually difficult to find even in forestry activities taking place in modern economic scenarios. The open access features of the Amazonian context is by nature one of lack of institutional enforcement, proper managerial practices and, consequently, fragile information systems. We have made the most of data availability, even though, some generalizations have been necessary. Bearing that in mind, our results will need to be seen under this perspective.

On the other hand, the application of depreciation estimation methodologies in that Amazonian context has proved to bring about issues which, though are theoretical and methodologically fully recognized, are not always revealed in other regional exercises. High timber stocks, lack of property rights and informal economic relations, are issues that require great deal of caution when one is applying economic depreciation methodologies. We hope that in addressing them, we have attached a greater value added to this methodological exercise.

Previous estimates for natural capital depreciation in Brazil faced the same data barriers, particularly in forest accounts for which estimate values with 1985 as the closing year[1] were used. Apart from being more comprehensive in methodological procedures, our study was able to rely on recent survey data and cover the 1990/95 period which can capture the dramatic deforestation process and the radical increase in timber production started in the late eighties.

Whatever the context, environmental accounting faces theoretical and methodological controversies. Even though sustainability principles can explain

[1] See Seroa da Motta (1995) for a general view of these studies and Seroa da Motta and May (1995) for the particular case of forests. It should be noted that the user cost approach was employed with sustainable output rather than net profit measures.

methodological differences,[2] some theoretical issues, such as appropriate discounting and dynamic optimal behaviour, play an important role. This study will attempt to address these issues on the lines of V&H (1997) to the Brazilian Amazon.

Section 2 presents an overview of the forest conversion pattern in the Brazilian Amazon and its relationship to the local timber exploitation activity. Following H&V (1997), methodological approaches are presented in the following section. Due to the Amazonian context, property right enforcement issues are analysed in Section 4. The following section describes our estimation procedures and analyses the results. The last section offers additional comments in the appropriateness of forest accounting in the Brazilian Amazon and raises some questions related to its usefulness for environmental planning in the region.

2 - FOREST CONVERSION PATTERN IN THE BRAZILIAN AMAZON

2.1 - Socio-Economic Factors

Preservation in Brazil is legally set in the Forest Code and water legislation basically by restricting land-uses. The Forest Code, published in 1934 and revised in 1965, regulates the use of wood from forests, defines conservation units, restricts farming and logging activities, set criteria for burning and chainsaw uses and states sanctions and fines. At the same time, water legislation, due to the need to protect watershed mainly for domestic supply, introduced very strict rules and norms for land uses to preserve forest areas at river basins.

Despite the severity of these regulations, forest clearing at large scale has not been avoided in Brazil. No more than 8% of the Atlantic Forest, previously located over the most developed areas of the country, is left standing. The area of the Savannahs of Cerrados, in the central region, has been already cleared in half of its original size for farming purposes. Although less than 10% of the Amazon Forests has been cleared, the annual deforestation rate is still very high.[3]

Sustainable management practices for logging are already incorporated in the Brazilian environmental regulation. However, they do not succeed since abundant wood supply is available from agricultural expansion and lack of monitoring in such large areas. Nevertheless, even with the introduction of sustainable criteria to agricultural practices, forest clearing will continue to be a major source of wood supply while governmental agencies fail to deter illegal clearing.

[2] See, for example, Atkinson *et alii* (1997) and Seroa da Motta (1993).
[3] See Seroa da Motta (1997) for detailed indicators on deforestation in Brazil and their respective analysis.

Forest land conversion is the main driving economic force on forest use. Therefore, the process of privatization of forest and its land, accomplished by assigning private individual rights based on clearing for further titling, has been very harmful for sustainable purposes in the region. Although a retreat on this driving force could be expected with the recent land taxation law, which offers exemptions for forestry and forest conservation, its enforcement may take several years to be fully implemented.

Summing up, deforestation in Brazil is driven mainly by agricultural and logging activities. The expansion of these activities into open access areas has been very active despite legal restrictions. Apart from institutional fragility to enforce norms and rules, deforestation of important ecosystems is also a result of several economic factors, namely:

a) A highly concentrated land tenure system where small farms (less than 10 ha) cover less than 3% of the total farming area while the share of large farms (more than 10,000 ha) represents above 40%. Additionally, agriculture in Brazil still presents very low average productivity levels per unit of area which acts as a push factor for continuous forest clearance.

b) Personal income is also highly concentrated with 66.1% of the total income accruing to the 20% richest families while just 2.3% accrues to the 20% of the poorest ones [Bonelli and Ramos (1993)]. Such inequality creates an immense surplus of low-income workers ready to seek occupations in frontier areas.

c) Favourable credit and fiscal system to agricultural activities with no regard to soil agroecological features and managerial practices which resulted in a mere replication of agricultural technologies already in place in areas with distinct ecological conditions.

d) And finally, regional development programmes in frontier areas, though are nowadays mostly phased out, have immensely contributed to stimulate economic activities and promote migration flows.

Some of these factors cannot be easily reverted since it would require long-term structural adjustments to alleviate social inequalities, accomplish a satisfactory land reform and even create the proper incentives and enhance human resource's capacity in governmental agencies.

2.2 - Open Access Features

As it was mentioned previously, one of the most important characteristics of the Brazilian Amazon is its open access feature. It is very important to understand the peculiar characteristics that allow agricultural peasants and timber loggers to penetrate the forest clearing it without any concern about resource scarcity and its economic consequences. Some of these peculiarities are presented below:

- Land titling of a property is based on land productive use, such as area allocated to farming. Only very recently has legislation on land taxes been changed[4] to consider standing forest legally recognized as productive use. Therefore, land titling and taxation have not only legalized clearing, but encouraged it. Forest land conversion to agriculture in the Amazonian region used to be allowed for up to 50% of the farm area. This percentage has been reduced to 20% in 1996 but with no effective enforcement so far. This legal clearing percentage has been used to issue conversion (clearing) permits and has become the main source of timber exploitation. Forestry activities, in fact, are financing forest clearing since extraction for this purpose is legal. Property rights for standing forests can only be viable with high enforcement costs.

- Illegal logging has, nevertheless, always been possible since no man-based regulation can be effective in such an enormous area as the Brazilian Amazon (western Europe size), particularly considering the existing social pressure and institutional fragility.

- It is known that sawmills are exploring areas where agricultural activities have not arrived due to the lack of infrastructure, consequently, the partnership between agriculture and sawmills will soon lead to other fronts of clearing.

- The Amazonian timber extraction process is characterized by a formal sector that works "by the books" with high costs and an informal sector working "freely" with low costs. This dual market structure is not economically feasible in such enormous area where outputs are not differentiated to receive compensatory higher prices.

- Amazonian forest is more heterogeneous and grows at lower rates than any other forest. Consequently, standing trees in this forest create low private values. Not only extraction costs increases as well as wood market shrinks to accommodate various species. Creaming is unavoidable without proper economic incentives. Heterogeneity in this case is on tree species as well as on tree incidence in different areas.

- Apart from that, states in Brazil are allowed to have their own state forestry policy and they usually have enough power to use parliamentary forces to curb centralised governmental protection measures in the region. Loggers and farmers are very politically "persuasive" in these states.

Based on these points, it has been claimed that forestry in the region is not undertaken with fully enforceable property rights. In other words, logging is carried out without proper account for scarcity parameters in a quasi-open access case,[5] as will be further developed.

[4] The new land taxation rules will be effective only in 1997.

[5] See, for example, Young (1997) for a discussion on this matter and Seroa da Motta (1997) for more details on property right's assignment in the region.

