OPTIMAL' DEFORESTATION IN THE BRAZILIAN AMAZON; THEORY AND POLICY: THE LOCAL, NATIONAL, INTERNATIONAL AND INTERGENERATIONAL VIEWPOINTS

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OPTIMAL' DEFORESTATION IN THE BRAZILIAN AMAZON AND THE POLICY RESPONSE: THE LOCAL, NATIONAL, INTERNATIONAL AND INTERGENERATIONAL VIEWPOINTS

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The Brazilian Amazon provides an abundance of public benefits at the local, national and international levels, and will supply unknown benefits to future generations. Deforestation provides private sector goods, and current deforestation rates threaten the forest's existence. Consequently, there is increasing international concern for the forest's fate accompanied by incipient efforts to slow deforestation. Satisfactory policies for slowing deforestation must account for the intertemporal costs and benefits of deforestation at the local, national, international and intergenerational levels, while respecting Brazil's sovereignty over the region.

I present a dynamic optimization model in which economic output is subject to ecological constraints. The model allows economic values and their intertemporal weight to vary according to local, national, international and intergenerational societal objectives. Values include both public goods from the intact rainforest and private goods derived from conversion to agricultural land. Ash from current period deforestation increases crop yields, but cumulative deforestation degrades the ecosystem and lowers yields. Forests can regenerate, but ecological degradation slows regeneration, and eventually leads to irreversible change.

I solve a continuous time version of the model, extrapolate parameter values from secondary sources, and graph steady state outcomes for a range of ecological scenarios and economic assumptions compatible with local, national and international societal objectives. I develop a discrete time version of the model and estimate the optimal time path of deforestation.

The models suggest that for any reasonable assumptions, societal objectives at the local level may lead to a high risk of irreversible deforestation in less than 50 years. National societal objectives may lead to irreversible forest loss, but probably not within the present generation's life span. Irreversible deforestation is unlikely if international or intergenerational societal objectives determine deforestation rates.

Policy alternatives are analyzed in light of model results. Deforestation cannot be slowed without international assistance and the national capacity to implement effective policies. Unfortunately, sufficient international resources are not currently forthcoming, and Brazil lacks the institutional capacity to seriously slow deforestation rates. As a result, prospects for slowing deforestation in the Amazon in the near future are poor.

Intergenerational ethical analysis suggests that it would be morally unacceptable to destroy the Amazonian ecosystem, but unfortunately moral acceptability rarely determines human behavior.

BIOGRAPHICAL SKETCH

Joshua Farley was born in Tompkins County Hospital in January, 1963, but left the region when only three years old. He earned a bachelor's degree in Biology from Grinnell College in 1985. Upon graduating, Joshua went to Alaska to build houses and earn money for seventeen months of travel throughout Latin America. The experience changed his interests from Biology to International Development, and after returning to the States, he began a master's degree in international affairs with a specialization in Economic and Political Development at Columbia University's School of International and Public Affairs. The high points of the degree included a summer spent in Liberia as a group leader for Operations Crossroads Africa, and a superb field course in Belize. Accepted to Cornell University's graduate school in Agricultural, Resource and Managerial Economics, Joshua returned to Ithaca to begin his Ph.D. in the fall of 1990. He won the Social Science Research Council's International Predissertation Fellowship Program Fellowship during his first year, and spent the following summer learning Portuguese in Recife, Pernambuco, Brazil, where he met his future wife, Andrea. The next four years were spent between Ithaca and Brazil. In August 1996, he began teaching Ecological Economics at the School for Field Studies' Centre for Rainforest Studies in Yungaburra, Australia, where he has developed an active interest in tropical rainforest restoration. In September 1998, Andrea gave birth to their first child, Liam Almeri Mello Farley.

I dedicate this dissertation to my wife Andrea, who supported me throughout, to my parents, without whose encouragement I never would have finished, and to my son Liam, whose birth two weeks ago put everything into perspective.

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INTRODUCTION

Statement of the Problem

There is considerable international concern that rainforests are being cleared too rapidly. Some 12 million km^2 of closed tropical forests remain (2/3 of which are rainforest), of an original 20 million km^2 (Park, 1992). Annual clearing rates in the late 1980s were estimated at 16.9 million hectares, an increase of 5.6 million hectares over the start of the decade (Kramer, Sharma and Munasinghe, 1995). Abundant evidence suggests that this rate will increase before it decreases. To make matters worse, there is evidence that beyond some unknown threshold, deforestation may be irreversible. Negative feedback from deforestation may even lead to spontaneous degradation of remaining forests, with unpredictable regional and global effects (Monastersky, 1990). Unless serious action is taken to address this problem, much of the remaining forest may be gone by the middle of the next century.

In addition to the rapid rate of deforestation, the concern over rainforest destruction can be attributed to the growing awareness of the wealth of goods and services, both public and private, which intact rainforests provide. Public goods are primarily service flows from the rainforest stock, and can be local, national or global in nature. Such benefits include maintaining soil quality, limiting erosion, stabilizing hillsides, modulating seasonal flooding, protecting against excessive siltation of rivers, streams, hydroelectric reservoirs and oceans, providing suitable conditions for economically valuable plant, fish and wildlife populations, maintaining stable climates locally, regionally and globally, preserving potentially valuable genetic resources, and preserving indigenous cultures and peoples, among others. The primary sources of private goods from the intact rainforests are the renewable resources which may be sustainably extracted.

Rainforest conversion supplies a variety of private goods, primarily lumber, fuel, agricultural land, and mineral deposits. At the cost of flooding vast tracts of forest, rainforest rivers can also supply abundant hydroelectric energy (Camargo and Reis, 1991; Dickinson, ed. 1987). Timber stocks alone are estimated to be worth 1.7 trillion dollars at 1984 prices (Repetto, 1988.). However, while managed timber extraction could be sustainable and maintain much of the flow of benefits from intact forests, destructive, unsustainable extraction is the norm. Rainforest soils are notoriously poor, and exhausted quickly by agriculture. Mineral extraction and hydroelectric power have high returns in relation to forest cleared, but are a relatively minor source of deforestation[1].

Given the abundance of benefits from intact rainforests, and the relatively meager returns to conversion to agropastoral (farming and ranching) land, why are the rainforests being cleared so rapidly? Fundamentally, rainforests are being cleared because for those doing it, it is perceived as the best available option. This perception is influenced by ignorance, the lack of better alternatives, a preference for immediate over future benefits (i.e. a high discount rate), and the ability to privatize profits from deforestation while sharing the costs (i.e. the market failures of public goods and negative externalities).

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[1] Though roads built to hydroelectric dams or to mineral extraction sites may lead to an influx of colonists and forest devastation.

Deforestation may be an attractive option not only for the individual engaging in it, but for forested countries and regions as well. The remaining tropical rainforests are located in developing countries, eager to increase the quality of life of their citizens. Intact rainforests are often viewed as economically unproductive, while rainforest conversion can provide foreign exchange, raw materials and capital to fuel industrial growth, and agricultural lands necessary to feed rapidly growing populations. The returns to deforestation are typically immediate, obvious and appear in national accounts, whereas the returns to conservation are frequently less visible, longer term, and ignored by traditional measures of economic welfare such as the Gross Domestic Product (GDP). Presently rainforests cover significant percentages of many of the countries they occupy, and if these countries have decreasing marginal utility for forest land, the value to them of the marginal unit may be quite small.

Further, while people recognize that rainforests provide valuable goods and services, history suggests that as resources are exhausted, technological innovations provide substitutes, and natural resources are therefore considered by some to be virtually infinite. Many economists and policy makers thus believe that exhaustion of rainforest resources may not be a serious problem, as long as it is carried out efficiently.

In addition, slowing or stopping deforestation may not even be feasible. If it is feasible, it will inevitably involve significant enforcement costs, and the countries responsible may prefer to apply their scarce resources towards other goals. Benefits from halting deforestation must be extensive to outweigh the opportunity and financial costs involved.[2]

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[2] As an example, Surinam is 90 percent covered by sparsely populated moist tropical

Policy measures to slow deforestation are further complicated by the fact that while certain benefits from rainforests may be global, the forests themselves are under national sovereignty, and their fate may be primarily controlled by local individuals and institutions. This situation increases the complexity of the public goods problem: there is no existing institution which can ensure the provision of an appropriate amount of the public good for international society. Any international efforts to curb deforestation would require negotiations with national and/or local governments and institutions, which in turn would face the difficult task of controlling deforestation locally. There are thus potentially several layers of transaction costs, which limit the prospects for Pareto improving trades.

The problem then is to estimate what is the 'optimal'[3] level of forest stock to strive for at each level of control, what is the optimal rate of deforestation en route to the final goal, and what are the best available policy measures to achieve these goals.

The remainder of the introduction looks at:

the obstacles to determining optimal deforestation rates and levels;

the Brazilian Amazon;

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there has been considerable international outcry over the decision of the government to sell the logging rights to several million acres to foreign companies. While this may not be optimal for the world as a whole, it is quite possible that the benefits to Surinam will outweigh the costs, and that the benefits could be distributed in such a way that no one is worse off than before. The same is probably true for states in the Brazilian Amazon such as Amazonas, Roraima and Amapá, which are still over 97% native forests, and perhaps even for Brazil as a whole.

[3] Given the extensive uncertainties (ecological, technological, economic) involved, and the limited potential for controlling deforestation, we cannot hope to determine 'optimal' policies, and can hope at best for satisfactory ones. Throughout this dissertation, mathematical analysis will solve for optimal solutions to the economic models presented. At best, these solutions will translate into satisfactory policies. In reference to policies and actual outcomes, 'optimal' and 'satisfactory' are used interchangeably.

the optimal deforestation rate for the individual;
the optimal deforestation rate for society;
distribution issues and property rights;
the objectives of this dissertation and procedures used;
a review of the literature, and the contribution of this dissertation; and
the organization of the work.

Obstacles to Determining Optimal Deforestation

While determining rough estimates of the 'optimal' deforestation rate in tropical moist forests could prove a valuable input into policy decisions, there are several serious obstacles involved. Some of the most important obstacles include:

1) the large number of benefits from rainforests, the difficulty of quantifying these benefits and the lack of a common metric for comparing the benefits from deforestation with those from intact forests;
2) the regionality of benefits;
3) the role of uncertainty;
4) the potential for irreversibility;
5) the abundance and significance of market failures;
6) the relevant time horizon;
7) the question of property rights; and
8) the impact of geophysical and biological heterogeneity on development, development policies and economic valuation.

This list requires further elaboration. First, rainforests provide a great variety of goods and services, either in their natural state or after conversion to cropland. Some of these goods and services are mutually incompatible, many are poorly understood, while others undoubtedly have yet to be discovered. Clearing the forests produces immediate measurable gains primarily in the form of agropastoral land, timber, hydroelectric power, and mineral wealth. Many of the benefits of the intact rainforest are diffused through time and space, more difficult to measure and are in the form of a constant flow rather than gains over a relatively short time span. To determine what is the optimal rate of deforestation and the optimal level of preservation, one must compare primarily quantitative with primarily qualitative benefits and costs.

Second, benefits from the rainforest vary according to the region and group being considered (Farnsworth, et. al. 1987; Sandler, 1993). Local public goods produced by the tropical forests include such benefits as nutrient recycling, protection against floods, provision of clean water and local climate stability. National public goods include the role of the Amazon in stabilizing regional climates and rainfall patterns, and protecting hydroelectric dam reservoirs, rivers, coastal waters and fisheries from excessive sedimentation. Among the global public goods are the role of the Amazon in storing $C0_2$, as a filter for air pollutants, as a regulator of the global climate and as a repository of genetic resources (Fisher and Hanneman, 1994). To complicate matters even further, some public goods serve only specific regions outside Brazil- for example some song birds that eat crop pests in the United States migrate back and forth from the Amazon (Sandler, 1993). The economically optimal level of preservation and rate of deforestation may therefore closely depend on the spatial level of analysis[4].

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[4] Obviously, each spatial level (local, national, international) corresponds to a different level of society. Throughout this dissertation, 'levels of society' will refer to local society, national society, and international society, and the corresponding institutions.

Third, there are several sources of uncertainty[5] with respect to exploitation of the rainforests, four of which I outline here. We are undoubtedly unaware of all the benefits provided by the rainforests. For example, thirty years ago, CO_2 storage was hardly considered a valuable service, and we can barely even guess at what new goods and services we will discover as we learn more about the rainforests. Rainforests are also tremendously complex ecosystems of global importance which we do not entirely understand. We therefore can only guess at the impacts of large-scale deforestation, and the trade-offs between supplying those goods which require conversion of the rainforest and those which require preservation (Farnsworth, et. al. 1987; Norgaard, 1981). Many benefits of the rainforests will depend on advances in technology (that either complement or substitute forest resources) which are themselves uncertain, and which will only become known in the future. Unpredictable discoveries of new species and new uses for known species will more than likely create new economic goods. Finally, we do not know what non-economic values future generations will attach to rainforests.

Fourth on the list, irreversibility compounds the problem of uncertainty. Studies indicate that extensive deforestation of the rainforests is for all practical purposes irreversible (Salati and Vose, 1984; Lovejoy, 1994), whereas the decision not to develop can always be

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[5] Uncertainty is a condition of incomplete information in which not only is the probability of outcomes not known, but the set of possible outcomes is not known either. Risk, in contrast, occurs when both the set of possible outcomes is well defined, and their probabilities are known. Under conditions of uncertainty, new information relevant to the decision making process is acquired over time, whereas in situations of risk, this is typically not the case (Perrings, 1991).

reversed. This makes it even more crucial not to exceed the optimal rate of deforestation.

A fifth obstacle to estimating optimal deforestation rates is the presence of numerous market failures associated with development of the rainforests. Many of the services provided by the rainforests are public goods, and many of the productive activities involving rainforests produce serious externalities. With poorly defined property rights and limited enforcement, much rainforest is treated as an open-access resource. Decisions by the individual are thus unlikely to lead to the economically optimal level of use. Also, since most of the environmental goods and services provided by the forests are not marketable or are not currently marketed, it is difficult to objectively assign values. Difficulties are only compounded by the spatial specificity of some of the public goods and externalities.

Sixth, the relevant time horizon can be very important in economic dynamic optimization models, and is largely determined by the discount rate used. In fact, for such models the discount rate is frequently the single most important variable in determining the optimal rate of resource use. Clearly, the discount rate is an abstraction from reality, but models are only useful if they simplify reality, and thus must depend on abstractions. Crucial abstractions, however, are those which have a crucial impact on the results of the model, and it is important to get them right (Solow, 1956). Selection of a discount rate, if one is to be used at all, will therefore have to be carefully explained and justified.

A seventh obstacle is the issue of property rights. Are the rainforests the property of the indigenous peoples who have lived there for thousands of years, of all the local inhabitants, regional government, or national government? Since the rainforests supply benefits to the whole world, should the international community have any property rights? Are rainforests the property solely of the existing generation, or do future generations also hold rights? Since many indigenous groups are at best marginal participants in the market economy, government control is a political issue, the international community lacks sovereignty and future generations cannot participate in today's markets, this is an ethical issue with potentially powerful economic implications. To whom property rights are assigned may determine not only what the optimal level of exploitation is, but also how to arrive there.

Finally, not only do different rainforests vary considerably from each other, but most individual rainforests are also extremely heterogeneous. Rather than merely a monotonous ocean of trees, the Amazon alone has at least 104 distinct vegetational ecosystems (including cerrado (i.e. lightly wooded savanna, ranging from grasslands with a few trees to scrubby woodland), bamboo forest, etc.) which can be further divided into 234 sub-systems (Minstério do Meio Ambiente, dos Recursos Hídricos e da Amazônia Legal, et. al., 1995). In addition, proximity to navigable rivers, roads, population centers- in short, market access- can have a profound impact on development decisions (Reis, 1992). Consequently, it is highly doubtful that any one optimal exploitation strategy would apply to an entire rainforest. However, any optimization model which attempted to divide the rainforests into homogenous zones with corresponding economic uses and benefits would quickly become unmanageably complex.

While taking all of these factors explicitly into account in a model would be extremely difficult, completeness demands that they be discussed and that at least their qualitative impacts be considered

Besides these technical issues, the major problem in determining an optimal deforestation rate and preservation level is deciding what is meant by optimal. Is simple Pareto optimality sufficient, or does distribution matter? Should optimality simply entail maximizing net present value, which implicitly assigns all property rights to this generation, or should we be concerned with intergenerational justice? Should the risk of catastrophic impacts affect the decision making process, possibly justifying decision making criteria based on the precautionary principle, minimax (minimizing the probability of the maximum negative outcome) or safe minimum standards? Does efficiency take precedence over sustainability (however defined), or is the latter more important? If sustainability is of primary importance, how is it to be defined, modeled and achieved? These questions are particularly important in the case of rainforests, since they could easily be irreversibly destroyed, if left intact they will supply benefits to future generations, and different use patterns benefit different people.

The Amazon

To make the analysis more concrete, this dissertation will use as a case study the moist tropical forests of the Brazilian Amazon. The Amazonian rainforest at approximately 5.5 million km^2 is the largest tropical rainforest on the planet. Some 3.8 million km^2 of the rainforest lie within the borders of Brazil.[6] Figure 1 shows the Legal Amazon, and Figure 2 the geo-phytological Amazon.

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[6] It is common to find widely varying figures for the for the area of the Brazilian Amazon. Some figures refer to the legal Amazon (approximately 5 million km^2), which "is basically a legal term, established by federal legislation, for the purposes of territorial planning and regional development. The term refers to the area of the States of Acre, Rondônia, Amazonas, Mato Grosso, Roraima, Pará, Amapá, Tocantins (above parallel 13 degrees south) and Maranhão (west of 44 degrees meridian)" (Integrated

Some states within the Brazilian Amazon are virtually untouched, while others are undergoing rapid deforestation. The region is a treasure trove of natural resources, and the intact forest provides services at local, national and international levels. Deforestation (measured by area) is occurring more rapidly in the Amazon than anywhere else on the planet (Fearnside, 1990b). As regions of the Amazon are among the most biologically diverse ecosystems on the planet (Erwin, 1988), this is a serious cause for concern. The best estimates of deforestation in the Amazon suggest that though little over

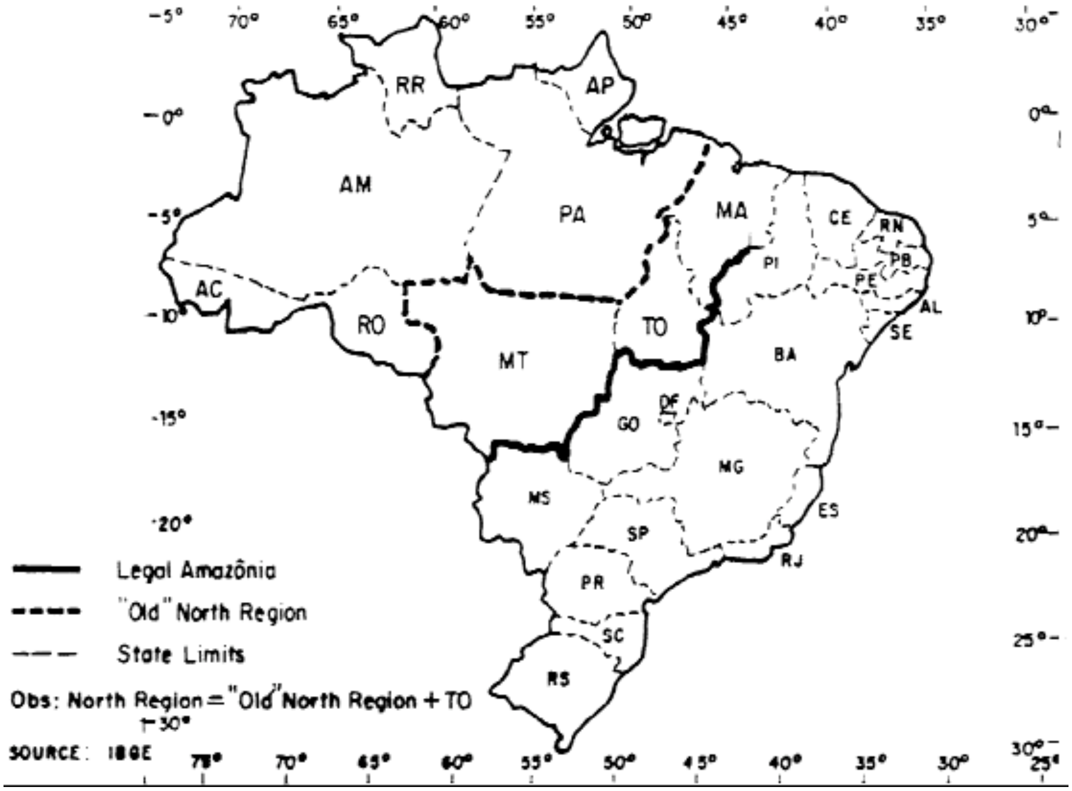

Figure 1: the legal Amazon (from Camargo and Reis, 1991)

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which also includes naturally non-forested areas. The figures given above refer to the geo-phytological Amazon, and not the political one (Fearnside, 1990b).

12.5% (Instituto Nacional de Pesquisa Espacial (INPE), 1998) has been cleared, collateral damage means that far more than this is degraded.[7]

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[7] Skole and Tucker (1993) estimate total deforestation as of 1988 at 5.6% but place associated degradation at 14.4%. If degradation has increased proportionately with deforestation since 1988, over 32% of the Brazilian Amazon would be suffering from degradation.

While the best estimates of deforestation probably come from satellite photos, estimates are unlikely to be exact. Different types of satellites have different limitations, and each satellite records images in a number of different wavelengths of the electromagnetic spectrum, which convey different information. Images from satellites must be checked by field tests to determine exactly how results correspond with actual vegetation. Satellites cannot always distinguish between primary and secondary growth, and when they can, some studies include secondary growth as deforested lands and others do not. Landsat images are among the best affordable ones, but make infrequent passes, so cloud cover is a problem. Studies may use images from different years to get a complete picture. Also, many studies divide the area deforested by the area in the legal Amazon, which is 35% larger than the forested areas of the Amazon. This will systematically underestimate the amount of deforestation by including naturally non-forested areas in the denominator but not in the numerator. For more details about the various estimates of deforestation, see also Fearnside (1990b); Nascimento (1991); Moran, et. al. (1994). For graphic illustrations of the different pictures seen by different remote sensing instruments, see O'Neill (1993).

Another means of estimating deforested area is through use of census data. Comparing census data with Landsat data for the same municipalities, I found discrepancies of up to 100%, i.e. Landsat showed zero deforestation in small municipalities near population centers where the census data showed 100% deforestation. Census data however showed negative rates of deforestation for certain years, and over 100% deforestation in some municipalities. There appears to be no available, fully reliable estimates of total deforestation or of deforestation rates.

Figure 2: the geo-phytological Amazon (from Camargo and Reis, 1991)

Though not high in percentage terms in comparison with most countries or ecosystems, the real problem lies with the rate of deforestation. From 1994-1995, the Legal Amazon in Brazil was undergoing deforestation at the rate of 0.81% per year, but over the same two years, Mato Grosso lost 4.86% of its forests, Maranhão 6.41%, Rondônia 5.5% and Tocantins 4.58% (INPE, 1998).

There is considerable literature examining the role of government subsidies and incentives in promoting deforestation (e.g. Binswanger 1991, Mahar 1989), and when many of these subsidies were officially ended in 1989, deforestation rates indeed fell. However, the period 1989 and 1994 was also marked by economic recession and high rainfall, which in conjunction with other factors probably contributed to the temporary decrease in deforestation. In 1995, with drier weather and economic stabilization, deforestation rates again rivaled the worst years of the 1980s (Veja, November, 1995). These rates of deforestation cannot be sustained, and must in future years level off as the forest is exhausted. However, it may be a long time before enough forest has been cleared for market mechanisms to slow the deforestation rate (Fearnside, 1986b; Cunha, 1986).

These characteristics make the Brazilian Amazon an ideal candidate for a comparative analysis of optimal deforestation rates at the local, national and international levels.

The Actual Rate of Deforestation- Conversion by the Individual

The greatest pressure on the Amazon rainforest currently comes from conversion to agropastoral land by farmers and ranchers, who deforest at a rate which is optimal from their point of view given the constraints they face (Fearnside, 1993; May and Reis, 1992; Hecht, Norgaard and Possio, 1988).

Though the underlying reasons why agropastoralists (i.e. farmers and ranchers) convert forest lands are varied- government policies, population pressures in settled areas, land concentration, land exhaustion and unemployment all contribute- presumably the basic rationale for conversion is that the risk adjusted private returns to production are greater than the corresponding costs. With perfect markets, perfect information, zero transaction costs (which together preclude the possibility of externalities to production), no public good benefits from forests, a private time discount rate equal to the social discount rate and ignoring the question of property rights for future generations, optimization by the individual would be the same as optimization by society. Unfortunately, none of these conditions are even approximated in the Amazon.

Among the reasons why the individually optimal deforestation rate will tend to be higher than the socially optimal rate three stand out: market failures, government policies which favor deforestation, and different discount rates for the individual and for society. These factors require elaboration.

Three related types of market failures in the Amazon allow the individual to gain most of the benefits from the area deforested while sharing many of the costs: the production of public goods by intact forests, negative externalities to deforestation, and open-access properties of the resource. As emphasized above, the intact rainforest provides a wealth of public goods. Conversion offers primarily private goods, so that the individual receives the benefits of conversion, while the costs (in the form of fewer public goods) are shared by society. Studies suggest that clearing land for crops may have a negative impact on crop yield on already cleared land (Lal, 1986; Ehui, 1987), yet farmers will ignore the negative externality to others' productivity in their own decision to deforest. Finally, weakly established and poorly enforced property rights lead in many cases to the treatment of forests as an open access resource, with the well known problems this causes (Hardin, 1993).

Government policies also interfere with the market mechanism and provide incentives for deforestation. Subsidies or financial incentives for clearing the rainforest were widespread from the late 1960s through the late 1980s (Mahar, 1989; Binswanger, 1991). The individual weighs them as a benefit, and the costs to society are again ignored. Under Brazilian law, to secure tenure to land, productive use of the land must be shown. Deforestation is the favored means of showing productive use, and the value of the title may outweigh the benefits lost by the rapid deforestation necessary to secure it. Inflation and economic instability (aggravated by government policies) promote land speculation, common in the Amazon, which leads to land being treated as a commodity apart from its productive capacity (Hecht, 1992)[8].

Finally, there are several reasons why the individual may discount the future more heavily than society and thus favor more rapid exploitation. First, if the individual has insecure tenure, he is more likely to favor short-term gains since in the long term, he may well lose the land. This insecurity also reduces incentives to invest in the productive capacity of the land. From the point of view of economic efficiency at the level of society, however, it is of little importance who owns the land. Second, the individual may discount the future because of other uncertainties, such as the risk of death, which again are irrelevant to society. Third, poverty may lead the individual to value immediate survival above all future production.

The Socially Optimal Rate of Deforestation

The socially optimal rate of deforestation is presumably that which maximizes the intertemporal well being of society, and therefore must consider all the costs and benefits, both private and public, of forest conversion. [9]

Even in the attempt to maximize simple private good production, there are several difficulties facing the economic planner. Deforestation

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[8] Almeida and Campari (1994) have also found that the value of land often appears to be independent of its productive capacity. Among solvent farmers, if productivity keeps up with land prices, then demand for land falls as land prices rise (which is normal for a factor of production). If productivity does not keep up, demand for land may become speculative, and may increase as land prices increase (which is normal for a portfolio asset).

[9] Whereas negative externalities to rainforest conversion can also be treated as public benefits of intact forests, this dissertation will treat the impact of one producer's actions on other producers' productivity as an externality. This approach allows the use of a utility function with separate arguments for private, quantifiable marketed goods and for non-marketed public goods where quantitative measurement is less empirical.

opens new lands for agriculture, and the ash from burned vegetation adds nutrients to the region's predominantly poor soil (for discussion and documentation, see Appendix A). However, clearing forests can alter microclimates, reduce soil fertility, and change hydrological regimes in a manner which may reduce regional agricultural productivity (Ehui, 1987; Salati, 1987). Studies by Ehui (1987) and Panayatou and Parasuk (1990) have shown this to be the case in the Ivory Coast and Thailand, respectively. The social planner must balance the gains from deforestation (increased agricultural area in addition to the short-term fertilization effect of ash) against the role of the forest in maintaining ecosystem health and with it benefits to long-term agricultural productivity (Ehui, 1987).

The issue is one of a negative externality of production. When the individual farmer deforests he retains all the gains from deforestation, yet shares the negative effects of environmental degradation with other farmers. Internalizing the externalities, perhaps with a Pigouvian tax on deforestation equivalent to the marginal social cost of environmental damage, would theoretically lead to the optimal level of deforestation with respect to agriculture. It would then be fairly simple to incorporate private returns to extractive production into the analysis, and determine the optimal level of deforestation with respect to the provision of private goods. Ehui et. al. (1987,1989,1990) address these issues in a model of deforestation in the Ivory Coast.

Complexity increases greatly if the public good benefits of the rainforest are incorporated into the model. One major issue is how society values public goods versus private goods. Related to this issue is the fact that different regions receive different public good benefits. Also, public goods will accrue differently to different groups; for example, since environmental goods are frequently considered luxury goods, the existence value of the Amazon (a public good) may be much higher for wealthier individuals. In addition, all of these public goods are potentially intergenerational. Much of the public good value associated with genetic resources may in fact only be available to future generations which have the technology to exploit them. The optimal rate of deforestation and level of preservation is therefore likely to change depending on the nature of the analysis, i.e. whether it is regional, national or global, and depending on the time horizon and discount rate.

Valuation of the public good benefits of the Amazon is particularly difficult due to our lack of understanding of the ecosystem and incomplete knowledge of the public goods it provides (Farnsworth, et. al., 1983).

Science also has little understanding of how deforestation and other changes to the ecosystem will affect the provision of public and private goods. The complexity of an ecosystem increases at an increasing rate as the number of species present increases. Since the Amazon has the greatest known concentration of species, it is likely to be among the most complex ecosystems on the planet, and is one of the least studied (Norgaard, 1981). We are barely beginning to understand the impact of human activity on the provision of many of the ecosystem’s public services, and are unable to accurately determine the environmental impact of deforestation or extractive production. The trade-offs between public and private goods therefore remain highly uncertain. Uncertainty may be resolved in the future, but if we err on the side of excessive deforestation now, there may be no way to correct our mistakes.[10]

It is worthwhile briefly outlining some of the differences between social optimization for different levels of society. Since this dissertation will focus on policy applications, the social aggregations chosen correspond to existing decision making levels- regional (which may be considered as individual states or the governments of the Amazonian states, jointly, with little difference), national, and international. An intergenerational vision of society does not necessarily correspond to any particular policy making level, but as virtually all societies have some concern for posterity, this too will be included.

Intertemporal social optimization at the regional level will include only local public goods. The only negative externality to production will be the decrease in crop output in the region itself as a result of deforestation. Since the region is still densely forested and sparsely populated, the local marginal utility of rainforest is likely to be quite low, while transport costs may make the marginal utility of local agricultural production quite high. If the policy planner focuses on income growth, the valuation for public goods relative to private goods may be virtually zero. At the level of society the discount rate is likely to be lower than for the individual. The Amazon region however has a low per capita income level relative to the rest of Brazil, especially in the rural areas

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[10] Abundant evidence suggests that deforestation of large areas is irreversible for all practical purposes. Tropical rainforests may take upwards of 400 years to reach the climax state (Wilson 1988). The ecosystem changes caused by deforestation prove serious obstacles to regrowth, and empirical studies show that second growth shows far less bio-diversity than primary growth (Lisboa and Prance, 1991). Walker et. al. (1995) suggest that 50% deforestation would lead to no rainfall at all for much of the year, which implies not only irreversible deforestation, but negative feedback which would lead to further degradation. For more details and additional references, see Appendix A.

where most deforestation occurs, and may favor current consumption over future consumption more than at the national level.

At the national level, the policy planner must look at both private good output and the national public good services of the intact rainforest. Studies suggest that deforestation may change extra-regional weather patterns, and specifically may lead to a decrease in rainfall in the cerrado, with a negative impact on agricultural productivity (Salati and Nobre, 1991). The cerrado is currently responsible for far more agricultural production than the Amazon, and per hectare yield in the cerrado is also far higher. The nation must then account for the negative impact of deforestation on crop yields from both the Amazon and the cerrado, and the latter may well outweigh the former.

On the other hand, though the Amazon has notoriously poor soils for agriculture or pasture, even the 9% (315,000 km^2) of moderate to high quality soils estimated to exist in the region would increase Brazil's agropastoral land area by over 60% if exploited (Cunha and Sawyer, 1991)[11].

Many non-economic factors (geopolitical, political) also enter into the calculus at the national level, but these will be set aside for the time being.

Finally, since many of the services they provide are global in nature, many people believe rainforests should be used in a manner which maximizes the social welfare of all mankind. To do so, the

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[11] Though as Kyle and Cunha (1990) point out, the difficulty of locating these fertile soils drives their economic value towards zero.

international good benefits of intact forests and negative externalities of production must also be considered.

However, the nations within whose borders the rainforests lie cannot be expected to simply forgo the benefits of developing them for their own advantage. Since there is no world authority with the right to legislate policy in Brazil, any policy agreements to 'optimize' the flow of the global public goods produced must be the result of negotiations, and logically Brazil will only agree to those negotiations which are in its own best interest. It seems likely however that there is substantial room for Pareto improvements, where other countries could pay for the services the Amazon provides, and provide Brazil with greater incentives to limit deforestation. The problems here are the same with the provision of any public good, i.e. determining how each country will pay for preservation according to the marginal utility received for preservation. Transaction costs are potentially quite high, and could seriously constrain the set of efficient outcomes. Free riding could also be a problem.

Distribution and Property Rights

Inevitably there will be trade offs between the provision of private benefits and public benefits. As the private and public benefits frequently accrue to different individuals, these trade-offs may have serious distributional impacts. Some studies have found that much of the value extracted from private goods supplied by the Amazon leaves the region, while the local inhabitants lose the local public benefits (Bunker, 1985; National Integration Policy for the Legal Amazon, 1995). Unless proceeds from conversion of the forest are invested for future generations with a high enough rate of return to compensate for the loss of environmental amenities, conversion of the rainforest also implies a redistribution of wealth from the future to the present. Even with investment, only by coincidence will the benefits accruing to the future exactly compensate for the loss of the services provided by the rainforest. Alternatively, if rural inhabitants of the Amazon are denied access to resources to protect the international public good benefits, this also has a distributional impact.

According to Coase's theorem, in a free market economy in the absence of transaction costs and wealth effects, it may not matter in whom property rights are vested when externalities are present. For example, if the externality is some form of pollution, paying for the right to pollute on one hand or paying to prevent pollution on the other will lead to the same level of pollution (Coase, 1960). Unfortunately, transaction costs can be very high, or even infinite in the case of intergenerational transactions (Bromley, 1991). Also, the wealth effect is likely to be profound: many inhabitants of the Amazon do not directly participate in the market economy, but cannot be justly left out of an economic analysis because of this. Property rights, both intragenerational and intergenerational, are therefore very important in determining an optimal outcome.

Unfortunately, time and space curtail detailed analysis to the case of intergenerational distribution.

Objectives of the Study

There is abundant literature examining the causes of deforestation in the Amazon and presenting various policy measures for preventing it (e.g. Hecht 1985,1989,1992; Fearnside 1986a, 1989; Repetto and Gillis, 1988; Nascimento, 1991; Mahar, 1989; Binswanger, 1991). A similar quantity of literature examines the potential impact of deforestation, both from a geo-physical and biological perspective- degraded pastures, species extinction, reservoir siltation, increased flooding, climate change, etc. (e.g. Dickinson, ed. 1987; Uhl and Vieira, 1989; Neal et. al., 1992; Lal, 1986), and from a social perspective- land disputes, violence, concentration of the wealth, etc. (e.g. Hecht and Cockburn, 1989; Bunker, 1985; Branford and Glock, 1985). In contrast, there is little literature that examines the characteristics of optimal deforestation rates while considering: both public and private good benefits from the forest; the potential for both forest regrowth and irreversible deforestation; the negative impact of ecological degradation on crop yields and forest regrowth; and the differences between optimal levels of deforestation for different levels of society- local, national, international and intergenerational.

The general objectives of this study are to:

1) show that both discount rates and public good values of the rainforest are likely to differ for local, national and international levels of society;
2) estimate optimal rates of deforestation and steady state forest stocks from the point of view of local, national, international and intergenerational society while accounting for both public and private goods as well as ecological constraints;
3) examine the theoretical likelihood of attaining a steady state equilibrium and the stability of such a state;
4) examine policies that affect the rate of deforestation and determine how locally and nationally optimal deforestation rates can be brought into line with internationally optimal rates;
5) examine the implications of intergenerational justice towards deforestation in the Amazon, which involved involves:

   a) analyzing the assumptions of dynamic optimization models regarding intergenerational property rights;
   b) outlining at least the minimum obligations of intergenerational justice; and
   c) examining the issues most relevant to intergenerational distribution, namely, market valuations, property rights; uncertainty and discounting;

6) propose new criteria for selecting an appropriate discount rate for large system, intergenerational analysis.

Procedures

To realize the objectives of this study, I will first develop a tractable theoretical model of the rainforest exploitation planning problem in the tropics that. The model will incorporate both public goods and private goods supplied by rainforests and rainforest conversion. Private goods are primarily returns to agropastoral activities. While sustainable extraction and logging are important in the Amazon, agropastoral activities are more widespread, generate more gross income and are responsible for more deforestation (Almeida and Uhl, 1994; Hecht, 1992). Logging alone causes forest degradation, but not deforestation (INPE, 1998). The greater simplicity of analysis in looking only at agropastoral production is felt to compensate for the lack of detail[12]. For public goods, exact values are difficult to determine.

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[12] The estimated value of reserves of just seven minerals (niobium, iron, kaolin, aluminum, potassium, copper and nickel) in the Amazon is 1.6 trillion dollars (1988 dollars and prices). However, mineral extraction is estimated to deforest 5882 times less per unit income than agropastoral production, and is responsible only for a very small percentage of the area deforested (though access roads to mineral deposits in some areas provide access for settlers, leading to more deforestation)(Camargo and Reis, 1991).

The model will use extensive sensitivity analysis to explore a range of values, and discussion will examine the implications of the resulting uncertainty. Ecological factors in the model affecting private good production include the nutrient inputs from current deforestation and the role of the forest ecosystem in maintaining agricultural yields. The model will also allow forest regeneration, with potential irreversible deforestation determined by ecosystem integrity. Finally, the model will use different valuations of rainforest benefits and different appropriate discount rates depending on the level of society used in the analysis.

After developing the model, I will estimate the model's parameter values from secondary literature and deduce reasonable discount rates and social valuations of the public good for each level of society. Next, I use Mathematica© to solve the model, and use extensive sensitivity analysis and three-dimensional Mathematica© graphs to examine the impact of a range of assumptions regarding economic and ecological parameters.

To determine the optimal time path of deforestation, I will construct a discrete time version of the model and use GAMS (General Algebraic Modeling System) to solve it. For sensitivity analysis, I will the same variety of conditions and assumptions as in the continuous time version.

The next step will be to estimate the cost of various policy options for slowing deforestation, relying as much as possible on the costs of existing policies, and census data from Brazil. I will then estimate the impact of proposed policy measures on the model variables, and use the model to determine the impact of these policies on the rate of deforestation and the optimal steady state forest stock. I will further evaluate policy options according to their political feasibility, their effectiveness and their affordability. This will be necessary to choose among the various options. Finally, I will make explicit the ethical assumptions underlying the analysis, particularly those involving our obligations to future generations.

Review of the Literature and Significance of the Current Work

Numerous studies have examined the issues of forest and natural resource management. Ehui et. al. (1987,1989,1990,1992) and Panayatou and Parasuk (1990) have looked at the negative impact of deforestation on soil fertility and agricultural yields on both the land deforested and adjacent lands. Hartman (1976) was one of the first to bring amenity values into the analysis of optimal deforestation, and Arrow and Fisher (1974), Clark and Reed (1990) and many others have added analysis of uncertainty and irreversibility. Sandler (1993) has studied the regionality of public goods from rainforests, Farnsworth et. al. (1983) have looked at ecological-economic interaction and Brazee and Southgate (1993) have looked at ethnobotanical knowledge.

Bromley (1991), Howarth and Norgaard (1990), Pearce and Turner (1990) and Daly (1991) tackle the economic problem of resource rights for future generations, while Daly and Cobb (1989), Barry (1989) and Rawls (1971) look at some of the ethical issues involved.

No model available examines uncertainty and potential irreversibility while still allowing for regrowth of the forest, yet Homma et. al. (1993a) note that most deforestation currently taking place is of second growth forests, while Dickinson, ed. (1987), Lovejoy (1994), Myers (1988) and Salati and Vose (1984) note that extensive deforestation is likely to lead to irreversibility.

This research will contribute to the literature in several ways. First, I will draw on Ehui et. al. (1987,1989,1990,1992) and Panayatou and Parasuk (1990) to look at the negative impact of cumulative deforestation on crop yields, but will extend their analysis by including the public good values of the rainforests. Drawing on Sandler (1993) and Farnsworth et. al. (1983), I will allow public good values to vary with the level of society under analysis. Heeding the research of Homma et. al. (1993a), my model will allow forests to regenerate, but excessive cumulative deforestation will slow and eventually reverse this process, as suggested by Salati and Vose (1984) and Lovejoy (1994).

Since poor data quality does not allow accurate estimation of the agricultural yield function, I will derive parameter estimates from secondary sources (primarily Ehui et. al. (1987,1989,1990,1992) and Panayatou and Parasuk (1990)),and use extensive sensitivity analysis. Sensitivity analysis is particularly necessary since uncertainty is a dominant feature of economic exploitation of the rainforests. The social welfare function was chosen to be similar to that used by Clark and Reed (1990), so that inferences can be drawn from their analysis of uncertainty.

Since public benefits differ at local, national and international levels, while the value of private benefits is unchanged, a primary difference between optimal levels of deforestation at the various levels of society is a function of different valuations for public goods. As the model will use an additively separable utility function, differences between local, national and international benefits can be modeled simply by changing a scaling factor for the relative value of public goods. The simplicity and clarity of this solution is felt to justify the degree of abstraction from reality it entails

Another factor affecting the optimality of intertemporal resource allocation is that discount rates are likely to differ at the local, national and international levels, while intergenerational analysis may not justify any discount rate at all. There are two primary reasons for this: different opportunity costs of money for different levels of society, arising in part from imperfect financial markets, and different time preferences for consumption, arising in part from differences in per capita wealth.

The present work will explore the relationship both between public good benefits and discount rates and the level of society being analyzed. Incorporating the results of this analysis into an economic model will allow a comparison between optimal time paths for deforestation and optimal steady state forest stocks at the local, national, international and intergenerational levels. This analysis is an important contribution to the debate over deforestation: only by understanding what constitutes a satisfactory rate of deforestation at each level can we strive towards that goal. Differences between satisfactory rates at each level will help determine to what extent national and international efforts will be necessary to address the problem locally, and also the urgency with which the problem should be addressed.

Sensitivity analysis will show the reaction of steady state outcomes to variation in the difficult to quantify ecological and economic parameters. Three-dimensional graphs will facilitate understanding the impact of variation in the parameter values, and graphically illustrate the range of joint economic-ecological equilibriums, versus economic 'equilibriums' which threaten ecological devastation.

The models suggest that many parameter combinations lead to steady states which approach irreversible exhaustion of forest stock with the potential for infinite costs to future generations. This result is possible because discounting to net present value implicitly places all resource property rights in the hands of the current generation. This is not an ethically neutral assumption. I will make explicit the ethical assumptions of the neoclassical model used, and examine how they fit into a theory of intergenerational justice. I will then discuss possibilities for making the neoclassical model compatible with intergenerational justice, including an alternative method for estimating an appropriate discount rate.

Finally, I examine some of the policy options for controlling deforestation at the local, national and international levels, taking into account the implications of the models with respect to differences between satisfactory rates of deforestation for each of these levels of society. Relevant policy options include those which:

1) internalize international public good values at the national level via an international Pigouvian subsidies for preserving forest;
2) provide international funding for monitoring and enforcement of existing legislation;
3) lower effective discount rates by providing subsidized credit for more sustainable productive activities, increasing the security of land tenure and local incomes;
4) increase research and extension for alternative, more environmentally benign production technologies;
5) create a market in deforestation through creation of tradable deforestation permits;
6) internalize national public good values at the local level by taxing deforestation when title is given or transferred, and indirectly by increasing the cost of forested land by closing the frontier (halting

extensive road construction) and increasing the opportunity cost of abandoning already cleared lands by improving local infrastructure; and

7) set aside and protect large blocks of conservation units to diminish the threat of crossing ecological thresholds.

In summary, the major contributions of this model are to combine several critical features of deforestation into one model, which will allow comparisons of optimal forest use for local, national, international and intergenerational levels of society. This in turn allows me to outline policy options for these same levels of society.

Organization of the Work

Chapter Two presents hypotheses about the agricultural yield function, the forest regrowth function, and the social welfare function, including the valuation of public and private benefits from intact rainforest and from rainforest conversion. These hypotheses are then used to build a tractable dynamic optimization model which can incorporate different valuations of the public good benefits of the rainforest and different discount rates for different definitions of society. Some analytical results are presented. Chapter Three estimates the model parameters using secondary sources, and presents extensive sensitivity analysis in graphical form. The chapter includes a discussion of economic and ecological equilibriums and makes conjectures regarding the implications of uncertainty. Chapter Four takes a discrete time version of the model, and examines the characteristics of the optimal time path for deforestation, under a variety of scenarios, using GAMS-MINOS software. Building on the results of Chapters Two, Three and Four, Chapter Five examines policy measures for bringing the actual deforestation rate closer to the optimal rate. The costs and impacts of these policies are estimated, and their feasibility discussed. Chapter Six examines intergenerational issues. Analysis includes a brief history of economic thought on intergenerational distribution, the application of Rawls' difference principle to intergenerational justice, and the role of uncertainty, ignorance, market valuation, and property rights. The chapter also analyzes the discount rate, and suggests a means for deriving a discount rate suitable for large scale, extended time analysis. Chapter Seven presents a summary and conclusions, and suggests further research opportunities. Appendix A briefly examines the geo-physical and biological features of the Amazonian ecosystem, focusing on how they create economic value and Appendix B examines economic and ecological aspects of existing productive activities and possible alternatives in the Amazon.

CHAPTER TWO:

THE MODEL

The Social Welfare Function

The economic and ecological factors that determine the 'optimal' level of conversion of rainforest to agricultural land are extremely complex. The capacity of a mathematical model to capture these intricacies is limited. Nonetheless, one can select certain factors which appear most important and gain insights into their impacts on deforestation with even a fairly simple dynamic optimization model. A central focus of this dissertation is to examine the differences between optimal deforestation rates and forest stocks when local, national or international goals are considered explicitly, and to examine the suitability of various policy options for achieving 'optimality'. The factors to be analyzed are chosen accordingly.

The public good value of rainforests is gaining increased attention in the economic literature (Clark and Reed, 1990; Fisher and Hanemann, 1994), including the difference in value depending on whose societal benefits are included, e.g. local, national, international, or intergenerational (Farnsworth, et. al., 1983; Sandler, 1993). Another interesting aspect of the deforestation problem, the negative impact of cumulative deforestation on agricultural output, has been explored by Ehui et. al., (1987,1989,1990,1992), Panayatou and Parasuk (1990), and Salati and Vose (1991) among others. Further, sustainability has received increasing attention from many economists (e.g. Pearce and Turner, 1990; Daly, 1991; etc.). Finally, it is widely accepted that appropriate discount rates for the individual and society will differ (e.g.

Pearce and Turner, 1990; Lind, ed. 1982), and equally obvious that appropriate rates are different for different definitions of society.

It is possible to develop an intertemporal dynamic optimization problem that focuses on these issues, while abstracting from the other factors that influence the optimal rate of deforestation. For the social welfare problem, let

$$W(S, F(t), D(t)) = \int_0^\infty e^{-\delta t}\left[v(S,t)V(F(t)) + U(\pi(F(t), D(t)))\right] \quad \textbf{\textit{eqn (1)}}$$

Where
W(.) = a measure of the net present value of intertemporal social welfare
V(.) = the social utility function for public goods
v(S)= the social valuation for public goods relative to private goods, which depends on S, where S = local, national, global, or intergenerational society.
π(.) = the output of private goods
U(.) = the social utility function for private goods
F(t) = forested area in million km^2, which produces a flow of public and private good benefits
D(t) = deforestation rate in million km^2/yr.
δ = the time discount rate

The social welfare function is assumed to be additively separable in public and private goods. The public good benefits of the rainforest are qualitatively different from the private good benefits (agricultural output in this simplified model) produced by conversion for at least four different reasons:

9) While private good output from the Amazon has almost perfect substitutes, it is likely that many of the life support functions of the Amazon have no substitutes, man made or natural;
10) Public good benefits by nature have no market and hence are difficult to value;

11) They do not generate income which can be saved or invested; and

12) They create different values for different levels of society e.g. local inhabitants, the nation, the world and future generations.