2.3 - Logging Activity Outline

As can be observed in Table l, Amazonian wood output share in the national production increased from 40.5% in 1980 to 75% in 1991. Although more up-to-date figures are not available, this impressive expansion in the analysed period clearly reveals the growing importance of Amazonian wood species in logging activities. Moreover, it is estimated that in the last ten years no more than 10% of the logging output is exported and its composition concentrated in few species, particularly mahogany which accounts alone for 50% of the total export value.

Table 1
Round Wood Production in Brazil

Region	1980		1990/91	
	1000m³	%	1000m³	%
North	11.476	40.5	39.087	75.0
Northeast	6.700	23.6	6.899	13.3
Central	2.625	9.3	3.519	6.8
Southeast	1.437	5.1	844	1.6
South	6.109	21.5	1.716	3.3
Brazil - Total	28.347	100.0	52.065	100.0

Source: Prado (1995)

The importance of logging expansion in the deforestation process can be observed in Table 2. Estimates of effective and potential wood commercial production from agricultural cleared areas[6] in the Amazonian region are presented for the period 1975/91 also based on Prado (1995).

Effective production is the wood output currently generated and potential production is an estimate of the wood output which could be generated from cleared areas. The ratio of these two output values offers a good indicator of how much wood extraction is taking place as a consequence of the clearing for agricultural purposes.

From Table 2 one may note that ratio values increased from 13% in 1975 to 95% in 1991. That is, wood extraction is currently strongly associated to clearing for agricultural purposes. Thus we have a circular relationship where wood extraction revenues finance clearing and legal licenses granted for agricultural clearing legalize wood extraction. This synergy generates private economic values to deforested lands much higher than those which could be derived from either preservation activities or sustainable agroforestry.

Field surveys in traditional logging Amazonian areas presented in Almeida and Uhl (1995), estimated financial rates of return higher than 300% for wood

[6] Cleared areas are those observed in the period and includes legal and illegal clearing.

extraction and processing activities with logging undertaken in rented lands (i.e., land for agricultural clearing). If supply of wood comes from sustainable logging undertaken in lands only devoted for logging activities, rates of return would drop to almost 20%. That is, saw-milling activities can count on low-cost legal and illegal supply of wood which allows for very profitable financial returns to which sustainable logging cannot compete.

Table 2
Effective and Potential Wood Production from Clearing Areas in the Brazilian Amazon

Time Period	Converted Forest Area (ha/year)	Potential Wood Extraction (PWE) from Converted Area (1000 m³)	Effective Wood Extraction (EWE) (1000m³)	EWE/PWE
1975/78	1.619.300	32.386	4.064	0.13
1978/80	2.323.550	46.471	11.476	0.25
1980/88	5.940.987	118.820	19.539	0.16
1989/91	2.064.600	41.292	39087	0.95

Source: Prado (1995).

This association was also observed for the past in the Atlantic Forest. In fact, logging activities in Brazil are still mostly relying on native forests from which more than 75% of round wood is produced.

Summing up, attempts to estimate timber depreciation in the Amazon have to take three regional features into account: *a*) the remaining size of the forest is still almost 90% of the original area despite the continuous deforestation process in the region; *b*) property rights are assigned by clearing which generates a continuous flow of timber output with the frontier advancement; and *c*) the association of agriculture expansion and logging exploitation seems to perpetuate the low capital and informal profile of forestry in the region. That is, large areas open for exploitation, fragile property rights and informal market structure are key factors preventing economic agent's perception of scarcity in the region.

3 - ACCOUNTING METHODOLOGIES FOR CALCULATING THE DEPRECIATION OF NATURAL CAPITAL

3.1 - Adjustment in National Accounts

Literature on depreciation accounting procedures of natural resource exhaustion is still open to debate about the most appropriate method.[7] Economic progress has been measured in almost every nation world-wide by the system of national

[7] Despite the continuous efforts of the UN Statistical Office to harmonize procedures, exhaustion accounting method is still without proper guidance. See for example Bartelmus (1996).

accounts using the Gross National Product (GNP). It uses market prices to measure the aggregate value of an economy's output in a given year. Despite being the most used indicator of economic progress, it is widely known that GNP is a very poor approximation of economic well being. Another indicator, Net National Product (NNP), is a much better measure of well being because it accounts for the depreciation of the wealth of a country. Man-made capital for example, depreciates through time and this loss in value is captured in the NNP measure. Nonetheless NNP, in its traditional measure, only takes into account the losses of man made capital, leaving aside the depreciation of natural capital.[8] This depreciation happens when the stock of a natural resource is decreased.

The idea of adjusting the system of national accounts to incorporate the losses due to the use of natural resources, is closely related to the concept of sustainability as an indicator of sustainable development.[9] Although there are many definitions of sustainable development, economic definitions have focused on sustainable development as non-declining *per capita* welfare over time [Pearce and Atkinson, (1995)]. The idea behind it is that every future generation must have the option of being at least as well off as its predecessor. Hence a sustainable path has the characteristic that along it, the overall productive capacity of an economy is not reduced.[10]

The productive capacity of an economy depends on the total stock of capital available, as well as on its productivity. If some capital is used up and not replaced, the possibilities of future production is decreased. This is not so much of an issue with physical capital, since it can be produced and replaced. Nevertheless, it is an issue with natural capital which cannot be created by mankind. Therefore, when natural resources are used up or destroyed, there is implicitly a question of substitution.

The question to ask is, at each point in time, how much of the natural capital productive base can be used up? The answer given by economic theory is based on two different approaches developed in a parallel way and yielding theoretically equivalent results. Both aim at measuring the impacts of resource depletion on long run human welfare, but while they are equivalent in theory, they will not yield necessarily the same result in practice.[11]

[8] It also leaves aside the depreciation of human capital. UN Statistical Office efforts on environmental accounting are aimed at correcting this omission.

[9] These adjustments should be broader than just calculating the depreciation of timber caused by deforestation, as we are doing in the present paper. They should include other factors that can affect the value of a forest and its land. Nevertheless these adjustments were out of the scope of the present study, although very important.

[10] Although sustainability and sustainable development are related concepts, they are not synonyms. Sustainable development is a much more vague concept that is commonly used in many contexts without a proper definition.

[11] For the importance of sustainability principles in environmental accounting, see, for example, Seroa da Motta (1994).

The first approach was derived in Hartwick (1977). He showed that so long as the capital stock of an economy did not decline over time, non-declining consumption was possible. We can illustrate Hartwick's idea with a simple economy consisting of two types of capital: physical and natural capital denoted by K_t and R_t, respectively. The net investment in this economy is given by the gross investment minus the depreciation in each of the form of capital: $I_t^N = dK_t/dt + dR_t/dt$. If the net investment is greater than or equal to zero, the country can at least sustain its actual consumption level. If this country produces a non-renewable resource, non-declining consumption is possible by reinvesting all Hotelling rents from the exhaustible resource in physical capital.

These rents are those resulting from an intertemporal efficient extraction programme. This is what is known in the literature as the *Hartwick rule*. It tell us the amount that we have to invest in other forms of capital when we extract a natural resource and earn rents on it. It was shown by Solow (1986) that it also represents a requirement to "keep capital intact". There are two important assumptions implicit in Hartwick's result. First, physical capital and natural capital are assumed to be close substitutes.[12] Second, the model assumes that an individual only derives utility from the consumption of goods and not directly from the environment.

The second approach was developed from the work of Weitzman (1976) on Net Domestic Product (NDP). We can define NDP for an economy with balanced trade[13] as, $NDP_t = C_t + I_t^N$. Weitzman (1976) demonstrated that under optimal growth, NDP should be though of as income in the Hicksian sense[14] interpreted as a long run measure of economic well-being, that is, the stationary equivalent of future consumption. In this sense, national wealth for a country would be given by the present value of the best consumption path into the future that society can afford.[15] Weitzman proved that Net National Product (NNP) in any year *t* is equal to the discount rate (social rate of time preference)[16] multiplied by wealth: $NNP(t)=\rho\, W(t)$. Based on this result, he argued that a true measure of NDP should include the value of changes in resource stocks. Consequently, the net investment should be defined taking into account the depreciation in all types of capital, not only physical. Weitzman (1976) result depends on two crucial assumptions: first that a country growth path is optimal and second that social welfare equals consumption.

[12] The elasticity of substitution is equal to one.

[13] Exports equal imports.

[14] Income defined as the dollar flow which could be consumed from wealth or capital while leaving wealth undiminished.

[15] This can be defined formally as $W(t) = \int_t^{\infty} C^*(s)e^{-\rho(s-t)}ds$, where ρ is the discount rate.

[16] In this model, ρ equals the marginal product of capital (interest rate) only under steady state growth and zero population growth.

In both of the approaches presented above, we need an estimate of the depreciation of natural capital in order to subtract it from the value of the capital stock. In this manner we would adjust the gross investment to net investment. For an exhaustible resource, Hartwick and Hageman (1993) define depreciation as the change in value of an exhaustible resource under optimal use.

If optimality conditions do not hold and substitution possibilities between physical capital and natural capital are restricted, then, the above approaches face criticisms on the basis of sustainability views. These approaches are regarded as based on the weak sustainability principle which sustains that natural capital can be permanently substituted by physical capital. Consequently, when natural resources are extracted, we can set aside part of its revenue to invest in physical capital and maintain intact the economy's productive capacity.

This idea is not widely accepted. For some natural resources serving as production factors, there could be thresholds, carrying or assimilative capacity, causing some types of natural capital to be hardly substitutable. Many assets are essential to human being survival in the long run and this point of view is expressed in the strong sustainability concept, based on the conservation of many types of natural capital (i.e. maintaining them intact for future generations) or recognition of their safe minimum standards.

Although depreciation methods can be analysed along these sustainability principles,[17] the proposed depreciation methodologies can be generalized as elaborated in V&H (1997) and summarized in the following sub-sections.

3.2 - The Change in Value Method

Depreciation of an asset over a period of time can be calculated as the value of the asset in the beginning of the period minus the value of the same asset in the end of the period. This method is known as the change in value method.

Adopting the definition of income as the level of consumption that could be enjoyed without diminishing the capital stock, we can define depreciation as the consumption of the assets in excess of this amount. More formally, depreciation exists when there is degradation of a resource. If we have the value of a resource at the end of a period and the value at the beginning of the period, we can calculate the depreciation of the resource as the difference between the two values.[18] Defining the value of a resource as the discounted sum of the resource

[17] See Atkinson *et alii* (1997) and Seroa da Motta (1994).
[18] Mathematically $D(t) = V(t+1) - V(t)$.

rents that are generated over time[19] and using some algebraic manipulation, we can express the depreciation of an asset as:[20]

$$D(t) = iV(t+1)/(1+i) - [pq(t) - C(q(t))] \quad (1)$$

The previous expression is known as the fundamental equation of asset equilibrium. Although in theory it is a good representation for the depreciation of an asset, carrying out the previous calculation in practice has many complications. We would need projection of the future flow of rents, in which case we need prices, quantities extracted and cost schedules into a future finite stream.

3.3 - Total Hotelling Rent as Depreciation

Hotelling rent (HR) is defined as the rent that exists on the marginal quantity of an exhaustible resource (price minus marginal cost) and it is considered a measure of the intertemporal scarcity of that resource. This rent exists because the resource is exhaustible and consequently, the owners of the resource extract less than the amount that would equate marginal revenue to marginal cost. Multiplying the HR by the quantity extracted of the resource, gives the total Hotelling rent. It is interpreted as the portion of profit that accrue to extractive firms because they are mining an exhaustible resource.

Hartwick (1988) proved that along dynamically efficient paths of extraction, Hotelling rent and economic depreciation (with a negative sign) are equals. Using this result, it is possible to use a short cut to calculate economic depreciation. Nevertheless, it is important to note that this equivalence is only correct under certain conditions, namely: *a*) resource extracted optimally, i.e., Hotelling's rule holds; *b*) price of extracted resource constant over time; *c*) marginal cost as an increasing function of the amount extracted, unrelated to the size of the reserve and constant over time; and *d*) constant discount rate over time.

3.4 - The Net Price Method (NPM)

As it was mentioned previously, under special conditions, economic depreciation of natural resources can be approximated by the Hotelling rent. This last term was defined as price minus marginal extraction cost (the profit on the marginal ton extracted), multiplied by the amount extracted. Hence we can use the following expression to calculate the depreciation of natural capital from the NPM:

[19] If the resource is non-renewable and using discrete time, we can express the asset value at time *t* by $V(t) = \sum_{s=t}^{T} (1+i)^{t-s} [pq(s) - C(q(s))]$; where p is the price of one unit of the extracted resource (constant over time), *q(s)* is the quantity extracted at period *t*, *C(q(s))* is the total cost of extraction and T is the period when the resource is exhausted. Expression $pq(s) - C(q(s))$ represents the current resource rent.

[20] Alternatively in continuous time $\dot{V} = rV(t) - [pq(t) - C(q(t))]$.

$$D(t) = -[\,p - C'(q(t))]\; q(t) \qquad (2)$$

In theory this method would be easier to apply than the change on value method. Nevertheless in practice, the data on marginal extraction cost is not generally available. Consequently previous studies that attempted to calculate depreciation of natural capital used the so called net price method. It uses data on average cost instead of marginal cost and calculates the depreciation as:

$$D(t) = -[\,p - C(q(t)) / q(t)]\; q(t) \qquad (3)$$

It is important to note that, as it was mentioned by several authors,[21] using the average net price instead of the marginal net price, one is calculating the total resource rent which overstates net accumulation (unless the *MC=AC* as in the case of a linear cost function).

3.5 - The El Serafy Method (ESM)

Alternatively to the net price method, El Serafy (1989) developed a method to calculate depreciation based on the concept of user cost. He equates the finite stream of rents earned by a resource to an annuity *X* earned forever, which can be obtained by selling the mine and depositing the value of the mine (*V*) in a bank account. Mathematically this is given by:

$$R_t + [1/(1+r)]R_{t+1} + \ldots + [1/(1+r)^n]R_{t+n} = X + [1/(1+r)]X + \ldots + [1/(1+r)^{\infty}]X \quad (4)$$

where *r* is the discount rate, *n+t* is the last year of the extraction, *X* is the annuity received and *R* is the rent defined as $R_t = p_t q_t - C(q_t)$. The expression *R-X* is a measure of depreciation, and El Serafy (1989) simplifies further the analysis to obtain a closed form solution.

Assuming that the rent is constant over time,[22] such that $R_t = R_{t+1} = \ldots = R_{t+n}$, the equation above is simplifies to:

$$R - X = R[1/(1+r)^{n+1}] \qquad (5)$$

The previous expression is the user cost or economic depreciation for the ESM. It is important to note that as Hartwick and Hageman (1993) pointed out, if *R(t)* changes over time, the measure *R-X* could be a poor approximation to *R(t+i)-X* in period *i*, consequently the ESM would yield a poor approximation of the depreciation value.

[21] See, for example, Hartwick and Hageman (1993), Seroa da Motta (1994) and Atkinson *et alii* (1997) for criticisms on these lines.

[22] That is, current rent is assumed constant to estimate user cost values in a specific year, although rent can vary each year for which user cost is estimated.