These qualitative differences mean that public good and private good benefits cannot be perfect substitutes, which is readily modeled by an additively separable logarithmic utility function. This approach has precedence in the literature (Clark and Reed, 1990).

Public goods produced by the forest are extremely varied, and cannot be reduced to some physically measurable numeraire commodity. Many of these goods (e.g. existence value) are ‘psychic fluxes’ (to borrow a term from Georgescu-Roegen, 1971) and simply cannot be physically quantified. Nonetheless, since public good output from the forest arises from the services provided by intact forests, current forest stocks are used as a proxy for public good outputs. In the model, the social utility function for these public goods is simply a function of land under forest cover at time t. It is assumed to be twice continuously differentiable and to exhibit positive but decreasing marginal utility, i.e.

$$\frac{dV(F(t))}{F(t)} = V_F > 0 \text{ and } \frac{d^2 V(F)}{d F^2} = V_{FF} < 0 \tag*{eqn (2)}$$

The public good utility function is also assumed to satisfy the limit condition

$$\lim_{F \to 0} V_F = \infty \tag*{eqn (3)}$$

Basically, this says that production of some public goods is necessary for an acceptable standard of survival. It appears that the intact Amazonian rainforest plays an integral part in global life support systems through climate and weather regulation as well as through biological interactions (migrating species, etc.)(Salati and Vose, 1991; Sandler, 1993). While zero forest stock may not literally mean annihilation of the human race, the assumption implies that such a state is an unacceptable outcome for the generation existing at the time it might occur.

While it is difficult to compare the utility of public goods and private goods directly, it is evident that local, national and international society will have different relative valuations of the two types of goods. These different relative valuations are captured by the term v(S) in equation (1). This term could be treated as time dependent for several reasons. If we assume that the Amazon shows decreasing marginal utility with respect to all rainforests, as rainforests are depleted elsewhere through time, the marginal utility of the Amazon increases, at least at the international level. In addition, new discoveries about the economic values of Amazonian species turn some of the rainforest's option and quasi-option values into use values, and the ability to make educated guesses about other option values increases with time, decreasing the uncertainty associated with them. To the extent one discounts uncertain values, diminishing uncertainty can potentially increase the value of v(S) through time. Further, if greater media attention is any evidence, there appears to be increasing concern over preservation of the rainforests, even on the part of those who may never visit them. At least anecdotally, then, it appears that the existence value of the Amazon has increased over the past decades as knowledge about the area has become more widespread, both in Brazil and internationally. Increasing international access to media and information promises to increase the existence value even more in the future, and if existence value is summed over individuals, increasing populations will have the same effect. While I do not attempt to explicitly incorporate a stochastically increasing valuation for public goods in the model, I discuss the implications in Chapter Three.[13]

The utility function for private goods is assumed to depend only on aggregate agricultural output at time t, and to be constant through time. The function is assumed to be twice continuously differentiable and to exhibit positive but decreasing marginal utility, i.e.

$$\frac{\partial U(\pi)}{\partial \pi} = U_{priv,\pi} > 0 \text{ and } \frac{\partial^2 U(\pi)}{\partial \pi^2} = U_{\pi\pi} < 0 \qquad \textbf{eqn (4)}$$

The model assumes that private good benefits arise only from returns to agropastoral land production, requiring conversion of forest to agropastoral land[14]. Agriculture and cattle ranching are by far the dominant causes of deforestation in the region, and are responsible for the vast majority of non-mineral income (Fearnside, 1987,1991). While sustainable extraction of forest resources (e.g. rubber, Brazil nuts, hunting and gathering, firewood, construction material) is widely practiced, the value of production is rather small and declining, and since much of the production is not marketed, difficult to quantify (Homma, 1989). Timber extraction is becoming increasingly important

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[13] There are at least two ways to incorporate an increasing valuation for public goods in the model. One would be to follow Fisher and Krutilla (1975) and let the discount rate δ=δ-b where b is the growth rate of the valuation for environmental goods. The other option is to let b(t) pre-multiply V(F(t)) as Reed and Clark (1990) do. In the context of the present model, this is identical to a stochastically increasing v(S,t).

[14] While agricultural output varies widely between areas, due to soil fertility, climate, crops, technologies, etc., the model implicitly assumes that the average value of aggregate agropastoral output is the same. The model also assumes that timber harvests subsidize the costs of forest conversion to the same extent throughout the Amazon. These are strong assumptions, but necessary for tractability, and suitable for answering the questions of this study.

economically, but is still minor compared to agriculture.[15] Also, much timber extraction is practiced on lands in the process of conversion to pasture or crops, and serves to subsidize the cost of conversion. Timber cutting typically is highly selective for marketable species,[16] and where not followed immediately by ranching or crops, clear cutting is rare (Uhl and Vieira, 1989). Timber cutting alone does not directly cause deforestation (INPE, 1998). In essence then, for this model private good production is simply net profits from aggregate agropastoral production.

Aggregate agricultural production can be thought of as a weighted index of agricultural yield in kilos/hectare times agricultural land area[17]. To more closely focus on the relationships outlined above, the model abstracts from all factors of production beside annual and cumulative deforestation, and combines them in an 'intercept' term which implicitly assumes that they are always applied in fixed proportion to the control variables. In addition to implicitly incorporating the price of agricultural output, the term can be thought of as including agricultural inputs such as fertilizer, pesticides and machinery, technology, soil fertility and composition, weather, slope, etc. The aggregate agricultural yield function is central to the model.

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[15] From 1975 to 1985, the gross value of wood, firewood and charcoal in the Amazon increased from 32% to 39% of total crop output (May and Reis, 1992). In the most heavily logged area of the Amazon, Paragominas County, Pará, Veríssimo, et. al. (1992) note that logging is responsible for 5-10 times the income generation of cattle, but provide no figures for agriculture.

[16] Selectivity depends on the distance from market. In very remote areas, it is only profitable to remove the highest value trees, such as Mahogany. In areas closer to market, lower value trees also become profitable (Uhl, 1989). Perhaps in the future, clear cutting will become a profitable alternative.

[17] According to the data compiled by E. Reis of IPEA (the Institute of Applied Economic Research), which relies in part on Brazil's annual agropastoral census, the major agropastoral outputs include cattle, dairy, annual crops (e.g. rice, corn, cassava, beans, wheat, potatoes, tobacco, soy) and permanent crops (e.g. coffee, cacao, banana, sugar cane, pepper, oranges).

The Aggregate Agricultural Yield Function

Following closely on Ehui (1987), I maintain several hypotheses about first and second order partial derivatives of the yield function for aggregate agricultural production in the geo-phytological Amazon.[18]

First, the nutrient rich ash resulting from burning bio-mass after deforestation enriches the soil, and hence I hypothesize that aggregate yield increases with the rate of deforestation[19],

$$\frac{\partial Y(\bullet)}{\partial D(t)} > 0 \qquad \textbf{eqn (5)}$$

Second, I hypothesize that aggregate yield decreases with increases in cumulative deforestation.

$$\frac{\partial Y(F(0) - F(t), D(t))}{\partial (F(0) - F(t))} < 0 \qquad \textbf{eqn (6)}$$

Ample evidence from studies in the Amazon suggests that this relationship holds due to a variety of ecological impacts of cumulative deforestation. Studies indicate that some 50% of the rainfall in the Amazon results from evapo-transpiration from the forest canopy, and deforestation will result not only in a decrease in rainfall, but also in a longer dry season. The latter effect is likely to have the most negative impact on agriculture (Sioli, 1989; Salati and Vose, 1984). Also, deforestation leads to an increase in local temperatures and a decrease

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[18] Ehui (1987) assumes a quadratic aggregate agricultural yield function, and estimates the parameters using data from the Ivory Coast. In contrast, I assume a transcendental production function, then estimate the data from secondary sources and use extensive sensitivity analysis.

[19] Output increases due both to higher yields and the increase in agricultural area from current deforestation. While yield will not actually increase on land deforested in previous years because of current deforestation, average yields should increase.

in humidity (Fearnside, 1991, Salati and Vose, 1984). Loss of forest canopy allows torrential rainstorms to fall directly on the soil, increasing erosion. Further, deforested lands are far less absorbent of water than those under forest cover, and greater runoff of rain also accelerates erosion (Sioli, 1991). Last, insect pests and crop diseases spread more readily as more land is cleared (Hecht, 1982). For more detailed examination of these factors, see Appendix A. In addition, cumulative deforestation was found to negatively affect crop yields in Thailand (Panayatou and Parasuk, 1990) and in the Ivory Coast (Ehui, 1987). This is indirect evidence that the same will occur in the Amazon.

Third, I assume that as deforestation becomes more rapid it is carried out on increasingly marginal soils, and in a more haphazard manner, so that addition of nutrients from burning has diminishing marginal benefits. Thus aggregate yield is hypothesized to show diminishing marginal returns to deforestation.

$$\frac{\partial^2 Y(\bullet)}{\partial D(t)^2} < 0 \qquad \textbf{eqn (7)}$$

Fourth, the cross partial of the yield function with current deforestation and cumulative deforestation is hypothesized to be negative,

$$\frac{\partial^2 Y(\bullet)}{\partial D(t)\partial(F(0) - F(t))} < 0 \qquad \textbf{eqn (8)}$$

since the greater cumulative deforestation is, the more marginal the remaining land undergoing deforestation. Even more important, the fertilizer effect from current deforestation must be averaged over all deforested lands (see equation (14) below for a detailed explanation).

Fifth, it is quite possible that marginal ecological disturbances from deforestation will become more serious as cumulative deforestation increases. This will be the case if there are ecological threshold effects, where drastic changes occur beyond a certain level of deforestation. For example, many researchers argue that beyond a certain level of deforestation, the ecosystem will degrade to the point that forest regeneration is impossible, and further degradation will be spontaneous (Shukla et.al., 1990; Lovejoy, 1994; Monastersky, 1990). If this hypothesis is true, then aggregate agricultural yield is likely to decrease at an increasing rate as cumulative deforestation increases. Hence, it is plausible to assume that

$$\frac{\partial^2 Y(\bullet)}{\partial [F_0 - F(t)]^2} < 0 \qquad \textbf{\textit{eqn (9)}}$$

According to much of the literature, it may be no exaggeration to claim that under current agricultural technology in the Amazon, deforestation is an essential factor of production. In the absence of adequate fertilizer application, agricultural production depends on the nutrient input from the ash of burned vegetation on freshly deforested land. Production is also impossible without some cumulative deforestation. The final hypotheses are therefore

$$Y(\bullet)\Big|_{D(t)=0} = 0 \qquad \textbf{\textit{eqn (10)}}$$

$$Y(\bullet)\big|_{F_0 - F(t)=0} = 0 \qquad \textbf{\textit{eqn (11)}}$$

The transcendental production function is suitable for modeling these hypotheses[20]. It is assumed that agricultural yield in the Amazon can be represented by:

$$Y(F_0 - F(t), D(t)) = A(t)D(t)^{\alpha_1}(F_0 - F(t))^{\alpha} e^{\gamma(F_0 - F(t))} \qquad \textbf{\textit{eqn (12)}}$$

Where

D(t)= annual deforestation
F_0= initial forest stock
F(t)= current forest stock
A(t)= all other inputs

As stated above, agricultural output is simply yield times agricultural land. Assuming that all land is forest in time 0 (which could be considered 1970, or for several states in the Amazon, with little exaggeration, even today) output $\pi = [F_0 - F(t)]Y(.)$, which is equivalent to

$$\pi(\bullet) = A(t)D(t)^{\alpha_1}(F_0 - F(t))^{\alpha+1} e^{\gamma(F(0)-F(t))} \qquad \textbf{\textit{eqn (13)}}$$

The parameter α is hypothesized to be negative, but $\alpha + 1$ must be >0. For notational simplicity, $\alpha+1$ will equal α_2 for the remainder of this study. Assuming constant returns to scale in the absence of ecological

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[20] Halter, Carter and Hocking developed the transcendental production function in 1957, which is of the general form

$$y = Ax_1^{\alpha_1} x_2^{\alpha_2} e^{\gamma_1 x_1 + \gamma_2 x_2}$$

While quite similar in appearance to the classic Cobb-Douglas function, and still relatively easy to estimate from agricultural data, the transcendental function allows variable elasticities of production. The elasticity of production depends on the amount of the relevant input, and returns to scale depend on the amount of both inputs. (Debertin, 1986) degradation[21], $\alpha_1 + \alpha_2 = 1$. This implies $\alpha_1 = -\alpha$, i.e. yield is homogenous of degree zero in the absence of ecological degradation: if twice as much land is cleared, the deforestation rate must be twice as high to provide the same level of ash fertilizer per hectare and achieve the same yield. While doubling both annual deforestation and cumulative deforestation has no impact on yield in the absence of negative ecological impacts, output will double. In the presence of ecological degradation, however, yield will decrease with scale while output must show diminishing returns. The parameter γ must therefore be negative, which means that as F_0-F(t) increases, output increases at a decreasing rate until $F_0\text{-}F(t) = -\alpha_2/\gamma$, beyond which point total output decreases with increases in cumulative deforestation.

The ash-fertilizer input from deforestation is a constant number of kilos per hectare burned, but the fertilizer effect must be ‘spread out’ over more acres as cumulative deforestation increases, i.e. the increased fertility of recently burned plots must be averaged over all agricultural land. Writing out the yield equation with annual deforestation measured relative to cumulative deforestation,

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[21] The assumption of constant returns to scale is somewhat simplistic. Clearly, there are far more inputs to agropastoral production than current and cumulative deforestation. However, for the questions being asked in this dissertation, the relevant control variables are current and cumulative deforestation. The model assumes that other inputs are in fixed proportion to F_0-F(t), and A(t) “might be thought of as the combined impact of these fixed factors on the production function” (Debertin, 1986). As a result, one would expect that $\alpha_1 + \alpha_2 < 1$. However, testing the sensitivity of this assumption with the specified functions, the value of $\Sigma\alpha_i$ for at least the range 0.5-1.5 appears to have no effect on steady state forest stock in the model. Rather, it is the ratio of α_1 to α_2 that matters. It would seem this result derives from the nature of the production function and the equation of motion for forest stock. Constant returns to scale are not possible in a transcendental production function with non-zero values for the γ_i. In addition, the equation of motion (see next section) means that current deforestation decreases the potential for future deforestation. The optimal intertemporal balance between current and future deforestation is thus determined by the ratio of α_1 and α_2, and not the sum.

$$
\begin{aligned}
Y(\bullet) &= A(t)\left(\frac{D(t)}{F_0 - F(t)}\right)^{\alpha_1} (F_0 - F(t))^{\alpha'} e^{\gamma_1(F_0 - F(t))} \\
&= A(t)D(t)^{\alpha_1} (F_0 - F(t))^{\alpha' - \alpha_1} e^{\gamma_1(F_0 - F(t))}
\end{aligned}
$$

eqn ***(14***)

it becomes clear that α' simply 'absorbs' the $-\alpha_1$ parameter. However, this implies that $\alpha' - \alpha_1 + \alpha_1 = 0$, or $\alpha' = 0$. That is, the direct effect of cumulative deforestation on yield is only felt through its impact on increasing the amount of hectares over which the ash from annual deforestation must be 'spread'. This is the result of the assumption of constant returns to scale in the absence of ecological impacts of deforestation. In summary, these parameters are hypothesized to have the following signs: $0 < \alpha_1 < 1$ from equations (5) and (7), $0 < \alpha_2 < 1$ from equations (6), (9) and (13), and $\gamma < 0$ from equation (9).

Equation of Motion for Forest Stock

In addition to the aggregate agricultural yield function, the equation of motion for the forest stock is also very important. Many works incorporate the assumption that deforestation is irreversible (e.g. Ehui, 1987; Clark and Reed, 1990). However, several studies (e.g. Homma, 1993b; May, 1986) have shown that much of the deforestation currently being carried out in the Amazon is on secondary growth, i.e. on land previously cleared then left fallow. There is no doubt that the rainforest has a significant ability to regenerate, yet excessive deforestation is in all likelihood irreversible. The differential equation for forest stock must reflect this.

An intact climax rainforest shows no net growth. Thus, the change in forest stock when no cumulative deforestation exists must arise solely from current deforestation. It is thus assumed that

$$\left.\frac{\partial F}{\partial t}\right|_{F_0 = F(t)} = -D(t) \qquad \textbf{eqn (15)}$$

Forest regeneration can only occur on deforested then abandoned land. Initially, increases in cumulative deforestation should therefore lead to higher rates of regeneration. However, as cumulative deforestation increases, disruption of the ecosystem (erosion, climate change, change in rainfall quantities and patterns, increasing distance of deforested land from existing forest stock for reseeding, etc.) leads to a decrease in the rate of growth of forest on abandoned agropastoral land. Eventually, changes in the ecosystem lead to irreversible deforestation, where the forest cannot grow back, and beyond that point to spontaneous degradation of the remaining forests (Salati and Nobre, 1991; Lovejoy, 1994). Assume that abandoned land is some fixed proportion of deforested land. Let F(max) = the forest stock at which regeneration is maximized, and F(irr) = the forest stock at which regeneration is zero, and beyond which spontaneous degradation occurs. It is thus assumed that

$$\left.\dot{F}\right|_{F_0 > F(t) > F(irr)} > -D(t) \qquad \textbf{eqn (16)}$$

$$\left.\dot{F}\right|_{F(t) < F(irr)} < -D_t \qquad \textbf{eqn (17)}$$

$$\left.\frac{\partial \dot{F}}{\partial (F(t))}\right|_{F(t) > F(\max)} < 0 \qquad \textbf{eqn (18)}$$

$$\left.\frac{\partial \dot{F}}{\partial F(t)}\right|_{F(t)=F(\max)} = 0 \qquad \textbf{\textit{eqn (19)}}$$

$$\left.\frac{\partial \dot{F}}{\partial F(t)}\right|_{F(t)<F(\max)} > 0 \qquad \textbf{\textit{eqn (20)}}$$

which of course requires that

$$\frac{\partial^2 \dot{F}}{\partial F(t)^2} < 0 \qquad \textbf{\textit{eqn (21)}}$$

A functional form that might serve as a proxy for the real time path of forest stock is a simple quadratic,

$$\dot{F}(t) = -D(t) + \beta_1(F_0 - F(t)) + \beta_2(F_0 - F(t))^2 \qquad \textbf{\textit{eqn (22)}}$$

where $\beta_1>0$ and $\beta_2<0$. $F(\max)= F_0+\beta_1/2\beta_2$. A steady state exists when $D(t)= \beta_1(F_0-F(t)) + \beta_2(F_0-F(t))^2$. This occurs as a 'corner solution' with zero deforestation and zero production when $F_0=F(t)$, or when $F(t)= F(irr)$. The steady state occurs in an 'interior solution'[22] at positive rates of deforestation for an inverted parabola connecting these two extremes. The maximum sustainable deforestation rate is possible at F(max) when $D(t)=-(\beta_1^2)/4\beta_2$.

Labor and Capital

Clearly, deforestation and agricultural production cannot occur in the absence of labor and capital, both of which are in short supply in the Amazon relative to available land (Kyle and Cunha, 1990). To keep

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[22] A corner solution steady state is one in which regrowth of the forest stock is zero, while an interior solution steady state is one where deforestation, regeneration and forest stock are all positive.

the model from becoming too complex, labor and capital are treated as simple constraints: if sufficient labor and capital are available, deforestation will take place according to the results of the unconstrained model outlined below. If labor and capital constraints are binding, deforestation will be constrained to the maximum level allowed by the binding constraint[23]. Government policies can potentially affect the supply of both inputs.

The Utility Functions

While the actual forms of utility functions are virtually impossible to identify, the simple natural log function has the appropriate characteristics and satisfies the assumptions in equations (2), (3) and (4)[24]. Further analysis thus assumes that

$$U(\pi(\bullet)) = \ln(\pi(\bullet)) \qquad \textbf{\textit{eqn (23)}}$$

$$V(F(t)) = \ln(F(t)) \qquad \textbf{\textit{eqn (24)}}$$

The Hamiltonian

The problem then is to

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[23] Labor and capital are treated as non-binding constraints in all analysis of steady state solutions. In Chapter Four, which examines optimal time paths, I show that incorporating capital and labor as binding constraints slows the initial rate of deforestation, but has no impact on eventual outcomes.

[24] While I am not aware of any publications using an additively separable natural log utility function in a similar context, Jon Conrad has used such a utility function for a simpler model to determine the optimal level of deforestation when forest land can be irreversibly converted into agricultural land. The current work has evolved from his suggestion.

$$\text{MAX} \quad W(S,F(t),D(t)) = \int_0^\infty e^{-\delta t}\,[v(S)V(F(t)) + U(\pi(F(t),D(t)))]$$ ***eqn***

(1)[*]

(from page 35)

subject to

$$\pi(F(t),D(t)) = A(t)D(t)^{\alpha_1}(F_0 - F(t))^{\alpha_2} e^{\gamma(F_0 - F(t))}$$ ***eqn (13)***

(from page 44)

$$\dot{F}(t) = -D(t) + \beta_1(F_0 - F(t)) + \beta_2(F_0 - F(t))^2$$ ***eqn***

(22)

(from page 47)

$$F_0 \;^3\; F(t) \;^3\; D(t) \;^3\; 0$$ ***eqn***

(25)

$$l_1 D(t) + l_2(F_0 - F(t)) \leq L$$ ***eqn***

(26)

$$k_1 D(t) + k_2(F_0 - F(t)) \leq K$$ ***eqn***

(27)

where

l_1 = man-days required to deforest one km^2 of forest

l_2 = man-days required for agropastoral production on one km^2 of forest

L= total labor available, in man-days, equal approximately to the total work force

k_1 =capital required to deforest one km^2 of forest

k_2 = capital required for agropastoral production on one km^2 of forest

K= total capital

---

[*] Note that equation numbers correspond to number of equation when it first appeared, and hence are out of order here.

All other variables are as defined in various places above, and as summarized in table 1 on the following page.

The current value Hamiltonian for this problem is

$$\tilde{H} = v(S)V(F(t)) + U(\Pi(F(t), D(t))) - \mu(D(t) - \beta_1(F_0 - F(t)) - \beta_2(F_0 - F(t))^2)$$

eqn *(28)*

The current value Hamiltonian "can... be interpreted as the total rate of increase in the value of assets" (Conrad and Clark, 1987, p.28)- in this case the rate of increase in total utility summed over time- from the perspective of period t (hence current value.) The first two terms represent the flow of net utility from public goods and private goods, respectively, from the forest at period t, equivalent to the rate of increase of accumulated dividends [i.e. utility]. The third term is the decrease in value of the forest stock as the result of a decision to deforest today, while taking into account forest regrowth- essentially the rate of decrease in capital assets. This term reflects all future revenues lost by deforesting today.

Table 1: definitions of model parameters

W(.) = a measure of discounted social welfare

V(.) = the utility function for public goods

v(S)= the social valuation for public goods relative to private goods, which depends on S, where S = local, national, international, or intergenerational society

π(.) = the output of private goods (agricultural output)

α_1 = the parameter on annual deforestation in the agricultural production function

α_2 = the parameter on cumulative deforestation in the agricultural production function

γ = the change in the elasticity of agricultural production with respect to cumulative deforestation; in other words, a measure of the negative impact of ecological degradation on agricultural output

β_1 = the regrowth rate of forest stocks on deforested land in the absence of negative ecological impacts of cumulative deforestation, which assumes a given proportion are left fallow

β_2 = the negative ecological impact of cumulative deforestation on the regrowth rate of forest stocks

U(.) = the utility function for private goods

F(t) = current forest stock in km^2, which produces a flow of public and private good benefits

D(t) = deforestation rate in km^2/yr

δ = the time discount rate

F0= initial forest stock

A(t)= all other inputs to agricultural production

l_1 = man-days required to deforest one km^2 of forest

l_2 = man-days required for agropastoral production on one km^2 of forest

L= total labor available, in man-days, equal approximately to the total work force

k_1 =capital required to deforest one km^2 of forest

k_2 = capital required for agropastoral production on one km^2 of forest

K= total capital available

Table 1: (continued)

$p_1 = 1 + {}^{\alpha_2}\!/_{\gamma F_0}$ (as defined in section on comparative dynamics) the proportion of remaining forest stock below which the marginal output of cumulative deforestation becomes negative

$p_2 = 1 + {}^{\beta_1}\!/_{\beta_2 F_0}$ (as defined in section on comparative dynamics) the proportion of remaining forest stock beyond which deforestation becomes irreversible

First Order Cconditions

Assuming an interior solution, first order conditions are

$$\frac{\partial \tilde{H}(\bullet)}{\partial D(t)} = U_\pi \, \pi_D - \mu = 0 \quad \Rightarrow \quad \mu = U_\pi \frac{\alpha_1}{D(t)} \pi(\bullet)$$

eqn

(29)

$$\frac{-\,\partial \tilde{H}}{\partial F(t)} = \dot{\mu} - \delta\mu = -v(S)V_F - U_\pi\left(\frac{-\,\alpha_2}{F_0 - F(t)} - \gamma\right)\pi(\bullet) + \left[\beta_1 + 2\beta_2(F_0 - F(t))\right]\mu$$
$$= -v(S)V_F - U_\pi \, \pi_F + \left[\beta_1 + 2\beta_2(F_0 - F(t))\right]\mu$$

eqn (30)

or

$$\dot{\mu} - \mu[\delta + \beta_1 + 2\,\beta_2(F_0 - F(t))] = -v(S)V_F - U_\pi\left(\frac{-\,\alpha_2}{F_0 - F(t)} - \gamma\right)\pi(\bullet) =$$
$$-\,v(S)V_F - U_\pi \pi_F$$

eqn

(31)

$$\frac{\partial \tilde{H}}{\partial \mu} = \dot{F} = -D + \beta_1(F_0 - F(t)) + \beta_2(F_0 - F(t))^2$$

eqn (32)

The parameter μ(t) is the value of an extra unit of forest at time t along the optimal trajectory, i.e. if the stock level is reduced one unit (by deforestation), its utility at time t will be reduced by μ(t). The parameter μ(t) is also referred to as the 'marginal user cost', or alternatively as the 'shadow price', which "refers to the fact that the asset's value is not its direct sale value but the value imputed from its future productivity." (Clark, 1990, p.106) Equation (29) indicates that along the optimal path, deforestation should continue until its marginal utility is just equal to the shadow price of forest stock. However, since existing markets do not capture public good flows, the market price of forest land will only reflect the present value of private goods.

The parameter $\dot{\mu}$ -δμ is the cost of employing one unit of forest capital at any point in time. The parameter $\dot{\mu}$ is essentially the expected capital gains (the increase in value of the stock), and -δμ is an interest charge (benefits foregone by not using the stock now) (Ehui, 1987). Equation (30) tells us that forest stock should be used up to the point where the change in the rate of increase in the total value of assets with respect to a change in forest stock is just equal to the social cost of employing one unit of forest capital. The right hand side of equation (30) is composed of the marginal opportunity cost of forest stock plus the value of regrowth. Marginal opportunity cost has a positive component, $U_{\pi}\left(\alpha_2 / F_0 - F(t)\right)$, corresponding to the marginal utility of increased agricultural output from increased farmland, and two negative components, corresponding to marginal loss of public good utility, $v(S,t)V_F$, and to the marginal utility cost from ecological damage, $U_{\pi}\gamma$. Since this model incorporates the regrowth of 'capital stock', it is possible to re-write equation (30) by modifying the interest charge term accordingly, as in equation (31).

Time Paths

The first order conditions provide the time path for forest stock, but a complete solution requires the time paths for μ(t) and D(t). Taking a complete derivative of equation (29) with respect to time,

$$\dot{\mu} = \pi_D U_{\pi\pi}(\pi_D \dot{D} + \pi_F \dot{F}) + U_\pi(\pi_{DD}\dot{D} + \pi_{DF}\dot{F}) \qquad \textbf{\textit{eqn}}$$

(33)

where

$$\pi_F = \left(-\frac{a_2}{F(0)-F(t)} - \gamma\right)\pi(\bullet) \qquad \textbf{\textit{eqn}}$$

(34)

$$\pi_D = \left(\frac{\alpha_1}{D(t)}\right)\pi(\bullet) \qquad \textbf{\textit{eqn}}$$

(35)

$$\pi_{DD} = \left(\frac{\alpha_1^{\,2}}{D(t)^2}\right)\pi(\bullet) - \left(\frac{\alpha_1}{D(t)^2}\right)\pi(\bullet) = \left(\frac{\alpha_1^{\,2} - \alpha_1}{D(t)}\right)\pi(\bullet) \qquad \textbf{\textit{eqn}}$$

(36)

$$\pi_{DF} = \left(-\frac{a_2}{F(0)-F(t)} - \gamma\right)\left(\frac{\alpha_1}{D(t)}\right)\pi(\bullet)^2 \qquad \textbf{\textit{eqn}}$$

(37)

substituting equations (29) and (33) into equation (31) yields

$$\pi_D U_{\pi\pi}(\pi_D \dot{D} + \pi_F \dot{F}) + U_\pi(\pi_{DD}\dot{D} + \pi_{DF}\dot{F}) - U_\pi\,\pi_D\,[\delta + \beta_1 + 2\,\beta_2(F(0) - F(t))]$$
$$= -\upsilon(S)V_F - U_\pi\,\pi_F$$

eqn (38)

Solving for $\dot{D}$:

$$\dot{D} = \frac{-\,\upsilon(S)V_F - U_\pi \, \pi_F - \pi_D U_{\pi\pi}\pi_F \dot{F} - U_\pi \pi_{DF} \dot{F} + U_\pi \, \pi_D \, [\delta + \beta_1 + 2\,\beta_2 (F_0 - F(t))]}{U_{\pi\pi}\pi_D^2 + U_\pi \pi_{DD}}$$

eqn (39)

Substituting specific functional forms into equation (39) yields

$$\dot{D} = \frac{-\,\upsilon(S)\big/F(t) + \left(\frac{\alpha_2}{F_0 - F(t)} + \gamma\right) + \left(\frac{\alpha_1}{D(t)}\right)\left[\delta + \beta_1 + 2\beta_2 (F_0 - F(t))\right]}{-\,\alpha_1 \big/ D(t)^2}$$

eqn (40)

Subsequent analysis of the $\dot{D}$ locus uses equation (39), which has more general applications, except where analysis requires knowledge of specific functional forms, as in equation (40).

It is clear from the fact that U(.) and V(.) are both concave functions that U_π , $V_F > 0$ and $U_{\pi\pi} < 0$. Since π_F is the marginal agricultural output of forest (accounting for the opportunity cost of foregone cropland, as well as the benefits of forest cover to agricultural production), it will be negative as long as cumulative *deforestation* has positive marginal output. Since γ basically measures the negative impact of diminishing ecosystem life support functions as a result of deforestation, and α_2 measures the returns to increased crop land, this will be true as long as $\alpha_2 > -\gamma(F_0 - F(t))$. π_{DF} measures the impact of an extra unit of forest on the marginal output from deforestation. It will have the same sign as π_F: when forest stock has a positive marginal output, it increases the marginal output of current deforestation, and when cumulative deforestation has a negative marginal output, it decreases the marginal output of current deforestation. π_D is always positive, and π_{DD} is always negative, so when the numerators of equations (39) and (40) are positive, $\dot{D}$ is falling.

It follows that

$$\dot{D} \overset{<}{\underset{>}{-}} 0 \quad as \quad \frac{v(S)V_F + U_\pi \pi_F + U_{\pi\pi}\pi_D\pi_F\dot{F} + U_\pi\pi_{DF}\dot{F}}{[\delta + \beta_1 + 2\,\beta_2 (F(0) - F(t))]} \overset{<}{\underset{>}{-}} U_\pi \pi_D \quad \textbf{\textit{eqn}}$$

(41)

Equation (41) is composed of four terms in the numerator. The first term is the marginal public good utility of forest stock, which is always positive, and increases as forest stocks decline. The second term is the marginal private good utility of forest stock, which is initially positive but negative for $F(t)>F_0+\alpha_2/\gamma$. The remaining two terms are of opposite signs, in all cases fall to zero as the forest stock approaches the steady state, and with the utility functions specified for this model exactly cancel each other on any optimal time path. They can be ignored in the following analysis. The denominator, the discount rate plus the marginal regrowth rate of forest stock, translates the numerator into the present value of the infinite utility stream.

From equation (41), it is possible to derive two important attributes of the $\dot{D}$=0 locus.

First, the denominator of equation (41) must always be positive if the discount rate δ is greater than the rate of forest regrowth in the absence of ecological degradation, β_1. The proof of this is that a steady state can only occur in the absence of spontaneous degradation of the forest. Spontaneous degradation occurs when $F(t) < F_0+\beta_1/\beta_2$. The denominator is positive as long as $\delta+\beta_1 > 2\beta_2(F_0-F(t))$. So a necessary condition for a positive denominator is $\delta+\beta_1 > 2\beta_2(F_0-(F_0+\beta_1/\beta_2))=2\beta_1$, which obviously will always hold in steady state if $\delta>\beta_1$.

With a discount rate less than β_1, the denominator will still only be negative for very low levels of forest stock. However, we will see, as one would expect, that the steady state forest stock is decreasing in δ, so a low δ implies a high forest stock. This means that in all cases, the denominator to equation (41) is likely to remain positive.

Second, If any deforestation occurs, the rate of deforestation must be falling through time. The proof of this is derived from the following ratio:

$$\frac{\upsilon(S)V_F + U_\pi \pi_F + U_{\pi\pi}\pi_D\pi_F\dot{F} + U_\pi\pi_{DF}\dot{F}}{[\delta + \beta_1 + 2\beta_2(F(0) - F(t))]} \qquad \textbf{\textit{eqn (42)}}$$

Equation (42) is a current measure of all future returns from an additional unit of forest, and hence can be seen as the conservation motive (to borrow a term from Ehui), while $U_\pi\pi_D$ is the deforestation motive. When the deforestation motive is greater than the conservation motive, the rate of change of annual deforestation is negative: less forest is cut each subsequent period. This occurs because net deforestation increases the conservation motive, slowing deforestation.

Initially, for forest stocks approaching F_0, it must be the case that $\alpha_2>-\gamma(F_0-F(t))$, so π_F and the marginal utility of forest stock must initially be negative. For the very low initial levels of agricultural output, U_π ought to be high (from equations (4) and (23)), while V_F will be relatively low for high forest stocks (from equations (2) and (24)). This is sufficient for $\dot{D}<0$ initially. Since both marginal public and private good utilities of forest stock are increasing as forest stock is depleted, $\dot{D}$ will increase with increasing cumulative deforestation, approaching zero as the summed marginal public good and private good utility approaches the growth rate adjusted discounted marginal utility of current period deforestation, $[\delta+\beta1+\beta2(F0-F(t))U_{\pi}(\alpha1/D(t))]$. That is, as long as the deforestation motive is greater then the conservation motive, the rate of deforestation is falling through time. On the optimal path to the steady state, the deforestation motive will dominate the conservation motive until reaching the steady state, and the rate of deforestation must always be falling.

In contrast, a conservation motive greater than the deforestation motive would mean that the optimal deforestation rate is increasing through time, which may initially seem peculiar. However, when the conservation motive dominates, there is no deforestation. As long as the deforestation motive dominates, deforestation is occurring. With less forest in each subsequent period, the marginal utility of forest becomes higher, and the rate of deforestation must fall.

If either labor or capital constraints are binding, presumably deforestation will occur at the greatest rate allowed by the most binding constraint. This will be discussed further in Chapters Four and Five.

Comparative Dynamics

It is interesting to look at the impact of changes in the various variables on the $\dot{D}$ locus. Comparative dynamics with respect to δ (the discount rate) and v(S) (the relative social valuation of the public good) give insights into the differences between optimal time paths of deforestation at the local, national and international levels. These different rates of deforestation may be even more important than the differences in optimal steady state forest stocks, since they give some indication of how fast the national or international reaction to deforestation must be if actual deforestation rates are higher than optimal rates at those levels of society. Also, comparative dynamics, in conjunction with the time path analysis of Chapter Four, will help suggest policy measures for guiding time paths towards a satisfactory steady state outcome.

Comparative dynamics of those variables with ecological components (β_1, β_2, α_1, α_2 and γ) can provide insights into the importance of uncertainties regarding the Amazonian ecosystem. Defining two new variables, done below, can simplify this analysis.

This section primarily determines the direction of change in the $\dot{D}$ locus resulting from a change in the other variables. Chapter Three examines the impact of a change in the variables on the steady state forest stock, and Chapter Four determines the time paths of deforestation for a discrete time version of the model, confirming the results found here. Detailed analyses of comparative dynamics are left for Chapter Four.

The Parameter p_1: the Proportion of Remaining Forest Stock Below Which the Marginal Output of Cumulative Deforestation Becomes Negative

Since the significance of α_2 and γ may not be immediately clear, it is convenient to combine the two into a single variable, p_1, which specifies the proportion of remaining forest stock at which the output of cumulative deforestation is zero. Hence

$$p_1 = 1 + {}^{\alpha_2}\!/_{\gamma F_0}$$ ***eqn (43)***

p_1 is the level of forest stock which maximizes total output with respect to cumulative deforestation, where the increase in output from greater agricultural land area is just balanced by the decrease in output from the ecological degradation caused by cumulative deforestation. While current deforestation may still increase agricultural output, the impact on output from cumulative deforestation becomes negative at forest stocks below p_1. p_1 is essentially an economic variable with an ecological component. The potential impact of technological change on p_1 is discussed in Chapters Four and Five.

The Parameter p_2: The Irreversibility Threshold

The variable β_1 (the growth rate of forests in the absence of ecological degradation) and β_2 (the negative impact of ecological degradation on the growth rate of forests) are conveniently combined into the variable p_2. This variable measures the proportion of remaining forest stock at which forests cease to spontaneously regenerate, and below which they spontaneously degenerate.

$$p_2 = 1 + {}^{\beta_1}\!\big/_{F_0\beta_2} \qquad \textbf{\textit{eqn (44)}}$$

The parameter p_2 is a crucial variable, in that it is a measure of irreversibility: if forest stocks fall to this level, they cannot recuperate. If forest stocks fall below p_2, they must eventually fall to zero, as must the public good and private good output of the Amazon. Hence, p_2 is an ecological variable which essentially measures the lower limit of ecological sustainability, i.e. the sustainability threshold. In the absence of ecological sustainability, economic sustainability is also impossible. Since the model shows infinitely negative utility for zero forest stock or zero agricultural production, no optimal solution can lead to a forest stock of p_2F_0 or less.

Conservation and Deforestation Motives in Terms of p_1 and p_2.

It is worthwhile rewriting equation (41) in terms of p_1 and p_2.

$$\dot{D} \lesseqgtr 0 \quad as \quad \frac{\frac{v(S)}{F(t)} + \frac{\alpha_2(F(t) - F_0 p_1)}{(F_0 - F(t))F_0(p_1 - 1)}}{[\delta + \beta_1 + \frac{2\beta_1(F(0) - F(t))}{F_0(1 - p_2)}]} \lesseqgtr \frac{\alpha_1}{D(t)} \qquad \textbf{eqn}$$

(45)

The left-hand side of equation (45) is the conservation motive, and the right-hand side the deforestation motive.

The Role of p_1

The derivative of the $\dot{D}$ locus with respect to p_1 is

$$\frac{\partial \dot{D}(t)}{\partial p_1} = \frac{\alpha_2 D(t)^2}{\alpha_1 F_0 (1 - p_1)^2} \qquad \textbf{eqn (46)}$$

Equation (46) is clearly positive. An increase in p_1 will lead to an increase in the rate of change through time of D(t). Since it was proven earlier that $\dot{D}$ must always be falling on the optimal path to the steady state, an increase in p_1 decreases the rate at which $\dot{D}$ falls. Since p_1 increases as α_2 decreases or γ increases, $\dot{D}$ will fall more quickly as returns to cumulative deforestation increase.

The derivative of the conservation motive with respect to p_1 gives

$$\frac{\alpha_1}{F_0(p_1 - 1)^2 \left[\beta_1 + \delta - \frac{2\beta_1(F_0 - F(t))}{F_0(1 - p_2)}\right]} \qquad \textbf{eqn (47)}$$

which is positive for any forest stock above p_2, i.e. for any forest stock that permits regrowth. An increase in p_1 increases the conservation motive, which implies lower deforestation levels for a given level of the deforestation motive. Hence, a higher p_1 leads to lower initial deforestation, but a faster decrease in the rate of deforestation. This result is verified by the GAMS analysis of the discrete time model in Chapter Four (see Figure 13b).

The Role of p_2

The derivative of the $\dot{D}$ locus with respect to p_2 is

$$\frac{\partial \dot{D}}{\partial p_2} = \frac{2\beta_1 D(t)(F_0 - F(t))}{F_0(1 - p_2)^2}$$ ***eqn (48)***

All terms in both the numerator and denominator are positive, so an increase in p_2 (which implies weaker regenerative abilities of the forest) must always lead to a slower rate of decrease in the deforestation rate. From inspection of equation (45), it is apparent that an increase in p_2 leads to an increase in the conservation motive, and therefore lower initial levels of deforestation. Qualitatively, a change in p_2 has the same impact on the time path of deforestation as p_1 , though as will be shown in the GAMS analysis of Chapter Four (see Figure 14), and as may be inferred from the Mathematica analysis of the steady state in Chapter Three (see Figures 6a-c) this effect is very slight.

The Role of α_1 (the Current Deforestation Parameter)

The derivative of the $\dot{D}$ locus with respect to α_1 is

$$\frac{\partial \dot{D}}{\partial \alpha_1} = \frac{D(t)}{\alpha_1^2}\left[\frac{-\alpha_2}{(F_0 - F(t))} - \gamma + \frac{v(S)}{F(t)}\right]$$ ***eqn***

(49)

Equation (49) will always have the same sign as the conservation motive, equation (42). When v(S)=0, this will be negative as long as $a_2/(F(0)-F(t)) > -\gamma$. Since the conservation motive must become positive in order for $\dot{D}$ to reach 0, and the denominator cannot become negative if the discount rate is greater than the rate of regrowth of forest (or else there is irreversible deforestation, and no steady state), eventually on the path to the steady state it must be the case that $\alpha_2/(F(0)-F(t)) < -\gamma$. That is, a steady state occurs only after marginal output of cumulative deforestation becomes negative. Even when cumulative deforestation offers zero marginal output, deforestation continues to offer positive marginal output, so, especially in the presence of a discount rate, it will make sense to continue deforesting.

With a positive value for v(S), equation (49) may or may not be negative initially. The higher the value for v(S), the greater the likelihood that deforestation will halt before reaching maximum marginal output of forest stock.

The Role of the Discount Rate

The derivative of the $\dot{D}$ locus with respect to the discount rate gives

$$\frac{\partial \dot{D}}{\partial \delta} = \frac{U_\pi \pi_D}{U_{\pi\pi}\pi_D^2 + U_\pi \pi_{DD}} = -D(t)$$ ***eqn***

(50)

Since D(t) can never be negative, equation (50) can never be positive. That is, an increase in the discount rate increases the rate at which the rate of deforestation decreases, and this effect is in direct proportion to the actual deforestation rate. At first glance this result might appear counter-intuitive. However, as cumulative deforestation increases, so does the marginal utility of forest stock and hence the conservation motive, equation (42) and the left hand side of equation (45). Since a higher discount rate implies a weaker conservation motive, it leads to greater deforestation initially. The more deforestation in one period, the greater the marginal value of forest in the next period, and hence the greater the decrease in the deforestation rate. A higher discount rate therefore leads to a more rapid decrease in $\dot{D}$ via a weaker initial conservation motive and more rapid initial deforestation.

Figures 16-17 in Chapter Four show optimal time paths of deforestation for varying discount rates.

The Role of the Social Valuation of the Public Good

The derivative of the $\dot{D}$ locus with respect to the social valuation of the public good gives

$$\frac{\partial \dot{D}}{\partial v(S,t)} = \frac{-V_F}{U_{\pi\pi}\pi_D^2 + U_\pi \pi_{DD}} = \frac{D(t)^2}{\alpha_1 F(t)} \quad \textbf{\textit{eqn (51)}}$$

Equation (51) is always positive. That is, as the social valuation of the public good increases, the rate of deforestation decreases more slowly. From inspection of equations (42) and (45) it is obvious that an increase in v(S) increases the conservation motive. An increase in v(S) therefore decreases initial deforestation rates, and also decreases the rate at which these fall. This can be seen in Figure 19, Chapter Four.

The $\dot{D}$ =0 Locus

It is now interesting to look at the $\dot{D}$=0 locus, which is

$$D(t)\Big|_{\dot{D}=0} = \frac{\alpha_1 [\delta + \beta_1 + 2\beta_2 (F_0 - F(t))]}{\frac{v(S)}{F(t)} + \left(- \frac{\alpha_2}{(F(0) - F(t))} - \gamma \right)}$$

eqn

(52)

In the case where v(S)=0, one can see that equation (52) will be undefined for $F(t)=\alpha_2/\gamma+F_0$, but it was shown previously that a steady state in this situation demands $F(t)<\alpha_2/\gamma+F_0$.

With a positive v(S), equation (52) is undefined for

$$F(t) = \frac{\gamma F_0 + \alpha_2 + v(S) \pm \sqrt{[\gamma F_0 + \alpha_2 + v(S,t)]^2 - 4\gamma v(S,t) F_0)}}{2\gamma}$$

eqn

(53)

This implies that the steady state will always require F(t) less than this. F(t) as defined in equation (53) is always greater than $\alpha_2/\gamma+F_0$.

Graphic analysis is the simplest means to analyze the $\dot{D}$ = 0 locus. Figure 3 is a graph of the $\dot{D}$ = 0 locus and the $\dot{F}$ = 0 locus showing two points of intersection.

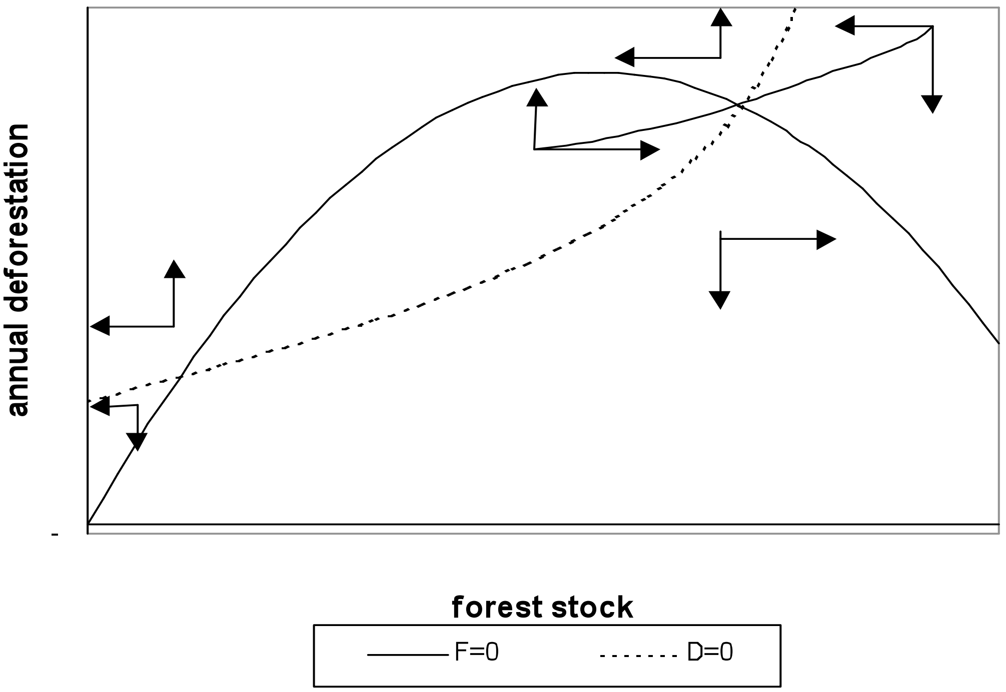

Figure 3: $\dot{F}$ *=0 locus and* $\dot{D}$ *= 0 locus in D(t)-F(t) space, with directional arrows.*

Figure 4 shows the same for varying values of the discount rate, δ, and relative social valuations of the public good, v(S), corresponding to different levels of society. When local objectives are considered, a reasonable discount rate is arguably quite high, perhaps as high as 40% or more[25]; v(S) on the other hand is likely to be quite low, or even zero. At the national level, δ is assumed to be less, perhaps around 5%, and v(S) assumed to be greater. At the international level, δ is assumed to

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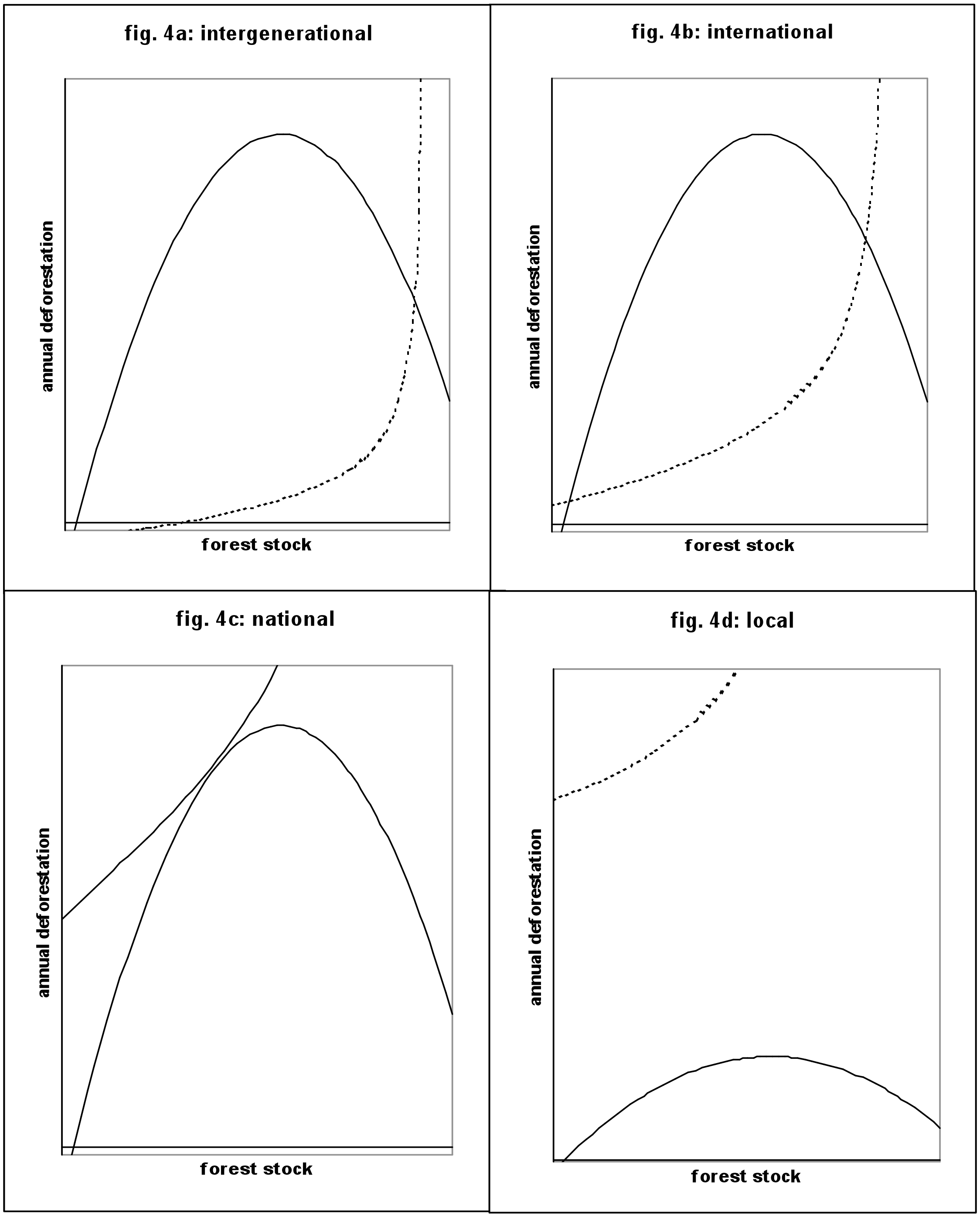
[25] Schneider (1995) gives real interest rates in September, 1992, on 32-day government bonds as 3%, which is equivalent to a 43% annual rate. Real interest rates on overnight accounts at the same time were 12% *monthly*. He suggests that those borrowing for relatively high-risk activities in the Amazon have to pay even higher rates. Similarly, Hecht, Norgaard and Possio (1988) state that discount rates ranged from 12 to 70% between 1970 and 1985. Presumably, by discount rates they mean real interest rates on loans or deposits. In my personal experience, in 1994 I was earning up to 5% a month above inflation in a normal savings account, though the rate varied considerably from month to month.

be very low, and v(S) relatively large. Finally, at the intergenerational level, δ is arguably between 0 and the growth rate of the system in question, while v(S) should be quite high. Figure 4 shows the qualitative effects of these assumptions, stylized to exhibit the four possibilities for the intersection of the $\dot{D}$ = 0 and the $\dot{F}$ = 0 loci:

1) a single point of intersection at a positive deforestation rate;
2) two points of intersection at positive rates of deforestation;
3) one point of intersection, where the $\dot{D}$ = 0 locus is tangent to the $\dot{F}$ = 0 locus; and
4) no points of intersection.

As illustrated, each of these possibilities corresponds to a different level of society: local, national, international and intergenerational. While these figures are stylized, I argue in subsequent chapters that it is likely that at the local level, the $\dot{D}$ = 0 locus never intersects the $\dot{F}$ = 0 locus; and hence there is no interior steady state solution. At the intergenerational and international levels, the steady state solution is likely to exist at relatively high levels of forest stock. At the national level, it is possible that there is no interior steady state solution, as in the local level case, or that there is a steady



Figures 4a-d: $\dot{D}$ *= 0 locus and* $\dot{F}$ *=0 locus in D(t)-F(t) space, for different discount rates and relative social valuations of the public good, corresponding to different levels of society: local, national, international and intergenerational.*

state solution, but at a lower forest stock than in the international and intergenerational cases.

Clearly, at levels of deforestation above the $\dot{F}$=0 locus, the level of forest stock must be decreasing, and at levels below this locus, it must be increasing. This allows us to place the corresponding arrows. Motion above and below the $\dot{D}$ = 0 locus is not as obvious. Recall however that on the optimal path, $\dot{D}$ must initially be falling. This implies that to the right of the $\dot{D}$ = 0 locus, the rate of deforestation must be decreasing, and to the left it must be rising. This allows us to position the remaining arrows.

In the case where there are two points of intersection, labeled 'international' in Figure 4b, we can see that one of the steady state points is a saddle point, while the other is unstable. Where there is only a point of tangency, labeled 'national' in Figure 4c, the steady state solution is unstable in response to a shock in three out of four directions.

Two important conclusions can be derived from this analysis. First of all, the fact that the steady state is a saddle point means that at best it is difficult to reach, and if attained, difficult to maintain. However, it appears that the greater the value of v(S) and the lower the value of δ, the easier it should be to attain and maintain the steady state. Why is this so? We can see from Figure 3 that in quadrants I and III, the time paths for deforestation rates and forest stock push towards the steady state, while in quadrants II and IV, the time paths lead away from the steady state. Quadrant IV leads to increased levels of forest stock, so there is no threat of irreversibility, and plenty of time to act. From quadrant II, it may be possible to push the system back into quadrants I or III, and hence set it on the path towards the steady state again. However, as δ increases or v(S) decreases, the $\dot{D} = 0$ locus intersects the $\dot{F} = 0$ locus at a higher rate of deforestation and lower forest stock. This effectively increases the 'width' of quadrant IV and decreases the size of quadrant III. Faster rates of deforestation in quadrant IV mean there is less time to act to force the time path back into quadrants I or III. This would appear to make the steady state more difficult to reach, and more difficult to maintain. A policy nudge could no longer return a destabilized system from quadrant IV to quadrants I or III: a policy bludgeon might be required.

Second, in the presence of high discount rates and low relative valuations of the public good, there would appear to be no interior solution steady state equilibrium. While infinitely negative utility for annihilation of the forests suggests that a solution where forest stocks fall below p_2F_0 could never be optimal, a corner solution increases the likelihood some external shock could lead to ecosystem extinction.

Steady State Forest Stock

In steady state,

$$\dot{F}(t) = 0, \dot{D}(t) = 0 \;\; \text{and} \;\; \dot{\mu}(t) = 0$$ ***eqns (54a,b,c)***

so, in an optimal steady state, from equation (32)

$$D^*(t) = \beta_1(F(0) - F^*(t)) + \beta_2(F(0) - F^*(t))^2$$ ***eqn***

(55)

from equations (52) and (55)

$$\frac{\alpha_1[\delta + \beta_1 + 2\beta_2(F_0 - F^*)]}{\frac{v(S)}{F^*} + \left(-\frac{\alpha_2}{(F(0) - F^*} - \gamma\right)} = \beta_1(F(0) - F^*) + \beta_2(F(0) - F^*)^2$$ ***eqn***

(56)

which is equivalent to

$$\gamma\beta_2 F^{*3} + [\alpha_1 - \alpha_2\beta_2 - \gamma\beta_1 - 2\gamma\beta_2 F_0]F^{*2} + [-\alpha_1(\delta + \beta_1 + 2\beta_2 F_0) + v(S)(\beta_1 + \beta_2 F_0 - \beta_2) + \alpha_2\beta_1 + \alpha_2\beta_2 F_0 + \gamma\beta_1 F_0 + \gamma\beta_2 {F_0}^2]F^* - (v(S)(\beta_1 F_0 - \beta_2 {F_0}^2) = 0$$

eqn (57)

This confusing expression is a cubic polynomial, solvable for three roots of F*. Of these roots, one is a saddle point, the other is an unstable node (both visible in Figure 3), and the third involves imaginary numbers. While a closed form solution is possible, the equation for the closed form is so complex that it conveys little information. However, the saddle point solution is possible to analyze and graph using Mathematica. The graphs are readily understandable, and can be seen in the following section.

For the case where v(S)=0, the solution is a much simpler quadratic.

$$\gamma\,\beta_2(F_0 - F^*(t))^2 + (\gamma\,\beta_1 + (a_2 - 2\,\alpha_1)\,\beta_2)(F_0 - F^*(t)) + a_2\,\beta_1 + \alpha_1(\delta + \beta_1) = 0$$

eqn (58)

which is readily solvable for (F_0-F*(t)) and hence for F*(t)

$$(F_0 - F^*(t)) = \frac{-(\gamma\,\beta_1 + (a_2 + 2\,\alpha_1)\,\beta_2) \pm \sqrt{(\gamma\,\beta_1 + (a_2 + 2\,\alpha_1)\,\beta_2)^2 - 4\gamma\,\beta_2\,[a_2\,\beta_1 + \alpha_1(\delta + \beta_1)]}}{2\gamma\,\beta_2}$$

eqn (59)

Of the two roots, that with the negative sign is the saddle point steady state and that with the positive sign the unstable one.

CHAPTER THREE:

PARAMETER ESTIMATION AND SENSITIVITY ANALYSIS

Parameter Estimation

Ideally, econometric analysis should provide estimates for the parameters in this model. Unfortunately, no database adequate for this task exists at the present time. In the future, it may prove possible to estimate the relevant variables from a database being compiled at IPEA, in Rio de Janeiro. However, drawing on the secondary literature, it is possible to make rough estimates for several of the parameters.

Estimation of β_1

The parameter β_1 corresponds to the rate of regrowth of deforested land in the absence of environmental degradation. If land from small, isolated slash and burn clearings returns to nearly normal conditions within 50 years, the base rate of regrowth is roughly 2%[26].

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[26] As seems to be the case with all the ecological parameters in this model, there is little agreement as to how long the forests take to regenerate. One source claims that second growth forest is indistinguishable from virgin forest in terms of biomass and canopy structure after 20 years (Moran et. al, 1996). However, it is difficult to believe, even in the Amazon, that 20 year old trees can attain normal canopy height, much less the height of emergents which form part of canopy structure. Wilson (1988) claims that it is still possible to distinguish second growth from primary growth at the Angkor Wat ruins in Cambodia, after 400 years. Extensive personal experience in the rainforests of the Wet Tropics of far north Queensland, Australia, shows that it is quite easy to distinguish selectively logged rainforest from virgin forest even after 30 years in terms of canopy structure. As a rough guess, after 50 years, biomass on abandoned land near a seed source of intact rainforest may equal that of virgin forest, but species composition and diversity almost certainly does not. In any event, forests will not realistically show a steady growth rate of 2%, but rather the growth rate is likely to vary with age and density of the stand. In this model it is simply meant to be an approximate average.

This only applies to land left fallow, say 30% of cleared land at any given moment[27]. Two percent of 30% is .6%,or .006.

Both exogenous ecological changes (e.g. global warming, ozone depletion) and policy measures which affect the amount of land left fallow may alter the value of β_1. Examples of such policies include the introduction of permanent crops or technological advances which reduce fallow requirements for annual crops, and policies which increase population density or decrease access to virgin lands, thus increasing pressures to shorten fallow periods.

Estimation of β_2 and p_2

The parameter β_2 corresponds to the impact of environmental degradation on the rate of regrowth, and is more difficult to estimate. While many scientists agree that regrowth will become impossible after some degree of deforestation, there is a wide range of estimates as to what this quantity is. Assume that regrowth becomes impossible if less than proportion p_2 of the forest stock remains, as defined in the previous chapter. Solving $\beta_1(F_0-p_2F_0)+\beta_2(F_0-p_2F_0)^2=0$ for β_2, we obtain

$$\beta_2 = -\frac{\beta_1}{F_0(1-p_2)} \qquad \textbf{\textit{eqn (60)}}$$

So, for β_1= .006, F(0)=3.8 10^6 km^2 (the approximate area of the phyto-geographic Amazon) and p_2 = 0.3, β_2 would equal 2.26 x 10^{-3}. Lovejoy (1994) suggests that p_2 might be as high as .6 or .7, which

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[27] Hecht claims that in many areas, some 50% of cattle ranches have been abandoned. Many slash and burn agriculturalists leave land after only 3-5 years. Permanent crops clearly are not abandoned as quickly. The area left in fallow doubtless varies considerably from region to region, but 30% seems to be a reasonable guess.

would give a β_2 a value between 3.95 10^{-3} and 5.26 x 10^{-3}. Walker et. al. (1995) estimate that the loss of 50% or less of forest cover would lead to no rainfall at all for much of the year, which could potentially cause irreversible damage to remaining forests.

As it is intuitively easier to understand its implications, further analysis will use p_2 instead of β_1 and β_2. Since it is conceivable that in the future advanced technologies will increase our ability to regenerate tropical forests, sensitivity analysis will examine the impact of values of p_2 ranging from 0 to 60%.

Estimation of α_1, α_2, γ and p_1

Secondary sources provide rough estimates of α_1, α_2 and γ. Both Ehui (1987) and Panayatou and Parasuk (1990) have examined the negative impact of cumulative deforestation on agricultural yields (for the Ivory Coast and Thailand, respectively), and extrapolation from their results provides estimates for this model.

Ehui's model includes the beneficial impact of current deforestation as a parameter, and in this regards is closer to the current work. He measures a yield elasticity for deforestation (ε_D) of .16, which in the actual model would correspond to an α_1 of .16 and an α_2 of .84. Ehui also calculates a cumulative deforestation elasticity ($\varepsilon_{Fo-F(t)}$)of -2.7. However, this is for the Ivory coast, where deforestation is far more advanced than in the Amazon. γ measures the rate of change in elasticity with respect to a change in cumulative deforestation,

$$\gamma = d\varepsilon_{Fo-F(t)}/d(F_0-F(t)) \qquad \textbf{\textit{eqn (61)}}$$

The current $\varepsilon_{Fo-F(t)}$ is given by

$$\alpha_2 + \gamma(F_0 - F(t)) = \varepsilon_{F_0-F(t)} \qquad \textbf{\textit{eqn (62)}}$$

Hence,

$$\gamma = (\varepsilon_{F_0-F(t)} - \alpha_2)/(F_0 - F(t)) \qquad \textbf{\textit{eqn (63)}}$$

With $\alpha_2 = 0.84$, and $(F_0 - F(t)) = 2.93 \times 10^6$ (corresponding to the same percentage deforestation (78.75%) as existed in the Ivory Coast at the end of Ehui's data series), γ would have to be equal to -1.21 for $\varepsilon_{F_0-F(t)}$ to equal -2.7. As defined in the previous chapter, let p_1 equal the proportion of remaining forest stock which maximizes agricultural output with respect to cumulative deforestation, and beyond which the marginal output of cumulative deforestation is negative (see equation 43).

The values of α_2 and γ derived from Ehui correspond to $p_1=0.82$, i.e. the marginal output of cumulative deforestation becomes negative when more than 82% of the Amazon is cleared.

Panayatou and Parasuk calculate the output elasticity of cumulative deforestation for various years, from which it is also possible to estimate a value for p_1. Since their double log linear model includes land and cumulative deforestation as separate variables, the parameter value for output elasticity of cumulative deforestation corresponds to the yield elasticity. By taking the yield elasticity of cumulative deforestation for two different years with two different values for cumulative deforestation, and given a value for p_1, it is possible to calculate a value for γ. From γ and p_1, it is subsequently possible to calculate a value for α_1 and α_2.

Panayatou and Parasuk found that the marginal output of cumulative deforestation was positive through 1984, when 46% of forests had been cleared, but had become negative by 1987, when 49% had been cleared. Since Thailand's forests are part of a much larger forests ecosystem extending over several countries, of which Thailand has deforested the most, .53 might therefore be considered a lower range estimate of p_1. In 1980, when some 41% of the forest had been cleared, $\varepsilon_{Fo-F(t)}$ = -.32, and in 1987, when some 49% of the forest had been cleared, $\varepsilon_{Fo-F(t)}$ = -.44. In the Amazon, 41% of forests cleared would correspond to a F_0-F(t)=1.558 10^6 km^2, and 49% of forests cleared would correspond to F_0-F(t)=1.82 10^6 km^2.

Yield elasticity of cumulative deforestation is

$$\varepsilon_{F_0 - F(t)} = (\alpha_2 - 1) + \gamma[F_0 - F(t)]$$ ***eqn (64)***

which after substituting

$$\alpha_2 = -\gamma(1 - p_1)F_0$$ ***eqn (65)***

becomes

$$\varepsilon_{F_0 - F(t)} = (-\gamma(1 - p_1)F_0 - 1) + \gamma[F_0 - F(t)]$$ ***eqn (66)***

The change in yield elasticity is given by

$$\Delta\varepsilon_{F_0 - F(t)} = -\gamma\Delta F(t)$$ ***eqn (67)***

and

$$\gamma = \frac{-\Delta\varepsilon_{F_0 - F(t)}}{\Delta F(t)}$$ ***eqn (68)***

Using the values from Panayatou and Parasuk's model gives $\gamma = -4.6\ 10^{-1}$. Substituting this into Equation (45) gives $\alpha_2 = 0.82$ and hence $\alpha_1 = 0.18$.

While the estimates of α_2 from the two extrapolations are quite close, there is a nearly three-fold difference in the values of γ and a substantial difference in the values of p_1. Extrapolating from smaller rainforests of far different composition, with different agricultural practices, different climate, etc., and from models with different structures and different parameters is a dubious practice at best. Due to the extremely rough nature of these estimates, they can only serve as general guidelines around which to base extensive sensitivity analysis.

Sensitivity Analysis

Sensitivity analysis is divided into two parts. The following section examines only the interior steady state solution, which, as pointed out in the previous chapter, is a saddle point, and hence may be difficult to attain and maintain. In addition, economic variables change, ecological variables are subject to exogenous effects, and uncertainty and imprecision abound, so with current knowledge it is impossible to determine any kind of true optimal steady state. Still, since a steady state decreases the risk of irreversible destruction of the forest, establishing one may be a worthy goal. The closer an imposed steady state is to a market determined optimal steady state (where the market somehow accounts for public good values and negative externalities), the easier it should be to arrive at and maintain. It is thus worth examining the characteristics of the steady state under different parameter values. The following chapter conducts sensitivity analysis with respect to the optimal time path of deforestation.

In both cases, sensitivity analysis examines the variables p_1, p_2, v(S) and δ, as these are the variables most relevant to policy analysis.

Mathematica software readily calculates the closed form solution F* for various values of the relevant parameters and can depict the results graphically. Given the extreme difficulty of maintaining an explosively unstable steady state, only the saddlepoint equilibriums are shown. Unless otherwise mentioned, $\alpha_1=0.17$, $\alpha_2=0.83$ and $\beta_1=0.006$.

The Social Valuation for Public Goods

The parameter v(S) is a proxy for the relative valuation given to public goods by the relevant policy making authorities, and is defined for S = local, national and international. The valuation for private goods is implicitly normalized to one.

For v(local), the problem is of the local (e.g. state) policy planner trying to maximize local GNP while presumably ignoring the public goods produced by intact forests, i.e. v(local)=0. While it is certainly not true that the rainforests produce no local public goods, given the abundance of intact forest in the Amazon the marginal utility of public goods might be quite low, and ignored by planners. In contrast, much of the agricultural production of the Amazon remains there, and replacing it with imports would be costly due to transportation cost. Agricultural production might therefore have a quite high marginal utility. In any case, striving to maximize quantifiable GNP while ignoring public goods is a common goal for policy makers. Sensitivity analysis considers the impact of values up to 2.

For v(national), the problem corresponds to a national policy planner who accounts for both private good output and national public goods, such as climate stabilization in crop producing regions, protection of river and ocean fisheries from sedimentation, etc. Agricultural production from the Amazon has ready substitutes[28] and therefore lower marginal utility than in the local valuation case. Since there is no objective means for determining the value of national public goods, v(S) is fairly arbitrarily set equal to 2, while sensitivity analysis considers values from one to five.

The parameter v(international) corresponds to international policy makers attempting to maximize utility for the current generation from all combined public and private good outputs from the rainforests. The value of the Amazon as a carbon depository, as a regulator of global climate, as a storehouse of biodiversity, etc. must all be taken into account. Agricultural output in contrast is even more readily substituted for at a global level. Again fairly arbitrarily, v(S)=4, while sensitivity analysis considers values from three to ten.

The Time Discount Rate

Appropriate discount rates will also vary between levels of society. Certainly for individuals, discount rates undoubtedly increase as one approaches subsistence level, becoming virtually infinite below that level as immediate survival takes precedence over all considerations of the future (e.g. a starving farmer will eat his seed corn, which may offer returns of several thousand percent over 4 months). Since the Amazon is among the poorest regions in Brazil, in the drive to increase current

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[28] According to Schneider (1990), most agricultural goods produced in the Amazon can be produced cheaper elsewhere in Brazil.

consumption, local leaders might discount future costs more heavily. Second, if the discount rate is also based on elected policy makers' re-election plans, or financial returns on the investments of politically influential people, the discount rate might be very high indeed. Estimates of the opportunity cost of capital, a reasonable proxy for the annual discount rate at the individual and perhaps state level, range in the Amazon from 12% to 70%, with recent estimates of greater than 40%[29]. Analysis uses 20% as a reasonable estimate for the local discount rate, with sensitivity analysis between 10% and 40%.

At the national level, per capita wealth is approximately double that of the Amazon region (Franco, 1995). Politicians have similar shortsighted views, but the Amazon's low population is of minor importance in national elections, and preferences of groups in the population centers will take precedence. Indeed, at a national level the Brazilian constituency is growing increasingly environmentally aware and in favor of preserving the Amazon, which might influence the time horizon for policy making. The most recent legislation on conservation/development of the Amazon, the 'Integrated National Policy for the Legal Amazon', explicitly emphasizes the need to conserve the region for future generations. A reasonable discount rate for national level analysis of a large-scale ecosystem might be 5%, with sensitivity analysis ranging from 1% to 10%.

Internationally, the countries with the ability and interest to influence Brazil's decision to deforest the Amazon are generally wealthy. There is less immediate pressure from their populations for rapid development, and a growing awareness of the long-term impacts of

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[29] See footnote 24, Chapter Two for details.

environmental destruction. With greater wealth, the developed countries are better able to account for the interests of future generations. Debate over nuclear waste disposal, global warming and ozone depletion show that western leaders are being forced to contemplate curtailing current growth in favor of future benefits, suggesting a lower discount rate. A discount rate equal to the rate of regeneration of the forest, 0.6%, is defended in Chapter Six as the appropriate discount rate for intergenerational analysis when the future is assumed to have some rights to natural resources. For an international community concerned about the future, 1% may be a reasonable discount rate. Sensitivity analysis considers rates between 0 and 3%.

Graphical Analysis

Figures 5a-c depict the interior solutions for steady state forest stock in delta-v(S) space, for various values of p_1 and p_2. As both p_1 and p_2 are influenced by the ecological degradation resulting from deforestation, they are likely to vary together: i.e. both should be relatively high or both should be relatively low. Since p_1 is a measure of when ecological degradation leads to decreased crop yields, and p_2 a measure of when ecological degradation leads to irreversibility, the former is likely much greater than the latter. Higher range estimates of p_1 and p_2 are 82% and 60% respectively. This is shown in Figure 5a, fig. 5a: p1=82%,p2=60%

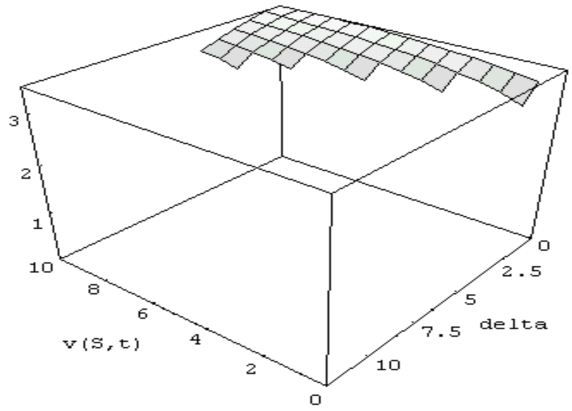


fig. 5b: p1=67%,p2=30%

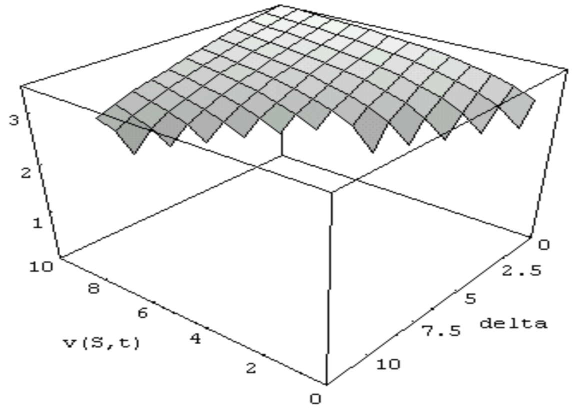
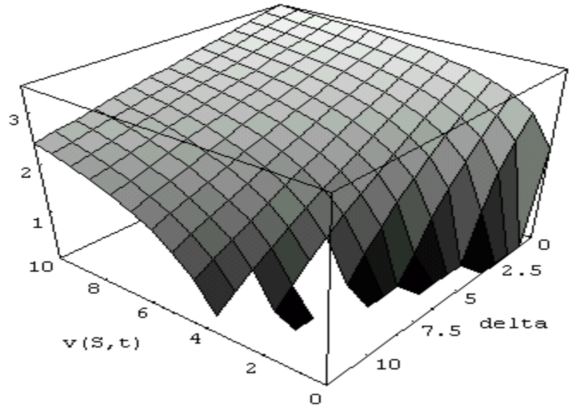


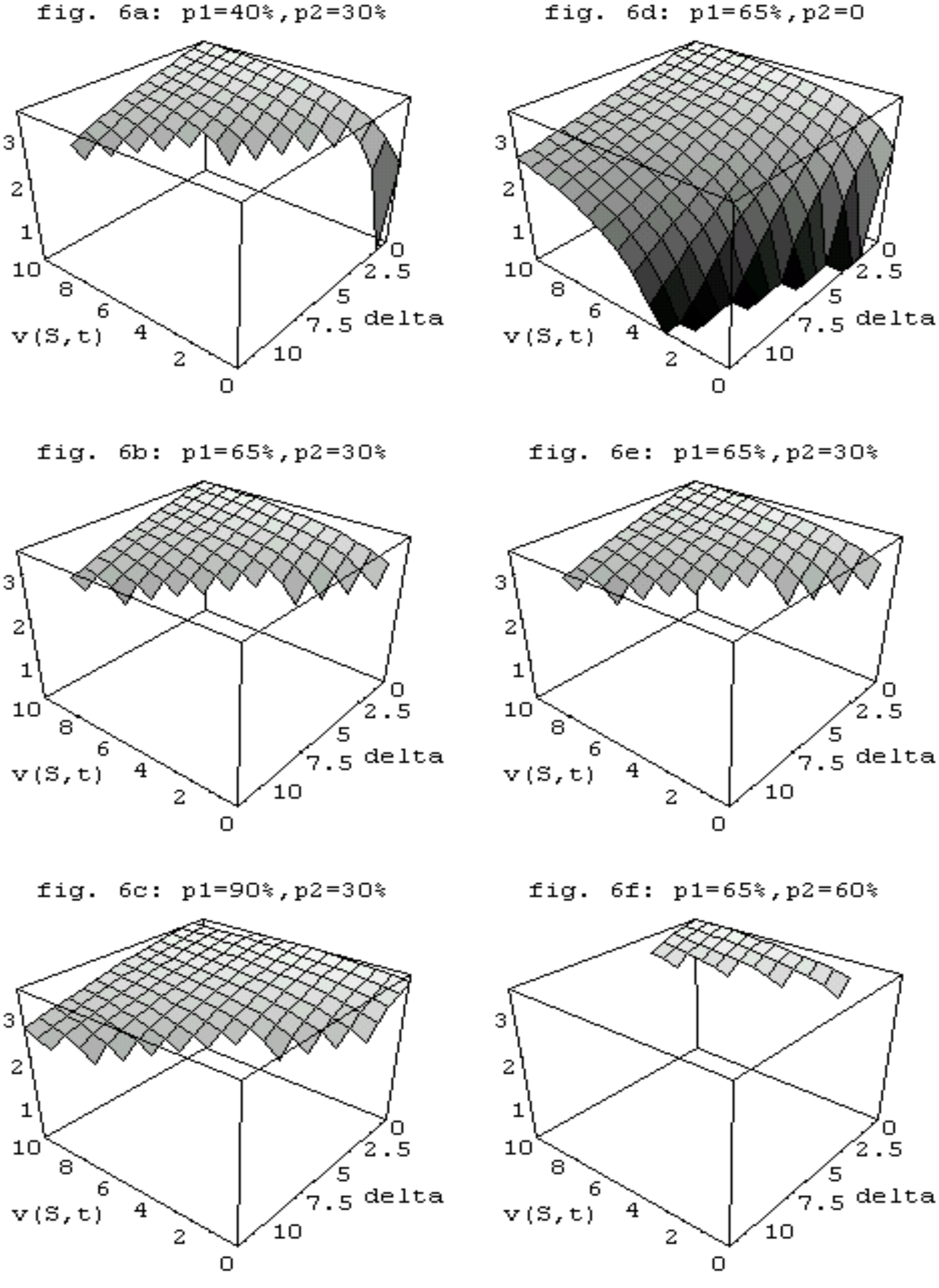
fig. 5c: p1=53%,p2=0



Figures 5a-c: Steady state forest stock in ν(S)-δ space. 5a has pessimistic ecological assumptions, 5b has semi-optimistic assumptions, and 5c has optimistic assumptions.

and will be referred to as the pessimistic case. A lower range estimate of p_1 is 53%, and the lowest possible p_2 is 0, shown in Figure 5c. This is referred to as the optimistic case. In the semi-optimistic case, p_1=67% and p_2=30%, which is shown in Figure 5b. The discount rate ranges from 0 to 12%. Discount rates of 0-1% approximate international preferences, 1%-10% approximate rational rates for national analysis, while local level decision makers are likely to use implicit discount rates greater than 10%. The relative social valuation for public goods ranges in value from 0 to 10, where local social good valuations may lie between 0 and 1, national valuations between 1 and 5, and international valuations between 3 and 10.

Figures 6a-f show the impact of variation in p_1 and p_2 separately, holding the other constant. In Figures 6a-c, p_1 is held constant at 65%, while p_2 ranges between 0 and 60%. In Figures 6d-f, p_2 is held constant at 30%, while p_1 ranges between 40% and 90%. The most striking result is that for the high discount rates and low social valuations of the public good likely at the local level, no interior steady state solution emerges, regardless of the assumptions regarding p_1 and p_2. Since infinitely negative utility can never be optimal for finite discount rates, the absence of an interior solution implies a 'corner solution'. Since a true corner solution where $D^*(t) = 0$ is not feasible, in a 'corner solution', forest stocks must asymptotically approach p_2, the sustainability threshold. The results of the GAMS model in the following chapter support this conclusion.



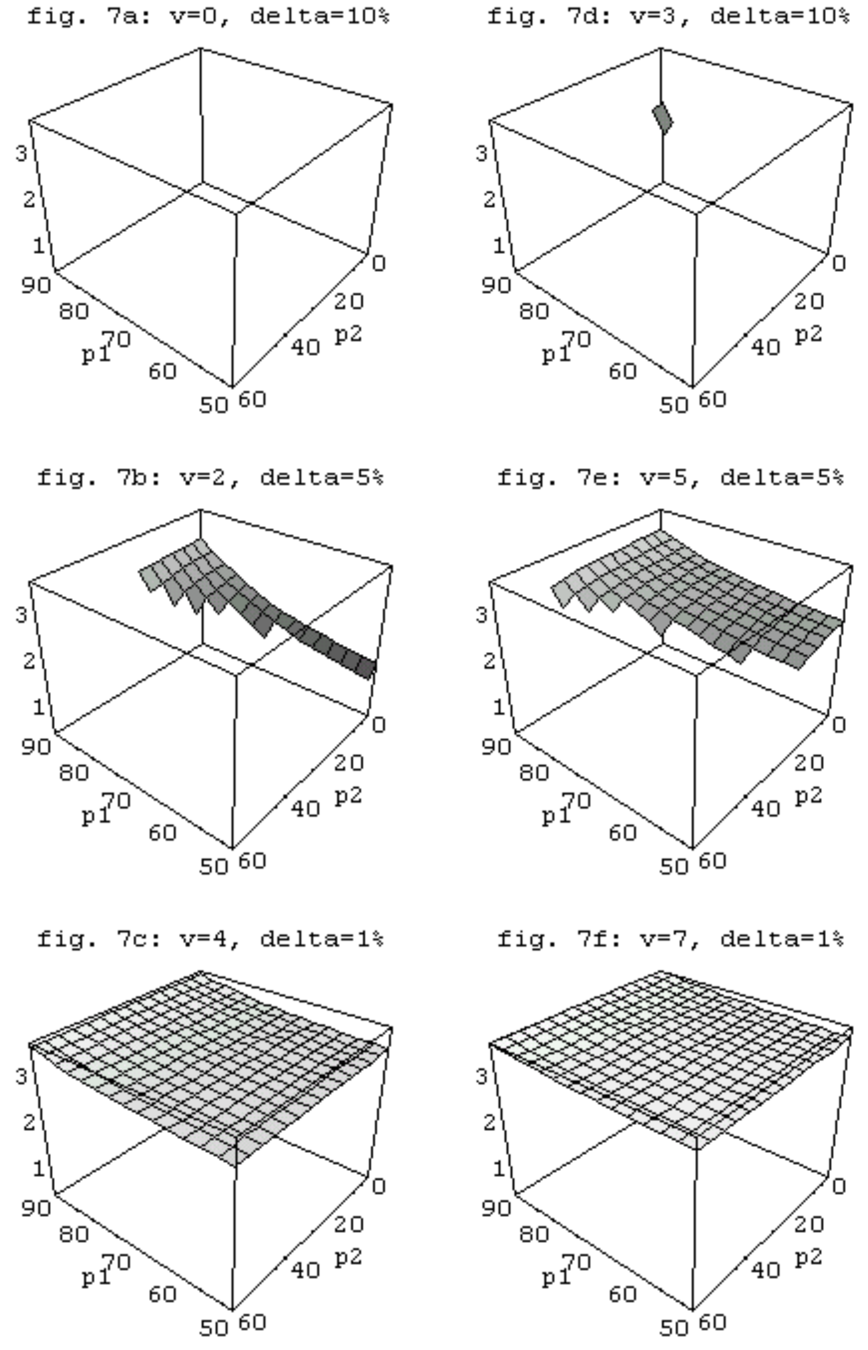
Figures 6a-f: Steady state forest stock in $v(S)$-δ space. In 6a-c, p_2 is held constant while p_1 varies, and in 6d-f, p_1 is held constant while p_2 varies.

While a corner solution steady state does not by itself imply extinction of the forest stock, it increases the possibility that some external shock could cause irreversible damage to the ecosystem. In contrast, the very low discount rates and high social valuations for the public good corresponding to the international level almost guarantee that an interior steady state solution is optimal. At the national level, with intermediate values for the discount rate and the social valuation of the public good, an interior optimal steady state solution may or may not exist. However, the likelihood of an interior steady state solution increases with the resilience of the ecosystem (i.e. the greater the level of deforestation that can be sustained without irreversible effects) and also with the sensitivity of agricultural yields to cumulative deforestation. These results are intuitive: lower returns to agriculture are a disincentive to deforestation, while greater ecosystem resilience decreases the likelihood of extinction.

Figures 6a-c show that both the likelihood of a steady state and the forest stock in that steady state increase as p_1 increases. Figures 6d-f show that while the likelihood of a steady state increases considerably as p_2 decreases, the forest stock in the steady state actually shows a very slight decrease, imperceptible in the graphs. Figures 7a-d and 8a-f show the flip side of Figures 4 and 5: $v(S)$ and δ are defined for local, national and regional, while p_1 and p_2 vary. Figures 7a-d show the impact of higher social valuations for the public good, while Figures 8a-f show the impact of a change in the discount rate.

Figures 7a-c show the optimal steady state forest stock at the local, the national and the international levels, respectively. Figure 7a shows a null set: there are no combinations of the ecological parameters which will lead to interior solution steady states under the assumptions used to model local level analysis. In Figure 7b, a steady state emerges only for very low values for p_2 and high values for p_1, which is highly unlikely in reality. In contrast, Figure 7c suggests that high steady state forest stocks are optimal at the international level for any reasonable range of ecological parameter values. Figures 7d-f show an increase in the value of v(S). Note that in Figure 7d, the discount rate is low for local level analysis, 10%, and value of the public good is set to three, almost certainly too high, and there are still virtually no feasible steady state interior solutions. This is done simply to emphasize that the steady state equilibrium will undoubtedly be a corner solution if public goods are undervalued and discount rates are high. Figure 7e shows that at the national level, interior solution steady state forest stocks are only possible for high social valuations of the public good, excellent regenerative abilities of the forest, and poor crop resistance to ecological change. Figure 7f simply shows that larger forest stocks are optimal in steady state the higher the social valuation of the public good.

Figures 8a-f look at the impact of changes in the discount rate at the national and international levels, since interior solution forest stocks compose a null set at the local level.



Figures 7a-f: Steady state forest stock in p_1-p_2 space. 7a-c show forest stocks at the local, national and international levels respectively under basic assumptions, and 7d-f show the impact of an increase in the social valuation of the public good.

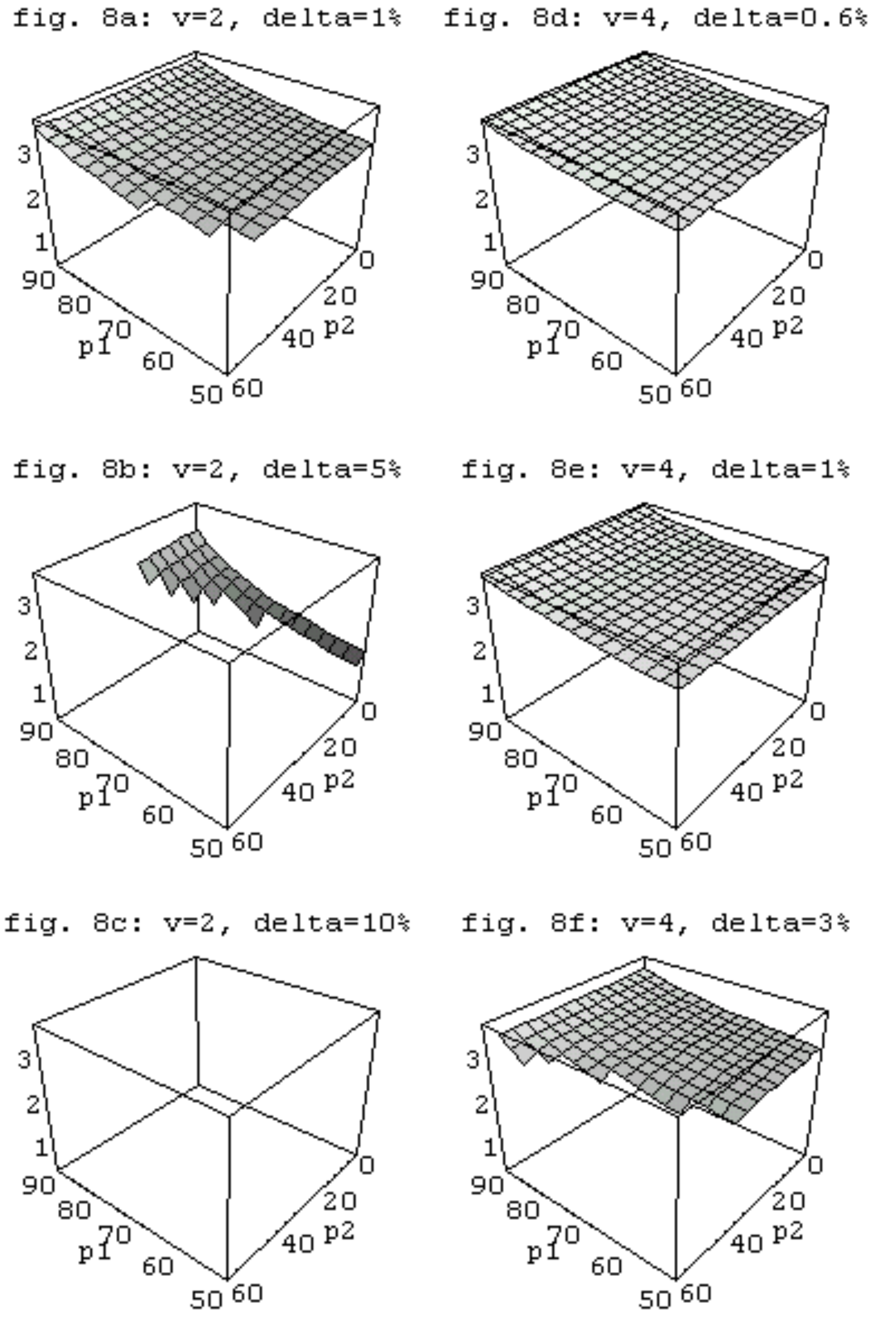


fig. 8a: v=2, delta=1%

fig. 8d: v=4, delta=0.6%

fig. 8b: v=2, delta=5%

fig. 8e: v=4, delta=1%

fig. 8c: v=2, delta=10%

fig. 8f: v=4, delta=3%

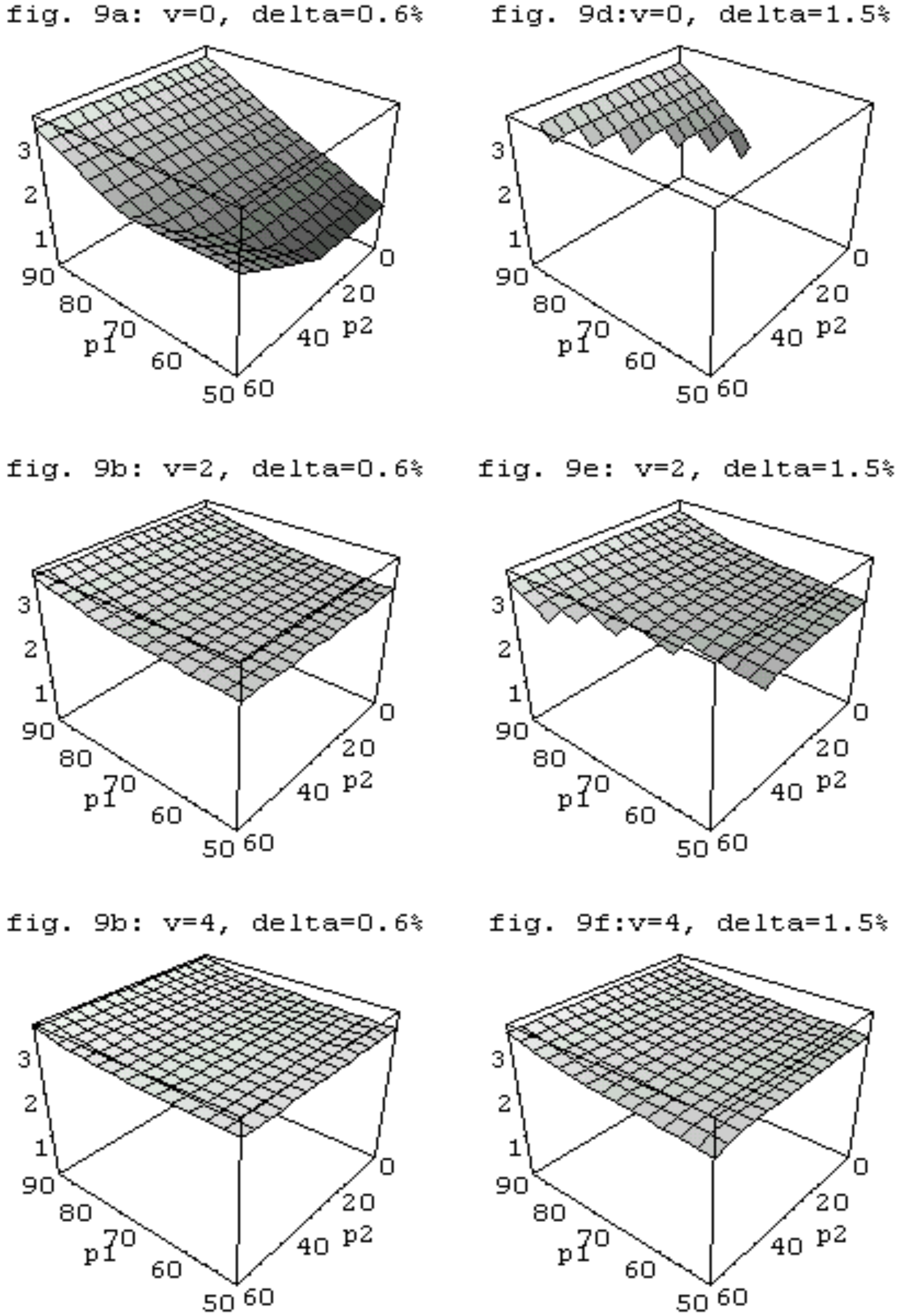
Figures 8a-f: Steady state forest stock in p_1-p_2 space. 8a-c and 8d-f show steady state forest stocks at the national and international levels respectively for varying discount rates.

At the national level, decreasing the discount rate greatly increases the likelihood of an interior solution steady state, while higher discount rates internationally allow for a corner solution steady state under certain circumstances.

Figures 9a-f show the effect of very low discount rates on steady state forest stocks. Such discount rates might apply at all levels if there were sufficient concern for future generations. Note that in the absence of public good benefits (Figure 9a) steady state forest stock increases in p_2 over one section of the graph. In this case, the steady state forest stock is an interior solution just equal to the corner solution. As long as the discount rate is no greater than the regeneration rate of the forest, an interior solution steady state always emerges. In contrast, if public goods are not valued, a discount rate as low as 1% is unlikely to produce an interior solution steady state for reasonable values of p_1 and p_2.

Figures 7-9 also help clarify the impact of changes in p_1 and p_2 discussed in relation to Figure 6. It is fairly obvious from the graphs that p_2 has relatively little impact on the level of forest stock in an interior steady state, but has a significant impact on whether an interior solution steady state exists. For discount rates greater than the rate of forest regeneration (β_1), steady state forest stock is decreasing in p_2. The elasticity of steady state forest stock with respect to p_2 is slightly negative for low values of p_2, but becomes increasingly negative as p_2 increases.

Eventually, as p_2 increases, an interior steady state solution ceases to exist. However, for values of δ below β_1, this relationship is



Figures 9a-f: Steady state forest stock in p_1-p_2 space for low discount rates. 9a-c show steady state forest stocks at the local, national and international levels for a discount rate equal to the regeneration rate of forest stock. 9d-f show a discount rate of 1%.

reversed: the elasticity of steady state forest stock with respect to p_2 becomes very slightly positive (too slight to see on the graph). The critical 'switching' value is $\delta=\beta_1$, when a change in p_2 produces no change in the steady state forest stock: discounting just neutralizes the value of future growth, so changing the proportion of forest stock at which irreversible deforestation occurs has virtually no effect.

For any given forest stock, the higher the value of p_2, the lower the current period deforestation that can be sustained. This means that a high value for p_2 either leads to saving most of the forests, or a high risk of irreversible deforestation, depending on the other parameter values, and especially the discount rate. With higher discount rates, a greater weight is placed on the present relative to the future, favoring current period deforestation in spite of the lower returns it implies for the future. When discount rates fall below β_1, the value of future forest growth outweighs the immediate returns to deforestation, and less forest is cleared.

The impact of an increase in p_1 is more obvious and more intuitive. The more quickly cumulative deforestation leads to negative marginal returns to agriculture, the less deforestation occurs. A higher p_1 leads to greater forest stocks in steady state and a greater probability of interior solution.

Steady state forest stock is in almost all cases fairly elastic with respect to p_1, and increasingly so as we move from international to local analysis. In essence, for discount rates greater than β_1, p_1 determines the level of forest stock in steady state, thus the output (and hence profitability) of agriculture, while p_2 determines sustainability, i.e. whether or not an interior steady state equilibrium exists.