In the ESM, *n* is the remaining years of life of the resource stock. This is estimated by dividing total reserves remaining by the year's quantity extracted. This calculation implicitly assumes that this year's extraction will continue into the future at the same rate. If *S(t)* is the remaining stock of the resource at period *t* and *q(t)* the quantity extracted of the resource in the same period, we can express ESM formula to estimate depreciation as:

$$D(t) = -[pq(t) - C(q(t))][1/(1+r)^{S(t)/q(t)-1}] \quad (6)$$

3.6 - Vincent and Hartwick Approach

Vincent and Hartwick (1997) suggested a transformation applied to the average cost in order to get a consistent estimate of depreciation. If the marginal cost curve is isoelastic in the quantity extracted and assuming a functional form for the total extraction cost as $C(q(t)) = \alpha q(t)^{1+\beta}/(1+\beta)$ they show that $MC=(1+\beta)AC$. Therefore we can express the expression for the Hotelling as:

$$D(t) = [p - (1+\beta)C(q(t))/q(t)]q(t) \quad (7)$$

Where β is the elasticity of the marginal cost curve with respect to the quantity extracted. It is important to note that on the previous formula, for relative elastic marginal cost curves ($\beta \geq 1$), unit price has to be at least twice as large as the unit average cost. Otherwise, one would witness a negative estimate of depreciation which would not make economic sense in presence of increasing depletion. This arithmetical trap is only due to the simplification of the isoelastic assumption of the marginal cost curve.

Another approach used by Vincent (1997), is to use the previous total cost function and the fact that under an optimal extraction path, the transversality condition implies that *MC=AC* when the resource is exhausted. As a result, it is shown that for the previous functional form, this transversality condition occurs if and only if *q(t)=MC=AC*=0 in the final period.

Using the Hotelling rule and the fact that *MC(T)*=0, Vincent (1997) derives the following expression for the Hotelling rent:

$$D(t) = -[pq(t) - C(q(t))](1+\beta)/[1+\beta(1+i)^{S(t)/q(t)-1}] \quad (8)$$

The previous expression is a generalization of the net price and El Serafy methods in the sense that it embodies both estimations as particular cases. If $\beta \to \infty$, equation (8) simplifies to the ESM and If $\beta \to 0$, the whole right hand side goes away and the Hotelling rent would just equal the total rent.

The usefulness of the previous formula is that in practice it is much easier to find data available for the average cost than for the marginal cost. However, estimating

β can be a practical complication. Obviously the elasticity of marginal cost will vary depending on the nature of the resource (timber, oil, etc.) and type of industries.[23]

Equations (7) and (8) are presented by Hartwick and Vincent (1997) as being equivalent. The choice of which one to use depends just on the availability of data. If data is obtainable on the average extraction cost, then one can use expression (7) to estimate the depreciation. If instead, data is available on the resource rent, Vincent (1997) has demonstrated that expression (8) is an alternative measure of the Hotelling rent. Nevertheless it is noted in Vincent (1997) that expression (7) would yield less accurate estimates of economic depreciation than formula (8). This would happen due to the fact that formula (7) is based on current marginal rent and, on the other hand, expression (8) is based on long run principles.

Although Vincent (1997) is correct in his concern for estimating long run instead of short run Hotelling rents, it is not clear in his argument why the formula from expression (8) would take into account out of equilibrium behaviour in the timber market. Since it also uses current price and costs of logged wood, any tendency of resource prices to fluctuate in the short run will be incorporated into his estimates using expression (8) as well as expression (7).

Moreover, since expression (8) incorporates a discount rate and formula (7) does not, any bias caused by fluctuation in prices could be compensated by biases caused by the choice of an incorrect discount rate. Consequently, it does not seem to exist any *a priori* reason why biases in the discount rate chosen would not be even worse than biases from price fluctuations or out of the equilibrium behaviour in timber markets.

In spite of previous points, our estimates of depreciation values will follow equation (8) and we will be assuming additionally permanent conversion of forest land to agriculture purposes. This would imply that we will not be considering any form of reforestation or second growth forest conversion.

4 - THE ECONOMICS OF TIMBER EXPLOITATION IN OPEN ACCESS REGIMES

Forests are usually characterized in the literature as renewable resources. Nevertheless, the overexploitation of forests can lead to its exhaustion. If the rate of harvest exceeds the annual natural growth rate, forests are going to be exhausted since the extraction pattern is unsustainable. In this case, timber exploitation can be treated equivalently as non-renewable resources. A special case of the previous situation occurs when timber is extracted and the land is

[23] Apart from being difficult to estimate, this function may vary over time and over place. Therefore, such mathematical simplification may loose economic meaning for prediction purposes. We thank this point to Salah El Serafy.

permanently converted for agriculture and cattle rising. This is very much, as discussed previously, the case of deforestation in the Brazilian Amazon.[24]

As it is well known, natural resources differently from other kind of produced goods, do not dissipate the producer surplus by competition in the long run. The rents associated with a natural resource will generally have two components: one static and the other dynamic. The static part of the rent is called the differential or Ricardian rent. It is defined as the excess of the market value of supramarginal units of natural resources over current scarcity rents. It is analogous to the Ricardian "diminishing returns" and it is viewed as a static surplus. These natural resource rents arise from heterogeneity in land quality (in this case, differences in the quality of natural resources) and are not related to time. Hence if exhaustible resources are heterogeneous, part of the rent is a differential or Ricardian rent.

The dynamic component of the total rent, the scarcity or Hotelling rent, is related to the characteristics of exhaustible resources. Scarcity creates economic rents that are captured by the owner of the resource if property rights are well defined. These rents generated by a natural resource are closely related to the concept of user cost. The user cost is the present value of all future sacrifices associated with the use of a particular unit of a natural resource in the present. Since any unit consumed today is lost for future use, the present extraction and consumption of the resource implies an opportunity cost, the value that might be obtained from this resource in the future.

Allocating the resource efficiently over time will imply extracting and selling a quantity that is lower than the one equating price to marginal cost. This difference between the marginal cost schedule and the price is the user cost. The scarcity rent can be defined as the user cost of the marginal unit being extracted at any point in time. In other words, it is the payment accruing to a natural resource owner when the user cost is positive. This is a forward-looking concept in the sense that it should anticipate future increases in demand and changes in extraction costs.

Developing countrie's natural resources are usually characterized by the weak definition of property rights, with numerous of them being characterized by an open access regime.[25] When perfectly defined property rights exist and given other regularity conditions,[26] agents exploiting resources will take into account the user cost and will maximise profits efficiently in a dynamic sense. However, if property rights are not well defined, economic agents will not take future scarcity into account in their maximization decision. In this situation, the existence of

[24] For a formal treatment of virgin forests as non-renewable resources, see Vincent (1997, p.30).
[25] We include in the open access resource definition situations where property rights over natural resources are defined by law, but there is no enforcement or monitoring over them.
[26] The definition of property rights is a necessary but not a sufficient condition for efficient exploitation of a natural resource. See Dasgupta and Heal (1979) for a formal treatment on necessary and sufficient conditions for efficient exploitation of natural resources.

positive rents is no longer guaranteed and scarcity rents will generally be driven to zero.[27]

Under an open access regime, economic agents will simply decide to enter the exploitation of the resource based on a comparison between the cost of entrance and the expected income they will get from the activity. If the net expected benefit from the activity is positive, they will always decide to enter and exploit the natural resource. The problem with this result is that the private evaluation of net benefits is different from the social evaluation. An economic agent deciding to exploit a given resource will not take into account the fall in other agent's income that is caused by his entrance. Hence, a negative externality is imposed on other economic agents. The intuition behind this result is that each agent acts under the assumption that there is no use foregoing some harvest today in the interests of having reasonably sized stock tomorrow because if he does so, the resource will be caught by another agent tomorrow since entry is "free" [Hartwick (1980)].

Therefore, in an open access situation, the economic agent will not be compensated by the market from restraining his harvest in the present in benefit of future gains. As Hanna *et alii* (1995) point out: "Under a regime of open access, claims to resources are realized at the point of capture, and owners have no specified duty to maintain the resource or constrain its use". Nevertheless, it is important to note that open access does not necessarily imply unlimited harvest of resources since there is always a cost to extraction.

Also, according to Hanna *et alii* (1995), property rights regimes must perform certain functions such as limiting use, co-ordinate users and respond to changing environmental conditions. These activities involve transaction costs of co-ordination, information gathering, monitoring and enforcement. The transaction costs are influenced by the particular structure and context of the property rights regime and the conditions of the ecological system. These costs are therefore a function of the amount of agents to be coordinated, the area over which the monitoring and enforcement is going to take place and the amount of information needed.

It is well known that observed market prices only reflect scarcity when there are no market failures in the economy. The clear definition and enforcement of property rights are basic assumptions in the calculation of changes in values of natural resources stock's. Hartwick (1991) makes explicitly clear that one of the basic assumptions of his results is that property rights are well defined and universal. Not enforceable property rights imply an inefficiently low shadow price on the stock of the resource causing rents to be dissipated. Scarcity rents will be decreased and taken to zero in the extreme case of complete open access.

The Brazilian Amazon seems to be characterized by an intermediate case between private property and open access. Although property rights are not defined *ex-ante*

[27] See the appendix for a simple model illustrating this situation.

in the frontier and beyond it, there are some stipulated mechanisms of getting property rights over deforested land.[28] During many years, this colonization pattern caused a race for new land motivated by speculative motives. Economic agents would move to the frontier, clear the land, start an agriculture or cattle raising activity and then wait to get the title for the land. Therefore, *ex-post*, property rights were defined assuring the economic agent with a stream of benefits into the future. This pattern explains why the race towards the frontier in the Amazon cannot be characterized as a pure open access situation.[29]

The implications of the quasi-open access situation to the calculation of economic depreciation are very important. Since the extraction of the resource is not optimal, Hotelling rule does not hold. The resource is going to be extracted faster than it would have been under an optimal situation. Since the equivalence between depreciation and Hotelling rent depends on the Hotelling rule, this will also break down. Part of the scarcity or Hotelling rent will be dissipated, so depreciation will appear to be lower than actually is.

Using the definition of Hartwick and Hageman (1993), depreciation is the change in the value of an exhaustible resource under optimal use. Since the value is calculated using the present value of all the expected net revenues from the stock, it will be lower under incomplete property rights. There will be an intertemporal externality, namely an agent extracting timber will adjust its harvest until the current marginal cost equal the current discounted average payoff and not the marginal payoff. Since the average payoff is lower than the marginal payoff, the discounted value will also be lower and depreciation will be lower.

This shows us that the previous definition of depreciation is not correct if the resource is not extracted optimally. This result should not be surprising. Since depreciation is the decline in the value of the resource and the resource is not valued correctly by the market, depreciation is also not going to be calculated correctly.

Under sub-optimal exploitation, Hotelling rule is no longer guaranteed and we could have any rule being used to form expectations over the evolution of the resource price. In this case, we could have idiosyncratic rules being used by individuals to form expectations with particular perceptions on the depreciation rate. Consequently, the decentralized allocation would differ from the planner's solution and the question of how to incorporate this into a coordinated formal model is still an open issue.

Summing up, the question for the application of current accounting techniques is whether depreciation may still be valued under these sub-optimal conditions based on Hotelling rent measures or this relationship will break down?

[28] Refer to the first part of this paper and Schneider (1995) for an explanation of such mechanisms.
[29] For a model on this process, see Young (1997). He characterizes this type of property right regime as quasi-open access.

5 - THE BRAZILIAN CASE STUDY

5.1 - The Estimation Sets

The model adopted, as said before, calculates the depreciation under the optimal use of an exhaustible resource, employing the Hotelling rule relationship and arriving into some estimations of depreciation approximated by the Hotelling rent, as proposed by Vincent (1997).[30] The main objective of this case study is to estimate depreciation values of forests in the Amazonian Region, a typical frontier area where user cost perception fades. It is assumed that timber is a non-renewable resource based on the fact, already discussed in Section 1, that forestland conversion in this frontier area is mostly devoted to agricultural production and cattle raising and the possibilities for second growth forest are almost nil. Consequently, our depreciation values will not consider any charges for forest regrowth.

As it was seen in the previous section, there are basically three shortcuts to calculate the depreciation of natural capital: the net price (NPM), user cost (ESM) and H&V approaches. The latter, is a generalization of the other two in the sense that, assigning different values to the parameter β, would provide us with the other two specific formulas. As discussed before, the theoretical advantage of the H&V approach is that it enable us to use data on the average cost, multiplying it by a conversion factor without getting an upward bias on the depreciation. This would yield, under optimal use of the resource, an accurate estimation of the scarcity rent since it is the Hotelling rent, and not the total rent, that is equivalent to the depreciation under optimal conditions.

The timber industry in the Amazon can be classified in two main activities: timber harvesting and wood processing. Generally the timber is harvested and transported to the sawmill where it is sold with the cut and the transport activities being performed by the same economic agent. In some regions, there is a third economic agent in the process, the "bufeteiro". He is a truck driver who gets the wood in the forest, transports it to the saw mills and sells it. More recently, this industrial structure has changed. There has been a trend of vertical integration taking place in the region with the increase participation of sawmills in the extraction process.[31]

Theoretically, the calculation of scarcity rents depends critically on the prevailing property right's regime in the region. If there exist an open access situation,

[30] We have pointed previously the limitations of this analysis for a sub-optimal situation. Nevertheless there is no alternative method developed for the measurement of depreciation in such cases.

[31] In Paragominas (Pará) in 1990, 63% of sawmills had some involvement with extraction. By 1995, 84% of small firms and 79% of large firms participated in timber extraction. On the other hand, in Tailândia (Pará), 23% of sawmills were involved with extraction in 1990, while by 1995 that number increased to 75%. See Stone (forthcoming) for more details on the process of vertical integration of sawmills in the Brazilian Amazon.

overextraction of timber is very likely to occur, causing the dissipation of rents. Despite the fact that property rights are not secure in the Amazon, there is some belief that it is not the case of the existence of an open access regime of exploitation. Consequently, the timber extraction would yield positive rents from the extractive activity.

The formula used to calculate scarcity rents is the generalized formula from H&V: $D(t) = -[pq(t) - C(q(t))](1+\beta)/[1+\beta(1+i)^{S(t)/q(t)-1}]$. It can be observed in the formula that the exhaustion period, $S(t)/q(t) - 1$, enters the calculation in an exponential way. This would make it the leading parameter in the final result. Any large exhaustion period would result into very low scarcity rent.

Previous studies[32] have already identified very large exhaustion periods for forestland conversion in the region. Being the largest tropical forest in the world, it is not surprising that, even at the actual extraction rates, it would still take some time to completely excerpt all kinds of timber available in the forest. This is basically the main problem when we perform these kind of calculations for the timber production in the Amazonian region as a whole. It seems as we could still harvest it for many years before scarcity is perceived. Because of this "bias" caused by the still enormous size of the Amazon,[33] we have also calculated the scarcity rent for a specific species of wood under threat of extinction and tried to observe how scarcity rent estimates alter in cases of lower available stock.