Humans probably have little control over p_2[30], and unfortunately an inadequate idea of its value. If we think the value for p_2 is lower than it actually is, we may deforest too much, and cross the threshold of irreversibility. On the other hand, select policies can potentially influence the remaining variables, δ, v(S) and p_1. Chapter Five outlines reasonable policy options for affecting these variables.

Economic vs. Ecological Equilibrium

In the model presented in Chapter Two, the parameters α_1, α_2, β_1, β_2 and γ all have ecological components, α_1 and α_2 also have economic components, and δ is generally considered a purely economic variable. The relative social valuation for public goods measures consumer preferences, and hence is an economic parameter as well.

I define an economic equilibrium as any steady state solution to the problem presented in equations (1), (13), (22) and (25-27) (p. 47), which has the characteristic that along the optimal time path, no other allocation of resources will lead to Pareto improvements in utility, given that the present generation has sole property rights to all natural resources. It is thus defined by intragenerational efficiency criterion. It may or may not correspond to renewable levels of forest stock in the steady state.

I define an ecological equilibrium as any situation in which the net level of forest stock is unchanging through time, or changing only on an evolutionary time scale. By an evolutionary time scale, I mean that changes are so slow that the majority of species are able to adapt

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[30] This is not strictly true: policies which increase population density may lead to shortened fallow periods and a lower percentage of land in fallow. Also, technological advances (e.g. fertilizer applications) may reduce the amount of fallow land. Among other effects, these changes would decrease the value of β_2 and hence p_2.

through evolution, or at least extinction rates are no faster than speciation rates. The 'natural' ecological equilibrium is one in which the Amazon forests remain untouched by humans, but this has probably not existed for at least many thousands of years.

A mixed economic-ecological equilibrium is one in which economic use of the forest maintains the net level of forest stock at a positive level- i.e. deforestation rates equal re-growth rates. This can only occur at forest stocks above p_2F_0. At p_2F_0, there is no deforestation and no regrowth. Steady state economics, property rights for the future or the sustainability paradigm[31] would seem to limit acceptable outcomes to mixed economic-ecological equilibriums.

Ecological parameters, in addition to being highly uncertain and subject to exogenous change, are extremely difficult to influence. While it is no doubt possible to speed forest regrowth rates through seeding, fertilizer and soil conservation, and change crops and technologies to influence α_1, α_2 and γ, these are difficult tasks depending on uncertain or as yet non-existent technologies, and better left to technicians, foresters, and agronomists.

The social valuation for public goods is an economic parameter in that it measures people's preferences. To some extent, at a given level of society, the value for v(S) arises from cultural/social values, education, and knowledge about the Amazon and Amazonian ecosystem. It is no doubt possible to influence people's utility functions, and indeed enormous amounts of energy and money are spent on this daily.

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[31] Daly (1991, 1993) provides an excellent definition and analysis of a steady state economy, Bromley (1991) and Howarth and Norgaard (1990) examine the issue of property rights for the future and writings on sustainability are ubiquitous (e.g. see Pearce and Turner, 1990)

It is fairly obvious from the various figures that higher values of δ seriously constrain the values of the ecological parameters which will lead to an interior solution steady state. An ecological-economic equilibrium is only guaranteed to occur for values of $\delta < \beta_1$, i.e. when the discount rate is less than the rate of regrowth of forests in the absence of ecological degradation. Since δ has a crucial impact on model results, it demands further analysis if we are to use it to justify risking irreversible deforestation of the Amazon in this simple model. This is done in Chapter Six.

Uncertainty

Another characteristic of this model is the tremendous uncertainty involved. Current understanding of the Amazonian ecosystem, and the extreme difficulty of gathering quality data, mean that it is at present virtually impossible to accurately determine any of the ecological parameter values. It is also apparently impossible to determine an objective value for δ, and for $v(S)$. Not only can these variables not be determined at present, they are subject to change through time due to exogenous factors. Extreme uncertainty is an integral characteristic of this model, and indeed of virtually any long-term analysis of ecological-economic interactions.

What is especially worrisome is the lack of knowledge of p_2, the proportion of remaining forest stock beyond which spontaneous degradation occurs. Not only is this not known for the present, and virtually unknowable until too late, it is no doubt subject to exogenous change as global weather patterns change naturally or due to anthropic influences. As long as $F(t)>p_2$, excessive deforestation can be corrected for. If p_2 is ever reached, recuperation of forests is virtually impossible, and all future generations will sustain an infinite loss.

Neither time, space nor ability permits me to analyze the impact of uncertainty in all of the model's variables. Drawing on the works of Clark and Reed, however, I am able to make inferences about the impact of stochastic uncertainty in v(S).

Using stochastic dynamic programming, Clark and Reed examine the case where a wilderness area produces amenity value plus the possibility of benefits arising from the genetic resources of wilderness areas, and irreversible development of the area also produces a service flow. The model assigns a probability distribution to the likelihood of unforeseen benefits arising from genetic resources. The future values of developed and wild land become apparent without exploratory development, but the likelihood of a breakthrough in creating economic value from genetic resources is dependent on the size of wilderness stocks.

The paper assumes that social welfare can be represented by an additively separable social welfare functional representing the goods and services derived from the forest itself and goods and services derived from development. The marginal utility of forests as the quantity of forest approaches zero is assumed to be infinite, while this is not so for development.

Allowing v(S) to vary through time, suppose that v(S,t) is a

> "stochastic process which evolves through time as geometric Brownian motion with drift governed by the stochastic differential equation
>
> $$\frac{dv(S,t)}{v} = adt + \sigma_v d\omega, \qquad v(S,0) = v_{S0}$$

> where α [is a] drift parameter representing [a constant upward] trend in the relative valuation of wilderness land... and σ_v^2 .. denotes the instantaneous variance in the relative valuation process. The stochastic process $\{w_1(t)\}$...[is a] standard Wiener process so that $\{dw_1(t)\}$...[is a] white noise process."

Assuming that $\sigma_v > 0$, and using the Itô stochastic calculus, Clark and Reed show that with irreversible development,

> "[a]ssuming size dependent land-service-flows: (i) The development of wilderness can only be optimal when the marginal services of developed land exceed those of wilderness by a suitable amount; (ii) The existence of land-development costs and scientific-breakthrough-possibilities reduce the optimal extent of land development at given wilderness valuations; (iii) Increases in valuation uncertainty increase the amount of wilderness that it is optimal to conserve at any wilderness valuation."

Quasi-option value (QOV) is defined as the difference between a certainty equivalence strategy and an optimal development strategy. QOV is shown to be positive and increasing with increasing uncertainty. This means that the present value of wilderness resources increases with increasing uncertainty.

The Clark and Reed model is different from the present one in that they assume all development is irreversible, but spontaneous degradation of remaining wilderness never occurs. For low levels of deforestation far from the spontaneous degradation risk zone, development in the present model perhaps need not be adjusted for risk (i.e. a certainty equivalent might suffice). However, as the deforestation nears the irreversibility zone, it seems an extremely cautious approach might be warranted, and deforestation should only proceed if the deforestation motive greatly exceeds the conservation motive (see equation 42 and accompanying explanation).

Summary and Conclusions

Sensitivity analysis of the model presented in Chapter Two, based on parameter estimates derived from secondary sources, shows that in spite of an infinite utility loss for future generations, under a wide range of circumstances it is economically efficient to risk irreversible deforestation of the Amazon. Economic equilibrium need not coincide with an ecological equilibrium if efficiency is to be the measure of optimality. However, these results depend closely on highly uncertain ecological parameters, highly uncertain social valuations for public goods, and even more uncertain future valuations for both public and private goods. The results also depend crucially on the discount rate chosen.

Before these results can be used to derive policy options, it is necessary to look at the optimal time path for deforestation. It is just as important to know how fast to cut as how much. This is the subject of the following chapter.

CHAPTER FOUR:

TIME PATHS OF FOREST STOCK

Simply estimating the optimal steady state forest stock under various scenarios, as done in the previous chapter, offers little guidance to policy makers. Several other questions must first be answered if this research is to have any practical implications. First, if policy measures can bring discount rates and public good valuation of the forest into a satisfactory range compatible with a steady state forest stock, will market forces then lead to a steady state spontaneously? Second, if a steady state is achieved, how stable will it be- i.e. will different initial conditions lead to the same equilibrium, and how will the equilibrium respond to external shocks? Given that the steady state solution in the continuous time model is a saddle point, the answer to these questions is not obvious. Third, what is the optimal rate of deforestation? How does this vary with different parameter values? The answer to this latter question should give some idea of the urgency of the deforestation question. If locally optimal deforestation occurs much faster than is satisfactory at a national or international level, there is more pressure to address the issue immediately.

To answer these questions, the current chapter analyzes the optimal time path of forest stock and of deforestation in the Brazilian Amazon under a wide range of scenarios. This is done using GAMS (general algebraic modeling system) software[32]. Since GAMS cannot solve an infinite time model, the model presented in Chapter Two is

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[32] To learn GAMS, I relied heavily on Jefferson and Boisvert (1989) and Brooke, et. al. (1992).

converted into a discrete time version, and forced into a steady state at year T.[33] Unless otherwise noted, results are reported for only 70 years, sufficient time to show relevant trends.

One of the most striking results of the analysis of Chapter Three was the wide range of parameter values for which no market determined interior solution steady state forest stock is feasible, even when the market is assumed to incorporate both negative externalities of deforestation and the public good benefits of intact forest stock. Given the model's additively separable logarithmic utility functions, either zero forest stock or zero agricultural output implies infinitely negative utility for future generations. Since positive agricultural output requires a forest stock sufficiently large to allow regrowth (and hence sustainable deforestation, a necessary input to agricultural production in the model), no optimal solution with a finite discount rate can lead to a level of forest stock below which irreversible degradation of the forest occurs. Thus, the minimum forest stock conceivable under optimal conditions is one which asymptotically approaches p_2F_0, the point at which deforestation becomes irreversible. The GAMS model therefore constrains forest stock to remain above p_2F_0.

Another feature of the GAMS results is that they provide values for the shadow price of forest stock. If the model could be accurately quantified, this shadow price would be equal to the Pigouvian tax on deforestation necessary to optimize deforestation rates (Ehui, 1987).

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[33] Trial runs with T=101, 301, 501 and 701 showed virtually no difference in time paths, though under certain circumstances (e.g. very low discount rates and high valuations for the public good) higher values for T led to almost imperceptibly lower steady state forest stocks. Under certain other circumstances (e.g. high discount rates and low valuations of the public good), GAMS was unable to solve for $T \geq 300$. Whenever this occurred, by time t=101 deforestation rates were close to zero, and forest stock was approaching p_2F_0, the corner solution steady state.

The Discrete Time Model

Analyzing the optimal time path of forest stock requires a discrete time version of the model in Chapter Two. Assuming a steady state from time T forward, let F* = steady state forest stock. This means that D* (the steady state deforestation rate) = β_1 (F_0-F*)+β_2 (F_0-F*)^2. The model becomes

$$Max\ W = \sum_0^{T-1} \rho^t [v_t(S)\ln(F_t) + \ln(\pi(D_t, F_t))] + \sum_T^{\infty} \rho^t [v_t(S)\ln(F^*) + \ln(\pi(D^*, F^*))]$$

eqn (69)

If the system is forced into a steady state at time T, the infinite utility stream from time T forward can be discounted to the net current value at time T simply by dividing current utility at time T by the discount rate. This quantity must then be multiplied by the discount factor ρ=1/(1+δ) to obtain net present value. The GAMS model is therefore

$$Max\ W = \sum_0^{T} \rho^t [v(S)\ln(F_t) + \ln(\pi(D_t, F_t))] + \rho^T \left[\frac{[v(S)\ln(F^*) + \ln(\pi(D^*, F^*))]}{\delta}\right]$$

eqn

(70)

subject to

$$\pi(D_t, F_t) = AD_t^{\alpha_1}(F_0 - F_t)^{\alpha_2} e^{\gamma(F_0 - F_t)}$$ ***eqn (71)***

$$F_{t+1} = F_t - D_t + \beta_1(F_0 - F_t) + \beta_2(F_0 - F_t)^2$$ ***eqn (72)***

$$D^* = \beta_1(F_0 - F^*) + \beta_2(F_0 - F^*)^2$$ ***eqn (73)***

$$F_t,\ F^* > p_2F_0;\ D_t,\ D^* \geq .0001 \qquad \textbf{eqn (74)}$$

Forest stock in the initial period was set at 3.325 million km^2 and cumulative deforestation at .2 million km^2, approximating current conditions (see footnote 7, Chapter One). The limit on F_t and F^* is the corner solution, and the limit on D_t and D^* prevents GAMS from reading low D_t values as the log of zero.

Results

The model was run for a wide variety of parameter values corresponding to different levels of society and different assumptions regarding ecological parameters. The same caveats apply here as in the continuous time model of Chapter Three: since the public good value of the forest is virtually impossible to objectively quantify, and so many of the ecological variables are at best rough estimates, results should be taken as more qualitative than quantitative. While I provide numbers in the analysis, these numbers should be regarded as ordinal rather than cardinal. Nonetheless, to the extent that the model corresponds to reality, the results can provide some insights into the urgency with which Brazil and the international community must address the deforestation problem, and the relative effectiveness of different policy options.

The base case parameter values are the same as in the analysis in Chapter Three of the continuous time version of the model: unless otherwise mentioned, F_0=3.8 (in millions of km^2), α_1=0.17, α_2=0.83, and $\beta1$=0.006. At the local level, analysis uses a discount rate of δ=20% and a social valuation of the public good of v(S)=0. Sensitivity analysis uses δ=10% and δ=40% (see footnote 24, Chapter Two) , and v(S)=0.5 and

$v(S)=1$. At the national level, corresponding values are $\delta=5\%$ and $v(S)=2$, with sensitivity analysis using $\delta=1\%$ and 10% and $v(S)=1$ and 4. At the international level, $\delta=1\%$ and $v(S)=4$, with sensitivity analysis using $\delta=0.6\%$ (the estimated regeneration rate of forest stock in the absence of ecological degradation- see Chapter Six for details) and 3% and $v(S)=3$ and 7. As in the sensitivity analysis of steady state forest stocks in Chapter Three, all cases were examined for optimistic, semi-optimistic and pessimistic assumptions regarding ecological parameters. In the optimistic case, irreversible deforestation only occurred after all forest stock had been cleared ($p_2=0$), and marginal returns to cumulative deforestation reached zero at $p_1=0.53$. In the semi-optimistic case, $p_2=0.3$ and $p_1=0.67$, and in the pessimistic case, $p_2=0.6$ and $p_1=0.82$[34]. Only selected trials are reported, as most lead to redundant conclusions.

Local, National and International Results

Figures 10a-b show the optimal time paths for forest stock under optimistic and pessimistic ecological assumptions for $\{v(S)=0, \delta=20\%\}$, $\{v(S)=2, \delta=5\%\}$ and $\{v(S)=4, \delta=1\%\}$ corresponding to the local, national and international levels of analysis. Figures 11a-b show the optimal time paths for annual deforestation under the same conditions. These time paths correspond to the steady state results shown in Figures 4a-c. In the optimistic scenario, locally optimal stocks converge towards the corner solution of 0, confirming the results of Figure 5c. Under the

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[34] The optimistic value for p_1 corresponds to Panayatou and Parasuk's (1991) results, while the pessimistic value is that extrapolated from Ehui's (1987) results (see Chapter Three, section 1.3) . Again, it seems reasonable that p_1 will be higher than p_2: returns to cumulative deforestation are likely to become negative before deforestation becomes irreversible.

optimistic scenario, locally optimal stocks converge towards the corner solution of 0, confirming the results of Figure 5c. Under pessimistic assumptions, both nationally and locally optimal stocks converge on the corner solution of 2.28, confirming the results of Figure 5a.

Under optimistic ecological assumptions, deforestation is more rapid than under pessimistic assumptions, and resulting steady state forest stocks are lower. With the economic parameter values likely at the international level, forest stocks in steady state remain quite high regardless of the assumptions regarding ecological parameters, and at the local level, optimal forest stocks asymptotically approach the irreversibility risk zone regardless of ecological parameters. In the national case, however, pessimistic assumptions increase the likelihood of a 'corner solution', where forest stocks asymptotically approach irreversible levels. Any external shock can then send the system into ecological collapse.

Figures 11a-b are useful for determining whether or not the model in corresponds to reality for at least part of the range of the

Figure 10a

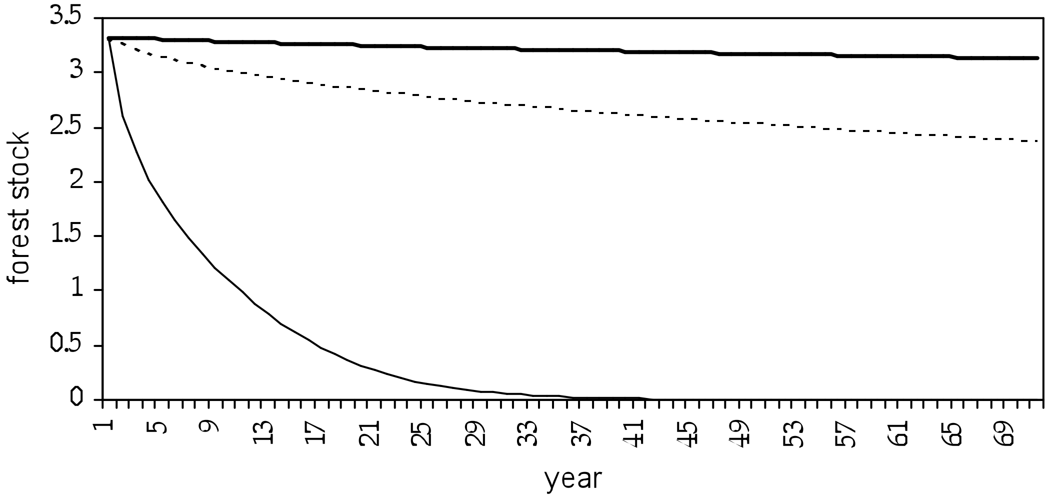
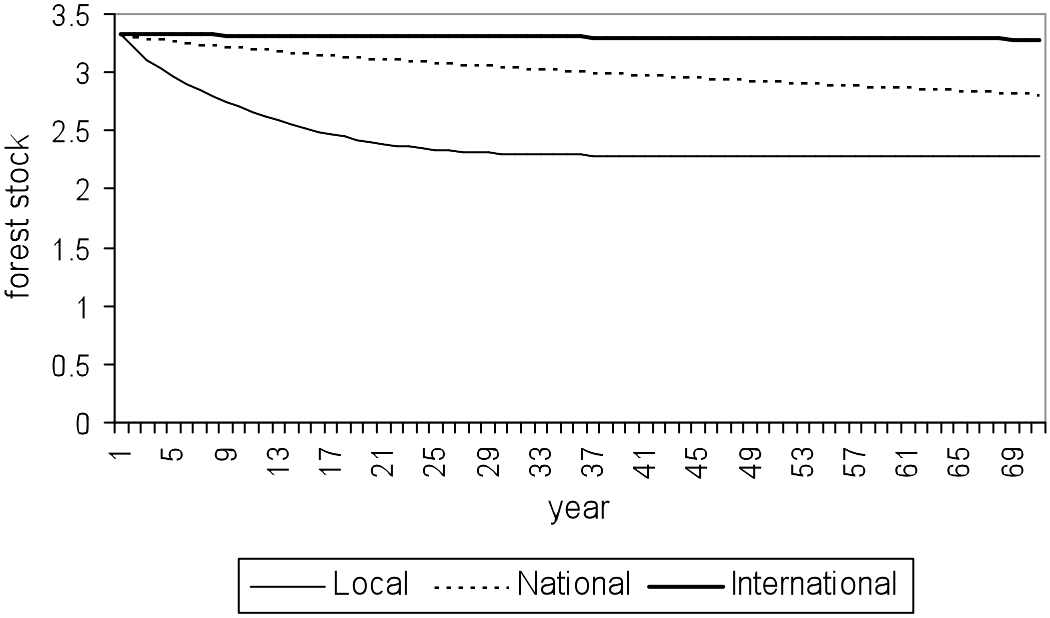


Figure 10b



Figures 10a-b: The optimal time paths of forest stock (million km²) under optimistic (10a) and pessimistic (10b) ecological assumptions and the base case parameter values for local, national and international analysis. (see text for exact parameter values)

Figure 11a

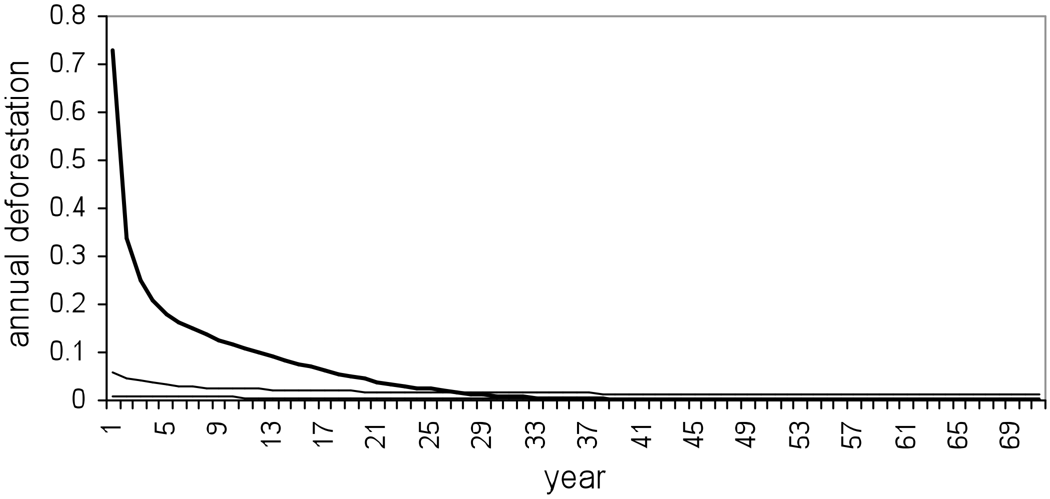
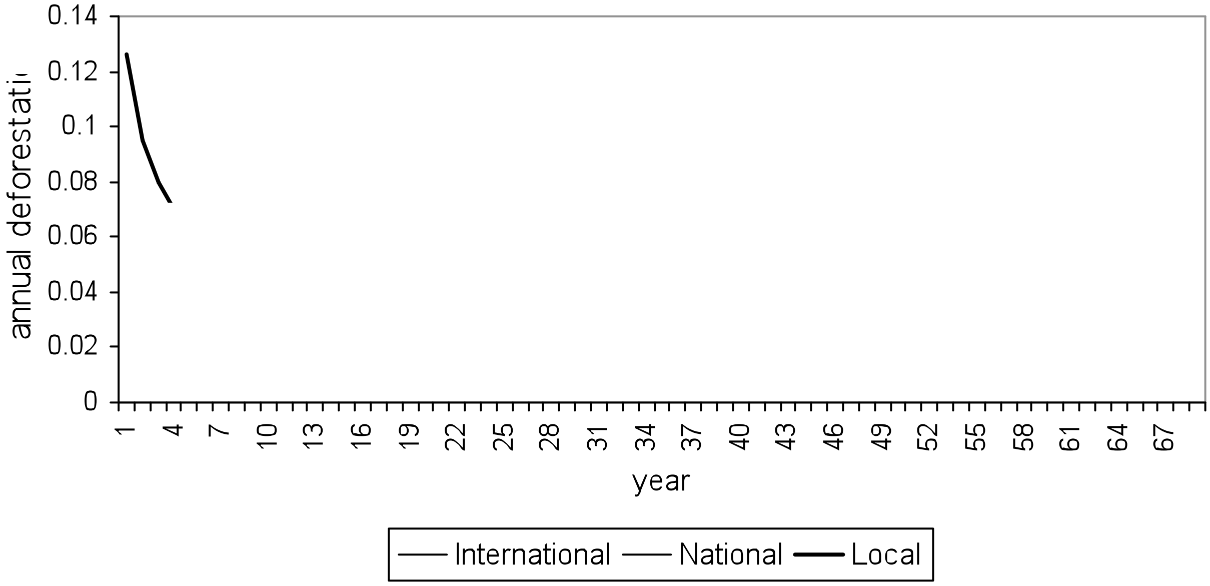


Figure 11b



Figures 11a-b: The optimal time paths of annual deforestation (million km^2) under optimistic (11a) and pessimistic (11b) ecological assumptions and the base case parameter values for local, national and international analysis (see text for exact parameter values) sensitivity analysis. At the international level, regardless of ecological assumptions, the optimal rate of deforestation is far below the actual three-year average of 20,000 km^2/yr. This corresponds to reality: there is considerable international pressure on Brazil to slow deforestation, and if memory serves, at the end of the 1980's the Group of Seven declared that deforestation in the Amazon was the environmental crisis of the decade. Internationally optimal forest stocks may be lower than current levels, but the along the optimal time path, it may take hundreds of years to get there.

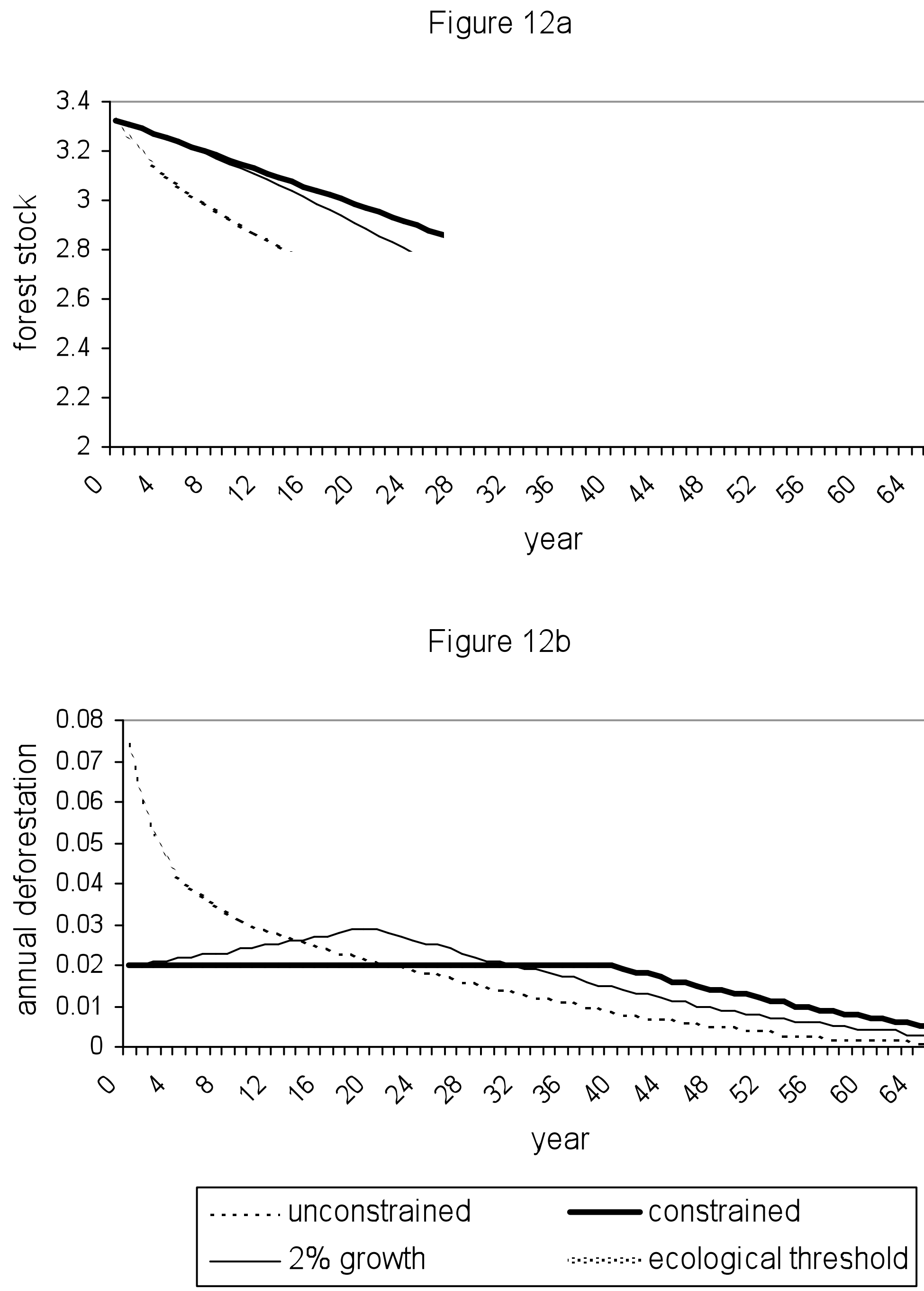
At the national level, the model indicates that under optimistic assumptions, optimal deforestation should be around 57,000 km^2/yr, far higher than actual levels. Under pessimistic assumptions, deforestation should be close to actual levels, around 16,000 km^2/yr. Forest stocks are beginning to fall to the point where nationally optimal deforestation rates are lower than actual deforestation. This again corresponds to reality: until recently, Brazil was actively encouraging deforestation, and only now has begun taking tentative steps towards slowing it. It is quite possible that nationally optimal deforestation rates are currently still greater than actual levels, and current efforts are primarily the result of international pressure. However, optimal deforestation rates are falling rapidly, and in the near future it should be in Brazil's interests to take serious steps towards slowing deforestation.

At the local level, the unconstrained model predicts deforestation rates far higher than actual levels. In reality however, it is highly likely that deforestation rates are constrained by labor and capital shortages, a contention supported by the dramatic increase in deforestation accompanying the economic revival of 1995. Figures 12a-b impose a capital/labor constraint on locally optimal deforestation (with pessimistic ecological assumptions), and compare it to the case with no constraint. Figure 12a shows the optimal time path of forest stock, and 12b of annual deforestation. Two versions of a constraint are shown. In the first version, insufficient capital and labor constrain deforestation to the 1995-1997 three-year average of 20,000 km^2 per year. In the second version, the constraint is 20,000 km^2 the first year, but grows by 2% per year. In either case, as the graph shows, the constraint is limiting. With no constraints, total deforestation after 50 years is growing dangerously close to the ecological threshold, while with a fixed constraint this takes 60 years, and with a growing constraint, 70.

Sensitivity to p_1 and p_2

Given the uncertainty regarding the values of p_1 and p_2, it is interesting to see how the optimal time path of deforestation reacts to alternative assumptions for these parameters. Figures 13a-b show the impact on forest stock and annual deforestation for different values of p_1, and 14a-b show the same for different values of p_2.

Decreasing the value of p_1 means that cumulative deforestation continues to increase crop yields for lower levels of forest stock, and logically leads to faster rates of deforestation and lower steady state forest stocks, as is clearly seen in Figures 13a-b.



Figures 12a-b: The optimal time paths of forest stock and annual deforestation (million km²) at the local level with optimistic assumptions, without labor constraints, with labor constraints, and with constraints relaxing by 2%/year.

Figure 13a

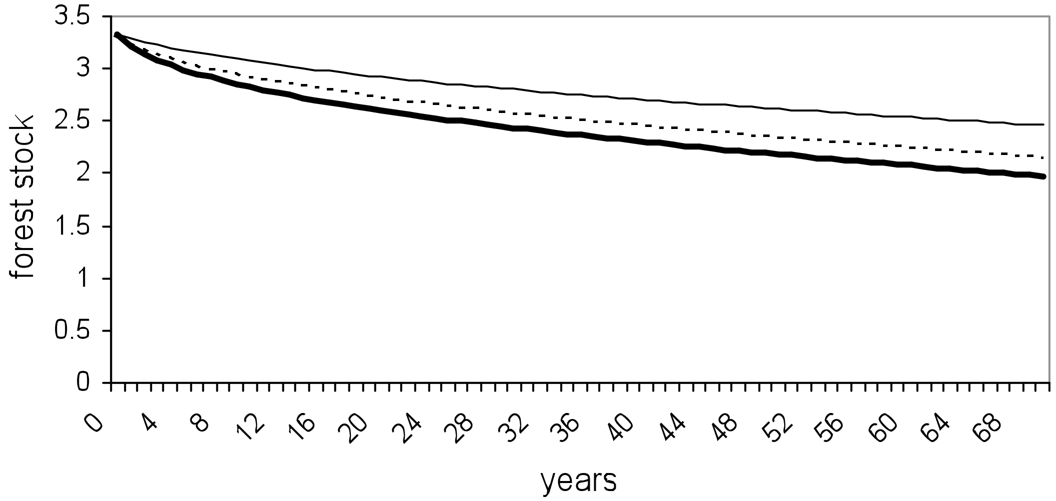
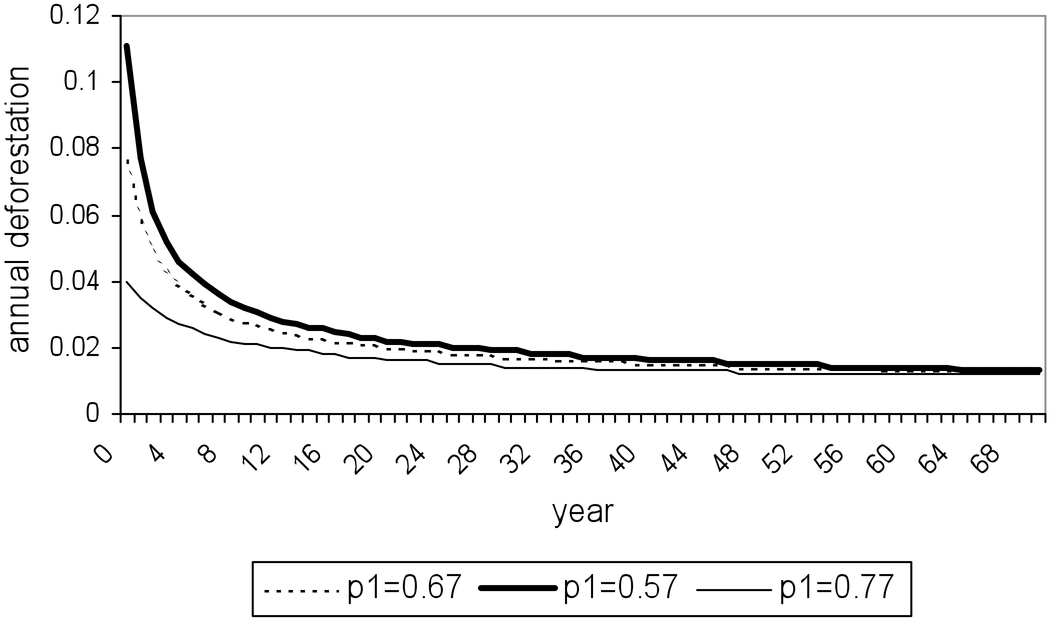
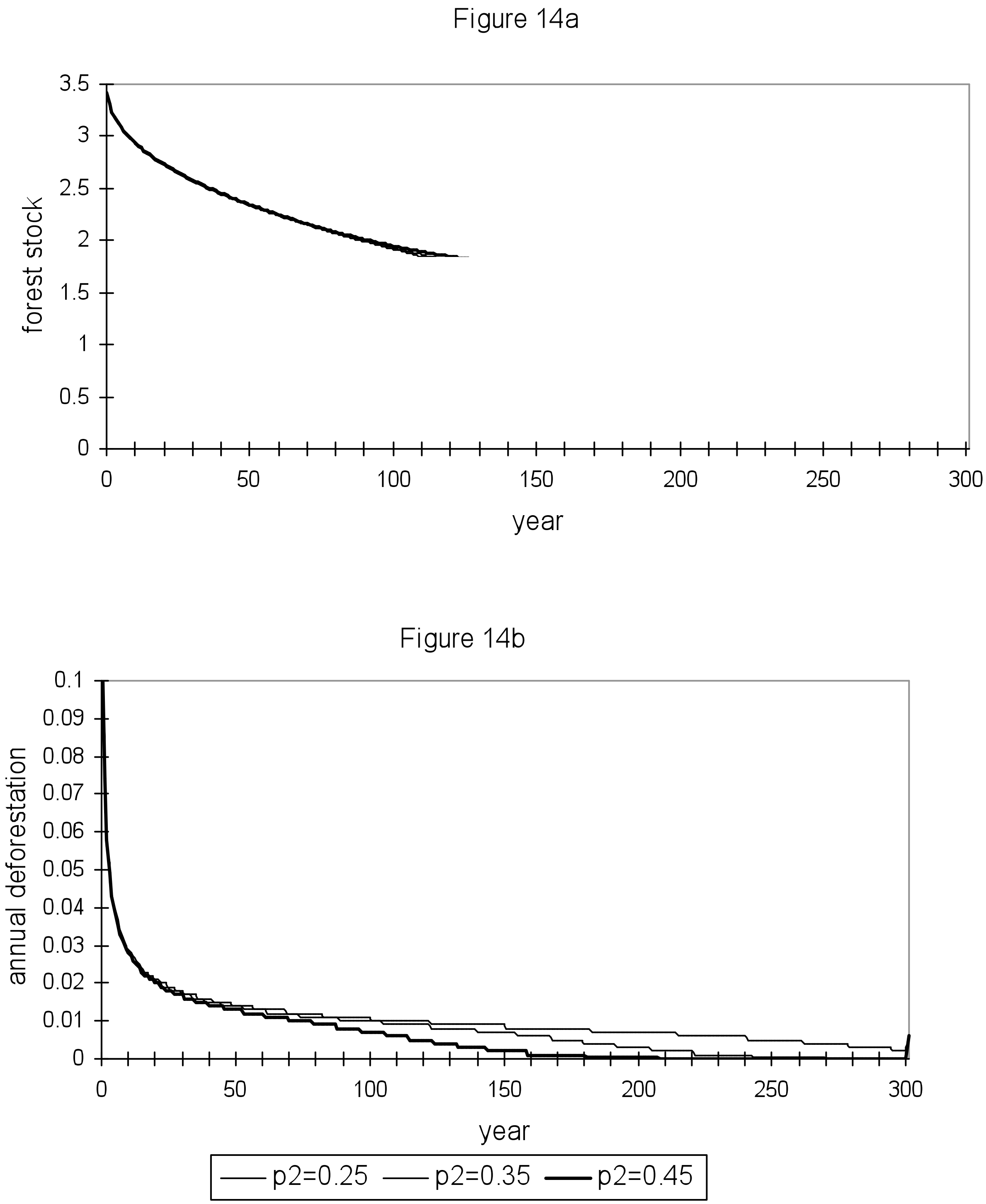


Figure 13b



Figures 13a-b: The optimal time paths of forest stock and annual deforestation (million km^2) for varying values of p_1 (p_2=30%, δ=5%, υ=1)



Figures 14a-b: The optimal time paths of forest stock and annual deforestation (million km^2) for varying values of p_2 (p_1=67%, δ=5%, υ=1).

Decreasing the value of p_2 has no direct impact on agricultural output, but allows faster regeneration for a given level of forest stock. As a result, as the sustainability threshold falls, the rate of deforestation increases very slightly, but the forest stock en route to steady state nonetheless remains very slightly higher initially since regeneration is more rapid. The most significant impact of a decrease in the sustainability threshold of course is that the ecosystem can sustain greater levels of cumulative deforestation, which is reflected in the lower steady state forest stocks. To see this effect, it was necessary to extend the time horizon considerably, to 300 years. For the parameter values in these examples, all time paths approach a corner solution steady state, though of course the corner solution is different for different values of p_2.

Figures 13-14 confirm the results of equations (46)-(48), and Figures 6a-f.

Stability and Robustness of the Steady State

The model so far has evaluated the optimal time path of deforestation starting from (approximately) current conditions. However, the national and international policy goals to bring local deforestation rates in line with satisfactory rates at these more encompassing levels of society will undoubtedly take a considerable length of time. During this time, deforestation will continue at locally optimal levels, or to the extent labor and capital constraints allow. Thus, if and when international accords to limit deforestation take place, the 'initial conditions' (i.e. forest stock and deforestation rates) will be different. Further, if the system ever did achieve a steady state, could an exogenous shock send it off to a different equilibrium? Rainfall or weather patterns may change exogenously, increasing or decreasing the rate of forest regeneration. Exogenous economic forces may increase or decrease demand for goods requiring deforestation, and political change may influence the ability of the state to limit deforestation. Therefore, one must determine whether the steady states so far analyzed are globally optimal or locally optimal, and if the latter, under what range of initial conditions do they hold?

Figure 15 shows the optimal time path for forest stock from initial forest stocks corresponding to 26%, 60% and 90% of the original forest, under the optimistic ecological assumptions at the national level. All initial values lead to time paths that converge on the same steady state forest stock over the long term. Thus, it is obvious that if not globally optimal, the steady state forest stock is at least locally optimal for a wide range of initial values. Note that this does not necessarily support the phase plane analysis seen in Figure 4 in Chapter Three. There it was found that when in a steady state, a shock which increases the deforestation rate (pushing the forest stock/deforestation rate into quadrant IV) may lead to increasing rates of deforestation and decreasing forest stock. A decrease in the rate of deforestation (pushing the forest shock into quadrant II) may lead to further decreases and an increase in forest stock. However, in the discrete time model as solved by GAMS, the steady state proved stable in all directions for interior solutions. There are several possible explanations for this. Forcing the GAMS model into a steady state at time T may change dynamics; discrete time models often have different dynamics than continuous time models, and the time paths in quadrant IV of Figure 4 lead to solutions involving imaginary numbers, not allowed in the GAMS model.

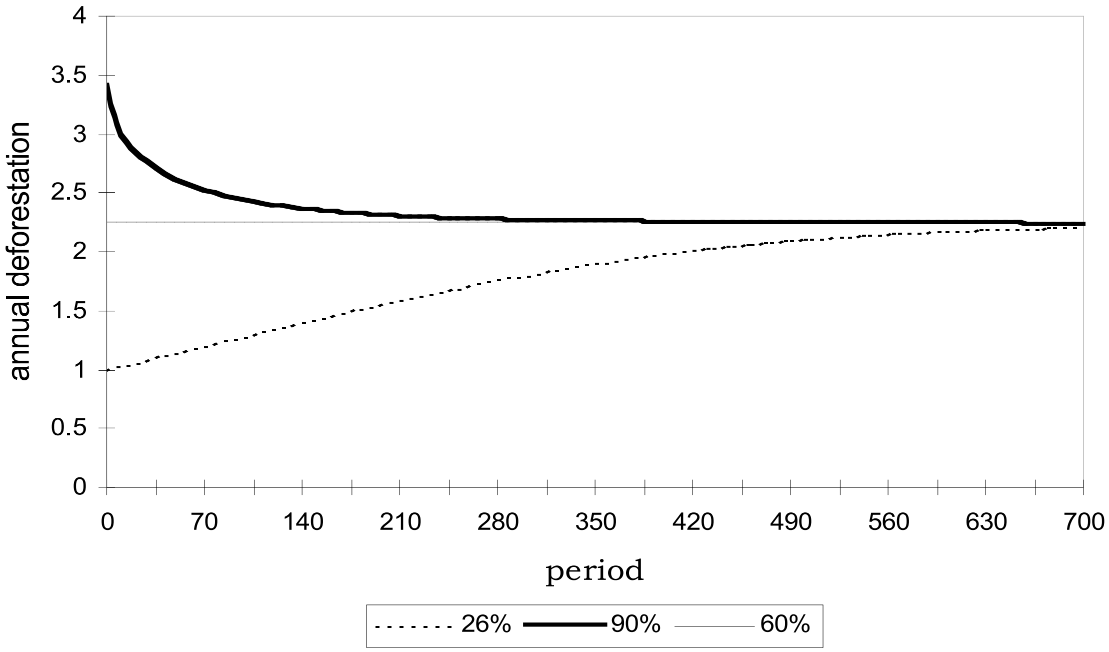


Figure 15: The optimal time path of forest stock (million km^2) at the national level under optimistic assumptions, from various initial conditions for the area of forest stock at t=0.

For time paths asymptotically approaching the 'corner solution' of irreversible deforestation, the steady state is clearly not stable. The extremely low rate of regrowth at these levels of forest stock make external shocks leading to irreversibility and spontaneous degradation far more likely than those leading to increased forest stock. If forest stocks hover too near the sustainability threshold, the likelihood of an external shock forcing irreversibility is high.

Policy Impacts

The individual drives current deforestation rates in the Amazon, with some influence by local and national government. The individual will ignore negative externalities and public goods, and since the forest has many of the characteristics of an open access resource, his discount rate may be virtually infinite. Government policies are required to address these issues and bring individual deforestation rates in line with socially optimal rates.

While local government policies may have the greatest potential to curb deforestation, the model suggests that at the local level, deforestation still falls short of what is optimal, constrained by lack of labor and capital. Amazonino Mendes, governor of Amazônia, distributed 2000 chain saws to constituents as part of his election campaign. He is now offering valuable incentives to entice lumber companies from Pará, where many have exhausted harvestable timber in their region (Veja, 1995). This evidence clearly suggests that from the point of view of local government, current deforestation rates are lower than optimal rates: the labor and capital constraints of the model come into play at the local level. The local government has little incentive to slow deforestation without outside intervention. National government offered considerable subsidies to activities requiring deforestation (fiscal subsidies, colonization projects, road construction, etc.) through the 1980s, but more recently is showing concern for conservation and has eliminated most of these subsidies and incentives. The discrete time model also predicts this: previous deforestation rates were less than the nationally optimal level, and now may be approaching optimal levels. The discrete time model predicts that nationally optimal deforestation rates are falling rapidly, however, and the government should begin to actively intervene if actual rates are not to exceed nationally optimal rates.

Feasible policy options to curb deforestation will be discussed in the following chapter. It is useful here to examine the relative impact of changes in various variables that might be affected by policies. In particular, I will examine the impact of lowering discount rates, increasing the social valuation of the public good benefits, and improving agricultural technologies.

It is important to remember that, in the absence of state intervention, the individual determines deforestation rates. There are thus two critical problems: making local and national governments interested in conserving forest, and determining the appropriate policies allowing them to control the individuals engaged in deforestation.

Discount Rates

It is clear from the Figures 4-8 in Chapter Three that higher discount rates lead to lower steady state forest stocks, and Figures 10-11 above show that higher discount rates also increase the speed at which the steady state is reached. Figure 16 makes this relationship more explicit by showing the impact of different discount rates on the optimal time path of forest stock at the local level (i.e. with 0 valuation for the public good) under semi-optimistic assumptions.

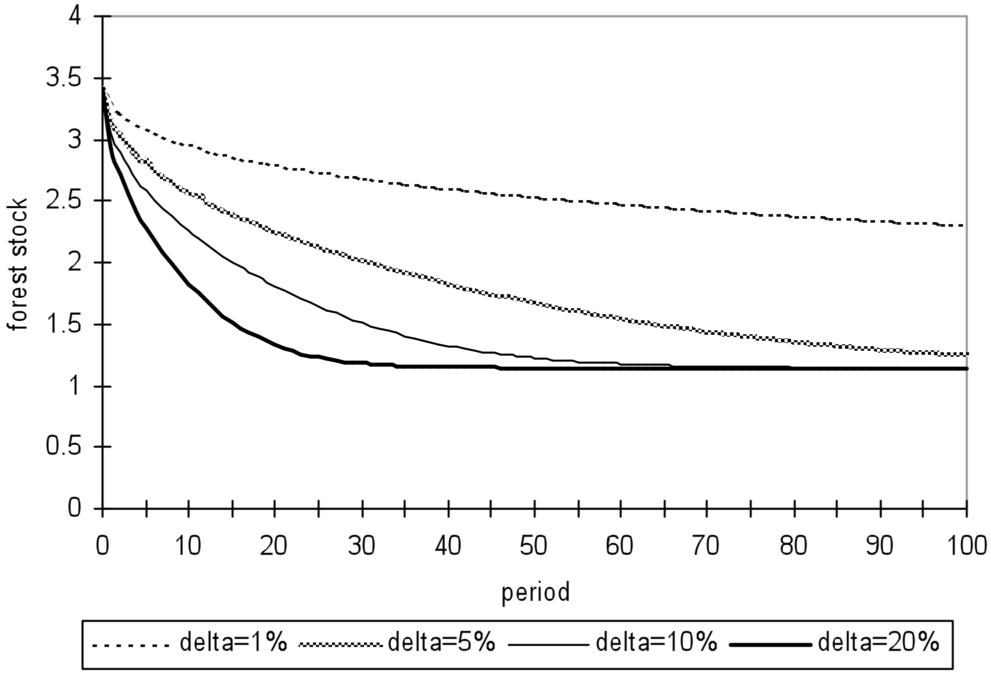


Figure 16: The optimal time path of forest stock (million km^2) for varying discount rates at the local level (i.e. v(S)=0) under semi-optimistic ecological assumptions

Lower discount rates reduce the rate of deforestation, as expected. Figure 9 in Chapter Three suggests that in the absence of public good values, even discount rates as low as 1% exclude interior steady state solutions for most reasonable values for p_1 and p_2. However, for sufficiently low discount rates, forest stocks may take several hundred years to approach the corner solution. Figure 16 suggests that the discount rate plays a larger role than ecological parameters in the time it takes to approach irreversible deforestation. At a 1% discount, after 300 years the forest stock remains safely above irreversible levels. At a 5% discount rate, it takes slightly over 100 years to reach irreversible levels, at a 10% rate slightly over 50 years, while at the 20% rate more likely to apply locally, forest stocks are dangerously close to irreversible depletion after only 25 years. For the parameter values analyzed here, halving the discount rate approximately doubles the time it takes to approach irreversibility.