The selected wood species was mahogany. Being the royal wood exploited in the region for many years, counting for almost 50% of the Brazilian timber export value, its stock has been decreasing rapidly during the past decade. Recently, its log and exports were temporally banned by the Brazilian Ministry of the Environment in 1996. As will be seen, mahogany prices are by far higher than any other timber variety.[34]

In this study, the all timber variable is a composite good for which the data on cost and output is not differentiated among species[35]. Consequently we treat timber as a single stock with an unique exhaustion time. Mahogany estimates, on the other hand, are specific for this specie and reflects its greater scarcity.

Although mahogany is part of the all timber composite good, its user cost is dissipated when we aggregate it with the all timber. Consequently, results on Table 4 show an aditivity bias. As it will be observed, for all values of the elasticity of the marginal extraction cost greater than zero, the depreciation value

[32] See, for example, Funatura/Itto (1993), Prado (1995) and Seroa da Motta (1997).
[33] This is a really important matter. If the Brazilian Amazon was smaller we would get a higher value for the depreciation.
[34] With that ban the Brazilian government understood that the inclusion of mogno at the Annex 2 of the CITES was not necessary as proposed in the last general conference in 1997.
[35] Ideally we would have data on cost, price, stock and output for each specie of timber in the Amazon. We would then calculate the depreciation charge for each specie separately. Due to the lack of data availability, this analysis is not possible.

for all timber is lower than mahogany depreciation. This occurs because as the elasticity of the marginal extraction cost increases, the exhaustion period becomes the driving factor in the depreciation result. When mahogany is included in the all timber variable, the average exhaustion period increases and its greater relative scarcity fades away.[36]

Implicitly, we are assuming for the all timber measurements that loggers see timber stock as a whole and do not differentiate species in their decisions on exploitation levels. If exploitation of species are treated separately, each specie's user costs, as those estimated for mahogany, should be separately measured and then added up.

Apart from depreciation calculation for all timber and mahogany separately, we also apply the three depreciation valuation approaches presented above. Based on the generality of the H&V formula, values of the elasticity of the marginal cost curve are set to zero for the NPM, infinity for the ESM and intermediate values for the H&V approaches. Finally we undertake a sensitivity analysis with discount rates of 2%, 4% and 10% to enable us to analyse the differences in the scarcity rents due to differences in time preference.[37] All estimation cases are carried out only for the years 1990 and 1995 due to data availability, although it covers an important and recent period of forest conversion in the region.

It is important to note that we are not estimating depreciation values for a single state or region, we are looking at the Brazilian Amazon as a whole. We are interested in the national macroeconomic perspective since the depreciation calculated would be deducted from the national GDP to incorporate a sustainability perspective in national accounts. Consequently, we are taking into account the fact that economic agents perceive stock of wood across political frontiers as equally accessible.[38] Naturally, if we had studied a highly cleared area, we would have obtained high depreciation values, but this verification would not yield any perspective on the Brazilian sustainability issue, unless the region had the majority of the timber extraction and could be regarded as a closed economy.

5.2 - Database

The study area will be the so-called Legal Amazon, only excluding the State of Mato Grosso due to the lack of data on timber stocks.[39]

[36] We thank Michael Linddal for pointing this out.

[37] This is specially important if comparisons on depreciation values are going to be made among developed and developing countries. Dixon, Hamilton and Kunte (1997) suggest values in the 2%-4% range for developed countries. However, according to Seroa da Motta (1988) capital opportunity cost in Brazil has been historically around 10%.

[38] In many cases the timber extracted in some state is converted into processed wood in some other state. For the sawmill there is no additional transaction cost, for a given distance, to bring timber from another state for processing purposes.

[39] That covers states of Amazonas, Pará, Rondônia, Amapá, Roraima, Acre, Tocantins and Maranhão. Mato Grosso State, here not considered, is not relevant in terms of rain forest against the other states.

As mentioned in Section 1, timber extraction in Brazil takes place mainly in the Amazon from primary forests, accounting today for more than 75% of the Brazilian production of logs. The State of Pará alone produces almost 80% of the timber output in the region. However, data on the timber sector in the region is very scattered, particularly economic information on the production side. Due to its enormous size, ecological complexity and economic dispersion, it is extremely difficult to perform any systematic survey of the sector. When data is available, it does not usually follow the same pattern and, consequently, aggregation becomes a very complex task.

Two kind of data were used in this study: official aggregated data from the National Statistical Office (IBGE) and specific and punctual studies undertaken for academic and research purposes with a more limited coverage. There is a trade-off in using each one of these sources. The official aggregated figures, although reliable, do not go in details for species and locations and are based on declarations which certainly avoid not legal output. On the other hand, specific studies present good data and particular information, but the generalization of this information for the Amazon as a whole has to be done carefully.

As it was presented in the previous sub-section, the data required for the estimation sets, following the generalized formulae, are log prices, output, average cost, stock and the elasticity of the marginal cost curve.

The extraction of timber and the production of sawnwood in the Amazon is very diversified. Not only it takes place in many of the states, but it is also carried out by many economic agents. A great variety of trees are harvested in a very heterogeneous way and, consequently, it is very hard to monitor the extraction of logs and its processing. As a result, a general database containing prices of wood, quantity extracted, extraction costs and stock of timber in the Amazon is not available.

It was possible to define two procedures to identify price series. One was the use of data from the IBGE on quantity extracted and value of production, dividing the former by the latter to obtain an implicit price for wood. This data was available on a time series and it would enable us to observe the evolution of the implicit price of wood through time. However, the estimated implicit prices appeared to be very erratic and with no relationship to export prices and other sources. The shortcoming of this source seems to be related to the lack of reliability on the figures on production value. Moreover, data is aggregated with no identification of species.

Another procedure used was based on two regional studies. The first one was Stone (1998) which utilises data from field surveys in the Paragominas region (State of Pará) elaborated by the Imazon (Instituto do Homem e Meio Ambiente da Amazônia) in 1990 and 1995. The survey included 33 wood processing firms in 1990 and 40 firms in 1995. Given the predominance of the Pará wood industry

in the region, these values can be considered to be fairly representative for the Amazon as a whole.

Stone (1998) presents an average price of logs and sawnwood and classifies them in five groups based on the value of the wood, from high to very low valuable wood.

The second regional data source was a study on wood extraction in the State of Rondônia conducted by the consultancy firm Tecnosolo-DHV (1997) which presents a very detailed wood price list. Although it is a very rich database, generalization with prices from Rondônia is less reliable due to the small representativeness of its timber industry in comparison with Pará. Nonetheless, cross checking with Stone (1998) data showed consistency if one takes into account the division of wood types.

Estimates of costs of extraction and processing of wood in the Amazon are very rare.

Once more, we have relied on Stone (1998) which presents average extraction costs and transportation costs for 1990 and 1995 for both small and large firms.

For the logging activity, the difference between small and large loggers is based on the number of chain saws, trucks, bulldozers and log-lifters used in the extraction process. For the sawmills, the size is determined in the sample, by the number of band-saws. Small mills operate with one band-saw while large mills operate with two or more. The data on the cost structure of logging for 1990 is based only on small firms. This is the only data presented in Stone (1998). This would not cause a huge bias since the majority of firms operating in 1990 were small (approximately 80%). However for 1995, we had data available for small and large firms. To calculate the unit cost, we created a composite cost as the average of costs from small and large firms, weighted by their relative contributions to the total production volume.

Man-made capital costs of extraction and transportation average costs were also calculated with the three discount rate scenarios[40] using the same rates applied for the depreciation formula.

Data on timber output was taken from the IBGE figures, although there was some concern about their poor spatial coverage, they were the only available source for the region as a whole.

Data on the total aggregated stock of timber in the Amazon was estimated by Prado (1995) for the year 1990, based mostly on IBGE data, in fairly detailed spatial coverage but without distinction for wood species. The only caveat was the

[40] Stone (1998) adopted a 20% rate since that was the bank rate prevailing in 1995 in Brazil after the Real stabilization plan.

absence of data for the State of Mato Grosso. In our estimates of the stock figures, we have deducted from the physical stock all the timber stock available in conservation areas.

To estimate the 1995 stock we have used data on the quantity extracted of timber from IBGE assuming that the stock evolution was proportional to the rate of change in the log extraction. This is a strong assumption since there is illegal logging that would not be taken into account in the IBGE and output lost in the harvesting process.[41] Both cases allow for an overestimation on the timber stock.

Mahogany stock and output time series were not available. However, Barros *et alii* (1992) has made some estimates for 1990. Consequently our calculations were restricted to 1990 in the case of mahogany.

Table 3 presents the selected data indicators for timber stock (*S*), output (*q*), price (*p*), average cost (*AC*) and net price (*NP*) for the years 1990 and 1995.

Table 3
Economic Indicators for Depreciation Estimation

Indicator	Mahogany 1990	All Timber 1990	All Timber 1995
Stock [a] (S)	21,000,000	11,549,565,600	11,334,419,900
Output [a] (q)	500,000	44,490,600	46,828,500
Price [b] (p)	148.29	33.02	40.81
Average Cost[b] (AC)	64.75	22.59	26.72
Net Price [b] (NP)	83.54	10.43	14.09

[a] m^3.
[b] 1995US$/$m^3$, AC at 2% capital rate of return.

The determination of the elasticity of the marginal cost curve (β) was not available in the literature for the Brazilian case, although it is widely recognized that in frontier areas it is highly dependent on transport costs. Efforts to obtain transport cost data to undertake an econometric exercise to measure β did not succeed as well. Therefore, we have assumed two arbitrary values for β — 1 and 3 — to apply the V&H approach following ranges assumed in the relevant literature for other cases.[42]

[41] Although Verissimo *et alii* (1992) estimated that for every cubic meter of wood that is logged, in the region of Paragominas in Pará state, there are two cubic meters that are lost, one cannot generalizes that for the whole region. Illegal logging figures is still more controversial since, as discussed earlier, clearing licenses legalizes logging output.
[42] Vincent (1990), for example, uses values varying from 1.5 to 4.5 while Vincent (1997) adopts value of 3 for Malaysia. In principle, other region's elasticity values may not keep any relevance for the Amazonian region. As we will observe later, higher elasticity values leads to results similar to those here employed.

5.3 - Results

Tables 4 and 5 present the depreciation estimates for the years 1990 and 1995, respectively. Exhaustion time for all the timber stock in the Amazon was estimated as 258.6 years for 1990 and 242 years for 1995. For the analysis of mahogany, the exhaustion period was 42 years for 1990.

Table 4
Depreciation Estimates in the Logging Activity for the Brazilian Amazon in 1990
(1995 US$)

Estimation Set				
i = 0.02				
β	0	1	3	∞
ALL TIMBER	464036540.8	5507983.2	3686575.0	2770433.7
MAHOGANY	41770000.0	25687223.5	21540361.8	18546306.5
i = 0.04				
β	0	1	3	∞
ALL TIMBER	429778809.6	33840.5	22560.9	16920.9
MAHOGANY	41380000.0	13809302.7	10358476.1	8287500.6
i = 0.10				
β	0	1	3	∞
ALL TIMBER	326560710.4	0.012908	0.008605	0.006454
MAHOGANY	40225000.0	1584123.5	1070130.1	807971.3

Notes: i = discount rate and β = elasticity of marginal cost curve.

Table 5
Depreciation Estimates in the Logging Activity for the Brazilian Amazon in 1995
(1995 US$)

Estimation Set				
i = 0.02				
β	0	1	3	∞
ALL TIMBER	659813621.4	11070093.8	7421567.9	5581872.1
i = 0.04				
β	0	1	3	∞
ALL TIMBER	618604537.8	97134.7	64759.8	48571.1
i = 0.10				
β	0	1	3	∞
ALL TIMBER	494509002.2	0.104609	0.069739	0.052304

Notes: i = discount rate and β = elasticity of marginal cost curve.

Note that scarcity in the case of all timber stock in the Amazon is not a real threat considering such a large exhaustion time, as our depreciation estimates will show. Nonetheless, the mahogany case, when considered alone, will be otherwise more prone to reflect depletion costs due to the possibility of taking into account its much lower exhaustion period.

As it can be observed in Table 4, as β increases the user cost becomes larger for mahogany relative to all timber. As already discussed in Section 5.1, this is a

consequence of the aditivity bias caused by the fact that mahogany specific user cost is not added up separately, but instead, aggregated into the all timber before estimating the depreciation value.

Increases in the discount rate decrease the depreciation values, as shown in Table 4. This result differ from other studies on the fact that changes in the discount rate for the net price method change the depreciation values. This could sound surprising since when $\beta=0$ the discount rate should not play a role on the depreciation calculations. Nevertheless, since we included charges for man-made capital costs (capital opportunity cost of machinery and equipments) on the calculation of total cost, discount rate will affect these charges and, consequently, net price estimates.

Therefore changes occurring to the depreciation based on the net price method is due to the differences on average costs when discounting rates varies affecting man-made capital charges and not due the adopted V&H depreciation formula which does not have any discounting on it for net price measures.[43] At 10% discount rate, all timber user cost and H&V values decrease significantly tending to an almost negligible value. Mahogany values are significant at all rates insofar mahogany exploitation presents lower exhaustion periods and larger net profits.

It should be noted that, even considering the underestimation of logging production figures due to illegal practices, say, exhaustion time for the total stock of timber would be still high enough to generate negligible depreciation values.

Our results are also consistent with the theory. As the discount rate increases, the present value of future flow of rents decrease, causing a substantial decrease in the depreciation measure. This result confirms the fact that depreciation values are very sensitive to the discount factor used in its calculation.[44]

Observing again Table 4, for given discount rates, depreciation values decrease as the elasticity of the marginal extraction cost increases. We can easily identify these differences in our estimates. The user cost estimate ($\beta = \infty$) is eminently lower than the estimate of the net price ($\beta = 0$). This result goes in the direction expected based on other estimates of depreciation in the natural resource accounting literature.[45]

The results for 1995 in Table 5 show that depreciation magnitudes are higher than the similar ones for 1990 in all cases, although still with low significance at 10% discounting. That upward variation is conformed with the adopted methodology due again to the increase in net profit magnitude and the reduction of exhaustion time. Also comparing the 1995 results across discount rate yields the same results

[43] Remember that if $\beta=0$ the formula used is $pq-c(q)$, although it can also be argued that net price method is the special case of zero rate of discount.
[44] This fact was already exposed in graphical terms by El Serafy (1989).
[45] That was also observed in estimations for natural capital depreciation in Brazil for 1980/90, see Seroa da Motta (1995).

observed for 1990, that is, increases in the discount parameter, diminishes substantially the depreciation estimates.

In this sense, the distinction between the methods is very important as noted by Atkinson *et alii* (1997), "The distinction between net-price and user-cost is not just of theoretical interest: for countries with very long-lived deposits, even small discount rates will yield user costs that are much smaller than current rents."

6 - FINAL COMMENTS

This study was primarily concerned with the estimation of forest depreciation in the Brazilian Amazon, measured as the timber scarcity rent. Considering the still large timber stock available in the region, depreciation values were not meaningful. Moreover, taking into account the quasi-open access features of timber exploitation in the region, an important question arises related to the existence and capture of this scarcity rent in the Amazonian context.