Social Valuations of the Public Good

Increasing the social valuation of the public good has the same qualitative impact on the time path of forest stocks as decreasing the discount rate. Figure17a shows the impact on forest stock of varying social valuations of the public good under semi-optimistic assumptions at the national level, i.e. with a discount rate of 5%. Figure 17b shows the impact on annual deforestation. As would be expected, increasing the value for v(national) leads to initially higher forest stocks, though with high interest rates, the steady state forest stock remains the same. As compared to the case of no public good value, a public good value of $v(S)=1$ reduces the initial rate of deforestation by over 60%, increasing it to 2 reduces the rate an additional 50%, and increasing it to 4 reduces the rate again by over 60%. Gradually deforestation rates converge, but at dramatically different levels of forest stock.

Figure 17a

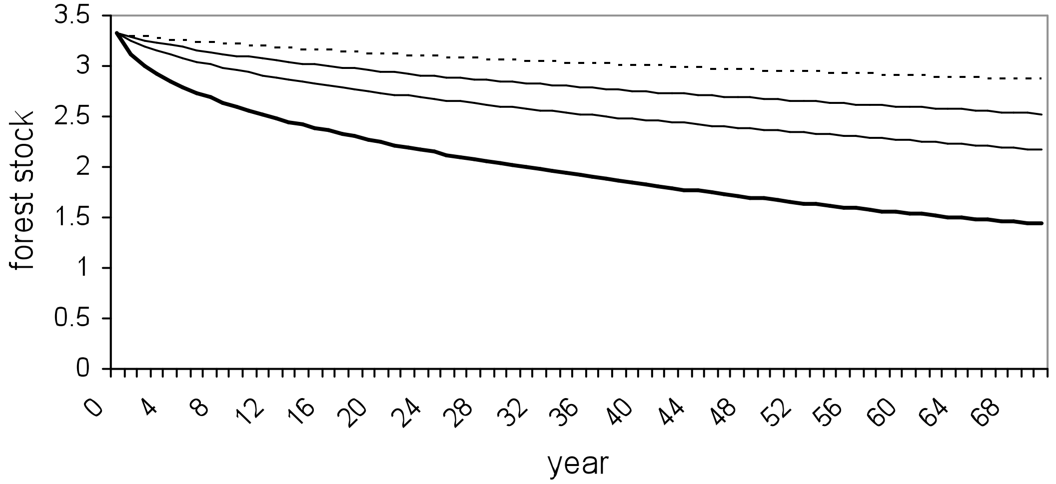
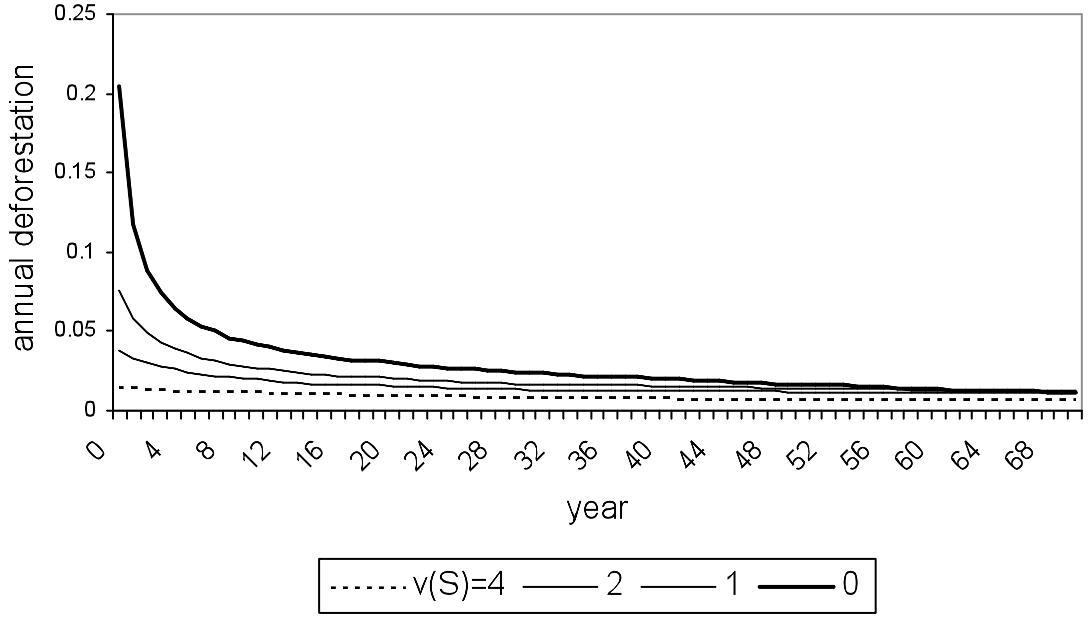


Figure 17b



Figures 17a-b: The optimal time paths of forest stock and annual deforestation (million km^2) for varying social valuations of the public good at the local level (i.e. δ=20%) under pessimistic ecological assumptions.

The Impact of Technological Change in Agriculture

In reality, it is likely that agricultural technology will improve in the Amazon over time.[35] Improved crops and crop management will increase yields. Organic and chemical fertilizers will decrease dependence on the fertilizer effect of annual ash from annual deforestation. Alternative crops and different technologies better adapted to the ecological changes resulting from cumulative deforestation may decrease the level of forest stock at which marginal returns to forest stock become negative.

In the problem presented in equations (70-74) such changes can be modeled by assuming an increase in α_2 and a decrease in α_1, such that both continue to add up to 1, i.e. returns to scale remain constant. Increasing α_2 implies that returns to cumulative deforestation increase and that the level of forest stock at which marginal agricultural output of cumulative deforestation reaches zero (i.e. p_1F_0) decreases. A decreasing α_1 implies that the fertilizer effect of ash from cumulative deforestation becomes less important.

Figure 18 shows the impact of different levels of technology on the forest stock at the local level. As the returns to cumulative deforestation increase, the initial deforestation rate increases as well to capture these returns. However, the reduced importance of annual deforestation quickly asserts itself. The less important annual deforestation is, the more quickly deforestation rates slow, so that in the medium run, forest

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[35] Though, as Norgaard (1981) points out, given the complexity of the ecosystem and our ignorance of it, the prospect for agriculture advancements which compensate for ecological damage is small. The article is worth reading for an insightful discussion of the nature of co-evolutionary development and the specific problems this presents in the Amazon.

stocks increase with technological change under this set of assumptions. In the long run, forest stocks still converge towards the irreversibility threshold.

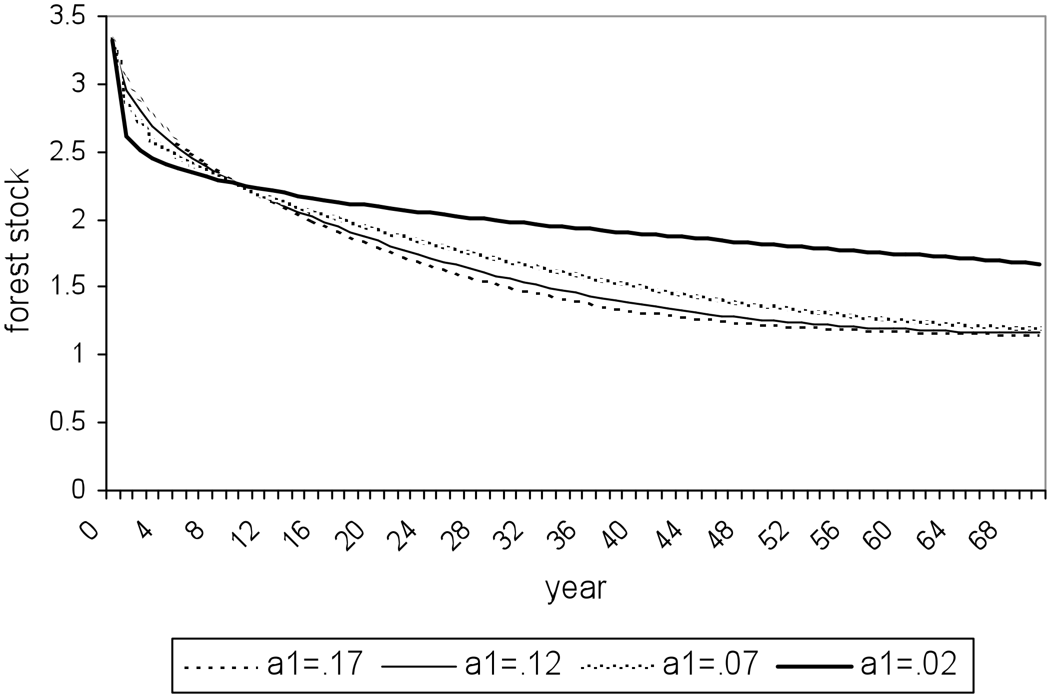

Figure 18: The optimal time paths of forest stock (million km²) with technological advances in agriculture at the local level (i.e. v(S)=0, δ=10%) semi-optimistic ecological assumptions.

In practice, initial rates of deforestation are likely to be constrained by labor and capital shortages, so that only the medium and long run impacts will be felt. When changes in technology are gradual, modeled by a 1.5% annual decrease in the value of a_1, the high discount rates prevalent at the local level overwhelm the impact of technological change, and the time paths of forest stock remain unchanged.

Qualitatively, the optimal time paths for forest stock under semi optimistic assumptions react the same to technological change for both local and national levels. Figure 19 shows the impact of different levels of technology on the forest stock at the international level (v(s)=4, δ=1%). The initial forest stock in the diagram is 3.2 million km^2, to clearly show that optimal steady state forest stocks are different for different technologies. The less the available technologies rely on deforestation, the greater the forest stock in steady state.

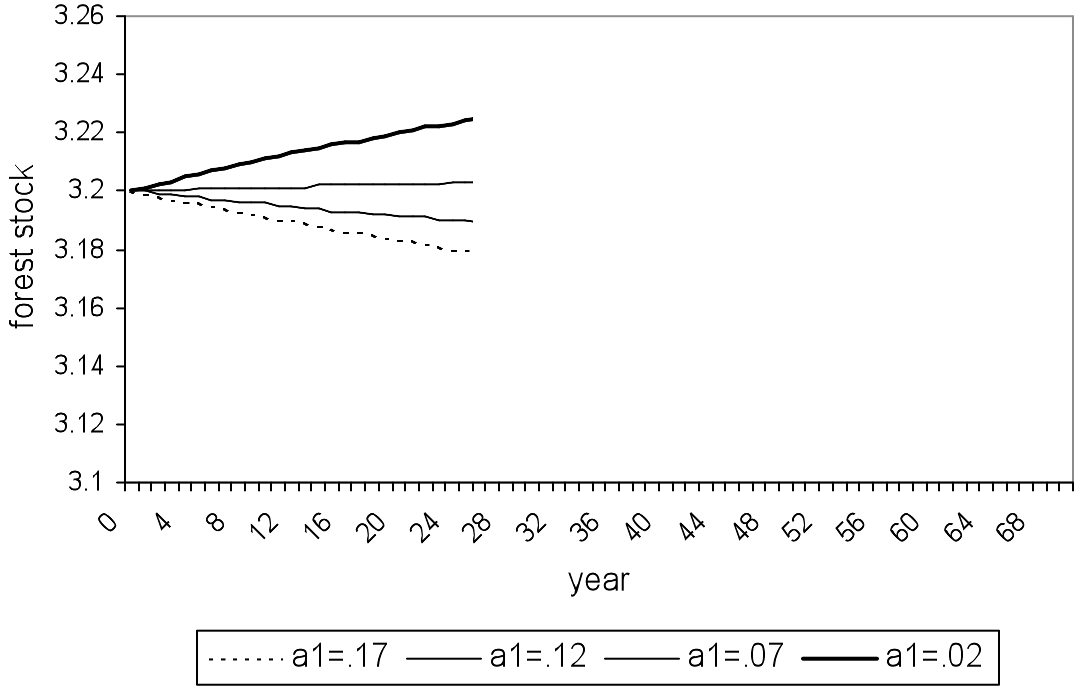

Figure 19: The optimal time paths of forest stock (million km^2) with technological advances in agriculture at the international level (i.e. v(S)=4, δ=1%) under semi-optimistic ecological assumptions.

Figure 20 shows the impact of different rates of continuous technological change at the national level under semi-optimistic assumptions. Change is modeled by a specified annual percentage decrease in a_1 while maintaining the constraint that $a_1 + a_2 = 1$. In the absence of technological advance, steady state forest stocks converge towards the irreversibility threshold. With technological advance, deforestation rates slow considerably in later periods, leading to noticeably higher forest stocks from year 50 onwards. Eventually, as annual deforestation contributes less and less to yields, forest stocks actually begin to increase.

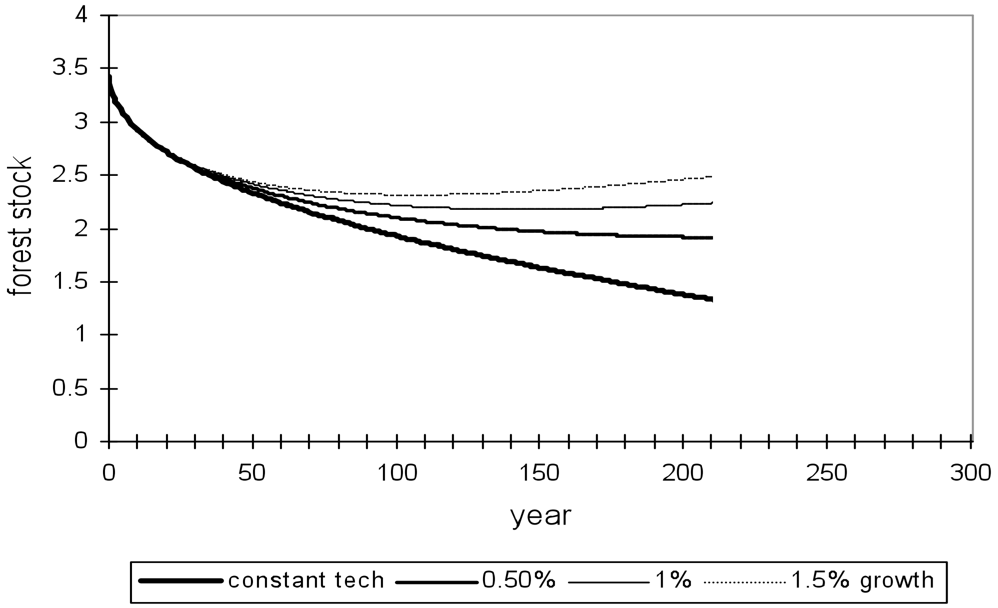

Figure 20: The optimal time paths of forest stock (million km^2) with annual technological advances in agriculture at the national level (i.e. $v(S)=2$, $\delta=5\%$) under semi-optimistic ecological assumptions

While this increase occurs only in the distant future, it is quite possible that exogenous ecological changes, such as global warming, ozone depletion, pollution, etc. can destabilize the Amazonian ecosystem, leading in the future to a risk of irreversibility at a higher level of forest stock than under present conditions. This would be less worrisome if forest stocks were increasing along with the threat of irreversibility.

The Characteristics of a Pigouvian Tax or Subsidy

In addition to providing the optimal time paths for deforestation rates and forests stocks, GAMS also provides the value of the shadow price of forest stock. As defined in Chapter Three, the shadow price of forest stock is not the forest stock's direct value, but rather the value of all its future productivity discounted to the current time. It is what society should be willing to pay to maintain an additional unit of land under forest cover at that time, i.e. it is the marginal social cost of deforestation. However, since the value to society of forest stock includes the public good benefits (defined to include negative externalities avoided by deforestation), and the market will not account for these, the 'market price' for deforestation will be less than the shadow price. In reality, the only direct cost of deforestation to the individual is typically that of labor and capital[36].

A Pigouvian tax [or subsidy] is a charge [or payment] per unit of forest stock deforested [or preserved] just equal to the shadow price, and would theoretically bring actual deforestation rates in line with optimal rates. Unfortunately, under current conditions in the Amazon, the plausibility of such a tax [or subsidy] is extremely limited. This will be discussed further in Chapter Five. It is still interesting to see what the characteristics of such a tax would be. Unfortunately, since it is so difficult to objectively value public good benefits of the Amazon in terms of dollars (or Reais -the current Brazilian currency) the GAMS trials can provide only qualitative information about the optimal time path of such a tax.

Figure 21 shows the optimal time path of a Pigouvian tax or subsidy on deforestation under semi-optimistic assumptions at the local, national and international levels.

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[36] Though the lumber industry must frequently pay landowners for timber rights, they rarely engage in clear-cutting, though often farmers or ranchers will clear-cut following timber extraction.

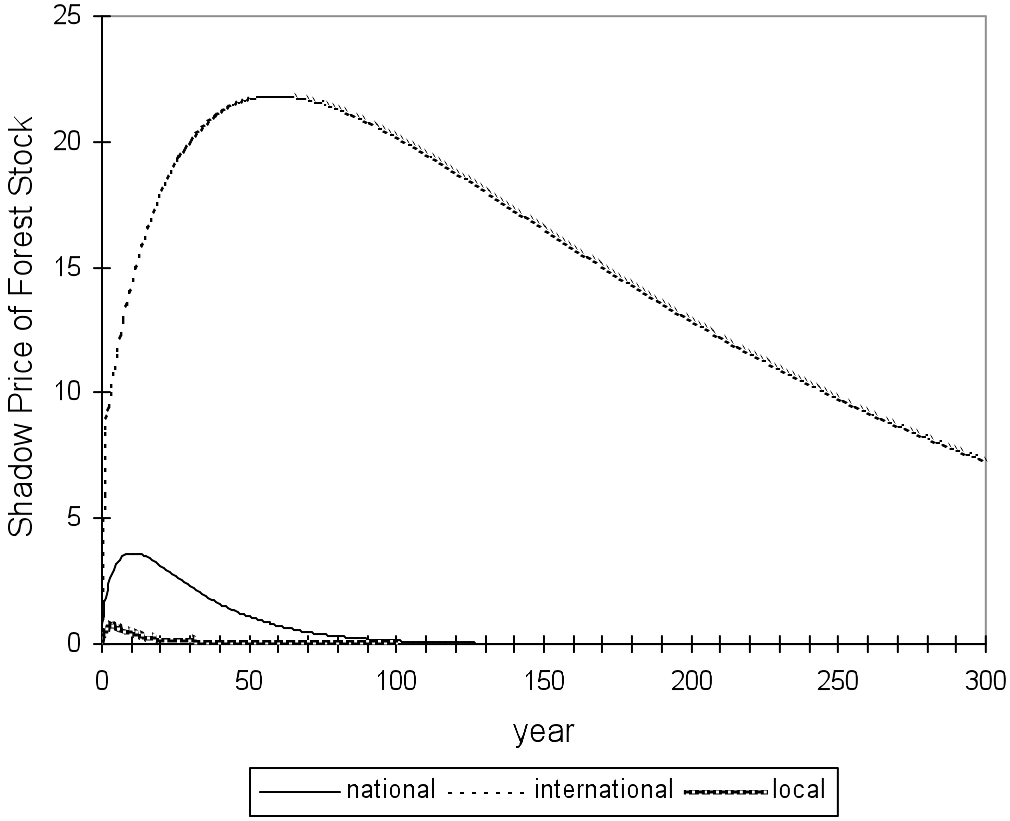

Figure 21: The optimal time paths of a Pigouvian tax or subsidy (i.e. the shadow price of forest stock) at the local, national and international levels, under semi-optimistic ecological assumptions.

As the definition of society decreases, so too does the necessary Pigouvian tax or subsidy. In all cases, the tax/subsidy is initially rising at a decreasing rate, until reaching p_1*F_0, the stock at which marginal returns to cumulative deforestation are zero. Beyond p_1*F_0, the optimal Pigouvian tax/subsidy falls. Below p_1*F_0, greater rates of deforestation enhance current period productivity both by the fertilizer affect of current period deforestation and by creating more agricultural land. However, the use of the transcendental production function means that the returns to annual deforestation are not as great as they would be if there were more cumulative deforestation. Hence, deforestation today robs the future of potentially greater gains from deforesting the same land in the future, and a tax/subsidy must reflect this cost. As cumulative deforestation increases (but remains below p_1*F_0), returns to annual deforestation increase, so the tax/subsidy must increase to keep deforestation at the optimal level. After reaching p_1*F_0, marginal returns to cumulative deforestation become negative, and the only benefit from current period deforestation is the fertilizer effect of the ash. With less incentive to deforest, the Pigouvian tax/subsidy begins to fall.

Unfortunately, the GAMS software required limits on D_t and F_t to function correctly, the former constrained to a minimum of .0001 and the latter to remain above p_2*F_0, as stated earlier. As forest stocks approach irreversible levels, the increase in utility from an incremental increase in forest stock is quite small, and hence the shadow price of forest stock is low. However, when forest stocks reach p_2*F_0, the shadow price of forest stock must be infinite, since agricultural output is zero at this level and hence its natural log is infinitely negative. However, GAMS requires the constraint $F_t > p_2F_0$, and can never show this infinitely negative shadow price. Therefore, one cannot be confident in the shadow price of forest stock GAMS provides as the model approaches a corner solution. Still, it appears that an optimal Pigouvian tax/subsidy should increase until reaching p_1*F_0, then begin to decrease.

Figure 22 shows the impact of different discount rates on the optimal Pigouvian tax at the local level. Since the Pigouvian tax should be set equal to the shadow price of forest stock (also known as marginal user cost) and this reflects all future value of that forest stock discounted to the current time, the Pigouvian tax must increase as discount rates decrease.

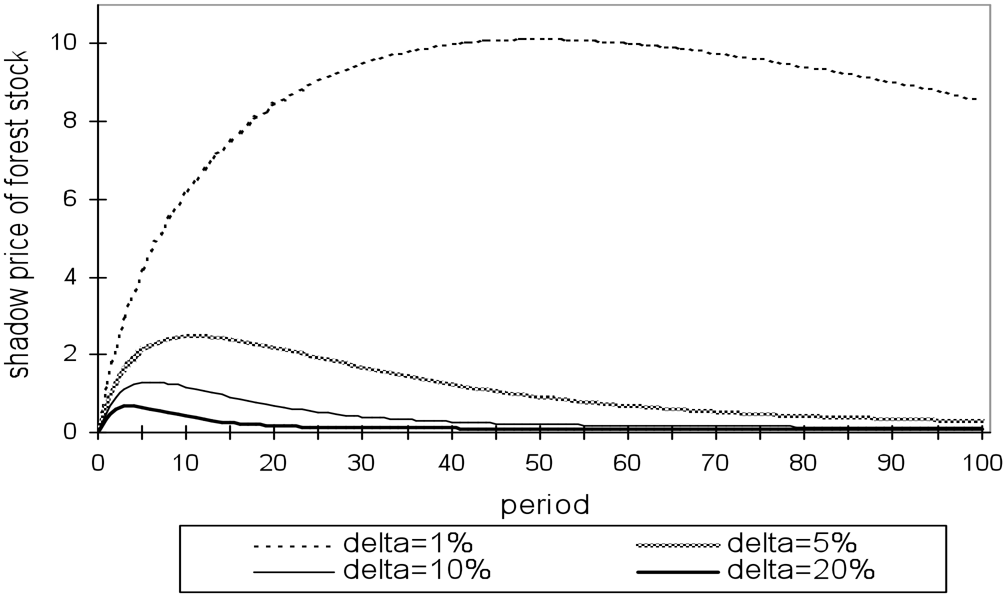

Figure 22: The optimal time paths of a Pigouvian tax (i.e. the shadow price of forest stock) at the local level under semi-optimistic ecological assumptions for varying discount rates.

This is clearly the case in Figure 22. The rule still holds however that the tax increases until reaching p_1*F_0 then begins to decrease.

Summary and Conclusions

Results from the GAMS analysis of the discrete time model corroborated the results of the Mathematica analysis of the continuous time model. The qualitative response to all parameter variations was the same, and the GAMS model showed time paths that appeared to asymptotically approach the steady state forest stocks found with Mathematica. By estimating optimal time paths of deforestation and forest stock, the GAMS model provided additional information useful to policy analysis.

Perhaps most important, GAMS analysis showed that under conditions likely to reign at the local level, deforestation will continue at a very high level until forest stocks are dangerously close to irreversible depletion. In fact, it may even be optimal for local governments to strive to increase the rate of deforestation by overcoming labor and capital constraints. The national government may still have a reasonable time frame for slowing deforestation without suffering sub-optimal returns to exploitation, but at the international level, economic losses may be quite high unless efforts are made to slow deforestation as quickly as possible. Even if the numbers used in this model are highly imprecise, the radical difference in optimal policies at the local and international levels suggests that international action should not be postponed while awaiting further research.

13) CHAPTER FIVE:
POLICY ANALYSIS

14) Introduction

Analysis so far is useful primarily to the extent it provides insights into the policy options available for addressing the problem of deforestation in the tropical forests of Brazil and the world. The goal of this chapter is to examine specific policies at the local, national and international levels that might help bring locally optimal rates of deforestation in line with globally optimal rates. The policies to be examined correspond to different variables of the models from previous chapters, which can help show the potential impact of such policies both in terms of how effective they might be, and how quickly their effects might be felt. The feasibility, effectiveness and affordability of these policies must also be considered so that they may be prioritized accordingly.

For any effective policy, two of the most critical factors are time and uncertainty. While frequently voiced fears that the forest may be totally eliminated within the next 50 years may be exaggerated, ecological degradation could easily threaten irreversible depletion of forest stocks within that time. The discrete time model of Chapter Four suggests that under pessimistic ecological assumptions, locally optimal deforestation may lead to forest stocks approaching a level below which they cannot regenerate (i.e. p_2F_0 in the model, referred to as the sustainability threshold), in less than fifty years. Even under the more realistic assumptions of labor and capital constraints, forest stocks could approach the sustainability threshold within 60 years if such constraints are relaxing at the rate of 2% per year and within 70 years even if constraints do not relax (see Figure 12a, Chapter Four). Unfortunately, there is little experience on which to base policies for slowing deforestation, and even if the correct policies are implemented, there may be a considerable lag between implementation and the desired results.[37] As the sustainability threshold is highly uncertain, a healthy degree of risk aversion suggests serious steps towards controlling deforestation must be made within the next thirty years if we are not to risk the potentially catastrophic loss of a unique ecosystem. Policies to be examined in this chapter will be evaluated according to their impact within this time frame.

15) Outline of the Chapter

First I will examine international policy options, which requires an analysis of Brazil's sovereignty, existing international agreements and the availability of resources. I focus primarily on two basic strategies: a mechanism for internalizing at the national level the international public good benefits of the Amazon and international funding for monitoring and enforcement of existing legislation. Second, I look at the issues affecting national and local policy options. This requires an examination of existing national legislation, institutions, and enforcement ability. I present several market-based policy options that theoretically could lower discount rates and increase the social valuation of the public good services supplied by intact rainforest. I also present research and extension options which can change the technologically influenced variables in the model. Third, I discuss direct,

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[37] For example, some policies may take time to fine tune (e.g. Pigouvian taxes or subsidies), while others (e.g. the research and development of appropriate technologies) mav take time to become effective.

non-market controls on deforestation, in particular a proposal for establishing conservation units over 40% of the Amazon to insure against crossing the sustainability threshold. For all policies, I estimate their cost and their likely impact on model parameters, and use the model to estimate potential outcomes. Finally, based on cost, impact, and implementation problems, I summarize and prioritize the policy options discussed in the chapter.

16) International Policy Options

This section will first examine existing international agreements. Next, I will provide rough estimates of the amount of international funding to slow deforestation that is justified by the public good services of the Amazon, followed by a discussion of the obstacles to providing these resources, and an example of a funding mechanism that might overcome some of these obstacles. I will then present the option of an international Pigouvian subsidy. In addition, national level policies presented later may only be viable with international support.

Existing Agreements

There have already been numerous international agreements that to at least some extent address the issue of deforestation in the Amazon. These include the 1978 Amazon Cooperation Treaty, the 1992 Convention on Biological Diversity, the FAO Tropical Forestry Action Plan, and “The non-legally binding authoritative statement of principles for a global consensus on the management, conservation, and sustainable development of all types of forests” (Adede, 1993). One of the few agreements that has sought to provide resources to slow deforestation is the Group of Seven’s "International Pilot Program to

Conserve the Brazilian Rain Forests" (PPG7). This program has promised US$1.6 billion (10% of which will be supplied by Brazil) (Secretaria de Coordenação dos Assuntos da Amazônia, 1997), over a number of years to be spent on "management of natural resources; establishment of Conservation Units (forest protection zones), of national forests and of extractive reserves; Demarcation of indigenous territories; Institutional Promotion and support for Demonstration Projects at grassroots level." (Deutsche Gesselschaft für Technische Zusammenarbeit (GTZ), 1997). In light of the substantial rates of deforestation in the 1990s, it would appear that these agreements have been highly ineffective.

Why have the existing agreements proven ineffective? The models in Chapters 2 and 4 (see Figures 5-9, Chapter Three for steady state solutions, and Figures 10-22, Chapter Four for optimal time paths) made it clear that there are profound differences between optimal deforestation rates and optimal steady state forest stocks at the local, national and international levels. One of the major factors contributing to these differences is the fact that Brazil and the local inhabitants of the Amazon receive only a small percentage of the benefits from intact rainforests, and have little reason to value the global public goods such rainforests provide. Brazil has no incentive to provide global public goods 'free of charge', and the global community cannot demand their provision. It is obvious that the international community must provide both incentives and resources to Brazil if it hopes to bring deforestation rates in line with its own societal objectives. While the PPG7 does offer some resources, I argue that the quantity offered is far less than what is necessary or justified.

Providing the Necessary Resources

The models of Chapters 2 and 4 suggest that the international community would benefit from helping conserve the Amazon even if costs were significant, but do not offer any cardinal values of the magnitude of expenditures that are justified. While most of the benefits from conservation cannot be readily valued in monetary terms, those that can be offer some idea of a minimum amount the international community should be willing to spend. As a concrete example of one service, Schneider (1995) estimates that current expenditures in developed countries on emissions reduction (e.g. a tax of $4950/100 tons CO2 in Sweden and the Netherlands, and $671 in Finland) equivalent to the carbon released from deforestation of one hectare of Amazonian rainforest are 4-50 times greater than the agricultural value of forest land on the Amazonian frontier (see Schneider, 1995, Annex E for additional details, and for a detailed comparison of land and carbon sequestration values). In a broader study of the valuation of some of the services provided by the earth's ecosystems, Costanza et. al. (1997) estimated that the 1,900 million hectares of tropical forest provide some $3.813 trillion dollars per year in benefits to the human economy, for a contribution of $2,007/hectare/year. Net of marketed goods (i.e. food production and raw materials), the estimated value of one hectare of rainforest is $1660. This implies that the external cost of current deforestation in the Amazon [approximately 2.9 million hectares in 1995, about 1.8 million hectares in 1996, and an estimated1.35 million hectares in 1997 (Instituto Nacional de Pesquisa Espacial (INPE), 1998)] is on the order of $3.3 billion/year. If the 10%-90% division of costs for the PPG7 reflects the division of public good benefits from the Amazon between Brazil and the world, then the international community should be better off paying Brazil any sum less than $1494 (i.e. 90% of $1660) annually to prevent deforestation of one hectare.

Since the value of agricultural land in the Amazon is less than the demonstrated willingness to pay for carbon sequestration and the estimated value of public good benefits from the Amazon, it should be Pareto improving simply to pay those who deforest not to. However, major obstacles confront such a swap or any transfer of resources in general.

First are the transaction costs involved, such as contract enforcement, contract facilitation (i.e. getting buyers and sellers together), determining whether land would be deforested in the absence of a payment, and threat making (i.e. "I'll deforest unless you pay me.") (see Schneider, 1995, Annex E for additional details.)

Second, the global community appears unwilling to provide substantial resources for combating deforestation. Several barriers to international payments for the provision of rainforest services exist. Many of the benefits of intact rainforests (and costs of deforestation) are affected by uncertainty. We are not certain that global warming is occurring, we do not fully understand how the Amazon forest affects global climates and weather, we do not know what future benefits the region's biodiversity will provide (i.e. quasi option value), and we do not know the forest stock below which the forest will not regenerate. Further, most people are unaware of the numerous ecological functions of rainforests, the services they provide, and their value, and hence are less willing to spend money for their conservation. Most of these services have no market and have traditionally been treated as free goods, making valuation extremely difficult. Another stubborn problem is that of providing public goods when free riding is an option. Finally, there is concern in most developed nations about national debts and deficits, the local environment, and numerous other pressing problems, combined with public pressure to cut taxes, and these issues typically take precedence over solving distant environmental problems.

Third, even if the international funds are raised, some mechanism must ensure that the resources are actually used to slow deforestation, overcoming the problems of a lack of knowledge about what is effective, and the inherent costs and difficulties in monitoring and enforcement. Developed nations will not supply money for slowing deforestation in the Amazon unless they can be relatively certain the money is effectively used towards that end. Fourth, Brazil clearly would not accept any policy that does not bring it benefits, nor any perceived to impinge on its sovereignty (Mcleary, 1991). In essence, the problem is to transfer resources in a manner acceptable to both the donors and Brazil that creates locally and nationally both the capacity and desire to slow deforestation, while making sure that the costs to the rest of the world do not exceed the gains. An international Pigouvian subsidy is presented below as a mechanism that meets these criteria.

The immediate problem is to convince the international community that providing the necessary resources to slow deforestation is Pareto improving. The international community has two options. First, it can delay action until sufficient uncertainties are resolved to make it clear that action is required or unnecessary, and the public is sufficiently educated on the topic to support the appropriate action. The problem is that one of the major uncertainties involves the level of deforestation the region can sustain without crossing the ecological threshold beyond which the forest enters into spontaneous decline. If we wait until this uncertainty is resolved, inherent irreversibility may make it too late to act. This suggests a second more prudent course of action based on the precautionary principle[38] (O'Riordan and Cameron, 1994): we act now to slow deforestation and reduce the risk of a possibly catastrophic loss in the future. Given the level of pure uncertainty concerning the potential impacts of deforestation in the Amazon, we cannot objectively quantify the costs of delay to compare with the costs of acting too early, but it is precisely this uncertainty that puts a premium on precaution. On the ethical assumption that we should not risk catastrophic losses for future generations, analysis will use pessimistic assumptions regarding the sustainability threshold of forest stock and the proportion of remaining forest stock below which increased deforestation reduces agricultural output.

Once the international community has been convinced that action is appropriate, a final obstacle is how to determine an equitable mechanism for generating the necessary funds on an international level. Existing international agreements such as the Montreal Protocol for Ozone depletion (French, 1992) show that the problem of free-riding is not an insurmountable obstacle once the severity of a problem is recognized.

The Gas Tax Option

One means of providing the resources for slowing deforestation in the Amazon (and elsewhere) would be a green tax on gasoline

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[38] The six basic tenets of the precautionary principle are: 1) preventative anticipation (i.e. we start to act before we have scientific certainty about likely damage, if further delay could lead to catastrophe); 2) safeguarding of ecological space; 3) proportionality of response or cost-effectiveness of margins of error; 4) duty of care, or onus of proof on those who propose change; 5) promoting the cause of intrinsic natural rights; 6) paying for past ecological debt (from O'Riordan and Cameron, 1994).

consumption in the developed countries. Gasoline taxes already exist in all these countries (ranging from an average of $18.1 federal tax and even higher state taxes in the United States (LA Mid-Continent Oil and Gas Association, 1997) to the $3.00 per gallon range in some European countries), so little new administrative structure would be necessary at the national levels. An equal tax across countries would eliminate the problem of determining how much each country should contribute to slowing deforestation, and would simultaneously reduce greenhouse gas emissions and other pollutants.

How much money would such a tax generate? The most recent federal gasoline tax increase was $.043 per gallon, and was implemented in 1993 to help reduce the federal deficit. Krupnick, et.al. (1993) estimate that such a tax would reduce gasoline consumption by 1.9% in the U.S., and probably less so in other countries, where it would represent a much lower percentage increase in the cost of gasoline. In 1994, gasoline consumption in the developed nations[39] totaled nearly 500 million gallons per day (Energy Information Administration, 1995). Assuming a 2% drop in consumption caused by the tax, the revenue from a $.018 per gallon gas tax would still provide some US$ 3.3 billion per year, approximately equal to Costanza et. al.'s (1997) estimate for the value of public goods lost from current deforestation in the Amazon.

Such a tax is only one option for financing forest preservation in the Amazon. It does however provide a yardstick against which to measure expenditures from potential policy options. For the policies

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[39] the United States, Canada, the European Economic Community, the Scandinavian countries, Switzerland, Japan and Australia

discussed below, I will calculate the per gallon tax on developed country gasoline production required to finance them. I will discuss the political feasibility of the resulting tax in the conclusion.

The International Pigouvian Subsidy Option

A Pigouvian subsidy[40] for reducing deforestation addresses many of the obstacles listed above, and theoretically could do so in an economically efficient manner. Of course, for optimal (i.e. efficient) results, internalizing the public good value of the rainforest requires knowing the marginal cost and benefit curves of conservation measures, and the marginal benefit curve is itself a function of the level of society under consideration. In reality, such values are virtually impossible to objectively estimate. Thus, while Chapter Four briefly defines Pigouvian taxes and subsidies, and draws some conclusions as to the theoretically optimal time path they should follow (Figures 21-22), in practice one cannot realistically strive to 'optimize' deforestation levels. Two basic options are available for determining the level of a Pigouvian tax. Policy makers could try to set the tax equal to the estimated marginal value of international public good benefits provided by the Amazon. Alternatively, policy makers could determine the maximum allowable rate of deforestation (MARD) based on economic and ecological considerations, and set the subsidy at a level that would lead to this outcome. The latter option would undoubtedly require considerable

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[40] A Pigouvian tax would theoretically achieve the same result as a subsidy, but it would of course be impossible for the global community to tax Brazil. In the case of pollution control, a tax is preferable to a subsidy, since a subsidy can lead to the entrance of more firms hoping to receive the subsidy for reducing pollution (Baumol and Oates, 1988). In the case of a subsidy for slowing deforestation, more 'firms' entering is not a problem: if a country plants trees in order to receive a subsidy for not cutting them down, it would be welcome.

trial and error. Given the difficulty in estimating the marginal public good value of the Amazon, a Pigouvian subsidy is unlikely to be efficient, but it should at least be cost effective (Baumol and Oates, 1990).

How would such a subsidy work? International society would have to pay Brazil for reducing the rate of deforestation. This obviously requires that some baseline level of deforestation is estimated- either a simple average of deforestation over the past several years or a more sophisticated model including variables such as rainfall and economic growth[41]. For example, the most recent available three year average of deforestation rates in the Amazon is in the range of 2 million hectares per year (average of 1995-1997, INPE, 1998). The international community could pay a given amount for every hectare deforestation falls short of 2 million. If too much deforestation still occurs, the subsidy can be raised, while if the subsidy is too costly, it can be decreased. Deforesting the full 2 million hectares would forego all subsidies, but there still would be no incentive to deforest beyond this point, since there is no incentive to do so in the absence of the subsidy[42]. Theoretically, local or national government would limit deforestation until the perceived added marginal cost of doing so (monitoring, enforcement, lost revenue from not developing, etc.) is

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[41] Alexander Pfaff at Columbia University and Eustáquio Reis at IPEA (Instituto de Pesquisa Economica Aplicada) in Rio de Janeiro, Brazil, have both worked on models of this type.

[42] The only incentive to do so might be threat making to increase the quantity of the subsidy, but this would be highly risky. If the subsidy did not work, it might simply be abandoned. Also, since the subsidy would be paid to the government, and it is the private sector that engages in deforestation, the government might actually have to subsidize deforestation to increase it.

equal to the marginal value of the subsidy plus the perceived marginal national public good value of conserving the Amazon[43].

There are several features that contribute towards the feasibility of an international Pigouvian subsidy. First, transaction costs are minimized. Increasingly inexpensive satellite photos are capable of providing increasingly accurate estimates of annual deforestation so monitoring costs would be small (Almeida and Uhl, 1995b). While interpretation of photos may not be an exact science, computer analysis can at least make it a consistent one, in which case quantitative precision is unnecessary. A subsidy can thus reflect the amount of forest preserved, though an exact dollars per hectare figure for the subsidy may not be accurate. Nor would it be necessary at the international level to pinpoint who is deforesting. Enforcement and accountability are not major problems, since funds would only be dispersed after conservation occurs; if deforestation is not slowed, no money is spent. However, once disbursed the subsidy could be spent as Brazil pleased, and this lack of complete accountability may not sit well with the international sponsors of the subsidy. The sovereignty issue would be insignificant, since Brazil would be under no obligations to change behavior. Finally, a subsidy could provide both the incentive and resources for local and national governments to slow deforestation. Of course, the Brazilian government would still be responsible for developing policies to slow deforestation, potentially using some of the options discussed in the next section.

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[43] In reality, of course, the initial subsidy value would depend on the degree of concern and the economic and political constraints on the participants in an accord, but could be adjusted if it did not preserve an acceptable amount of forest. Though such adjustments theoretically cause inefficiencies, it is doubtful their impact would be greater than typical upheavals in Brazil's often chaotic economy.

Analysis of the discrete time model can give some idea of the potential costs and impacts of an international Pigouvian subsidy. For this and subsequent analyses, I assume that labor and capital constraints limit deforestation to a maximum of two million hectares/year (the average from 1995-1997). Also, as stated above, I will use pessimistic assumptions: i.e. p_1 (the proportion of remaining forest stock below which the marginal output of cumulative deforestation becomes negative) = 0.82 and p_2 (the proportion of remaining forest stock beyond which deforestation becomes irreversible) = 0.6. The subsidy will be paid on the difference between current deforestation and the nationally optimal level of deforestation, which will vary according to the size of the subsidy. Since primarily local interests control deforestation rates, they may already be excessive from the national point of view, but not yet worth expending scant national resources on lowering them. Part of the subsidy will therefore supply the resources necessary to simply lower the deforestation rate to the current nationally 'optimal' level (if it is indeed below the actual level), and part will provide both resources and incentives to lower it further.

Since the monetary value of the public good benefits of the Amazon is so difficult to objectively estimate, it is equally difficult to determine what impact a subsidy will have on the social valuation of the public good. Determining an appropriate subsidy will almost certainly require trial and error. An effective subsidy must provide the resources and incentives necessary to slow deforestation, yet cannot be higher than what the developed nations prove willing to pay. A lower limit might be between \$31 and \$90/ha, or the estimated net returns to cattle and agricultural production respectively in Paragominas county, Pará. Unfortunately, because of the transaction costs discussed above (e.g. threat making), it would be highly impractical to simply pay individuals not to deforest, and an effective Pigouvian subsidy might need to be greater than returns to deforestation. An upper limit would be the $1494/ha estimated by Costanza et. al. (1997) as the global public good benefits of the intact rainforest. A mid-range option is also worth examining. For the sake of discussion I will assume that a $31/ha/year subsidy corresponds to a public good value of 2, a $90 subsidy to one of 3, a $750 subsidy to one of 7, and $1494 subsidy to one of 10. While the only realistic means to determine the actual impact of each subsidy and hence the payment required would be by actually implementing one, these assumptions can give some idea of what the impact of raising the subsidy would be on both the rate of deforestation and the total cost. Table 2 shows the results derived from the discrete time model under these assumptions and Figures 23a-b show the time paths for forest stock and deforestation in the presence of various levels of an international Pigouvian subsidy over thirty years.

For any of these subsidy levels, the nationally optimal steady state forest stock will still eventually converge towards the ecological threshold, though very slowly. Nationally optimal deforestation rates will decrease because of the subsidy, but locally optimal rates will initially remain at the maximum allowed by labor and capital constraints (assumed to be 0.02 million km^2). The subsidy will reach a maximum when forest stocks reach 263 million hectares, then decline towards zero. This occurs because at a 5% discount rate, the steady state stock is the same for any of these subsidy levels.

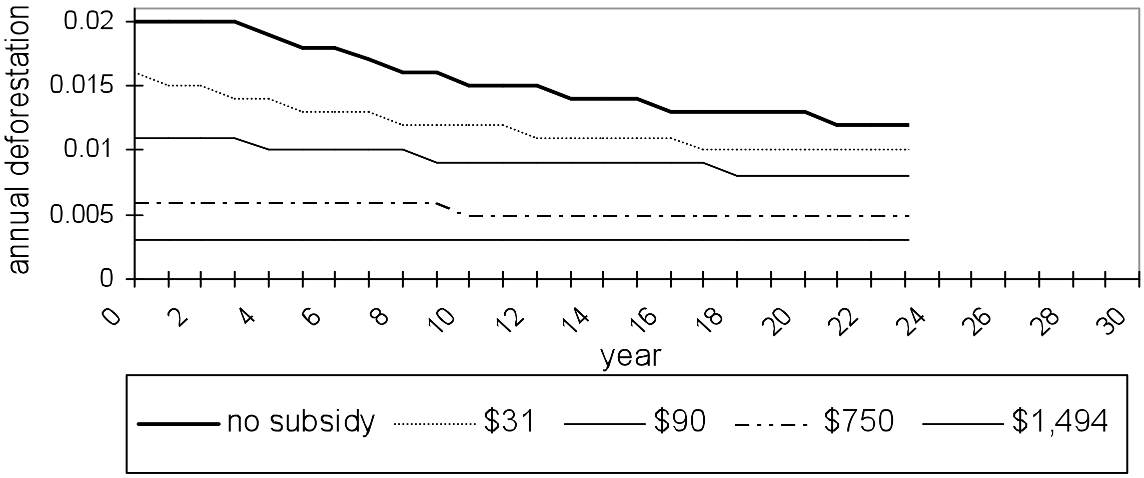
While this analysis gives some idea of the costs of a Pigouvian subsidy, and a basic idea of how costs will change over time, trial and error will be required to see how much deforestation responds to different subsidies. The most politically feasible policy would probably be to start with a Pigouvian subsidy at the low end of this range, then increase it as necessary. At the high end of the range, the subsidy could potentially be greater than the value of all existing exports from the Amazon, approximately $2.5 billion in 1995 (IPEA, 1997). If this were the case, Brazil could afford to implement policies promoting conservation just as it currently promotes exports.

Table 2: Estimated cost and impact of various levels of an International Pigouvian subsidy for reducing deforestation in the Amazon.

Per hectare subsidy	Initial de-forestation (a)	forest stock in 30 years (a)	cost in year one (b); (c)	maximum likely subsidy (b); (d)	maximum possible subsidy (b); (e)
$0	2	288.4	0	0	0
$31	1.6	305.0	12.4	43.4	62
$90	1.1	311.8	81	135	180
$750	0.6	322.6	1005	1275	1500
$1494	0.3	328.5	2540	2689	2988

a) in millions of hectares per year
b) in millions of dollars per year
c) calculated as the difference between current deforestation and expected deforestation after implementation of the Pigouvian subsidy.
d) the maximum subsidy that would be required according to the discrete time model if the subsidy changed public good values as suggested above. This payment would be required when the labor/capital constraint seizes to bind (according to the model), which under the assumptions here occurs when forest stocks reach 263 million hectares.
e) the payment that would be required in the highly unlikely event that all deforestation ceased after implementation of the subsidy.

Figure 23b



Figures 23a-b: The optimal time paths of forest stock and annual deforestation (million km^2*) at the national level with different levels of an international Pigouvian subsidy (see text for details on parameters).*

There are several serious problems that would have to be overcome in order to institute a Pigouvian subsidy. First, it is highly unlikely in the short run that the international community will provide the level of funding necessary to make a Pigouvian subsidy work. Second, much of the money would undoubtedly be siphoned off by corruption, even though the money would only be paid if deforestation were slowed. In any case, of course, the subsidy will only work if Brazil can implement the policies necessary to slow deforestation, and Brazil will only do so if the subsidy is worthwhile. Even then, it is not at all clear that Brazil has the ability at the national level to slow deforestation. Some policies Brazil might pursue are analyzed below. I will return to a discussion of the feasibility of Pigouvian subsidies and other policies after these national policy options have been reviewed.

17) National Policy Options

While the transfer of resources from developed countries is almost certainly necessary for slowing deforestation, it will not be sufficient. This section will outline policy options that can be implemented with the money made available through international transfers.

Existing National Legislation and Institutional Capacity

Modern national policy regarding deforestation can be roughly divided into two phases. During the 60s, 70s and early 80s, both national and state governments actively pursued development of the Amazon region through road building, subsidies and other incentives, and deforestation was considered a necessary first step (Mahar, 1989). The economic and ecological problems resulting from these strategies, helped by an increased understanding of and concern for rainforest ecosystems, brought national and international pressure on Brazil to protect the Amazonian ecosystem. Since 1988, increasing legal (and to a lesser extent financial) resources have been devoted to slowing deforestation in the Amazon (Vieira, 1993), with little apparent success.