Timber industry in the Amazon has also a complex productive structure. Monopsonic sawmill power can be easily enforced when extraction are undertaken in a complete open access region. Recent studies using local surveys, as those mentioned in our database section, have however, pointed out a trend towards vertical integration in the timber industry. This trend is probably a consequence of higher profitability on the logging activity with the enlargement of the frontier *vis-à-vis* the requirement of heavy investments on milling and more costly transportation.

Stone (1998) brings about net profit data on the timber extractive and processing activities in the Amazon for 1990 and 1995 and it can be observed that in this period, profit margin of the extractive (including transportation to processing facilities) activities has not only dropped from 11 to 8%, but it has come down to losses of about -3% in the processing activity.[46] This results would suggest that, if scarcity rents are captured by prices, they are captured in the extraction process.

As said before, apart from the still large stock of timber, the quasi-open access features of timber exploitation in the Amazonian region may also lead to poor scarcity rent perception by economic agents in the timber industry structure. Our results on depreciation measures have been consistently low, although their magnitudes were dependent on the assumed discount rates and marginal cost elasticities for which we were not able to estimate objective values. Moreover, other economic factors, as well as institutional and legal aspects, may be affecting logging activities in the region during the analysed period and a distinct trend may take place if these constraints are relaxed in the near future. However, if full scarcity rents are really part of supply pricing is still an open issue considering the

[46] Even if lower capital costs were taken in Stone's estimations, large firms would still face a decline profitability.

quasi-open access features of the Amazonian region. Our results can, however, make a modest contribution to this debate.

Estimated depreciation values for the timber extraction activity in the Amazon as a whole were very low in the ESM and V&H approaches due mainly to very high exhaustion periods. Even considering overestimation biases of our stock figures, say, by 100%, exhaustion time would be significant, over 100 years, and still leading to low depreciation values due to discounting procedures.

Their relative magnitude when charged against the timber activity value added[47] were close to zero, apart from values at the very low discounting rate of 2%, as shown in Table 6. Even though, user cost and H&V relative values were very low varying from 0.24% to 0.69% of the value added. As it can be observed, the percentage of depreciation as a proportion of the timber value added are only meaningful for the net price approach estimates which accounted for 41.17 % in 1995 and 39.72% in 1990. However, it was already argued that such approach could only grasp scarcity rents in very special cases.

Table 6
Depreciation Measures as Proportion of Timber Value Added (%)

1990				
i = 0.02				
β	0	1	3	∞
All Timber	39.72	0.47	0.32	0.24
1995				
i = 0.02				
β	0	1	3	∞
All timber	41.17	0.69	0.46	0.35

Notes: i = discount rate and β = elasticity of marginal cost curve.

It could be claimed, considering the forestland conversion process in the region discussed in Section 2, that these depreciation values should be instead compared to the regional value added from cropping and cattle raising activities. If we perform such comparisons, these relative values would be even lower since agriculture value added is almost four times bigger than timber extraction's.

On the other hand, mahogany depreciation measures compared to timber value added have revealed higher percentages, as shown in Table 7, even at 10% discount rate. These results are mainly a consequence of the substantially lower exhaustion time of mahogany in the Amazon.

[47] Value added figures for timber extraction were not available for the region from national accounts, therefore, we constructed these figures using the survey data used for the depreciation estimates. It should be noted that we are measuring value added as a GDP measure, that is, gross of capital costs.

Table 7
Depreciation Measures of Mahogany Extraction as Proportion of All Timber and Mahogany Value Added (%)

1990				
i = 0.02				
β	0	1	3	∞
All Timber Proportion	3.58	2.20	1.84	1.59
Mahogany Proportion	59.03	36.30	30.44	26.21
i = 0.04				
β	0	1	3	∞
All Timber Proportion	3.54	1.18	0.89	0.71
Mahogany Proportion	58.48	19.52	14.64	11.71
i = 0.10				
β	0	1	3	∞
All Timber Proportion	3.44	0.14	0.09	0.07
Mahogany Proportion	56.85	2.24	1.51	1.14

Notes: i = discount rate and β = elasticity of marginal cost curve.

Charges of mahogany depreciation against its own value added may reach up to 36% with i = 2% and $\beta = 1$. Although this charging procedure may not be appropriate when mahogany can be substituted for other species, these figures gives again a clear picture of the sensitivity of the results to the exhaustion time of the resource.

As the forest is used up, considering the transversality condition, the ratio between the Hotelling rent and the total rent tends to one, achieving this value when the resource is exhausted completely. This ratio, using our 1990 all timber V&H depreciation values (with β = 1) to total rent (β = 0) at a 2% rate, is very small around 0.012. At higher discounting rates, this ratio decreases dramatically to negligible values, confirming the absence of timber scarcity rent in the Amazonian context.

However, for mahogany, this ratio is approximately 0.62 at 2% discounting and only reduced to 0.34 at 4% rate. These ratio magnitudes suggest that mahogany exploitation is being exhausted in a *mining* process and scarcity being captured at market transactions. It also emphasises once more the importance of exhaustion time over the discounting rate in the estimation of scarcity rent.

However, taking into account all timber depreciation measures, these results indicate that depreciation charges against the forestry sector as a whole in the Amazon lacks sound economic meaning and will not bring about the sustainability issue of the forest. Charges related to other forest services are, therefore, a paramount to make environmental accounting an useful tool for planning in the Amazonian context.[48]

[48] Seroa da Motta and May (1995) had already brought about this issue since user cost measures were also very small for their estimates.

Consequently, the debate on the controversy of methodological approaches covered in the literature, and put forward in the previous sections of this study, may lose importance when one is planning in regions where high exhaustion time and lack of property rights are the cases.

Although they are not the aim and scope of this study, we also bring about some policy concerns at the light of our results. If scarcity rents are not fully perceived, or they really do not exist in such huge supply conditions as our estimates may suggest, an increase in timber exports may accelerate the deforestation process without the promising trade welfare gains.[49]

Apart from, usually ineffective measures of trade barriers, in term of environmental policy, such perspective leads to actions aimed at the changing of the property right system and enforcement controls. Scarcity has to be introduced into economic agent's behaviour by market mechanisms. Therefore, the current initiatives of the Brazilian Ministry of the Environment to create large areas of National Forests for concession schemes, for timber exploitation at sustainable basis, are important steps into promoting the exploitation of the Amazon[50] taking into account user costs. These are issues for which applied economics research may prove to pay high dividends.

[49] See Chichilnisky (1994) and Ferraz (1997) for a discussion of this issue.

[50] See Seroa da Motta (1997) for the rationale of this initiative and its institutional and legal problems.

APPENDIX

User Cost Dissipation Under Open Access

We can illustrate the situation of absence of scarcity capture using a simple example adapted from Baland and Platteau (1996). Suppose we have a forest that is an open access, and assume the entire stock of timber is given by *S*. Let us consider an input called man-with-a-saw, *n*. The total amount extracted of timber *Y* depends on the amount of *n* employed represented by the function *F(n)*. Using as an example a quadratic production function, $Y = an - bn^2$, and normalising the price of timber to one, we can characterise the equilibrium situation. Under open access, the average product *Y/n*, is equal to *w*, the price of the input.[51]Therefore the open access situation is characterised by:

$$n^o = (a - w) / b.$$

The rent from this activity is $F(n) - wn$. Using the previous result in the rent equation, we can observe that under open access the rent is completely dissipated,

$$F(n^o) - wn^o = 0.$$

If the extraction activity was privately owned, the necessary condition for profit maximization would be the equality between the price of the input, *w*, and the marginal product (not the average product as in the open access situation). This equilibrium condition will lead to:

$$n^* = (a - w) / 2b.$$

Substituting this condition in the rent equation, it can be noted that we will have a positive rent:

$$F(n^*) - wn^* = (a - w)^2 / 4b.$$

[51] For a detailed discussion on this result see Weitzman (1974).

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