The initial reaction against the government sponsored deforestation of the Amazon is evident in the Brazilian constitution of 1988 and the subsequent Nossa Natureza (Our Nature) program of the same year, which, along with other laws and decrees, provided the Amazon with substantial legal protection. Under the constitution, Brazilian citizens are guaranteed the right to live in an ecologically balanced area, and by law private property must be used in a socially responsible way. Civil and criminal sanctions apply to those responsible for damaging the environment, including strict liability, where the responsible party must pay to correct environmental damages. It is the duty of public power to defend the environment, which includes establishing protected areas and ensuring protection of biodiversity. Public officials who fail to carry out measures to halt illicit acts are theoretically even subject to penalties. The constitution also gives the right to states to impose additional environmental legislation, and both state and federal laws must allow a given forest activity for it to be legal (Vieira, 1993; Rehbinder, 1993; Machado, 1993).

The apparent results of the new constitution and the Nossa Natureza program were heartening: deforestation slowed significantly beginning around 1989. It is likely, however, that factors other than legislation played a major role. Possible influences were unusually high rainfall and economic recession (Keck, 1991). Attesting to the inadequacy of these legal measures, with economic reform and renewed growth in 1995, accompanied by low rainfall, deforestation rates soared to record levels (INPE, 1998).

The Brazilian government has responded to the recent increase in deforestation rates with a spate of new policies. A recent policy manifesto, the Integrated National Policy for the Legal Amazon, while notably pro-development, recognizes both the public good benefits of the Amazon and the negative externalities of deforestation. This policy emphasizes the need to secure stable access to the land, provide credit, prioritize research and provide extension services, retain the profits from exploitation within the region and distribute them equitably. In addition, the policy accepts the need for international resources and recognizes ethical obligations to future generations (Ministério do Meio Ambiente, dos Recursos Hídricos e da Amazônia Legal (MMA), 1997).

More recently, President Cardoso has passed several decrees, including: a suspension of logging of Mahogany and Virola for two years, a maximum limit of 20% clearing of forested properties, no additional deforestation allowed on properties with already existing non-productive deforested areas, and suspension of all concessions for forest use when the conditions of concession are not met. (IBAMA, 1996). In a separate initiative, Cardoso has signed the Protocolo Verde (green protocol) which promises to change lending policies to make sure that government supplied credit and potentially private credit does not cause adverse environmental impacts (Ussach, 1996). Just this year (February, 1998) Cardoso signed into law a new bill which attempts to limit deforestation in the Amazon. Among other measures, the bill bars new settlements in virgin forest, ends the granting of land titles on land cleared without authorization, increases credit to small farmers to provide them with alternatives to slash and burn agriculture, restricts credit in areas covered with virgin forest, and establishes fines and prison sentences for infractions of environmental laws (The Associated Press, March 14, 1998). Most recently, in April 1998, President Cardoso committed the country to tripling the area of federal conservation units in the Amazon to 10% of the region (United Press International, April 29, 1998).

While it is still too early to determine the outcome of the most recent policy initiatives, it seems unlikely that alone they will significantly reduce deforestation. For many years both policy guidelines and legislation have appeared to be adequate for rational exploitation of the Amazon, so continuing high rates of deforestation must be explained elsewhere.

The enforcement capacity of existing institutions[44] is decidedly weak, though recently signed laws have helped strengthen it (United Press International, April 29, 1998). In 1995 IBAMA had only 82 officials responsible for monitoring and enforcing federal environmental policy in the legal Amazon (Veja, 1995), and in 1996 only 650 agents, 120 vehicles, 30 boats, 300 flight hours and a $6 million budget (IBAMA, 1996). Legislation goes unenforced- for example, IBAMA estimates that only 1% of those burning in the Amazon during 1995 actually acquired the necessary license.[45] (Veja, 1995). Another

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[44] A partial list of existing institutions includes IBAMA (the Brazilian Institute for Renewable Resources and the Environment) the federal institution primarily responsible for environmental legislation. INPA (the National iInstitute for Amazonian Research) is responsible for research, and INPE (the National Institute for Space Research) for satellite monitoring of deforestation. FUNAI protects Indian rights, INCRA (the National Institute for Agrarian Reform) surveys colonization areas and distributes land titles, ELECTRONORTE (Northern Brazil Electricity Board) plans energy use, SUDAM (the Superintendency for the Development of the Amazon) promotes development and the Bank of Amazonia provides credit. The presidential cabinet includes a national minister of the environment (Uhl, Bezerra, & Martini, 1992).

[45] Acquiring a permit to burn is a difficult and lengthy process. First, the farmer

problem is that in Brazil, law and institutions are not the main instruments of social control, but rather clientele relationships dominate, making additional legislation of little use (Rehbinder, 1993). Finally, more pressing social and economic problems absorb government attention: environmental issues apparently take a back seat to inflation, unemployment, poverty, land reform, federal deficits, etc. It is clear then that while legislation exists to control deforestation in Brazil, resources, institutional strength and the political will necessary to enforce it are lacking.

All of this suggests a joint national-international policy option for slowing deforestation in the Amazon. The international community could simply finance efforts to enforce existing legislation in Brazil, which alone could bring about a substantial reduction in deforestation. There are however problems with this approach.

Many of the environmental decrees and much of the legislation in Brazil may stem largely from a desire to appease the national environmentalist constituency and the international community. It is quite possible that all existing policies would not have been written into law if there were any suspicion they might one day be enforced. Even if Brazil could enforce these policies at no cost (i.e. if the international community paid for enforcement) it might not be in Brazil's best interests to do so. Brazil will still account for only the national public

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Second, the farmer has to register the 50% (now 80%) of his land that must be preserved as forest by law, a process which costs up to nearly $500, a fortune for a small farmer. Third, the farmer has to travel to the state capital to get three more licenses from the state environmental institute. Fourth, the farmer must publish details of the license in the state newspaper, and finally he must visit IBAMA and pay an additional sum for the actual license. Even IBAMA's division chief for monitoring and enforcement in the Amazon admits the process is impossible. (Veja, 1995) good benefits of the forest, and these are unlikely to justify slowing deforestation to internationally optimal levels.

Further, some of Brazil's environmental legislation could impose very high costs on the inhabitants of the Amazon. For example, if the policy that landowners must obtain a permit to burn were followed, almost no burning would occur, since even IBAMA admits that under few circumstances does the cost and effort involved in obtaining a permit justify the returns (Veja, 1995). If this policy were enforced, it could seriously disrupt the local economy and lead to severe hardship.

Finally, financing all existing environmental legislation in Brazil could be quite expensive. Monitoring and enforcement of legislation in an area the size of Western Europe with limited infrastructure is a daunting task. As mentioned above, the current (1996) $6 million budget brought only 1% compliance with the policy regarding burning permits. Enforcing total compliance with all legislation could potentially cost hundreds of millions annually. Not only would the international community balk at this type of expenditure, the resulting level of enforcement may not be politically acceptable in Brazil. A more reasonable goal might be to increase the 1996 budget five to ten-fold. An international contribution in the range of $30- $60 million per year should be more feasible at both the international and national levels.

Hence, while international payments to finance existing environmental legislation is unlikely to lead to 'optimal' outcomes, it is quite likely to reduce deforestation. Brazil logically will balance the marginal benefits of slowing deforestation with the marginal costs. Lower costs will justify more conservation.

National Level Policy Options for Controlling Deforestation

The models of previous chapters suggest at least three policy goals that could help to substantially slow deforestation in the Amazon via market mechanisms. The first is to lower discount rates, the second is to internalize the public good value of the Amazon, and the third is to develop and disseminate new technologies less reliant on deforestation, or less destructive of ecological functions. Various policies that could theoretically achieve these goals are examined here in terms of feasibility, efficacy and cost.

18) Lowering Discount Rates

The lower the discount rate, the greater the weight of future income in economic decision making. Since non-sustainable activities have low or zero future income by definition, these will be seen as less reasonable alternatives as discount rates fall. In the theoretical models of previous chapters, the discount rate was one of the most important variables in determining both the rate of deforestation and the forest stock in the steady state. As explained in Chapter Three, discount rates for individuals in the Amazon are likely to be particularly high for a number of reasons. First, the opportunity cost of money, for which the interest rate on loans is typically used as a proxy measure, can be very high (Schneider, 1995). Second, the region suffers from considerable poverty, and the poor are likely to show a decided time preference for current consumption over future consumption. Third, land tenure for many of the inhabitants is highly insecure, and people discount the future value of their land by the likelihood of its loss. In what follows, I will present policies that could potentially address these problems.

19) Lowering Interest Rates

Studies consistently show that most farmers in the Amazon engage in slash and burn farming, rapidly depleting soil nutrients, then abandon the land or turn it over to pasture. Ranchers often overstock, and quickly exhaust pastures (Fearnside, 1989;Hecht, Norgaard and Possio, 1988). The lumber industry takes only the most valuable trees, using destructive harvesting techniques, and does virtually nothing to facilitate re-growth (Veríssimo et. al., 1992). Yet studies in the Paragominas region show that more sustainable agropastoral and timber harvesting techniques are potentially far more profitable in the long run (Almeida and Uhl, 1995a; see table 3 below) and create more employment and more tax revenue. Unfortunately, these more sustainable alternatives require greater initial investments. Given the choice between unsustainable mining of the soil for initially high but rapidly falling returns, or more sustainable production that requires large initial investments or has lower initial returns, higher interest rates make the individual more likely to choose the former option[46] (see Schneider, 1995, for a detailed discussion and graphical analysis).

Table 3: Gross returns, profit, taxes, initial capital and jobs created for various land use alternatives in Paragominas, Pará. (From Almeida and Uhl, 1995a)

	gross returns /ha/yr.	profit /ha/yr.	taxes /ha/yr.	initial capital/ha	ha/job created
slash-burn	$90	$33	$15	$24	16

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[46] In areas such as Paragominas, higher land prices have favored more intensive production. However, in the absence of credit at reasonable rates of interest, ranchers typically pay for investments by selling timber rights to their forested lands. More sustainable ranching thus comes at the expense of forest degradation from logging (Almeida and Uhl, 1994).

agriculture					
intensive agriculture	$2,366	$802	$367	$2,695	1.4
extensive ranching	$27-$31	$2-$6	$5	$307	29
intensive ranching	$104	$55	$18	$539	29
unmanaged logging	$31	$11	$4	$27	573
managed logging	$92	$28	$11	$83	166

The question is, would simply lowering interest rates also lower the discount rate? To the extent that interest rates are a measure of the opportunity cost of capital, and to the extent that the opportunity cost of capital determines discount rates relative to time preference for consumption, theoretically it should. However, it is completely unfeasible to infuse as much subsidized capital into the system as would be required to reduce overall discount rates for the region as a whole. At best, subsidized credit could be targeted for specific projects or technologies with a low environmental impact. Reducing the discount rate specifically for such projects could make them the most attractive investment option.

As mentioned above, the opportunity cost of capital in the Amazon, for which interest rates on loans are an appropriate measure, is quite high, and in order to discuss mechanisms for lowering interest rates, one must understand why this is so. In recent years, a tight monetary policy in Brazil has restricted credit and driven up interest rates in order to combat inflation (Guimarães, 1996). However, interest rates for government agricultural loans are not particularly high: 12% for standard agricultural credit and 9% for small farmer credit (Montiel, 1998). Why then do farmers pay up to 40% for credit (Schneider, 1995)?

As is common in rural financial markets everywhere, small farmers in the Amazon typically lack access to formal sector credit. First, there are serious transaction costs involved. Low population densities discourage private sector financial institutions, which remain few and far between. The vast distances in the Amazon increase the direct and opportunity costs of travel to visit the nearest source of formal sector credit, and repeated visits may be necessary. Many farmers are illiterate or unaccustomed to dealing with the bureaucracy involved in obtaining loans, and for many banks, the administrative costs of small loans are not worth the effort. Second, many farmers lack the collateral (e.g. land title) necessary to obtain formal sector loans. Third, agricultural activities are risky in general: the formal sector may be unwilling to accept these risks at the interest rates they offer, and the informal sector naturally charges higher interest rates to compensate for the greater risk. As a result, the greater availability and lower transaction costs of informal sector loans may make these a better choice for small farmers (Bottomley, 1983).

While many countries have developed popular credit institutions which reduce the costs of rural credit (Bouman, 1983), the vast distances in the Amazon and the social instability resulting from the economic cycle of exhausting local resources then moving on (Bunker, 1985) suggests such institutions may be slow to develop.

20) The Option of Subsidized Credit

Credit subsidies have long been a popular approach to encourage agricultural modernization and reduce rural poverty, both in Brazil and elsewhere. Brazil in particular has used credit subsidies as a policy tool. In 1977, agricultural credit subsidies amounted to 25% of total expenditures by all levels of government in Brazil (Sayad, 1983). In 1982, agricultural credit actually reached 80% of agricultural output, though only 3% of this went to the Amazon region (Shirota, et. al. 1990). Real interest rates on these loans were typically lower than those available on other loans, and often negative. While due to the fungibility of capital it is difficult to determine the full impact of subsidized credit, Brazil's loan policy in the 1980s probably did contribute to increased adoption of modern inputs and the planting of permanent crops as intended (Shirota, et. al. 1990). This suggests that subsidized credit for environmentally sustainable projects should be politically acceptable in Brazil, and could help lead to the adoption of more benign technologies.

Further, while credit subsidies often address the symptoms and not the causes of rural sector problems, they may be justified if they help to correct a market failure (Yaron and Benjamin, 1997). In this case, credit subsidies for technologies which require little deforestation could lead to the greater provision of public goods from the intact Amazon rainforests.

In general, unsubsidized credit is unlikely to meet the needs of more environmentally sustainable regional development for several reasons. First, more sustainable projects such as reforestation or planting of perennial crops face initial costs, then typically several years of maintenance costs before any returns are realized. Given the prevalence of pests, uncertain ecological factors, lack of knowledge of appropriate crops and production technologies and lack of knowledge of future market conditions, such projects are also highly risky. For such projects to prove profitable, loan conditions must be appropriate, with low interest rates and a sufficient grace period (McGaughey and Gregersen, 1988). Subsidizing interest rates is justified if this leads to land uses that reduce deforestation, and the total returns to society are greater than the opportunity costs of alternative investments on which the subsidies could have been spent. The latter condition grows increasingly likely as the definition of society expands from local to national and international.

There are compelling arguments for a program of subsidized credit as a means to lower discount rates, slow deforestation, and thus help provide the public good of maintaining the ecological functions of the Amazon. Unfortunately, there are serious obstacles to implementing a program of subsidized credit, and the potential for highly adverse effects if such a program were to be implemented.

Perhaps the most serious problem is the fungibility of money, which allows the diversion of credit to other activities. A loan may be targeted for a specific environmentally sustainable project, but given people's preferences and the costs of monitoring and enforcement of targeted loans, it is unlikely all the money will go directly to that project. Even if sufficient money were available to monitor loans, inflation and exchange rate variations can make this process extremely difficult (Von Pischke and Adams, 1983). In practice, much of the large infusion of subsidized capital necessary to lower discount rates would undoubtedly be diverted to other activities with higher returns (including on-lending at higher interest rates), many of which require deforestation. Certainly in the past, this has been the case in Brazil (Sayad, 1983; Shirota and Meyer, 1990).

It is best not to look at subsidized loans as an input into a particular activity. In general, subsidized credit will be treated by the borrower the same as any other money he has. One way or another, it is likely that the money will either go towards non-targeted activities, or free up other funds that can go towards those activities (Von Pischke and Adams, 1983). Even if subsidized credit could lower discount rates from their current levels, this increased availability of capital would weaken the labor and capital constraints that currently bind deforestation in the Amazon. The net effect of lower discount rates and greater capital availability would probably be an increase in total deforestation.

Another serious problem with subsidized credit is the seemingly inevitable concentration of the subsidies among a few wealthier farmers. Smaller farmers typically have less experience with formal credit markets, and higher transaction costs (e.g. distance to travel, illiteracy) than wealthier farmers, as explained above. They are thus likely to apply for credit. In addition, banks rationally try to compensate for lower interest rates by requiring more collateral and loaning to borrowers with more liquid assets. In general, it is wealthier borrowers that are able to meet these criteria. Subsidized credit can thus exacerbate the unequal distribution of wealth which plagues Brazil (Sayad, 1983).

A third problem is that there is a general lack of knowledge regarding more sustainable options for development in the Amazon, and this is likely to be more pronounced for small producers. Unless credit subsidies are effectively targeted towards more sustainable activities, they will not achieve the desired end. Considerable research and extension is necessary to develop and disseminate sustainable technologies.

A fourth serious problem is the quantity of funds that would be necessary for a subsidized credit program. I make rough calculations of the amount required below, and discuss the feasibility of its provision

An additional problem that will not be discussed in detail is the likelihood that subsidized credit programs will lead to the suppression of private sector rural financial markets (Besley, 1992).

It is worth examining current initiatives in Brazil, to see if they might be able to overcome some of these problems.

The Cardoso government has launched an initiative for providing credit at a 6.5% annual interest rate for sustainable productive activities in the Amazon--the Protocolo Verde, or Green Protocol. Currently, the initiative is working with state and federal banks, with future plans to include all banks in Brazil, both public and private.

Under the Green Protocol, State and Federal banks will target credit towards more sustainable forms of production, and end it for projects with negative environmental impacts (Ussach, 1996). This includes the cessation of public credit for projects in areas with virgin forests and to companies/ producers who have broken environmental laws (Montiel, personal communication, 1998), as well as extension of "credits to farmers who plant crops suited to [the Amazon's] ecosystem" (The Associated Press, March 14, 1998.) To determine project suitability, participating banks are implementing an internal project rating system, and expanding requirements for environmental impact assessments (EIAs) (Ussach, 1996). With sufficient monitoring to prevent arbitrage, cheaper credit could theoretically lower discount rates and slow deforestation.

The Green Protocol program also seeks to address the issues of access to the formal credit sector, technical capacity, initiative, and ability to elaborate and initiate sustainable projects. Environmental development agents will be trained to actively seek out suitable farmers and help train them in the necessary extension techniques (Montiel

1998). Both the participating banks and IBAMA will be responsible for training these agents, with the option of seeking international assistance (Ussach, 1996). While these agents are currently at work in the Brazilian North East, they have not yet been trained for extension in the Amazon. Under current conditions, the primary bottleneck in the Green Protocol initiative appears to be finding and training suitable loan recipients (Montiel, 1998).

In summary, the Green Protocol does address some of the problems outlined above: it is available only to relatively low environmental impact projects, it includes extension efforts to attract and train small farmers, and it stops credit for those who break environmental laws. Unfortunately, the Protocol seems to do little to control the fungibility of the loans, and the threat remains that reduced capital constraints would accelerate deforestation.

Still, if accompanied by other policies, it is possible that some type of subsidized credit program could be part of an overall strategy to slow deforestation. It is thus worth looking in more detail at the costs of such a policy.

21) The Costs of Subsidizing Credit

How much money would be required to lower discount rates in the Amazon via subsidized credit, or, more realistically, how much money would be required to make renovation of degraded agricultural lands more financially attractive than deforestation of new ones? While a precise answer to this question would be extremely difficult to determine, it is possible to make some rough estimates. Table 3 above provides estimates of the start up costs of various production activities which use relatively little land. This data can be used to estimate credit requirements if one accepts the following assumptions:

1) Newly deforested land will be divided between pasture, temporary crops and permanent crops in the same proportion as already deforested land[47];
2) Land use in the geo-phytological Amazon as a whole is approximately proportional to land use in Pará, Rondônia, Amazonas, Mato Grosso and Tocantins (the only five states of the Legal Amazon for which 1995-1996 census data are available);
3) The costs and benefits of the different land uses in the Amazon as a whole are approximately the same as those in Paragominas, Pará;
4) Subsidized credit can lower the discount rate for the particular project for which it is made available, though perhaps not the over all time preference for consumption. However, at a low enough opportunity cost of capital and with sufficient extension, more sustainable land uses become more profitable than those that require deforestation, and primary producers will choose higher profitability;
5) The cost of providing subsidized credit is simply administration and extension costs plus the percentage difference between the unsubsidized interest rate and the subsidized one, multiplied by the quantity of credit issued.

Of land currently devoted to pasture, temporary crops and permanent crops, approximately 83% is in planted pasture, 15.5 % in

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[47] A flaw with this assumption is that typically, small land holders clear land for crops, and after a few years as fertility decreases, convert the land to pasture. In general however, the resulting estimates should be reasonably accurate.

temporary crops and 1.5% in permanent crops[48]. Between 1995-1997, INPE (1998) estimates that deforestation in the Amazon averaged 2,008,570 hectares/year. Extrapolating from existing land uses, newly deforested land each year should consist of approximately 1,670,063 hectares in pasture, 310,026 hectares in temporary crops and 28,480 hectares in permanent crops.

If subsidized credit and extension were made available to convert existing cleared land to more profitable and sustainable land uses, farmers would have incentive to invest in currently deforested lands rather than deforest new lands. Based on extensive interviews, Almeida and Uhl (1995a) estimate that land intensive (i.e. technologies which produce more on less land) sustainable agriculture[49] requires an additional initial investment of $2671/hectare as compared to slash and burn farming but provides an additional $769 in per hectare profits. Similarly, Arima and Uhl (1997) estimate that restoration of degraded pasture costs approximately $260/hectare ($47 less than the establishment of new pastures), but provides an additional $49 in per hectare profits.

While clear cutting for pasture and farmland are the major causes of deforestation in the Amazon, the logging industry is growing rapidly, contributes substantially to forest degradation, and subsidizes deforestation by providing roads and covering some of the costs (INPE,

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[48] The IBGE census data for agropastoral production for 1995-96 for the legal Amazon has not yet been released on the Internet. However, data are available for the states of Pará, Rondônia, Tocantins, Amazonas and Mato Grosso, which are responsible for the vast majority agropastoral production and deforestation in the region, and contain most of the land area. The Censo Agropecuario 1995-95 for Brazil (IBGE, 1998) provides the hectares in each land use, which were used to calculate percentages, which are rounded to the nearest 0.5 to avoid rounding errors. These percentages should be quite close to those of the Amazon as a whole.

[49] See the original article for more details.

1998). Subsidized credit could also help address the logging issue. For an additional $46/hectare, logging can be carried out in a far more sustainable fashion which reduces the sustainable harvest rotation from 70-100 years to 30-40 years. With prospects for renewed logging in as little as 30 years, the timber industry may be reluctant to allow clear felling of selectively logged forests by farmers and ranchers. In addition, coupling improved management with more efficient milling could reduce the land required to maintain current output by as much as two-thirds (Uhl and Barreto, 1997). Currently, many timber companies have exhausted local supplies and are faced with relocation or abandonment of their investment (Veja, 1995): they are therefore likely to prove amenable to adoption of improved management techniques. In 1995, 50,802,498 m^3 of wood were removed from the Amazon (IBGE, 1998), at an average of 40 m^3/ha (INPE, 1998). This suggests that approximately 1,270,062 hectares were logged.

The remaining factor needed to estimate the cost of a subsidized credit program is some idea of the administrative costs involved. Only small amounts of credit currently reach producers in the Amazon: 7.5% of producers in Mato Grosso received credit in 1995, with corresponding figures for Para, Rondonia, Amazonas and Tocantins of 2.5%, 3.2%, 1.8%, 3.0% respectively (IBGE, 1998). This means that little data on administrative costs for the extent of loans to be administered are available. Existing research suggests “that small loans processing costs can range between 15 and 40 percent of the loan size” (Besley, 1992 citing Braverman and Guasch, 1989). Geography, isolation, lack of infrastructure, monitoring to avoid arbitrage and the need for extension are likely to make administrative costs quite high in the Amazon. However, the extensive nature of the credit package being discussed here should bring both economies of scale and positive externalities with respect to extension, i.e. people will imitate their neighbors who have successfully implemented new strategies. I will use the higher end estimate of 40%, but assume that it includes the cost of extension. The resulting cost of the credit subsidy in the first year is shown in table 4.

Table 4: Estimated Costs of a Subsidized Credit/Extension Package for the Amazon, assuming 40% administrative/extension costs.

activity	ha/yr	cost/ ha (b) US$	administ'n extens'n costs (40%)	cost with 5.5% subsidy (c)	cost with 11.4% subsidy
farming	310,026	2,671	331,231,778	376,776,148	425,632,835
ranching	1,670,063	260	173,686,552	197,568,453	223,187,219
logging	1,270,062 (a)	56	28,449,389	32,361,180	36,557,465
TOTAL				606,705,781	685,377,519

a) to get this figure, I determined the total m^3 of timber harvested from the Amazon (Pará, Rondônia, Amazonas, Acre, Amapa, Tocantins and Mato Grosso, IBGE, 1998) and divided it by the average harvest of 40 m^3/ha (INPE, 1998).

b) This is the difference between the costs of land extensive (i.e. technologies with low productivity/ha) and land intensive (high productivity/ha) production options.

In subsequent years, the subsidy will need to be paid on outstanding debt. However, a simple glance at table 3 above shows that the increased tax revenue from more sustainable production techniques will readily cover ongoing subsidy costs.

The calculations here show the net costs of a credit subsidy/extension services package under the assumption that credit could be provided only to those who would otherwise deforest. The gross cost would of course include the capital loaned, which would total slightly over $1.33 billion/year. For comparison, total agricultural credit in Brazil for the agricultural year 1996/97 was greater than $5 billion reais, or about US$5 billion (Ministério de Relações Exteriores, 1997), but little of this went to the Amazon.

There are possibilities for obtaining the necessary capital. So far, three State banks are participating in the initiative in the Amazon: The Banco do Brasil, the Banco da Amazonia SA, and the Banco Nacional de Desenvolvimento Econômico e Social, and they should provide around $1,000,000 per bank per year for projects in the Amazon. Dialogue has begun with 200 private banks to gain their participation. In addition, IBAMA is seeking out foreign banks to participate in the initiative, and is currently negotiating with several German banks, one of which has already agreed to provide $30,000,000. Such foreign contributions targeted towards environmental projects and sustainable development are referred to as 'ethical funds' (Montiel, 1998). There is considerable future potential for procuring funds of this type[50]. If loans for environmentally sustainable development could generate substantial foreign exchange earnings via the International Pigouvian subsidy discussed above, the Green Protocol could potentially attract a significant share of the R$22 billion available annually for agricultural and industrial loans from participating public banks (Ussach, 1996). The Pigouvian subsidy could provide the money for the subsidy and extension work.

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[50] Private sector funds directed towards 'environmental' investments in developing countries already exceed $700 billion. The Coalition for Environmentally Responsible Economies alone handles an international fund of some $150 billion directed towards environmentally ethical investments. Many companies hope to be certified as environmentally sound under the ISO 14000 initiative, and may prove willing to invest their resources accordingly (IBAMA 1998)

The cost of the subsidy is the difference between the standard 12% loan for agricultural investment and the loan under the subsidy, e.g. a 5.5 % subsidy corresponds to the 6.5% interest rate offered under the Protocolo Verde. Given the history of credit subsidies in Brazil, and the potential availability of money if an international Pigouvian subsidy were to be implemented, this policy might be politically feasible. The question is, would it be the best way to spend available resources? There are two primary reasons why a credit subsidy is definitely an inappropriate policy.

First, it would be virtually impossible to target credit subsidies and extension only towards those who would deforest in their absence. As a result, deforestation would continue alongside the subsidy. Second, and far more important is the seemingly insuperable problem of fungibility. Credit subsidies in one form or another would free up money to invest in activities that require deforestation, and the risk that the policy would accelerate deforestation is unacceptably high.

There is one way to overcome both of these problems. If more environmentally sustainable technologies could be made more profitable than the alternatives, and the technology and awareness of its profitability disseminated, there would be no incentive to divert credit subsidies towards other activities. People would then invest in these activities rather than those that required deforestation whether or not a credit subsidy existed. Of course, under these circumstances, a credit subsidy would not be needed, and deforestation would not be a problem to begin with.

22) Providing Secure Land Tenure

Another possibility for lowering discount rates is to provide secure land tenure for farmers and ranchers in the Amazon. While the number of squatters in the Amazon reported in census surveys has decreased considerable over the past two decades, insecure land tenure is still a serious problem as can be seen in Table 5.

Empirical studies suggest that insecure tenure contributes to deforestation (Southgate, 1990; Southgate and Runge, 1990). Insecure tenure makes investments in the future productive capacity of land risky and favors mining of the soil, extracting what is possible before losing the land. Uncertainty over the future, particularly over asset ownership, is widely believed to increase discount rates. In the Amazon, insecure tenure makes forested land approximate the conditions of an open access resource, and theoretically, exploitation of open access resources will proceed as if the discount rate were infinite (Clark, 1990). In addition, many farmers lack the capital to make investments in their land, and lenders may either require land title as collateral on loans or charge higher interest rates for unsecured loans (Bottemley, 1983). Titling land may thus increase both the incentive and means for investments in future productivity, and reduce the need for new deforestation.

Table 5: Land Tenure in the Amazon: Area Held by Squatters (all figures from IBGE (1998). Calculations performed by author)

State	1975 squatters as % of:		1995-96 squatters as % of:		1995-96 land held by squatters in:	
	all properties	all land	all properties	all land	# of properties	# of hectares

Mato Grosso	29.9%	2.9%	9.8%	1.3%	7,719	647,915
Pará	45.9%	17.2%	15.7%	3.7%	32,405	833,248
Rondônia	28.7%	20.4%	7.6%	3.1%	5,849	275,604
Amazonas	67.0%	13.3%	33.1%	9.5%	27,569	315,644
Tocantins	44.6%	23.0%	12.4%	4.2%	5,569	704,160
Totals					79,111	2,776,571

Unfortunately, securing land tenure in the Amazon is a complicated process. Land records in Brazil are kept by several different bureaucracies, and titling would require they be combined and collated (Uhl, Barreto and Verissimo, 1995). The existing titling process must also be decentralized and simplified if it is to succeed. Currently, colonists may be forced to travel long distances, deal with several bureaucracies and pay for expensive licenses. Travel is expensive, travel time is unproductive, and poorer colonists are likely to be unfamiliar with bureaucratic structures. The difficulty and expense of the process increases the likelihood that primarily colonists with greater financial and human capital will secure tenure. Streamlining the titling process should increase equity as well as efficiency (Bunker, 1985; Schneider, 1995).

Under the current situation, how much would it cost to establish secure tenure? While it is difficult to find figures specifically for the Amazon, President Cardoso has announced a new plan for agrarian reform in Brazil known as the ‘Cedula da Terra’ (i.e. ‘land title’). This plan will provide subsidized credit for households to purchase land. An estimated 4% of costs is expected to cover administration, land registration and monitoring. Over the next three years, $150 million has already been set aside for the program (Braga, 1997). In 1995

Schneider (1995) found that land values in Pará, one of the more developed states with higher land values, ranged from $2.5 to $300 per hectare. In the last two years, according to INPE (1998), land prices in the Amazon have suffered a 'vertiginous' decline. In addition, squatting is more common in frontier areas (IBGE, 1998), which have lower land values (Schneider, 1995). Assuming a land price of $150/ha for the purposes of a rough calculation, outright purchase of all land held by squatters might cost in the neighborhood of $420 million. Under the 'Cedula da Terra' plan, households are given loans to purchase land, with a three year grace period. The net cost of the project is the cost of the subsidy plus administration, etc. Assuming a 12% interest rate subsidy plus four percent administrative costs gives a rough estimate of $67 million per year for three years. The costs of establishing tenure could be covered in part by another policy recommendation discussed below: a tax on deforestation paid when title is awarded or exchanged.

23) The Impact of a Reduction in the Discount Rate

Taken together, secure land tenure, credit subsidies for environmentally sound production, and increased incomes resulting from increased investment should work to lower discount rates. Assuming rates could fall as low as the opportunity cost of capital on loans offered under the Green Protocol initiative, what impact would this have on the rate of deforestation? Figures 24a-b show the impact of different discount rates on annual deforestation and forest stock.

Even with a 6.5% discount rate, the discrete time model suggests that the optimal time path for deforestation, when public goods are not valued, will remain at the maximum allowed by existing labor and capital constraints for the first 25 years. In actuality, there would even be a high risk of accelerated deforestation due to relaxed capital constraints. Only if discount rates could be lowered to 2% or less would optimal deforestation rates fall below the current capital and labor constrained rate. Larger credit subsidies cost more, but since loan administration comprises the bulk of the costs, the relative difference in cost between a subsidy of 5.5% and one of 11.4%is not great, only about $78.7 million. In fact, the discrete time model suggests that a larger subsidy may in fact have lower net costs (or even profits) than a smaller one when the Pigouvian subsidy is factored in. This can be seen in Figure 25, which shows the net cost of subsidized interest rates of 6.5%, 3%, 1% and 0.6% in the presence of a $750/ha international Pigouvian subsidy.

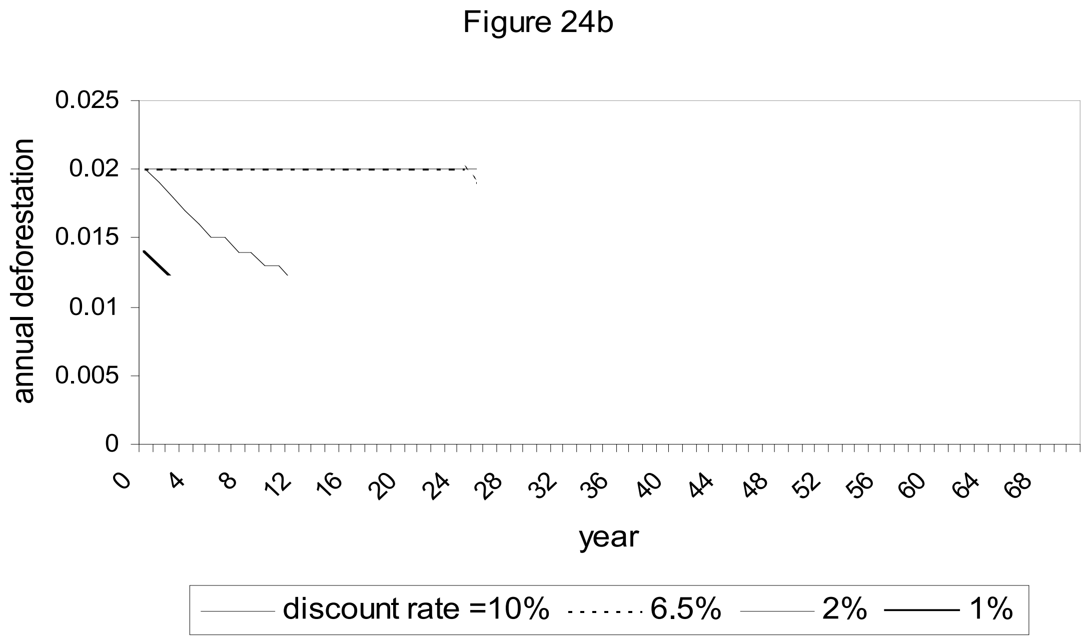
Figure 24b

Figures 24a-b: The optimal time paths of forest stock and annual deforestation (million km^2) at the local level with different discount rates

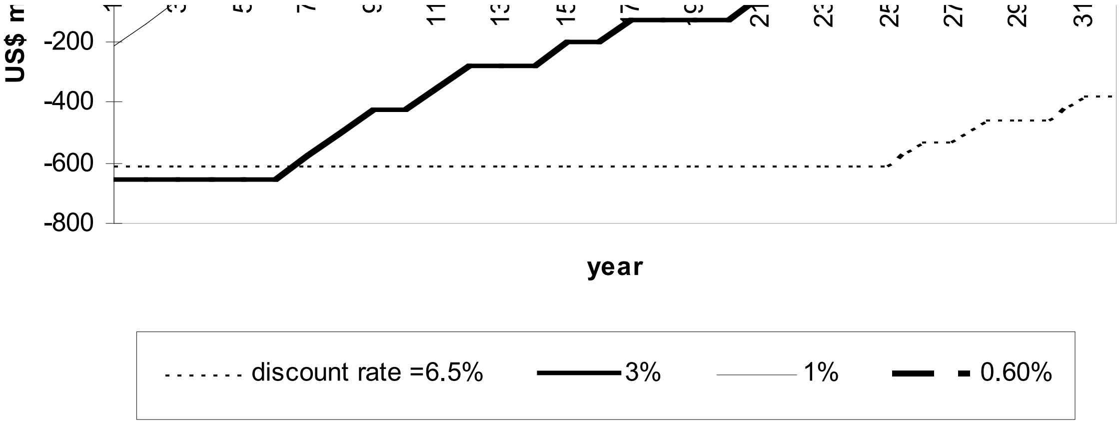

Figure 25: The net cost of different credit subsidies in the presence of a $750/ha international Pigouvian subsidy assuming the only result is a reduction in discount rates (i.e. the impact of extension is ignored). (see text for details on parameters).

Still, according to the model, if a credit subsidy plan does nothing more than lower discount rates, even a $750/ha international Pigouvian subsidy would not cover the costs initially of such a plan unless it could bring discount rates as low as 0.6%, which is highly unlikely. If fungibility of credit were not a problem so that selective targeting of the credit subsidy were possible, the subsidy would simply need to make sustainable activities more profitable than unsustainable ones requiring deforestation. The over all time preference for consumption would not need to be brought down to such low levels, only the discount rate for the more sustainable activity. Given the tenacity of the fungibility problem, however, sustainable activities would have to be more profitable than unsustainable ones even in the absence of a targeted subsidy. In the absence of this unlikely event, lowering discount rates by means of subsidized credit must also realistically relax capital constraints.

In any case, extension is an essential part of the credit subsidy proposed here, and hence the two have to be considered together to determine the total impact.

24) Technological Change: Research and Extension

Improved research and extension is absolutely necessary for the success of the subsidized credit policy discussed above, and even alone could help reduce deforestation. Most available literature on the subject argues that the typical technology of exploitation in the Amazon is sub-optimal from an economic and ecological point of view. Ignorant of alternatives, colonists typically transplant technologies from their areas of origin, which in the Amazon frequently leads to low yields and rapid exhaustion of the soils (Fearnside, 1990; Almeida and Campari, 1995). Agropastoral production in the region was initially widely acclaimed as a total failure, viable only in the presence of government incentives and subsidies (Goodland, 1980; Hecht and Cockburn, 1989). More recently, as colonists have had time to experiment and have become more familiar with the region, agropastoral production is not only becoming profitable in the absence of government interference, but more sustainable as well. Moran (1989) suggests that this is typical for colonization projects: settlers must learn to adapt to a new environment.

Unfortunately, primary producers in the Amazon receive very little in the way of technical support (see table 6), ranging from 28% of households in Mato Grosso to only 3.8% of households in Pará. Less than half the extension services reported in the Amazon are of government origin, but the free market is unlikely to provide an appropriate level of either extension or research for several reasons. First, technology has characteristics of a public good. Technology is non-depletable (one person using a particular technology does not reduce the amount someone else can use) and to the extent people can learn by seeing technologies applied, and intellectual property rights do not exist or are not enforced, it is non-excludable. From the government point of view however, non-excludability is a positive externality of extension services. Second, high discount rates will discourage market driven research which is time consuming and expensive and may show returns only far in the future, and will discourage technologies requiring substantial investments. Third, if the public good output of the Amazon is under-valued, insufficient effort will be made to discover technologies that preserve it.[51] As a result, unless research is publicly funded, either nationally or internationally, technological advance and adoption may be quite slow.

Table 6: The percentage of households in the Amazon receiving technical support, and the share of support provided by the government (IBGE, 1998.)

state	households receiving technical support	share of support from government sources	share of support from non- gov't sources.
Pará	3.80%	46.30%	53.70%
Rondônia	10.00%	63%	37%
Amazonas	6.10%	20.60%	79.40%
Tocantins	12.80%	44.60%	55.40%
Mato Grosso	28.00%	36%	64%

The problem is that if technological advance is too slow, it may be of limited use. Technological advance requires both research

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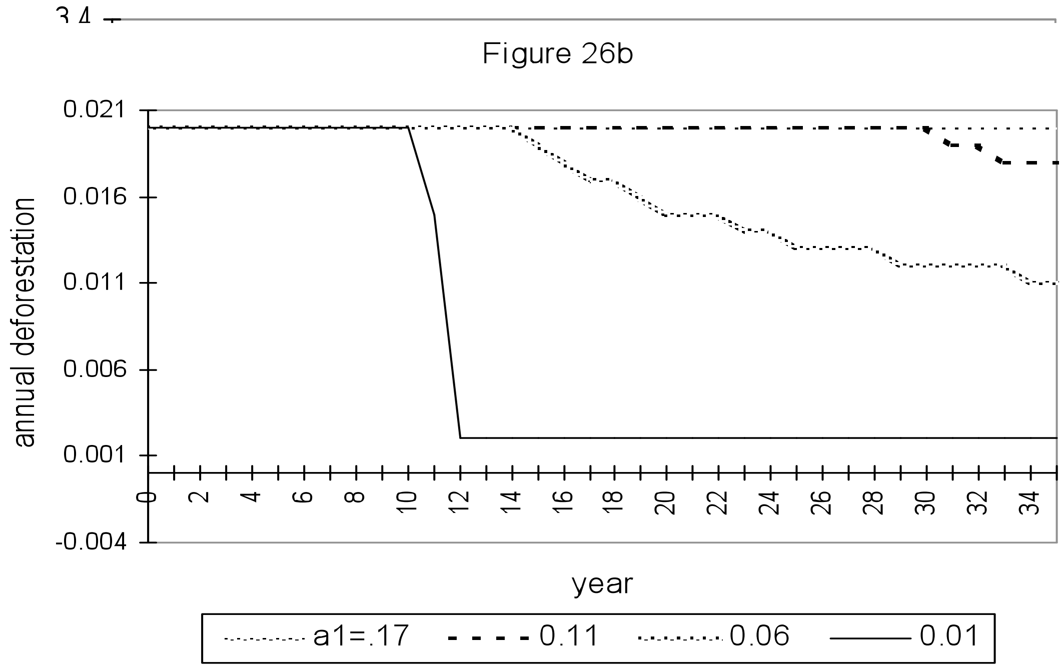
[51] This does not mean research will not be undertaken. At both the local, national and international level it is recognized that an extensive research and extension program is necessary to overcome ignorance about suitable production techniques and about the effect of change on the Amazonian ecosystem. Former governor of Amazonas Mestrinho (1994) suggests establishing multi-national research institutes to explore sustainable, profitable uses of regional resources which address the needs of local inhabitants. The Integrated National Policy for the Legal Amazon also emphasizes the need for additional research into more suitable technologies, and proposes consolidation, institutional strengthening and funding for the appropriate institutions (MMA, 1997).

investments and time, but the Amazon is changing rapidly. Populations are increasing steadily, and deforestation threatens to change ecological and agricultural conditions. Until some sort of equilibrium (ecological, economic and population) is reached, the learning process may be one of dynamic adaptation to a moving target. For example, for small populations, slash and burn farming with long fallow periods is sustainable (Homma, 1993b), but for larger populations, alternative technologies may be required. The greater the rate of change (e.g. in land use, populations) the less time for acquiring and diffusing knowledge before it becomes obsolete, the greater the likelihood of sub-optimal land use, and the less likely technology will be able to adapt.

Technological innovation may take many different forms, each of which by itself is likely to have different impacts on deforestation rates and optimal steady state forest stocks. Several of these potential innovations are captured by different variables in the model. Certain technologies may increase crop yields on cleared land without breaking the dependence on deforestation (e.g. with improved seed stock, or higher value crops). In terms of the model, this will essentially increase the value of private goods relative to public goods, which can be modeled by a lower value for $v(S,t)$, weakening the conservation motive (see equation 42, Chapter Two) particularly at the local level. Other technologies could make agricultural output less dependent on the ecological conditions created by intact forests (e.g. more heat, drought and pest resistant seed stocks) essentially increasing the value of a_2 (the parameter on cumulative deforestation in the agricultural production function) and decreasing p_1 (the proportion of remaining forest stock below which the marginal output of cumulative deforestation becomes negative). These types of technological innovation will benefit the local economy, but will also increase the locally optimal rate of deforestation, and have a negative impact on global welfare.

To preserve the public good value of the Amazon, the best technologies to pursue are those that make agricultural output less dependent on the fertilizer effect of annual deforestation (e.g. silviculture, permanent crops, greater fertilizer use, improved stock, pasture rehabilitation, etc.) This can be modeled by decreasing the value of a_1(the parameter on annual deforestation in the agricultural production function). Figures 26a-b shows what effect different values for a_1 have on the time path of deforestation and the time path of forest stock. Even if everyone adopted sustainable technologies that did not depend on the fertilizer effect of ash from deforestation, and a_1 fell as low as 0, only in the twelfth year does the rate of deforestation fall below

Figure 26a



Figures 26a-b: The optimal time paths of forest stock and annual deforestation (million km^2) at the local level with different technologies affecting the impact of current deforestation on agricultural production, i.e. with different values for a_1. (see text for details on parameters).

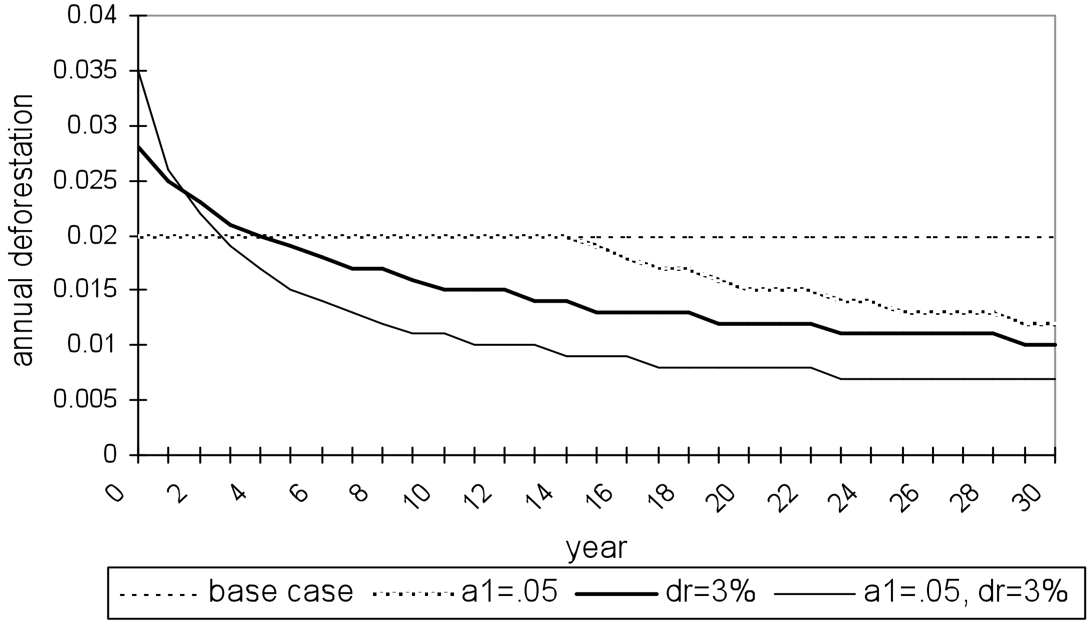
the current labor constrained level. However, the subsequent drop is quite sharp, and the forest stock in year 30 is significantly larger (by 32.5 million hectares) than if no change in technology occurs. If a_1 falls to .05 (e.g. fewer people adopt the sustainable technology, or the technologies developed slow the rate of degradation of deforested land, but do not eliminate the need for new deforestation), deforestation rates drop after year 15. If a_1 falls only to .11, deforestation rates do not drop until the 31st year.

However, for any new technology, adoption will be very slow without substantial investments in extension activities and subsidized credit. In reality, subsidized credit will also relax capital constraints.

Figures 27a-b show the impact of removing capital constraints and lowering discount rates to 3% when accompanied by technological improvements (a_1=.05) brought about by a credit subsidy in conjunction with research and extension. For comparison, the time paths for no policy change (a_1=.17, discount rate = 10%), only improved technology (a_1=.05, discount rate =10%) and only lowered discount rates and relaxed capital constraints (a_1=.17, discount rate = 3%) are also included.

Combined, these policies show a far more dramatic impact than either one alone. Technological advance alone requires sixteen years to lower deforestation rates with respect to the status quo, and after thirty years predicted total deforestation reaches 24.5% compared to the 26.5% predicted for the status quo. A credit subsidy that lowers discount rates, when accompanied by relaxation of the capital constraint, leads to more rapid deforestation initially. This effect is

Figure 27b



Figures 27a-b: The optimal time paths of forest stock and annual deforestation (million km²) at the local level with no policy change, with technological change alone, with a lowering of the discount rate alone, and with both combined. (see text for details on parameters).

accelerated even more when accompanied by technological advance, since productivity increases on deforested land. Quickly, however, the reduced discount rate slows deforestation, as does the decreased dependence on annual deforestation that accompanies technological advance. A simple reduction in discount rates to 3% accompanied by relaxed capital constraints leads to lower deforestation rates within six years, forest stocks become greater than the status quo by year twelve, and total deforestation after thirty years is predicted to reach 22.6%. A credit subsidy accompanied by technological change leads to lower deforestation rates within four years, higher forest stocks than the status quo within nine years, and predicted total deforestation after thirty years of less than 20%.

Of course, the possibility of subsidized credit lowering discount rates to 3% is remote indeed. If instead subsidized credit was only able to lower discount rates to 6.5% (also a very optimistic scenario) but still relaxed capital constraints, it would take nearly fifty years before forest stocks were greater than predicted in the absence of change. With credit subsidies accompanied by technological change, it would take 19 years for forest stock to rise above the predicted stock for status quo, and 20 years to rise above the predicted stock for technological change alone.

A necessary complement to extension work is basic research. Much research is already being carried out by non-governmental organizations (NGOs), Universities and other research institutes. Nicolaides III et. al. (1983) have carried out promising long term studies of intensive cultivation in Yurimaguas, Peru. The remaining indigenous tribes have thousands of years of accumulated knowledge, much of which could undoubtedly be adapted to modern agriculture (Posey

1993). More recent immigrants are also experimenting with different crops and cropping patterns. As pepper, cacao and coffee have succumbed to disease and lower prices, farmers have adopted a wide range of intercropped perennials which show considerable promise. Intercropping means less susceptibility to disease, decreased risk resulting from a wider range of crops, and a greater diversity of economically valuable species which often harbor greater native biodiversity. A recent study of 136 polycultural smallholdings revealed 108 different agroforestry configurations using 72 different species (Smith, et. al. 1996). Ranchers have also developed effective techniques for renovating pastures (Almeida and Uhl, 1995a). As these techniques have been developed by local farmers or indigenous peoples familiar with economic and ecological conditions, they are more likely to respond to local needs, and more likely to be accepted locally, than techniques developed purely by research agronomists. While this work has shown that sustainable production is technically possible, such farming requires considerable inputs and knowledge. One priority should be to gather information on existing sustainable technologies, then supply extension and credit so that these will be adopted.

At the risk of redundancy, it is worth repeating that research has the characteristics of a public good. Once developed, technology is non-rival, the marginal cost of sharing a technology can be very low, and in the absence of intellectual property rights, and assuming people can copy their neighbors, agricultural technology may verge on non-excludable. As a public good, it should receive increased government funding.

While it is very difficult to say exactly how much research and extension is optimal and how much it would cost, some rough estimates can give an idea. One research organization, IMAZON, has pursued an integrated approach to researching the existing problems with primary production in the Amazon and developing and disseminating more sustainable alternatives. Among their many successes, they have produced a manual for more sustainable logging techniques, which appear to be gaining acceptance among loggers in Pará (Pacchioli, 1997). This institution has an annual operating budget of approximately $600,000 - $700,000 per year (André Guimarães, personal communication). Given the heterogeneity of the Amazon, what works in Pará might not work elsewhere. Adequate levels of research might require three such institutions for each of the three states undergoing the most deforestation (perhaps one focusing on ranching, one on agriculture and one on timber production), and one each for the remaining states. For institutions modeled after IMAZON, this should cost in the area of $8.4 million per year. The additional financing required can be compared to the $15.1 million over 6 years the PPG7 has provided for the “Expansion of scientific centres and promotion of applied rain forest research” (Deutsche Gesselschaft für Technische Zusammenarbeit (GTZ), 1997).

Extension costs are similarly difficult to calculate. Extension work in more densely settled areas is likely to cost less because of accessibility, the potential for assistance from existing universities, government organizations and NGOs, and the ability of farmers to learn from the example of their neighbors. Extension work in more remote areas would be more expensive due to the absence of infrastructure, lack of educated extension workers, and the lack of neighbors to learn from. This suggests that expenditures on extension will show diminishing marginal returns. On the other hand, extension packages may be fairly expensive to prepare. For example, one ‘communication for development’ project in Latin America found that the cost of preparing a basic audiovisual pedagogical package was $25,000. If administered to one hundred farmers, the cost per farmer for the package would be $25, and if administered to one thousand farmers, only $2.50[52]. (Balit, 1996).

Worldwide, there are approximately 600,000 extension workers, who help bring appropriate technologies and useful educational programs to about 1.2 billion agriculturalists annually (Baier, 1994). Given the poor quality infrastructure and vast spaces of the Amazon, extension workers may be only 25% as efficient as the world average. Accepting this very rough estimate, one extension worker can reach about 500 farmers per year. College educated researchers earn about $15,000 per year at a ‘typical’ NGO in the Amazon (Guimarães, 1996), and a well-qualified extension worker might earn approximately the same. Taking the number of farms in the Amazonian states undergoing most rapid deforestation (Mato Grosso, Pará, Rondônia, Amazonas and Tocantins), and using the figures in Table 6 above referring to the number of farms that receive extension services, I calculate that there are approximately 441,900 farm households in the Amazon that receive no extension services. One extension worker per 500 households at $15,000 year provides a rough estimate of $13,257,100 in wages annually to provide extension services to the majority of farmers in the Amazon. Perhaps $20,000,000 annually would cover the total costs of developing and disseminating appropriate extension packages.

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[52] Balit (1996) cites a World Bank study which found that video based extension projects such as the above mentioned project may cost only 1/3 to 1/5 as much as more traditional approaches.

Research and extension will only make a credit subsidy viable if it leads to sustainable technologies that are more profitable than the alternatives. In reality, it is extremely difficult to predict the rate of technological advance, and the form it will take. It is unlikely that new technologies will meet the demanding criterion of such high profitability in the near future. However, it is safe to say that research directed towards technologies which increase production, use already deforested land and replace some of the life support functions of the intact forest should increase economic and ecological benefits. This in turn will make it politically easier to close the frontier and prevent further deforestation. Perhaps most important, research on ecosystem function should eliminate uncertainties, and reduce the likelihood that we unknowingly undertake activities with catastrophic outcomes. Research will also help establish the value of the Amazon for local, national and international society. The closer we come to determining the value of the Amazon, the more rationally we can plan its use.

25) Accounting for the Social Valuation of Public Good Benefits $v(S,t)$

If a commodity has private good value and public good value, the market determined price will not reflect the latter since by the nature of public goods, the individual purchasing the commodity will realize only a fraction of the public good benefits. In the Amazon, this means that forested land is likely to be cheaper than is socially optimal, research into forest conserving alternatives will be insufficient and undervalued, individuals may be justified in deforesting, and State governments in encouraging deforestation[53].

As the destruction of public goods produced by rainforests in the Amazon can be considered a negative externality of private good production, market solutions to the problem of negative externalities can serve to increase the supply of public goods. Tradable deforestation permits are a widely discussed option, which has some serious drawbacks. A Pigouvian tax on deforestation is also theoretically sound, and with some modification, could be feasible. Alternatively, driving up the price of forested land could also have the same effect as taxing deforestation.

26) Tradable deforestation permits

There is a large body of literature concerning marketable emission permits for various forms of pollution, and such permits have been used in the United States (Baumol and Oates, 1988). Theoretically, tradable deforestation permits could have the same properties as marketable emission permits, i.e. they could be a cost effective and potentially efficient means to bring current deforestation rates more closely in line with optimal ones. Such permits would ideally be internationally tradable. If the marginal value of forest preservation to conservationists were greater than the returns from exploitation to developers, conservationists would buy the permits and deforestation would not occur. Countries, conservation organizations, individuals and developers could all participate in the market. In order to be successful,

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[53] Many state governments do very little to stop deforestation, while others such as that of Amazonas, actively encourage lumber mills to move to its territory (Veja, 1995).

such a policy would have to address the issues of the quantity and nature of permits allowed, initial allocation of the permits, development of a market, and monitoring and enforceability.

Essentially, such permits would distinguish between property rights to land and property rights to forests on that land. It would be possible to make title to both land and forests necessary to deforest, or they could be made independently marketable, in which case one individual could own the forests on another individual's land. Selling permits to deforest state owned land would be little different than charging royalties on timber extraction, and will not be further discussed here. If rights to deforestation were sold independently of land rights, it should be easier to develop a market, since anyone would be able to participate in the market for the timber. If the right to deforest required both land rights and a deforestation permit, then only landowners and conservationists would bid on the permits, and the market would be thinner.

If the permits were issued to landowners, the owner would be able to sell the property rights to the intact forest. This option would be quite feasible politically, but would provide no revenue for the government. If rights were awarded as a percentage of property owned (for example, landowners could be issued permits to deforest the 20% of total cover allowed by legislation), the policy would be regressive. Large landowners would gain a correspondingly large potential source of income. Alternatively, the government could essentially nationalize the forests, then sell permits for a determined amount of deforestation. This alternative could provide the money necessary for monitoring and reinforcement, but would meet with resistance from often politically powerful landowners.

Brazil has sovereignty over the Amazon, and it obviously must be responsible for determining the quantity of permits to be issued. Since both the marginal social cost and marginal private benefit curves for deforestation are unknown, the quantity of permits issued cannot be determined on the basis of optimality. Brazil could issue permits for a maximum acceptable rate of deforestation to be determined by economists and/or ecologists. Alternatively, Brazil could try to maximize revenues from permits if it chose to auction them.

Permits could be issued annually, or else could give the right to a certain amount of deforestation every year. Annual permits have the advantage of providing a constant revenue inflow that may be necessary for monitoring. Permanent permits may prove more attractive to conservationists, since a one-time purchase would guarantee protection. However, permanent permits are more difficult to adjust on an annual basis to respond to ecological or economic changes. One solution is to make the permits valid for a certain percentage of a deforestation quota. This however would allow the Brazilian government to increase the quota, for example, if it deemed that conservationists had purchased too many deforestation permits. Indeed, the Brazilian government would have an incentive for doing this because of the difference between national and international public good benefits of the intact forest.

Tradable deforestation permits have several positive features. With sufficient monitoring and enforcement, it would be possible to determine precisely the amount of forest to be cut, and this could easily be changed from year to year. Economic factors would not determine the maximum allowable quantity of deforestation, and there would a lower risk of crossing ecological thresholds as a result of economic booms. Ecological sustainability would not be hostage to economic conditions. Since different areas of forest presumably have different marginal benefits, it would be possible to make the permit valid only for specific geographic areas, or for a general zone. Prices could differ between zones. Only one mechanism would be needed at the national and international level, simplifying implementation.

However, several problems make this tradable deforestation permits highly impractical. Marketable emission permits have been tried in the United States with only moderate success, because a thriving market has failed to develop. If too many permits are made available, the price may be too low to develop an effective market. Given exchange rate fluctuations and economic cycles, the price of permits might vary considerably from year to year. Developers could not plan in advance, and investments might be unnecessarily risky. International participation could drive up the price of permits substantially, often beyond the means of Brazilians.

The truly prohibitive obstacles however are monitoring and enforcement, particularly the latter. Monitoring would have to be quite accurate and therefore expensive, since the permits would need to be for fairly precise physical units. Enforcement would be extremely difficult, due to geographic, infrastructural and social conditions in the Amazon. As a result, there would inevitably be a problem of illegal deforestation, and the question of how to compensate those actors who paid for preservation. Even if squatting and illegal deforestation could be prevented, feasible monitoring techniques are simply not precise enough to avoid problems. Under current conditions, tradable deforestation permits are simply not a feasible policy.

27) Pigouvian Taxes Revisited

Whereas Pigouvian taxes on deforestation are not feasible at the international level, while Pigouvian subsidies are, the opposite is true at the national level. Paying a subsidy for all land left as forest would be absurdly expensive, would unduly award large landowners, and would require payments for preserving forest under no immediate threat of deforestation. Paying a subsidy only for land immediately threatened by deforestation is unfeasible for two reasons: first is the problem of deciding what land is threatened by deforestation, and second is the potential for landowners to threaten deforestation simply to receive the subsidy. A simple annual Pigouvian tax on all deforestation is also impractical, since monitoring and enforcement would be extremely difficult. For example, the existing Rural Land Tax (RLT) was paid by only 20% of landowners in Paragominas in the early 1990s. Effective enforcement of the RLT requires information regarding land use,[54] yet as of 1995 fewer than 1000 INCRA employees monitored 4.5 million properties in Brazil, and 1978 was the last time land use was characterized in the Eastern Amazon (Almeida and Uhl, 1995a).

However, a Pigouvian tax on deforestation could be feasible and effective if charged only when land title is conferred or transferred. Historically, deforestation has been required to show use of land when seeking land title (Mahar, 1989), and apparently many landowners believe that this is still true (INPE, 1998). Obviously then, conferral of land title has traditionally involved establishing the extent of

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[54] The RLT varies from 0.02% to 3.5%, increasing with the size of the property. It is not charged on the legal forest reserve, nor on land unsuitable for farming, ranching or forestry. A discount of up to 45% is offered depending on the degree of land utilization (i.e. usable land which is in use) and up to an additional 45% depending on the intensity of use (Almeida and Uhl, 1995).

deforestation. An appropriate tax would virtually eliminate deforestation as a means to gain land title. Landowners would also be less likely to deforest to show land is being used and therefore not subject to expropriation in the even of agrarian reform. This would prove a disincentive to holding land for speculation purposes. When land is sold, the buyer would make sure that the amount of existing deforested area was not understated, since that would increase his tax burden on a future land sale. The seller would make sure deforestation was not overstated, since that would increase his tax burden[55]. Combined, this would obviate the need for monitoring by INCRA or IBAMA. In addition, those who deforested more than the 50% previously allowed and the 20% currently allowed could be fined accordingly when land is transferred.

One problem would be how to assess the tax on land on which deforestation took place both before and after the tax, since it would be unfair to tax someone for what was previously an encouraged practice[56]. In this case, currently deforested area would have to be compared with the area deforested at the time the law was established. This could be accomplished by using remote sensing, global positioning systems (GPS) and geographic information systems (GIS), which

> "in combination, may provide a solution to the daunting challenge of land monitoring and taxation in Amazonia… Satellite images (Landsat and SPOT) when properly classified, provide accurate information on land use and are available at affordable prices." (Almeida and Uhl, 1995b)

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[55] Though of course, the cost of the tax would be split between the buyer and the seller.

[56] See Almeida and Uhl (1995) for suggestions for overhauling the existing Rural Land Tax to make it an effective tool against deforestation.

Landsat and or SPOT photos from the time of the sale would have to be compared with photos from the year the law is declared.

A second problem is the level at which to set the tax. Revenue from the tax should be at least sufficient to cover the costs of implementing it. A tax in the region of $31/hectare (the estimated annual per hectare returns to slash and burn farming) should be sufficient to achieve this, and would also provide a major incentive for more profitable yet more sustainable productive activities.

28) Relative Slopes of Marginal Cost and Benefit Curves

While both tradable deforestation permits and a Pigouvian tax on deforestation could theoretically lead to economically efficient outcomes, neither would in practice due to uncertainty over marginal cost and benefit curves. If tradable deforestation permits were to become feasible, could anything be said about which of these policies might be most efficient in practice?

The relative slopes of the marginal cost and benefit curves when there is uncertainty can help determine which policy is likely to be most efficient. If the curves are unknown exactly, but it is known that the marginal cost of preventing deforestation curve is rising relatively steeply compared to the marginal benefit from preventing deforestation curve, then subsidies are a less distorting policy. Under these circumstances, if costs of preventing deforestation are higher than expected, then tradable deforestation permits will lead to the pre-determined preferred level of forest stock, but at a very high price for developers. If costs are lower than expected, then significantly more forest could be preserved at a low price. On the other hand, if the marginal benefit from preventing deforestation is rising faster than the marginal cost, permits are the less distorting policy. This is because the cost of controlling deforestation will vary little over a wide range of permit quantities, while the quantity of forest preserved will vary significantly over a narrow range of subsidies.

What can be said about the relative slopes of the marginal cost curve and the marginal benefits curve? Benefits are composed of the public goods and avoided negative externalities of production so often discussed. Under the assumption of decreasing marginal benefits to rain forest, the benefit curve will have increasing slope as forest stocks decline. Prevention costs are composed of the actual costs of curbing deforestation, as well as the output lost. Returns to deforestation in the Amazon are not particularly high, and since Brazil is increasingly an open market, should be fairly constant (since the country can replace output loss with imports or domestic production elsewhere.) The cost of preventing deforestation would arguably be negative for the first units (e.g. halting road construction, ending fiscal incentives for deforestation), though to prevent all deforestation would undoubtedly prove quite costly. The deforestation prevention cost curve should therefore have a gradually increasing slope as forest preservation increases in each time period. Each time period will have a different marginal cost curve, however, since preventing deforestation is a constant effort. In sum, little can be said about the shape of the marginal cost curve through time. The marginal benefit curve almost certainly shows an increasing slope as stocks decline. This suggests that while taxes may initially be the preferred policy, tradable deforestation permits will become increasingly preferred as the forest stock declines.

29) Raising Land Prices and Closing the Frontier

Land in the Amazon has historically been very cheap[57], and in the past two years land prices have fallen 'vertiginously', which can contribute to increased deforestation (INPE, 1998). With abundant land readily available, farmers substitute land for scarce capital and labor (Kyle and Cunha, 1990). It becomes more economical to mine the soil and move on than to import fertilizers and pesticides to depleted soils[58], and more economical to log only the most valuable trees from vast areas, with virtually no incentive to manage forests for timber (Uhl, et. al., 1995). Only when land becomes sufficiently scarce or expensive does it pay to invest in its productive capacity.[59]

There are several reasons for low land prices. First, private markets do not fully value the public good benefits of the rainforest, and hence these benefits are not reflected in the price. Second, the expanding road system provided by local and national governments as well as by the timber industry is constantly opening up new land to colonization, and the increasing supply drives prices down. Third, the

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[57] Schneider (1995) gives current agricultural land prices in the Amazon as varying from $2.50/ha on the more distant frontier in Pará to $300/ha in the Paragominas region near Belém. Espírito Santo and Faleiros (1992) give weighted 1991 average undeveloped land values as varying between $21/ha for Roraima to $169/ha for Mato Grosso. Almeida and Uhl (1994) provide 1990 values of $273/ha for the Paragominas region. These prices are relatively low for Brazil.

[58] I include pesticides because agricultural pests in the Amazon tend to be opportunistic local species, and are less of a problem on freshly cleared land (Hecht, 1982; Homma, 1993b).

[59] The price of land is of course closely related to its supply and demand. In the Paragominas region, most land is titled and 34% is cleared. Real land prices have increased by over 500% since 1973, when unclaimed land was still available, and prices were only $44/ha (Almeida and Uhl, 1994). Roraima is among the least densely settled states, has roads providing access to lands, and land is cheapest. In Mato Grosso, all land is apparently in private hands, and the open access regime has ended. Land there is consequently the most expensive on average in the Amazon (Espírito Santo and Faleiros, 1992). Either increasing demand or decreasing supply will drive up land prices.

lack of accessible credit may mean less money is available for land purchase, and the resulting lack of demand lowers prices (Schneider, 1995).

If land is purchased to provide private benefits that require deforestation, than raising the price of forested land has the same impact as a Pigouvian tax on deforestation. Once forested land becomes expensive, then raising the price of deforested land increases the incentives for investing in its productive capacity.

The price of forested land is best increased by reducing the supply, and banning road construction into primary forests is the most effective means to achieve this (Schneider, 1995). Road construction is essentially a subsidy for procurement of forested land, and eliminating the subsidy will eliminate the market distortions that accompany it, as well as reduce government expenditures. Timber companies are also major road builders. Road construction is very expensive, but becomes necessary as accessible timber stocks are exhausted (Veja, 1995). Implementation of more sustainable logging techniques should reduce the need for expensive new logging roads.

Schneider (1995) discusses a number of policies for increasing the price of already cleared land by driving up demand, which I briefly summarize here. Improving existing roads and providing services (schools, hospitals, etc.) to existing settlements will increase demand for land blocks nearby. Improved roads can drastically reduce transportation costs[60], lower the price of inputs and increase net

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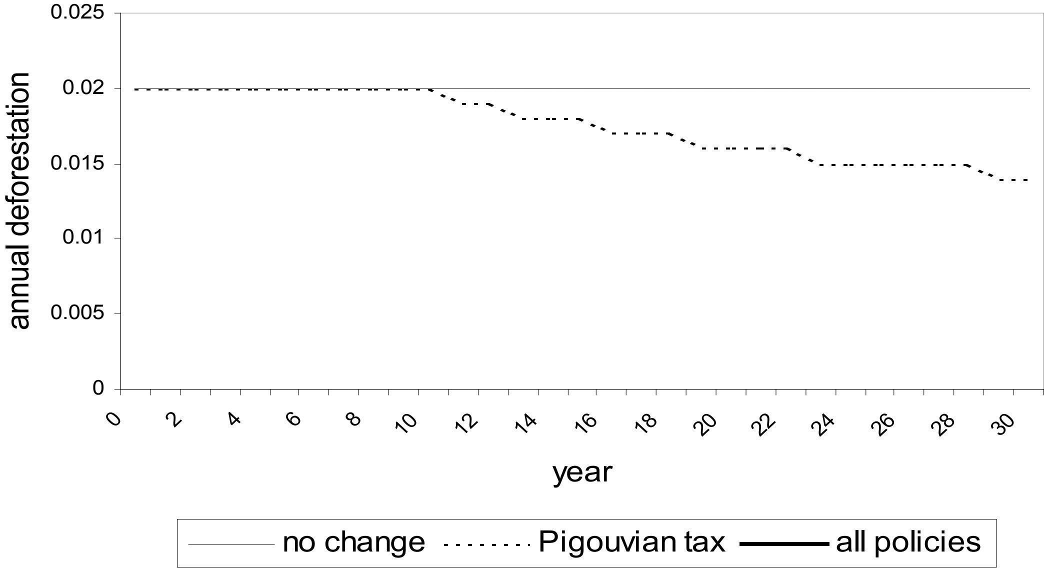
[60] Depending on the product, transport costs over unimproved roads can consume over 50% of potential profits. For example, transporting cassava by burro troupe 50 km to market costs 57% of the cassava's value. On improved roads, transport costs for trucks equal only 6% of the cassava's value for the same distance. (Guimarães and Uhl, 1995)

revenue from output. Accompanied by improved services, road intensification will increase the opportunity cost of abandoning lands to colonize new areas of the frontier. Road intensification (building more roads in settled area) helps more people per kilometer than road extensification (extending roads into new areas), and to the extent it slows deforestation elsewhere is a benefit to all society. Replacing a policy of extensive road building with one of intensive road building could be revenue neutral and is far likelier to receive local support than simply eliminating road construction all together (Schneider, 1995; Guimarães and Uhl, 1995). Secure land tenure, as discussed above, should also increase land prices.

If we assume that a $31 tax on deforestation has the same impact on the public good value as a $31 dollar Pigouvian subsidy, it should raise the public good value of intact rainforest to 2. Increasing the price of land might then further raise the public good value to 3. Figures 28a-b show the impact at the local level of an increase in the public good value to 3 alone and in combination with technological change (a_1=.05) and policies which lower the discount rate to 3%. Simply increasing the public good value only leads to a slowing of deforestation rates after 13 years, and total deforestation of 22.6% in 30 years. However, if all the policies described are implemented, so public good valuations increase, discount rates are lowered and technologies are made more sustainable, deforestation rates begin to slow immediately, and total deforestation is only 13.4% after 30 years.

Figure 28b



Figures 28a-b: The optimal time paths of forest stock and annual deforestation (million km²) at the local level with no policy change, with a Pigouvian tax on deforestation and higher land prices to increase the valuation of the public good, and with all policies discussed: higher public good value, lower discount rate, and more sustainable technologies. (see text for details on parameters)

30) Direct Controls

The most straightforward means of limiting deforestation are direct controls. In the absence of enforcement, however, such controls are virtually useless. For example, there has long been a law on the books limiting deforestation to 50% of any plot, and this limit has recently been decreased to 20% (Martins, 1997). Lack of enforcement meant that the 50% limit was ignored, and making it stricter is unlikely to help. Any direct controls must include money for monitoring and enforcement. Fortunately, now that the congress has passed a law allowing IBAMA to impose and collect fines, much of this monitoring and enforcement can become self financing. However, the simplest type of direct control is simply setting aside land for conservation, and providing the resources to ensure that this status is respected. There are two basic mechanisms for the international community to achieve this: debt for nature swaps and outright purchase and protection of land.

Debt for Nature Swaps

Debt for nature swaps are a widely discussed and frequently used approach to preserving endangered ecosystems in developing countries. The mechanics and suitability of debt for nature swaps have been well covered by Kyle (1990), and are simply summarized here.

The mechanics of debt for nature swaps are fairly simple. The country or organization interested in preserving nature purchases debt from the holding institution at a discount that reflects the likelihood the debtor country will pay. The debt is then exchanged for debtor country currency. The debtor country may pay full price for the debt, or may receive a discount. The funds are then directed toward wilderness conservation, often some highly visible project such as creation of a national park. The advantage to the debt purchaser is that the purchased debt can be exchanged for more than was paid for it, and the advantage to the debtor is that debt may be paid with national currency.

There are however serious drawbacks to this policy. First, the debtor country must either print more money or transfer funds from other uses to purchase the debt. This can cause inflation under the first option, or else reduce funds for some other purpose that the debtor country initially considered more important (or else the funds would have been allocated for nature preservation in the first place.)

Alternatively, the funds are simply transferred from another nature preservation project.

Second, debt for nature swaps have limited possibilities. Debt must be purchased from private banks. World Bank and IMF funds are not sold for discounts, since they are the first repaid by debtor countries. Private banks may be reluctant to sell their debt, since once some is sold at a discount, accounting procedures apparently demand that all debt from the country in question be discounted at the same rate. Banks may be reluctant to do this.

Third, of the three actors in a debt for nature swap- the debt purchaser, the creditor and the debtor- the only clear beneficiary of this policy is the creditor. No bank would sell debt at a discount if it expected the debt to be repaid, nor would they sell the debt for less than it is worth. To the extent the debt would not be repaid, the debtor country gains nothing with a debt for nature swap. The debt purchaser nominally obtains a better exchange rate with which to purchase nature preservation, but as pointed out above, the debtor country must switch funds from some other area or print more. It could be that funds would be switched from some program that addresses root causes of environmental destruction (e.g. anti-poverty programs, etc.).

In summary, Kyle argues that direct payments for nature preservation are a better option. Direct payments are a source of new funds for developing countries, and do not require funds to be switched from another area. None of the benefits go to banks, and thus more money is available for its intended purpose.

Direct Conservation: an Application of the Precautionary Principle

A policy option at the national and or international level would be to provide the government or national organizations[61] with the funding to set aside and protect conservation areas, such as national parks, biological reserves, ecological stations, national forests, environmental protection areas, extractivist reserves or Indian reservations, as mandated in the constitution (Rhebinder, 1993). This is a form of direct control on deforestation, and on the surface does not attempt to equate the marginal benefits of deforestation with the marginal benefits of preservation. However, there is a solid rationale for such an approach. The idea would be to purchase and protect a portion of the Amazon sufficiently large to ensure that the ecological threshold (p_2F_O) beyond which additional deforestation leads to spontaneous degradation cannot be passed. The assumption of the model is that the marginal cost of passing the ecological threshold is effectively infinite (i.e. unacceptable), since it would lead to the loss of the present Amazonian ecosystem.

The obvious problem with such a policy is that currently there is little notion of what minimum level of preservation would be required. The precautionary principle would argue for a margin of error that would insure against irreversible outcomes. Given the current state of knowledge, this would demand the protection of over 70% of the Amazon (Lovejoy, 1993), which is entirely unrealistic under current circumstances. Currently, some 3.5% of the Amazon is set aside as federal conservation units, and another 16% as Indian Reserves. Cardoso has just pledged (April, 1998) to triple the federal conservation

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[61] In order to defuse any questions about sovereignty, it would be best not to attempt direct purchase on the part of an international entity.

area to 10% of the Amazon (adding 25 million hectares to the existing 13 million). Including Indian reserves, this would bring conservation units up to 26% of the area of the Amazon.

However, many environmentalists are skeptical that Brazil will carry through with its commitment (Agence France-Presse, 1998; United Press International, 1998), and this may well be the case if they do not receive significant international assistance. In addition, it is quite possible that conservation of 26% of the Amazon would be inadequate insurance against ecological catastrophe. Setting aside 70% of the Amazon in conservation units, which would provide substantial insurance against irreversible deforestation, is simply not feasible at present. A more modest goal would be to select, purchase, establish and maintain conservation units over 40% of the geo-phytological Amazon. As more knowledge accumulates, and we develop a better estimate of the relevant ecological threshold, either more land could be purchased, or some of the purchased land could be developed.

How much would this cost? While an up to date, detailed study would be a massive undertaking, the cost of conserving 30% of the legal Amazon (approximately 150 million hectares) was estimated in a 1992 study by the Fundação Pro-Natura (FUNATURA)[62] (Espírito Santos and Faleiros, 1992). While only 40.6 million hectares of the legal Amazon was set aside in conservation units at that time, and there are now 74.1 million hectares set aside[63], some of FUNATURA's estimates can provide

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[62] Selection looks at biophysical, cultural and socioeconomic factors. Establishment includes demarcation, land purchase and infrastructure adequate for the intended function. Maintenance costs include enforcement and upkeep. All estimates include salaries, equipment costs, transportation costs, etc.

[63] i.e. 19.5% of 380 million hectares (from Agence France-Presse, 1998; United Press International, 1998)

a basis for calculating costs under current circumstances[64]. FUNATURA estimated the average costs for purchasing undeveloped land at $53.40/ha, for demarcation, management plan, infrastructure and equipment at $11.72/ha, for regularizing existing conservation units (i.e. paying compensation to former owners and providing adequate infrastructure and protection) at $13.10/ha, first year maintenance costs at $0.66/ha, and annual maintenance costs at $0.61/ha[65]. Table 7 shows the costs involved. The World Bank has already agreed to provide $30-$40 million to carry this out (Agence France-Presse, 1998; United Press International, 1998).

Table 7: The Estimated Costs of Establishing and Maintaining Conservation Units in the Amazon Rainforest. All monetary figures in US$1000. (cost data from Espírito Santos and Faleiros, 1992; calculations performed by author).

Conserv'n units	ha (in millions)	Regulariz'n	Demarcat'n, mgm't plan etc.	first year m'ntenance	annual m'ntenance
existing	74.1	$970.7		$48.9	$45.2
pledged (a)	25.0		$293.0	$16.5	$15.3
proposed (b)	53.2		$623.5	$35.1	$32.5
totals	152.3	$970.7	$916.5	$100.5	$92.9

total initial cost	$3,912.1	total initial cost/ha	$25.69
total annual cost	$92.9	total annual cost/ha	$0.61

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[64] Most of the costs FUNATURA estimated were for land purchase (Espírito Santos and Faleiros, 1992), and given the sharp decline in land prices in recent years (INPE, 1998) the estimates should still be reasonably close despite inflation. With the reduction in costs of satellite imagery and the availability of GPS (Almeida and Uhl, 1995), real demarcation costs have probably fallen as well.

[65] FUNATURA provided total costs and hectares, calculations for average per hectare costs were performed by the author.

a) additional conservation units pledged by Cardoso
b) additional units proposed by author

Even if these estimates were off by a factor of two, it would appear that conservation units may be a cost effective way to ensure that forest stocks remain above the sustainability threshold. However, in the short run, conservation units are likely to do little to slow deforestation. This is especially true if the costs of establishing conservation units are minimized by purchasing the cheapest land, which is likely to be furthest from the agricultural frontier.

31) Summary and Conclusions

This chapter has outlined numerous steps that can be taken to slow deforestation in the Amazon. The remaining question is, which should be adopted? Appropriate policies must be theoretically sound, politically feasible, effective in practice and affordable. Most important, there must be incentives to slow deforestation, and this may not be the case at all levels of society.

At the local level, the models suggest that deforestation is probably less than is optimal under current conditions, but is constrained by a lack of capital and labor. At the national level, the model suggests that current deforestation rates may be reasonably close to the optimal level. This result is supported by the fact that the Brazilian government has ended many policies that encourage deforestation, but has taken few effective steps towards slowing it. Brazil might prefer slower deforestation, but apparently not if this requires considerable expenditures. However, while deforestation rates may be acceptable locally and nationally, it seems there is still considerable room for more efficient exploitation of the Amazon with less resource wastage. Hence, research, development and extension services may well be the best policies to pursue at these levels.

Significant expenditures to slow deforestation in the Amazon may only be justified if the international public goods it provides are accounted for. As long as the developed nations continue to free-ride on the provision of these goods, the current level of deforestation is unlikely to change. However, if international resources are forthcoming it may be possible to slow deforestation, allowing time to resolve uncertainties and progress towards a more satisfactory outcome.

Theoretical justification exists for all the policies described in this chapter. The satisfactory provision of global public goods justifies an international Pigouvian subsidy and international funding of existing environmental legislation. The precautionary principle combined with the risk of crossing irreversible ecological thresholds justifies establishment of conservation units over large areas of the Amazon. The rational discrepancy in discount rates between the wealthy and poor and individuals and society justifies credit subsidies (assuming that they could lower discount rates). The negative externality of public good loss from deforestation justifies deforestation taxes and tradable deforestation permits. The tragedy of the commons argument justifies establishing secure land tenure. The public good nature of knowledge justifies government or international community support for research and extension.

Political feasibility weakens the international Pigouvian subsidy option. There is little likelihood such a policy would find support in the international community, largely because it would lack solid accountability. While Brazil would only get the money if deforestation slowed, the funds themselves would be highly fungible. Corruption would undoubtedly account for much of it. Feasibility also weakens the option of international funding for existing environmental legislation in Brazil, since it is doubtful that Brazil is serious about enforcing it. Still, it would probably be in the best interests of both Brazil and the international community were Brazil to accept the level of support that the international community is likely to offer.

Effectiveness in practice further undermines the international Pigouvian subsidy, and virtually dooms the credit subsidy option outright. A Pigouvian subsidy assumes that the Brazilian government has the ability to seriously affect the rate of deforestation in Brazil, and this is highly questionable. Credit subsidies are fungible, would relax capital constraints, and could therefore lead to an increase in deforestation. Securing land tenure affects only a small percentage of land in the Amazon, and is unlikely to have a substantial impact. Debt for nature swaps are likely to be less effective than similar expenditures that bypass the banks, and therefore need not be considered further.

Affordability is largely determined by the willingness of developed countries to pay for the public good benefits provided by the Amazon Rainforest. As mentioned above, the PPG7 has agreed to provide $1.6 billion towards slowing deforestation in the Amazon over a number of years, of which $291 million has been approved (GTZ, 1997). The World Bank has agreed to provide $30-$40 million towards establishing conservation units in the Amazon, has stated its intention to help conserve 10% of global rainforests by the year 2000, and has $2.57 billion in the GEF for the next three years (Agence France-Presse, 1998; United Press International, 1998). These numbers give some ball park idea of the financial constraints imposed upon the policies examined in this chapter. Table 8 summarizes policy costs, feasibility, effectiveness and affordability for comparison.

An international Pigouvian subsidy large enough to be effective would cost in the neighborhood of $1 billion per year, several times more than the global community has been willing to contribute. Credit subsidies are less costly, but in light of their ability to do more harm than good, are far too expensive to experiment with. While the purchase and protection of conservation units is expensive, the expense can be spread out over several years, and the per hectare cost of conservation is quite low.

The criteria used here eliminate the international Pigouvian subsidy and subsidized credit as policy options. The remaining options are to some degree effective, feasible and affordable, and can now be prioritized.

Perhaps the highest priority at the international level should simply be funding of existing environmental legislation. The cost is moderate, it is nationally and internationally feasible, and it should prove reasonably effective even in the short term. Given the importance of public goods from the Amazon, simple market solutions may never lead to adequate conservation. Brazil must develop the institutional capacity to control deforestation in the region, and international assistance can help it do so more quickly. Satisfactory policies that can be administered by existing institutions may be more cost effective than superior policies that rely on creating new ones.

Table 8: A summary of the annual cost, political feasibility, effectiveness and affordability of various policy proposals.

Proposal	Annual cost (US$mil'n)	Political feasibility	Effectiveness at slowing deforestation	Affordability
Status quo	$0	high	zero	high
Pigouvian subsidy of $90/ha	$81-$135	low	low	medium
pigouvian subsidy of $750/ha	$1005-$1275	very low	depends on national level policies	low
Pigouvian subsidy of $1494/ha	$2540-$2689	nil	depends on national level policies	very low
subsidized interest rates	$607-$685	medium (a similar policy exists)	very low to negative	low
secure land tenure	$67	medium	low	medium
research & extension	$8.4 $20	medium to high	low in short term, medium in long term	high
$31/ha deforest'n tax, higher land prices	$0 or negative	medium	high	high
funding existing legislation	$30-60	medium at international and national levels	medium	medium
40% of Amazon in conservation units	$3912 (total cost)	medium	low in short term, high in long term	medium to high if spread out over time

International funding for establishing and protecting conservation units should also be high priority. There is a proven willingness to pay for such ventures on the part of the international community, and Brazil has pledged to undertake such activities. While there may be little immediate impact, if sufficient conservation units are established and adequately protected, they can ensure against irreversible ecological damage. With most of the other policies suggested, deforestation of the Amazon will still depend on economic factors, and there is always the threat that economic conditions will eventually lead to forest stocks dangerously close to the sustainability threshold. Setting aside a portion of the forest based on ecological principles can remove this threat. Different strategies for exploiting the remainder of the forest can then be pursued without the risk of catastrophic results. The conservation units can be established gradually over years or decades. While total costs are quite high, they can be spread out over time, and the cost per hectare preserved is modest

Research and extension is also essential. Development of the Amazon will continue. Only adequate research and extension can teach us how to develop the region more sustainably, and how to profit from doing so. Even if deforestation rates are appropriate at the local and national levels, there is obviously potential for less wasteful, more profitable technologies. The current level of effort is woefully inadequate (see Table 6). Funding requirements are quite modest, though far more is needed than has been made available so far.

A deforestation tax payable upon transfer of title should certainly be attempted. The cost of implementation should be small, and easily covered by the returns. This option requires no international funding. Securing land tenure is of secondary importance. It is unlikely to have a large immediate impact, and is already being carried out at the national level. Perhaps it is best to see how effective the latest Brazilian efforts are before seeking additional international support.

If the international community donated $60 million per year to enforce existing legislation, $250 million per year to purchase and protect conservation units, and $28.4 million for research and extension, the total expenditures would be a bit less than $350 million per year. While this is equivalent to a global gas tax of about 2/10 of a cent per gallon, it is quite a bit more money than is currently being considered by existing programs designed to reduce deforestation in the Amazon. In addition, World Bank funding is in the form of loans, not donations, which implies that the Amazon is still basically perceived as a market good and not a public good. Further, many of the costs presented here may be optimistic estimates of what is required to achieve the impacts suggested.

In the near future, then, it seems highly unlikely that sufficient international transfers will be made available to noticeably slow deforestation in the Amazon, and exploitation will continue to ignore what are probably the most globally valuable goods and services the region provides. Under these circumstances, deforestation is likely to continue virtually unabated for some time to come.

However, as policy makers and the general public learn more about the ecological function of the world's rainforests, substantially higher levels of funding may be provided in the future. This may make increase the feasibility of other policies. Given the limited practical experience to draw from in developing policies to slow deforestation, resources which may become available in the near future should be directed towards pilot projects experimenting with different policies over small areas. This will provide the experience necessary to refine the workable polices, and discard unworkable ones.

In conclusion, too rapid deforestation is probably not a controllable phenomenon at present, given available resources. If substantial resources do become available in the future, it will still require time to develop institutional capacity and workable policies. However, as we come to understand more and more the vital functions of rainforest ecosystems and the Amazon in particular, it seems increasingly likely that the benefits to be gained justify substantial efforts. The following chapter examines our ethical obligations to address the deforestation issue.

CHAPTER SIX:

IGNORANCE, UNCERTAINTY, IRREVERSIBILITY, DISCOUNTING AND INTERGENERATIONAL JUSTICE

Introduction

Previous chapters discussed the optimal rates of deforestation in the Amazon at the local, national and international levels, but largely avoided intergenerational analysis. If society has an obligation towards future generations, this is a critical omission.

In fact, regardless of culture or economic system, it is widely accepted that this generation does have some sort of obligation towards future ones. Even the dispute between conservationists and anti-conservationists tends to focus as much on means as ends.[66] Anti-conservationists generally argue that technology will compensate for damage caused today, and man-made capital can replace lost natural capital. Few argue that we are entitled to leave nothing to future generations. Indeed, the increasing focus on sustainability in the economic literature is an implicit acceptance of some notion of intergenerational justice.

Many believe our obligations include a specific duty to preserve the Amazon ecosystem for future generations. The Charter of Principles (May, 1995), signed by the Governors of the States of the Amazon Region, declares that "it is essential that actions carried out in the Amazon region be guided by clear ethical principles, that they respect

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[66] At least for anthropocentric conservationists. Deep ecologists believe that man has no greater right to exist than other species.

Mankind's right to development in a conserved natural environment, which is in turn our legacy to future generations." At a national level, the Integrated National Policy for the Legal Amazon (1995) professes the same goals.

There are at least four factors which have a profound impact on long term environmental economic analysis and hence on the distribution of resources between generations: ignorance (defined here as lack of understanding of the current state of nature and its 'economic' value), uncertainty (defined here as inability to know future outcomes)[67], irreversibility and intertemporal discounting. These factors all affect what future generations will inherit, and how we choose to deal with them is as much an ethical as an economic issue.

Ignorance relates to our lack of knowledge both of ecosystem functions and of the value of the non-marketed services provided by the ecosystem. In terms of the model, ignorance of ecosystem function means we do not know the magnitude of the negative impact of ecological degradation on crop yield (γ) and on forest regrowth (β_2). In fact, we are not even certain of the rate of forest regrowth in the healthy ecosystem (β_1). The difficulty in determining the social value of public goods ($v(S)$) is compound-- in the absence of markets, we may be unable

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[67] Ignorance and uncertainty as defined here are also referred to as subjective ignorance and objective ignorance. For example, some theoretical physicists postulate that if one could know the position and velocity of all particles in the universe, one could determine all past and all future positions and velocities, and hence know the past and future. This would mean that any inability to predict future change would be the result of subjective ignorance: the only reason we can not predict the future is that we do not have total knowledge of the present. Other physicists however suggest since black holes capture particles but release nothing (they absorb information and release none), even in theory the future cannot be predicted. This is objective ignorance: certain aspects of the future are inherently unpredictable. Objective or subjective ignorance has the same results in economic analysis: there are certain changes that cannot be predicted ex-ante, and systems undergoing these types of changes cannot be modeled for predictive purposes.

to value even the functions we do understand. While development decisions made with insufficient knowledge clearly affect the present generation, the fact that functional change in ecosystems often follows structural change by a significant time lag means that future generations may feel an even greater impact. Research can help diminish ignorance of ecosystem function, and valuation methodologies for non-marketed goods may potentially address the value problem. However, research takes time, and human intervention may be changing the nature of the Amazonian ecosystem faster than we come to understand it.

Uncertainty is critical with respect to technological advance and ecological change. Research and experience with production systems in the Amazon are likely to change the aggregate agricultural yield function which is at the core of the model presented in Chapter Two. As discussed in Chapters Four and Five, new technologies may lead to increases in the value of α_2 or decreases in the value of γ, both of which are reflected in the variable p_1 (the proportion of forest stock beyond which cumulative deforestation has a negative impact on agricultural output). This variable (p_1) in turn is an important determinant of private good benefits from the Amazon with a significant impact on the optimal deforestation rate. Alternative crops or production technologies may alter the value of p_2, the sustainability threshold. However, time too is a critical component of technological advance: the greater the rate of change in the ecosystem, the less time technologies will have to adapt, and the less likely the above parameters will evolve.

With respect to ecological change, irreversibility compounds the problem of uncertainty. With sufficient data, one could roughly estimate the probable value of p_2, the point at which deforestation becomes irreversible, though this value of course will be influenced by global weather patterns, cyclical weather changes, ozone depletion, etc. However, what happens when forest stocks fall below p_2 is inherently unpredictable, yet has profound implications for future generations. Again, time is a critical factor: the faster ecological change occurs, the more we risk inadvertently falling below p_2, and the more we risk catastrophic change. This is true for at least two reasons. First, as mentioned, there may be a significant time lag before structural change (change in the actual structural components of an ecosystem: species populations, vegetative cover, etc.) manifests itself in functional change (change in rainfall patterns, climate, life support systems, etc.).[68] When structural change occurs too quickly, we may only understand its full impact much later. Second, though species can migrate or evolve in response to new conditions, both events require time.

The discount rate is thus critical to intergenerational analysis for several reasons. First, the higher the discount rate, the less we value the future, and the less we value sustainability. Second, high discount rates generally imply a faster rate of depletion of resources, and thus less time for knowledge to accumulate before it becomes obsolete, and less time for technologies and species to adapt to ecosystem changes. Also, the discount rate is implicitly related to the question of intergenerational property rights, an integral component of any notion of intergenerational justice.

The basic goal of this chapter is to determine a minimum standard for intergenerational justice, and examine the impact of

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[68] For a good explanation of structural and functional features of tropical forest ecosystems, see Farnsworth, et. al., 1983

ignorance, uncertainty, irreversibility and discounting on achieving that standard. These results will then be used to re-evaluate the conclusions of the previous chapters.

Brief History of the Intergenerational Distribution Question in Economics

Intergenerational distribution has long been a topic of concern in economics, but the way the issue is perceived has evolved along with the advance of technology and the increasing importance of the human impact on natural resources and the environment.

Some of the earliest writings on the subject were by Malthus and Ricardo. Both saw that continually growing human populations were not compatible with finite resources, and must eventually lead to generalized subsistence survival. It is important to note that these two were writing near the start of the industrial revolution. Prior to this, the rate of advance of human technology was so slow as to be scarcely noticeable in a given generation. Only with the advent of the industrial revolution did technological change begin to rapidly accelerate. The pessimism of Malthus and Ricardo may have simply reflected the infancy of the technological age at the time of their writings.

Up through the mid 20th century, some economists continued to worry about resource exhaustion, but continuous advances in technology and standards of living led most intergenerational analysis to focus on the optimal savings rate issue. How much capital should one generation accumulate for the next, at the cost of current consumption? One of the most influential results of this analysis was Phelps' Golden Rule of Capital Accumulation (Phelps, 1961,1965). Basically, the idea was that current generations should sacrifice for future generations until the maximum sustainable per capita consumption was achieved. Since successive generations were living better owing to the contributions of past generations, it was virtually taken for granted that we should sacrifice for the greater well being of future generations.

As human populations and per capita resource consumption continued to grow, it became clear that humans had the potential to exhaust certain resources in the foreseeable future. The intergenerational distribution debate in economics shifted to the question of exhaustible resource use and non-sustainable use of renewable resources. Hotelling (1931) offered perhaps the earliest important contribution, that a non-renewable resource should be exhausted at such a rate that the price increases at the same rate as returns on capital[69]. In terms of renewable resources, economists suggested harvesting rates which maintained the maximum sustainable yield were unlikely to be economically optimal, while in some cases, resource extinction could be (e.g. Clark, 1990). In the 1970s, Rawls (1971) published his seminal work on justice, which had a significant impact even in economics. Solow (1974) and others explored the implications of resource exhaustion for intergenerational equity. The emerging consensus appeared to be that imminent resource exhaustion led to higher prices and hence incentives to innovate substitute resources or use existing backstop resources. Self-regulating market mechanisms made non-market intervention unnecessary. While many scientists were alarmed by the imminence of resource exhaustion (e.g. The Limits to Growth, Meadows et. al., 1974), economists generally tended towards greater complacency.

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[69] While theoretically compelling, there is apparently little empirical evidence that this ever holds true

The 1960s and 1970s also brought increasing attention to environmental degradation. Pollution was becoming a serious problem, which many economists recognized as a market failure. The field of environmental economics evolved quickly, and developed mechanisms for valuing environmental goods and internalizing externalities to the production process. Economists recognized that uncertainty and irreversibility were critical aspects of environmental issues, and incorporated these into their models. Still, the general belief has been that if we resolve the problems of externalities and public goods, and include option values to compensate for uncertainty, market prices will determine the optimal usage of resources and environmental goods.

In recent years, scientists have become increasingly aware of the life support functions of ecosystems, many of which may be essential to human survival; of the difficulty or impossibility of predicting ecological change; and of the increasing size of the economic system in relation to the global ecosystem which sustains it. In combination with resource depletion and pollution, this has led to an increasing emphasis in the economics profession on sustainability. Unfortunately, our ability to understand causality in complicated ecosystems and our ability to predict the future is not sufficient to illuminate a clear path to follow towards sustainability.

Intergenerational Justice

Before we can attempt to discuss intergenerational obligations, we must understand clearly what the nature of the problem is. There are three important ways the current generation can have an impact on future generations: population growth, the amount of man-made and the amount of natural capital we leave. Man-made capital can be subdivided into capital goods (infrastructure, machinery, etc.) and knowledge (technology, culture, etc.). Natural capital can further be subdivided into three categories with distinct attributes: non-renewable natural resources, renewable resources (defined to include the waste absorption capacity of the environment), and environmental goods (which include life support functions of ecosystems, amenity values, genetic resources, climate stability, etc.).

It is also necessary to define what intergenerational justice is. As Barry states, "the central issue in any theory of justice is the defensibility of unequal relations between people" (Barry, 1989, p.3). One theory of justice, introduced in Plato`s Republic is that justice arises from mutual advantage. Succinctly, "[j]ustice is the name we give to the constraints on themselves that rational self-interested people would agree to as the minimum price that has to be paid in order to obtain the cooperation of others." (Barry, 1989, p.7) Glaucon in Plato`s Republic says that someone capable of inflicting injustice without suffering it would be 'insane' to make a pact prohibiting him from doing so. In this view, there is no such thing as intergenerational justice, since we are capable of inflicting any injustice on future generations without fear of reprisals. If we accept that we have ethical duties to future generations, then we must believe in an alternative theory of justice.

Perhaps the most widely accepted alternative theory is commonly referred to as 'justice as impartiality', or 'justice as fairness'. Under this theory, it is just to give to others that which they cannot demand, but which would be fair (Shue, 1992). It is this understanding of justice which motivated John Rawls' Theory of Justice (1971).

Examining intragenerational justice, Rawls theorized what the distribution of goods would look like in a just society. He first assumed that a person's wealth and position in society arose as a result of three morally arbitrary lotteries: one for parentage and natal social position, a second for luck, and a third for genetic potential. Since all inequalities in wealth and power arose from morally arbitrary lotteries, the only initially justifiable position must be one of equal distribution. However, equal distributions remove incentives. By providing incentives, allowing inequality would lead to greater wealth, and could improve the welfare of everyone over the initial equal distribution. As long as increasing inequalities improved the welfare of everyone (Pareto improvements), everyone would agree to it. However, beyond a certain point, increasing inequality might make some groups better off while making others worse off. If we would arrive at one of these positions starting from equality, we are going beyond mere Pareto improvements.

What Rawls concludes is that inequality should be increased until it maximizes the welfare of the worst off group. While those at the bottom should favor this since it maximizes their welfare, it is possible that some groups would have higher welfare with lower inequality, and would therefore favor a stop to increasing inequality where they maximized their welfare. Rawls asserts roughly that as differences arise from morally arbitrary advantages in the first place, what was fair to the worst off group must also be fair to any group better off then they are. Basically then, the worst off group has veto power over the degree of inequality. Rawls refers to this concept as the difference principle. It is equivalent to maximizing a Bergsonian social welfare functional with zero weight on all groups except the worst off (Kreps, 1991).

This analysis cannot easily be extended to deal with intergenerational justice. It is clear in Rawls work that the dominant intergenerational question in his mind was that of capital accumulation rather than resource depletion, yet applying Rawls' difference principle to intergenerational justice would lead to us doing nothing to make future generations better off than we are. Rawls himself realized this problem, and did not attempt to apply the difference principle to issues of intergenerational justice. In fact, Rawls states that

> "…the question of justice between generations… subjects any ethical theory to severe if not impossible tests… I believe that it is not possible, at present anyway, to define precise limits on what the rate of savings should be. How the burden of capital accumulation and of raising the standard of civilization is to be shared between generations seems to admit of no definite answer." (quoted in Solow, 1974)

Rather, Rawls offers a

> "deliberately vaguer principle, given by the balance between what a typical person feels it is reasonable to ask of his parents and what this same person is prepared to do for his children." (Solow, 1974)

This 'vaguer principle' is similar to the frequently heard claim that as long as we care about our children and grandchildren, the free market will lead to the appropriate amount of resources for future generations. This might be true if determining an optimal savings rate were the only problem, but it ignores the potential for very long term environmental problems, such as global warming, nuclear wastes, etc. Our actions today can affect generations far enough in the future that kinship is scarcely felt.

Rawls' problem with applying his difference principle to intergenerational issues was apparently his belief that 'raising the standard of civilization' should be a goal. The difference principle fails because it does not lead to the increased well being of future generations. Since Rawls wrote, however, the intergenerational distribution debate has increasingly shifted towards sustainability, i.e. making sure future generations have as much as we have, or at least enough to comfortably survive. We are no longer at all certain that future generations will be better off than our own, and the worry is that they may be worse off. What implications does this have for extending Rawls' analysis to intergenerational issues?

Certainly, the generation into which someone is born is morally arbitrary. This would then imply that an equitable division of resources and capital between generations would be just. Renewable resources could only be used at the rate which they can replace themselves, a constant capital stock would be maintained and passed on to the next generation, and exhaustible resources would be divided equally among generations. There are two absurdities inherent in this result. First, human capital accumulates as long as we make advances in science and technology: in the absence of catastrophe or fundamental changes in human society, future generations will inherit more knowledge. Second, equitable division of exhaustible resources over infinite generations leads to each generation receiving an infinitely small amount. Any other division which awards finite quantities to a finite number of generations is a Pareto improvement- those generations receiving the resource will be better off, while those not receiving it will be no worse off than before.

The difference principle would not hold one generation responsible for making the next generation better off, but at a minimum it would seem to forbid one generation from causing subsequent ones to be worse off than they would have been with equal division of resources. Since equal division of resources implies zero use of non-renewable resources, there would appear to be no special obligation for one generation to share exhaustible resources with future generations, as long as:

32) The waste flow from resource use does not overwhelm the absorptive capacity of the environment, or if it does, compensation is left for the future.

33) Future generations are not left dependent for survival upon resources in danger of exhaustion. This implies human populations cannot rely on exhaustible resources to exceed the carrying capacity of the earth, or at least must cease to do so before the necessary resources are exhausted.

34) The well being of the generation using the exhaustible resources would be no better than that of future generations if neither used the resource. If in the absence of the exhaustible resource some generations would be worse off than others, than these generations would have the right to use those resources.

With respect to renewable resources, the difference principle implies that if they are harvested at greater than maximum sustainable yield, the future must be compensated. If yields exceed this maximum yet remain sustainable (i.e. the same yield may be taken every year, without further degradation of the resource), compensation need only match the utility lost by a future generation decreasing its harvest of the renewable resource until stocks increase sufficiently to again support the maximum sustainable yield. If renewable stocks are harvested beyond their capacity to recuperate, compensation must be an equivalent resource flow from an alternative stock for infinite time

Exhaustion of exhaustible resources or extraction rates of renewable resources which are sustainable but below the stock providing maximum sustainable yield are finite losses, whereas exhaustion of a renewable resource is an infinite loss. Compensation to future generations should reflect this.

It is worth noting that under Rawls' difference principle, those generations living at or below the subsistence level would have no obligation to future generations.

It would appear that in the real world, some resources are being depleted at such a rate that future generations may suffer the negative impacts of the resource use without having the benefits of the resource itself. Hydrocarbon fuels and global warming is a good example. Future generations are also being left dependent for survival upon exhaustible resources. Without oil for energy, fertilizers, pesticides and transportation, it might be very difficult to maintain sufficient agricultural output to feed Earth's population[70]. Some renewable resource stocks are also being irreversibly exhausted. The question is, does our accumulation of man-made capital compensate future generations? This question depends on the unknown costs of

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[70] While it certainly may be possible to develop agricultural systems which could feed the earth's present population without non-renewable inputs, developing and implementing such systems may be costly and slow. Cuba, for example, is no longer able to import the fuel, pesticides and fertilizers it formerly relied on for agricultural production, and is now returning to animal traction, bio-pesticides and organic fertilizers. Given the relatively well educated workforce, the extensive studies of alternative agricultural systems before the crisis hit, and the high concentration of scientists in this field (Cuba, with only 2% of Latin America's population, has 11% of the region's scientists), Cuba is better situated to convert to sustainable farming than almost any other developing country. Nonetheless, food production has plummeted, and per capita caloric consumption has declined by as much as 30% (Rosset and Benjamin, 1994). This does not mean that such conversion is impossible, just that it is difficult and costly. I argue that the obligation to future generations demands we be able to convert to sustainable systems before the relevant non-renewables are exhausted.

environmental damage to future generations, and the unknown benefits of man-made capital accumulation. Uncertainty therefore is a crucial factor that must be considered.

Before examining the role of uncertainty, what are the generalizations that can be made about man-made versus natural capital? Perhaps the most important distinction is that natural capital can be irreversibly damaged or destroyed. Worse, we typically do not know when irreversible change occurs in ecosystems or renewable resource dynamics, and in the ecosystem case we rarely understand the full implications. Second, the first law of thermodynamics tells us that man-made capital must always rely on natural capital- the two are ultimately complements, and man-made capital can never completely substitute natural capital[71]. Third, there is as yet little evidence that man-made capital can substitute for the life support functions of ecosystems. Fourth, capital goods depreciate, and if they are left to the future in compensation for an exhausted renewable resource, the resource flow necessary to maintain them must be left as well. Fifth, man-made capital tends towards obsolescence[72]. Sixth, technology is not always beneficial[73], and even beneficial technologies may have seriously negative side effects, many of which are not immediately apparent. Seventh, probably the most important man-made resource

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[71] It might seem that knowledge could exist even in the absence of natural resources. However, humans rely on natural resources for their existence, and knowledge is irrelevant without us.

[72] A well-maintained road system left for the future to compensate for global warming will be of limited use if the future no longer uses cars. If global warming becomes a serious problem, many of our fossil fuel consuming technologies may become obsolete even before fossil fuels are exhausted. Any technology that relies on exhaustible resources will eventually become obsolete.

[73] The technology for weapons of mass destruction, crack cocaine, and certain harmful chemicals, for example, probably leave the future worse off

we leave for future generations is accumulated knowledge, which will lead to new technologies. However, prior to the invention of a new technology, nothing can be said with certainty about what it will be[74]. Hence, we cannot say with certainty if future technologies will compensate for natural resource depletion.

To what extent can man-made capital replace natural capital theoretically? One article on intergenerational ethics by Solow (1974) proposes a model with essential resources in which as resource supply approaches zero, efficiency of use approaches infinity. In another article, Solow (1973) goes so far as to state that, because of resource substitution, production may be possible with virtually no resources whatsoever.

Both the assumption of increasing efficiency and resource substitutability do have significant empirical support. As Britain used up its forests for charcoal, this induced the development of coal mines and coal burning technologies. As human populations have expanded beyond the productive capacity of a given food producing technology, new technologies have increased the productive capacity of land, leading us from tribes of simple hunter-gatherers to genetic engineering and the modern agriculture of today. Imminent exhaustion of a resource does spur research and development of substitutes or greater efficiency. What's more, there is a greater number of scientists alive today than in

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[74] Clearly, many inventions are predicted. Jules Verne for example predicted travel to the moon and submarines. He could not have assigned any realistic probabilities to when these inventions might occur. This only became possible when knowledge and technology had reached a more advanced level. Verne could not have predicted the mechanics of jet engines, nor the computer technology required for space flight, nor the transistors which set off the computer revolution. Application of known principles is less invention than innovation.

all of human history combined. Many economists thus claim that Malthus has been proven wrong.

Indeed, it is possible to envision a world where production occurs in the absence of virtually all resources. Imagine a world where the ozone layer and perhaps most of the atmosphere is destroyed, all life on earth except man and e. coli extinct. All minerals have been mined and used up, so the earth's crust is a homogenous mixture of all elements. All we would need are three feasible technological advances. First must come highly efficient solar energy. Plants currently capture a small fraction of the sun's energy which strikes the earth. With a solar technology that captured 50% of the sun's energy, we would no doubt have available abundant energy to extract minerals from a totally homogenous mixture with the same composition as the earth's crust.[75] We could live below ground, protected from radiation, pollution, storms, etc. Second, it may not be long before we understand the chemical process of photosynthesis sufficiently to replicate it in the laboratory with our own waste products and elements extracted from sea water. We could obtain food directly from the sun, with oxygen as a by-product. The final technology necessary would be virtual reality. As computer technologies advance, virtual reality will be able to recreate any outdoor experience we can currently enjoy, as well as wild fantasies currently impossible. Computer programs could easily be designed to mimic evolution. Basically every activity or product available today would be available in this future with virtually no resources apart from technology.

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[75] Ayres and Miller (1980) suggest some sort of fusion technology for extracting elements from a homogenous mass composed of the elements found in the earth's crust.

However, it is not immediately obvious whether this vision of post environmental apocalypse is paradise or hell. We cannot replace the existence value of certain environmental resources. As Fisher and Krutilla (1979) point out, the value of a perfect forgery of a great work of art is a fraction the value of the original. Even the suspicion of forgery, where even experts disagree, greatly lowers the value of the work. It is no doubt much the same with connoisseurs of environmental goods.

While it is possible to envision production in a world with virtually no resources, this does not mean we can ignore resource scarcity. First of all, while scarcity does induce innovation, technological advance is a function of accumulated knowledge. Accumulation of knowledge requires both time and effort. Natural resource prices respond to political turmoil and imperfect markets, and price increases may thus be far faster than expected, greatly decreasing the time available for developing substitutes and more efficient technologies. Also, the quicker a resource is exhausted, or the more sudden the price surge as a crucial resource nears exhaustion, the more likely is economic disruption. Severe disruption can slow down the creation of substitute resources: for example, during the great depression, or the recent breakup of the Soviet Union, economic chaos led to the unemployment of numerous scientists and decreased investments in research and development. Yet, the faster resources are depleted, the more rapidly technology will have to advance to compensate. Thus, there is no guarantee that efficiency increasing and resource substituting technologies will develop at the same rate as depletion of resources. This suggests that it would be safer to slow resource use while substitutes are being developed rather than await imminent resource exhaustion to trigger research into alternatives[76]. Regulations slowing resource use create artificial scarcity, inducing research into substitutes more quickly, and avoid the economic disruption which may accompany more sudden resource exhaustion.

Nor does the fact that Malthus has so far been wrong prove the assumption of infinite substitutability of resources. We are living in a constantly evolving world. Every day sees a greater increase in the world population and a greater depletion of renewable and non-renewable resources than any previous day. Population growth has accelerated far beyond what it was in Malthus time. It is difficult to base predictions on past experience when such unprecedented changes are occurring. Blind faith in the ability of technology in a free market system to overcome resource and environmental constraints as they occur, and thus compensate for depleted natural resources, seriously jeopardizes the well-being of this and future generations.[77]

In summary (and at the risk of redundancy), intergenerational justice at a very minimum calls for sustainability. Though we are not necessarily obliged to guarantee a standard of living equal to ours for future generations, we are obliged to ensure they are no worse off than they would have been under an equal division of resources. Since all

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[76] Agriculture in the US provides a good example. We currently depend on petroleum for producing and running farm equipment, for transporting goods produced, for manufacture of pesticides, herbicides and fertilizers and indirectly for almost every other facet of modern agricultural production. There are feasible substitutes for all of these petroleum based inputs, but to implement all rapidly as petroleum supplies run down will be costly. Food supplies might suffer, and the consequences could be severe. Given the instability of oil prices, and the paramount importance of maintaining constant food supplies, relying on as yet undiscovered technologies may be a very risky strategy. See footnote 73 above.

[77] A good example is nuclear power. When nuclear generators were first built, the full dangers of radiation were not understood. The assumption in the 1950s was that technology would develop a means for safely disposing of nuclear wastes when they became a problem.

natural resource inputs return to the ecosystem as waste outputs, the faster we exhaust resources, the more likely we are to overwhelm the waste absorption capacity of the environment. The faster we exhaust renewable resources, the more likely we are to decrease sustainable output or even cause irreversible damage. These losses will require compensation with man-made capital. Yet, technology itself requires time to develop. The basic dilemma is that faster resource use demands more technological compensation yet allows less time for this to occur.

To know whether we are managing to offset natural resources losses with man-made capital gains, we must be able to value resources.

Ignorance, Uncertainty and Market Valuation

The number of possible interactions in an ecosystem increases exponentially with the number of organisms in the ecosystem. As the Amazon exhibits the greatest biodiversity on the planet, it also exhibits the most complexity. As one of the planet's last frontiers, with difficult access, scientific knowledge about the region is minute compared to its complexity (Norgaard, 1981). As a result of this extreme ecological complexity and rapid social, economic, and environmental changes, ignorance and uncertainty are more characteristic of development in the Amazon than almost anywhere else on earth. Uncertainty becomes even more critical when we look at the long time horizons relevant to intergenerational issues.

If the market is to be used to determine the optimal rate and level of deforestation in the Amazon (or in other ecosystems), it is essential we know the value of the benefits produced by forests. Unfortunately, valuation would appear to require knowledge of ecosystem function beyond our present understanding. Can the market cope with these shortcomings?

Neoclassical economics offers several means of valuing resources. The simplest is obviously the price of a private good determined on the free market in the absence of negative externalities. For non-marketed goods, one can use the price of a marketed alternative, if one exists. In valuing negative environmental impacts, one can use the cost of undoing them as an upper limit. Recognizing the limitations of these methodologies, environmental economists have proposed contingent valuation, hedonic pricing and the travel cost methodologies as alternatives. However, none of these methods are suitable for valuing the innumerable benefits of intact ecosystems in the presence of ignorance and uncertainty.

First, many products and services of the rainforest are not marketed and have no marketed substitutes (e.g. biodiversity and climate regulation). In addition, there is no real way to estimate the costs of restoring some of these services once damaged, owing to the lack of theoretical and empirical knowledge, while other changes may be irreversible. Certain services could not conceivably be marketed, such as the existence value of the rainforest. Still, to the extent that these processes are understood, it might be possible in theory to estimate their value to this generation using contingent valuation methodologies.

There is however, at least one very serious flaw with such methodologies as contingent valuation. The fact is that many benefits of the rainforest are unknown, or at least “information about contribution to individuals’ well being is poor” (Costanza et. al., 1991, p. 10). We are now beginning to understand some of the global implications of ecosystem destruction, but even our most knowledgeable experts cannot possibly understand all the ramifications of destruction of the Amazon. If even the experts are ignorant about what deforestation implies, how can we value ecosystem preservation based on the opinion of the average person?

In addition, the most serious problem with valuation may be future generations. Unless we maintain that the future has no right to natural resources or ecosystems, we cannot ignore the fact that they too will value the environment. Future values are made even more uncertain as a result of two unpredictable outcomes: ecosystem damages and technological advance. If future generations cannot bid on natural capital, we run the risk of the market determining too low a price. What does the notion of intergenerational justice outlined above suggest about intergenerational property rights, and how will uncertainty affect this?

Property Rights

Neo-classical economics often ignores distribution questions, but by defending property rights and free markets tacitly justifies the initial allocation. In the case of intergenerational issues, the fact is that this generation does have control over resources and therefore de facto property rights. It is up to our ethical sense to decide to what extent the relationship between this generation, future generations and resources is one of privilege for us and no rights for the future, or duties for us and rights for the future. Intergenerational justice suggests that future generations do have rights.

How we treat uncertainty over future values depends on what we perceive our relationship with future generations to be. If we believe this generation has property rights for all resources, then we can rely only on efficiency criterion to determine our resource policy. While uncertainty is involved, the future will suffer the costs of our policies until it can be determined that inefficiency is involved.

If we believe that the future has inalienable rights to a clean environment, then when uncertainty is involved with respect to negative environmental impacts of an activity, this generation must bear the costs by refraining from the relevant activity. This implies we cannot innovate technologies with harmful side effects on the assumption that future technologies will cope with those side effects.

If our responsibility towards future generations is one of liability, then we can continue with uncertain activities, knowing that if they prove environmentally damaging, we must compensate future generations. Intergenerational justice seems to demand at least liability. However, if we are uncertain about both future environmental damages and the future value of technologies we create today, is it possible to operationalize liability? To answer this requires a more detailed analysis of uncertainty and of time discounting.

Uncertainty

There are two types of uncertainty which arise from two types of change in social and biological systems: risk and novelty.

In determining the optimal rate at which he should deforest the Amazon, the individual faces considerable uncertainty. He cannot know whether he will lose his land in conflict with a powerful landowner, whether squatters will attempt to seize part of his land, whether crops will fail or whether prices will be favorable. A well informed individual could, however, make rational estimates of the probabilities of possible outcomes, and based on these probabilities, maximize expected utility.

This type of uncertainty, predictable stochastic change, is known as risk.

Over the longer run, an entirely different type of uncertainty dominates. New inventions might render a formerly worthless plant extremely valuable (such as the car did for the rubber tree), or a formerly valuable resource relatively worthless (a breakthrough in fusion technology might make giant hydro-electric projects obsolete). Inventions by their nature are largely unpredictable, and one cannot determine accurate probability distributions of what they might be and when they might occur. Also possible is the discovery of previously unknown negative environmental impacts of production (such as depletion of the ozone layer by chlorofluorocarbons). Increasing knowledge resolves uncertainties, but at any given level of knowledge, countless unpredictable events will affect the Amazon. Such uncertainty, where neither the possible set of outcomes nor their probabilities are known, is referred to as novelty.

In an analogy to biological evolution, Faber and Proops (1990) refer to the changes which produce risk and novelty as phenotypic evolution and genotypic evolution respectively. Phenotypic evolution is a change in the degree to which potential is realized, and genotypic evolution is a change in the potential of an economy. A simple illustration clarifies the concept. An invention is a change in the genotype of an economy- more potential is created. Before the invention is innovated, genotypic change has occurred without phenotypic change. Innovation of the invention is phenotypic change. Phenotypic change is by its nature predictable, while genotypic change is unpredictable.

Another way of looking at this is that phenotypic change is change realized within the boundaries of the economy, and genotypic change is a change in the boundaries. As most economic production from the Amazon relies to some extent on the public good output/life-support functions of the ecosystem, the ecosystem imposes constraints (boundaries) on economic production. Therefore, ecosystem changes are genotypic changes (Faber and Proops, 1990).[78] Whereas typically in ecological systems phenotypic is far faster than genotypic change, human interference can greatly accelerate the latter.

In the Amazon, both invention and environmental change are important determinants of economic value. The case of rubber was already mentioned. Advances in chemistry, medicine and agriculture may similarly create new economic values for the gene pools of the Amazon in the future. While we can say with some certainty that these advances will occur, we cannot predict what species will prove useful, nor what specific inventions will be, nor when they will occur. Environmental change will also affect the economic uses of the Amazon. Deforestation prohibits sustainable extraction of forest products, and eventually, if the hypotheses of Chapter Two are correct, diminishes agropastoral output. The importance of invention and environmental change suggests that the value of the Amazon in the future is objectively unpredictable.

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[78] The phenotype-genotype dichotomy is particularly relevant as applied to natural resource and environmental economics. The depletion of a natural resource is phenotypic change. We can guess that induced innovation may result in the development of some substitute resource. Environmental change is genotypic. In a delicately balanced, poorly understood and complex ecosystem, we cannot predict the outcomes of environmental disturbances.

The further we peer into the future, the greater the likelihood of novelty. The more rapidly humans alter the ecosystem, the greater the chance of unpredictable change. There is also the probability that continued deforestation of the Amazon will reveal a sustainability threshold, where beyond some critical level of damage, the ecosystem will lose the ability to recuperate, and spontaneous degradation will occur. Essential life support functions may be lost. This suggests the possibility of unpredictable catastrophic events occurring to future generations because of our exploitation of ecosystems today.

Both risk and novelty are directly related to the parameters of the model presented in Chapter Two. With a sufficient understanding of the Amazonian ecosystem, it would be possible to make rational estimates of the value of p_2, the sustainability threshold of forest stock, and of p_1, the forest stock beyond which marginal returns to cumulative deforestation become negative. Some studies have already ventured estimates of p_2 (Lovejoy, etc.), and with an adequate data base, it might be possible to econometrically estimate p_1. However, the present level of ignorance with respect to the Amazon means that in fact, while perhaps not entirely unpredictable, estimates of these variables are at best extremely rough. In general, risk combined with ignorance is quite similar to novelty.

What will happen to the Amazonian ecosystem when forest stocks fall below p_2, on the other hand, is by nature almost entirely unpredictable (though perhaps broad generalizations are possible). Changes of the magnitude which are likely to result from irreversible deforestation will create intense evolutionary pressures. Modern theories of organic evolution suggest that even under virtually identical evolutionary pressures, radically different results are possible- if the earth's clock were rewound, chances are virtually nil that the same species and ecosystems would evolve a second time (Gould, 1989).

Also, as mentioned in the introduction to this chapter, technological advance can potentially alter the production function for agriculture, and hence p_1. As invention by nature is unpredictable, we cannot predict this change either. We can say however, that the rate at which deforestation occurs will affect the ability of technology to respond, and also the ability of the ecosystem to adapt. As a result, how we treat time may have profound implications for intergenerational justice.

It appears then that intergenerational justice demands at least liability: if we deprive future generations of their share of natural resources or environmental goods, we must compensate them for the loss. The faster we exploit natural resources, the more likely we are to cause irreversible ecological damage (if only inadvertently). Discounting future costs to net present value means that catastrophes far in the future carry virtually no weight today. As is well known, high discount rates also favor the immediate returns to deforestation over the slower, steadier flow of ecosystem benefits. As Perrings (1991) points out, "[t]he effect of discounting in this case is thus both to increase the potential for unexpected future costs, and to eliminate those costs from present consideration." (p. 155) Faster resource exploitation also diminishes the capacity of technology to compensate for exhausted resources, increasing the chances we will not meet our obligation of liability towards future generations. If discounting in the face of uncertainty may be contrary to notions of intergenerational justice, it must be closely examined.

The Discount Rate, a Positive or Normative Assumption?

Dynamic optimization problems with long or infinite time horizons are very sensitive to the choice of a discount rate, and such is the case for the models of Chapters Two and Four. Unfortunately, the choice of a discount rate is frequently highly subjective, and debate still exists over the validity of discounting under certain circumstances.

Though much ink has been spilled over the issue of discount rates, little consensus on a 'correct' rate appears to be emerging. For example, in analyses of global warming, Cline (1992) argues for a rate in the region of 1.5%, while Nordhaus (1994) claims the rate should be nearer 6%[79]. All economic models must simplify reality, and discount rates are a widely accepted means of doing this. However, no less an economist than Robert Solow has pointed out two serious caveats. First, as Solow says,

> "[a]ll theory depends on results which are not quite true. That is what makes it theory. The art of successful theorizing is to make the inevitable simplifying assumptions in such a way that the final results are not very sensitive. A "crucial" assumption is one on which conclusions do depend sensitively and it is important that crucial assumptions be reasonably realistic." (Solow, 1956, p. 15)

Second, Solow admits that discount rates may not be appropriate for intergenerational issues (Solow, 1974). Therefore, a credible intergenerational resource use model requires a justification of the discount rate used.

Discounting is so widely used because in many circumstances it makes excellent theoretical and empirical sense. But is discounting a

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[79] Though in the Nordhaus model the rate drops to 3% at an arbitrary time in the future.

valid procedure in every type of intertemporal economic analysis? What are valid discount rates for extremely long-term analysis? Should discount rates vary according to the size of the system (relative to the entire economy, or to the global ecosystem) being analyzed? How can one determine the appropriate discount rate? What are the implications of using too high a discount rate?

To answer any of these questions, we must explore the rationales for discounting.

Future Generations and Market Determined Discount Rates

The two most common justifications for discounting the future are the opportunity cost of capital and the assumption of increasing per capita wealth through time in conjunction with the diminishing marginal utility of wealth.

Since money can be invested, a dollar today is worth more than a dollar in the future. Presumably, however (and in agreement with neo-classical economic theory), the opportunity cost of money changes depending on the level of investment. The first unit invested may have very high returns, while if all money except that necessary for subsistence survival were invested, marginal returns might fall to zero or even become negative. The relevant discount rate would thus appear to be the marginal opportunity cost of capital (MOCC).

Related to the MOCC is the individual preference for consumption now over consumption in the future, commonly referred to as the pure time rate of preference (PTRP). Theoretically, this should be the same as the MOCC. Because of the time preference for consumption, people will make investments as long as future returns compensate for consumption foregone today. Eventually, as people keep investing, the best investments are no longer available, and the MOCC decreases until it is just equal to the PTRP. If we accept the MOCC as the appropriate discount rate, then we are choosing our discount rate by consumer impatience.

One serious problem with this is that returns in the free market rarely reflect externalities to production, frequently ignore the provision of public goods, and often undervalue natural capital or treat it as a free resource. Surprisingly, this fact is commonly ignored even in economic models which deal explicitly with negative externalities and provision of public goods (or protection of a global commons) (e.g. see Nordhaus, 1994). Still, these factors can theoretically be internalized, and the result might be called the marginal opportunity cost of *total* capital (man-made and natural). As natural capital is not increasing under current exploitation regimes, the marginal opportunity cost (MOC) of total capital should be lower than the MOC of man-made capital.

A second serious problem is that discounting future values to net present value means future costs and benefits are only considered in terms of their value today. As market determined rates cannot reflect the preferences of future generations, if we use a market determined discount rate, we are saying not only that present consumption carries more weight than future consumption for the individual, but that this generation's preferences carry more weight than preferences of future generations. That is, discounting according to the MOCC/PTPR implicitly awards all property rights to this generation. This is an interpersonal comparison, and while it can be defended, is blatantly normative[80].

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[80] Nordhaus (1994) for example, argues that because individuals do show a preference

Some economists argue that this is not so: such a discount rate merely assumes that reinvestment opportunities will always be available to future generations and future generations will have the same utility function. In the extreme case of an infinite discount rate, it is clear that discounting does award all property rights to the current generation. Nor is such a rate a mere hypothetical conjecture, but rather it is the rate which may be individually rational in exploitation of open access resources (Conrad and Clark, 1991). Clearly, in this case future generations have no rights, and actions today will eliminate investment opportunities for tomorrow.

Under most circumstances, however, people do not have infinite discount rates and discount according to their time preference rate, only making investments when returns exceed this rate. Presumably, some level of investment is necessary just to maintain per capita capital stock. If the preference for current consumption is too high, this level of investment will not be achieved, and future generations will be worse off.

This does not mean that discounting necessarily makes future generations worse off. It is quite possible that the time preference for consumption is such that investments increase per capita capital stock.

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hypothetical view of how societies should behave or an idealized philosophy about treatment of future generations." (p. 125) Of course, much of neo-classical economics is indeed based on "a hypothetical view of how societies should behave." What's more, cultures evolve in response to environmental pressures. For most of human history, human actions had little impact on future generations- each generation lived much as the former had, and to the extent change occurred, it was virtually unnoticed over the space of a generation. There was little need to worry about intergenerational ethics, just as prior to the 1940s, there was little cause to worry about the ethics of nuclear weapons. Now that we do have the ability to harm future generations, it makes a great deal of sense to worry about these issues. "Idealized philosophies" (e.g. democracy) are frequently driving forces in the evolution of human culture. To ignore this fact is close minded and conservative in the extreme.

Assuming both decreasing marginal returns to investments and that returns to investment will reach the consumer rate of time preference before we reach zero capital stock, even if society were currently consuming its capital, it would eventually reach the point where marginal investment opportunities would compensate for reducing current consumption. In either case (increasing or decreasing capital stocks), an equilibrium should eventually emerge, where new investments are just sufficient to maintain the capital stock. In equilibrium, who 'owns' resources would not matter, since all generations would enjoy the same level of consumption. Hence, while discounting according to the consumer time preference rate can lead to a better, worse or equal standard of living for future generations, what future generations inherit depends on the intertemporal utility function of the present generation, not on any inherent rights of future generations.

Still, the standard of living for the average man has been steadily increasing on average for much of history, and if future generations too will be richer, it seems that we can ethically justify discounting. However, if the wealth of future generations depends in part upon how we discount the future, the assumption of increasing wealth can hardly be used as a guide to choosing the discount rate. If we are overly optimistic about future growth, we may end up actually consuming capital and leaving the future worse off. There is in fact growing evidence that increasing wealth for future generations is far from inevitable.

In addition, even discounting according to the MOC of total capital presents a paradox in terms of the wealth of future generations. A shift in demand for current consumption over future consumption is an increase in the time preference rate of consumption. Since people will not invest in activities with lower returns than their time preference for current consumption, investments decrease and the MOC of total capital increases. With less investment, the future will be worse off, yet the discount rate has increased.

Because we treat natural capital as a free resource in national accounts, and because of the difficulties in measuring trade-offs between natural and man-made capital, it is difficult to know if we are building up or depleting capital stocks (man-made plus natural), and whether we are leaving more or less for future generations. There is an additional factor which adds weight to this question. If discount rates are so high that we are consuming the capital stock, this means that society's wealth is decreasing. If discount rates are inversely related to wealth, as they seem to be[81], it would be possible to eventually consume all capital stock and leave nothing for the future.

The decision to grant all property rights to the present generation does not even depend on efficiency criteria, since Howarth and Norgaard (1990) have shown that we could distribute property rights however we chose and still use resources efficiently.

Determining a Discount Rate

There is no one appropriate discount rate. For the individual considering investing in a project for profit, the returns on the next best use of that money is the reasonable discount rate. For a fairly small social investment, or one concerned merely with the present generation

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[81] The rationality of an infinite discount rate for those living at or below the subsistence level has already been mentioned. It should also be fairly clear that if one is extremely wealthy now, but there is doubt about future income, it might be worth saving money even at negative rates of interest (e.g. where money is eroded by inflation).

and economic efficiency, the market determined rate should be adjusted to account for negative externalities, the provision of public goods, under-priced natural resources, resource depletion and other market imperfections as appropriate. When analyzing a huge, poorly understood system with global and intergenerational benefits, such as the Amazon rainforest, the marginal opportunity cost of capital may not even be a reasonable starting point for determining an appropriate discount rate.

A discount rate should be determined in part by the relevant goal, such as maximizing profits or maximizing social welfare. Sustainability is becoming an increasingly high priority goal in debate over exploitation of the Amazon and in economic analysis in general. If the discount rate ignores ecological factors, if it is determined solely by the economic decisions of the current generation, there is no guarantee that the economy will not exceed the constraints imposed by the ecosystem. When the Earth's population was in the hundreds of millions, we had limited capacity to seriously alter the ecosystem and exhaust resources (though both were done occasionally). In this limitless resource world, a market determined discount rate reflecting the 'growth rate' of capital was ideal. Now however, resources are no longer limitless, and we must heed boundaries to growth imposed by the global ecosystem.

The argument that people's preferences are what matter, and that if market determined rates do not value the future, then society should not, ignores the fact that cultures and institutions adapt in response to change, but adaptation is not immediate. The market as it currently exists may be an institution extremely well suited to a planet with virtually infinite resources. Resource limitations demand new institutions, but existing institutions are resistant to change.

Adaptation is driven by debate and questioning of the dominant paradigm.

One can consider two basic approaches for estimating a discount rate appropriate for a planet of limited resources. First, one can look at a market determined rate which accounts for all externalities, all public goods, and the cost of depletion of natural resources, i.e. the MOC of total capital. As has been made abundantly clear, however, many future costs and benefits are unpredictable by nature, so this task is essentially impossible. Also, since future generations cannot participate in the market, this approach is only valid if we believe future generations have no rights.

If we do believe that future generations have rights, then the discount rate cannot be determined by the current generation's pure rate of time preference, expressed as the MOCC. However, ignoring the opportunity cost of capital would also be foolish. A discount rate for intergenerational analysis should instead be determined by the *average* opportunity cost of total capital (AOCTC). The AOCTC is simply the rate of growth of total capital in the economy, i.e. the rate of growth of the entire economy, including man-made and natural capital.

There are several justifications for using such a discount rate in intergenerational analysis. The faster the economy is growing, the more wealth future generations will have, and the higher the discount rate. This means the present will not make excessive sacrifices for a richer future. Second, the social goal of sustainability may conflict with the individual rate of pure time preference. The higher the rate of pure time preference, the more individuals in the current generation will consume, and the less they will invest. Thus, economic growth will slow, and the social discount rate, the AOCTC, will decrease[82]. Conversely, if individuals are relatively indifferent between present and future consumption, they will invest more, the economy will grow faster, and society will discount at a higher rate. Social investment decisions will counterbalance individual investment decisions, which may be necessary to ensure sustainability.

However, the optimal discount rate for societies at the subsistence level may still be nearly infinite, since survival takes precedence over sustainability.

The problem arises of course in determining the AOCTC. A ceiling value would be the rate of growth in per capita GNP over long periods. In the United States, an off the cuff estimate shows slightly less than a 2% annual increase in per capita GDP between 1885 and 1985[83]. Of course, this figure is exceptional by international standards, counts defensive expenditures as positive and ignores the depletion of natural capital. The Brazilian population and world population is growing substantially faster now than the US population grew over that period, and whether growth in gross global product or Brazil's GNP over the next hundred years can parallel growth in the US GDP over the previous hundred years is highly questionable. This ceiling figure probably vastly exceeds a realistic estimate of AOCTC.

Daly and Cobb (1989) and have made attempts to incorporate resource depletion, non-remunerated work, income inequality and

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[82] Note that the MOCC, in contrast, is likely to increase the more people consume. Higher consumption reflects a greater preference for current over future consumption. People will only invest in activities that give returns at least as high as their time preference for consumption.

[83] This figure was derived by using census data from 1880 and 1990, extrapolating population data for 1885 and 1987, and using GDP at constant prices for the US from Liesner. 1989.

defensive expenditures into national accounts in a measure they refer to as the 'Index of Sustainable Economic Welfare' (ISEW). Of course the measure is imperfect, as the authors admit, but it does seem to convey a better idea of AOCTC than simple growth in GNP. For the United States, they find that ISEW parallels growth in GNP up to the late 60s. The ISEW stagnates from 1970-1980, then begins a slight decline. This suggests that under the current parameters for man-made capital accumulation and natural capital depletion, intergenerational justice might even demand a *negative* discount rate.

Alternatively, rather than trying to modify GNP to arrive at a measure for AOCTC, one can make an extremely rough estimate by looking at the sources of growth in the global economy, which boil down to three.

First, we can increase the rate at which we exploit natural resources. However, if we value our natural resources positively, then simply increasing their rate of exploitation beyond the rate at which they can renew themselves is not growth. Using resources now that would otherwise be used in the future is an intergenerational transfer of resources. Also, increasing resource use implies increasing the waste flow back into the environment. Depleting renewable resources to below the stock which provides maximum sustainable yield, and overloading the waste absorption capacity of the environment is in the long run negative growth. It decreases the productivity of the ecosystem, and decreases the carrying capacity of the planet.

Only to the extent that we can maintain or increase ecosystem productivity, can we have real growth from this source.[84] However, as

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[84] For insights into the problem of increasing ecosystem productivity in the Amazon, see Norgaard (1981)

Norgaard (1981) has pointed out, increasing ecosystem productivity is a co-evolutionary process between human culture and the ecosystem. The less we know about the environment, or the more complex the environment, the less likely we are to experience beneficial co-evolutionary development. Knowledge accumulation requires both effort and time. The faster the rate of ecosystem change, therefore, the less likely technology and culture can adapt to make the change beneficial. Owing to ecosystem complexity and the current rate of exploitation, beneficial change in the Amazon is particularly unlikely.[85]

Second, we can increase the use of labor. This however is not possible exponentially, and could never be used to justify an exponential discount rate.

Third, we can make more efficient use of labor and resources, through technological improvements and technologies which create new resources. This is a real source of economic growth. While it is true that efficiency of use of a given resource cannot increase exponentially forever, this is not necessarily true about our ability to create new resources. Technology may thus be a real justification for a discount rate.

However, as stated earlier, technology develops complements for resources as well as substitutes, and can be harmful as well as beneficial. If technology makes a resource more valuable in the future, economic efficiency would demand slower use of that resource. The effect would be opposite that of a discount rate. While technology is

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[85] We no doubt have the ability to develop technologies that will make agriculture thrive even in the Amazon, and hence make the ecosystem more productive of food. What is highly unlikely is that we can increase the total productivity of the Amazon: food, life support functions, timber etc. without a considerable increase in knowledge about the ecosystem. Rapid change does not allow knowledge to accumulate.

therefore a motor of real economic growth, it may not justify discounting the future value of natural resources if efficiency is a criterion.[86] This may hold particularly true in the Amazon. Technology requires knowledge applied to resources. Given the extent of our ignorance concerning resources in the Amazon, it is highly likely future technologies will greatly increase their value.

Real economic growth then only arises from the flow of renewable resources from the ecosystem (and solar system) and from technological advances. I maintain the discount rate for large system analysis should reflect the net growth rate of the system.[87] In the case of the model in Chapter Two, this would be the renewal rate of the natural resource in question, the Amazon rainforest itself. With the model parameters specified, the appropriate intergenerational discount rate would be .006. This is the rate used for international level analysis throughout this dissertation, under the assumption that the international community is inherently interested in sustainability, but institutions are slow to respond to economic and ecological changes. If the model were to incorporate technological growth, it might justify changing the discount rate. However, technology is at least as likely to increase the value of

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[86] It is interesting that sustainability and intergenerational justice make no demands for increasing the well-being of future generations. Thus, if a resource is increasing in value faster than the discount rate, sustainability or intergenerational justice criterion might allow us to use the resource, whereas efficiency criteria might not.

[87] Perrings (1987,1991) and Daly have a similar argument. To quote Perrings (1991),

"The argument against the rates of discount embodied in current real rates of interest is then an argument about the actual or potential growth rate of the system, and the position taken by those seeking to integrate the environment in the analysis of economic systems is that the marginal efficiency of capital assessed over the current capital base (which excludes natural capital) is a highly misleading proxy of the growth potential of the whole system (which includes natural capital)."

While I thoroughly agree with this for small system analysis, when the system being analyzed is large compared to the entire system, it is no longer reasonable to look at marginal opportunity costs. One must look at average opportunity costs.

rainforest stocks as it is to increase the productivity of agricultural land, and hence its impact on discounting is not clear.

This discount rate is far below those typically chosen for dynamic optimization models. I suggest however that it may not be out of line with traditional economic analysis. As we become more and more aware of the negative impacts of resource depletion, pollution and ecosystem destruction, we may find that including negative externalities and resource depletion costs in financial calculations could very well lead to such a low opportunity cost of capital, especially over the very long term.

Another advantage of such a low discount rate is that it will never demand an infinite sacrifice by this generation for future generations, nor would it impose catastrophic costs on future generations.

From Chapter Three, we can see that a discount rate equal to the growth rate of the system being analyzed also meets sustainability criterion, for this model and presumably others of its kind. The longer time horizons implied by such a discount rate mean slower exploitation of resources, hence slower environmental change, more time for technology to adapt, and less uncertainty. By discounting the future only to the extent that economy, broadly defined to include man-made and natural capital, is growing, we are ensuring that we are liable to future generations for our actions.

Summary and Conclusions

Applying Rawls' difference principle to the question of intergenerational justice, it may not be possible to deduce all our obligations to future generations. However, one can determine at least the minimal obligations: we must ensure that future generations are not worse off than they would have been under an equal intergenerational distribution of wealth. This ensures sustainability to the extent that it is feasible, and implies that property rights of future generations impose the obligation of liability on the present one. The fact that this generation has damaged life support functions of ecosystems, polluted the environment, and diminished certain renewable resources below the stock providing maximum sustainable yield means we are obligated to compensate future generations with man-made capital accumulation or an increase in other renewable resources.

However, compensation depends on two unpredictable events: ecosystem change and technological advance. The faster change occurs, the more likely we will cause unpredictable change in ecosystems, and the less likely technology will be able to compensate.

Discounting places a lower value on future events, and shortens our planning horizons. Discounting in general also leads to faster exploitation of natural resources, hence faster environmental change and a more unpredictable future. Since unpredictable uncertainty increases in likelihood the farther into the future we look, discounting means we pay less attention to it. By increasing the likelihood and decreasing the importance of unpredictable change, too high discount rates may mean we fail to meet our intergenerational obligations. Discounting the future according to AOCTC, as defined above, in contrast to more typical discount rates based on the MOCC, is compatible with intergenerational justice and sustainability.

CHAPTER SEVEN:

SUMMARY, CONCLUSIONS AND SUGGESTIONS FOR FURTHER RESEARCH

This chapter summarizes the main conclusions of the work, discusses its limitations, and offers suggestions for future research.

The Brazilian Amazon is a source of numerous public good benefits with value at the local, national and international levels. Deforestation allows production of private good benefits. The benefits of conservation and conversion should be balanced to maximize the region's contribution to the social welfare, yet it is likely that this balance will differ depending on the level of society (local, national, international, intergenerational), and whether or not future generations are considered. The fact that the international community considers deforestation in the Amazon a serious environmental threat, while state governments in the region actively seek partnerships with non-sustainable logging firms suggests that locally optimal deforestation rates already exceed globally satisfactory ones.

The objectives of this research were to estimate the 'optimal' rate of deforestation and steady state forest stock in the Amazon, examine feasible policy options for achieving them, and analyze some of the most relevant ethical issues concerning rainforest destruction. I attempted to synthesize various works on tropical deforestation by incorporating several critical economic and ecological factors into a dynamic intertemporal optimization model of deforestation in the Amazon. These factors included:

1) the fertilizer effect of current deforestation;

2) the negative impact of cumulative deforestation on crop yields;
3) forest regrowth, the negative impact of cumulative deforestation on regrowth, and the potential for irreversibility;
4) public good benefits from intact forests and private good benefits from forest conversion; and
5) different social valuations of the public good benefits depending on the level of society in question: local, national, international or intergenerational.

Results from the model were used to help examine potential policy options for optimizing deforestation rates and achieving an optimal steady state forest stock. I further evaluated policies according to their theoretical soundness, their political feasibility, their effectiveness and their affordability.

Finally, I presented ethical arguments concerning the current generation's obligations to future generations, and the implications of these arguments for the appropriate discount rate to apply to future benefits from the Amazon.

Chapter summaries

Chapter Two, using hypotheses supported by others' work (e.g. Ehui, 1987; Panayatou and Parasuk, 1990), developed a model incorporating the five critical economic and ecological factors listed above. Public good benefits were given simply as the natural log of forest stock, and their social valuation depended on the level of society in question. Private benefits were represented by aggregate agricultural yield, using a transcendental function. Regrowth of forest stock was modeled by a simple quadratic.

Analysis suggested that deforestation is driven by two factors: a deforestation motive which is determined largely by the one time benefits of the fertilizer effect of current deforestation, and a conservation motive which accounts for all future utility from a unit of forest stock. The terms are borrowed from Ehui (1987). If any deforestation is optimal, the rate of deforestation will fall over time. Phase plane analysis suggested that the model could enter a saddle point steady state, and that this would be more likely at more encompassing definitions of society.

Chapter Three estimated the relevant model parameters from secondary sources and conducted extensive sensitivity analysis of the steady state. Steady state forest stocks increased as the sustainability threshold increased. The likelihood of attaining a steady state increased as the discount rate fell, as the social valuation of the public good rose and as agricultural yield become more sensitive to ecological degradation, but decreased with increases in the sustainability threshold. Reasonable parameter values at the local value suggested a corner solution, where forest stocks approached the sustainability threshold, was the optimal choice. In contrast, reasonable parameter values for international level analysis suggested that optimal forest stocks should remain well above the sustainability threshold. At the national level, it was indeterminate whether or not optimal forest stocks would approach the sustainability threshold.

Chapter Four developed a finite, discrete time version of the same model, and estimated optimal time paths using GAMS-MINOS software. The results supported those of the previous two chapters, and suggested that lower steady state solutions were accompanied by more rapid deforestation. Modeling policy variables suggested that lowering the discount rate would slow deforestation rates considerably and lead to higher steady state forest stocks. Increasing the social valuation of the public good would slow deforestation rates but would still lead to corner solutions for the higher discount rates likely at the local level. The discrete time model also suggested that a Pigouvian tax should at first be increasing, until agricultural output begins to show negative returns to cumulative deforestation, whereupon it should start to fall.

Most important, Chapter Four suggested that for virtually any reasonable parameter values, optimal deforestation at the local and national level was much faster than at the international level. This suggests that to slow deforestation, the international community will need to create incentives for Brazil to preserve forest. Further, it appears that the international community should act quickly if it is not to suffer significant utility loss. In fact, optimal deforestation at the local level may well be greater than current deforestation rates, which may be constrained by a lack of labor and capital. At the national level, the discrete time model suggests that current deforestation rates may be more or less optimal. In any case, the facts suggest that currently Brazil is unwilling to dedicate sufficient resources to slow deforestation below its current level, much less to a level that would be satisfactory for the international community.

Chapter Five examined numerous policy options for controlling deforestation. International policy options included a Pigouvian subsidy paid for reductions in annual deforestation over some base level, international financial support for monitoring and enforcement of existing environmental legislation and decrees in Brazil, and the direct purchase and protection of conservation units. National policy options examined included a credit subsidy targeted at more sustainable technologies (much like the existing Protocolo Verde), research and development of more sustainable technologies and extension work to disseminate the results of such research, a program to provide secure land tenure, tradable deforestation permits, an end to extensive road construction and a tax on deforestation to be paid when land title is given or transferred. However, without international support, it is unlikely that Brazil will make a serious effort to slow deforestation.

For each of these policies, the discrete time model was used to estimate the impact over a thirty-year period. Thirty years was chosen because the model suggests that unless we begin to slow deforestation within that time period, we may risk irreversible losses. Policies that internalized the public good value of the forest and lowered interest rates were most effective at slowing deforestation rates. No single policy was sufficient to bring actual deforestation rates in line with internationally optimal rates. Instead, the model showed that only a combination of policies that raised public good values, lowered discount rates, and made existing technologies more sustainable would bring about immediate, noticeable decreases in deforestation rates.

The discrete time analysis did suggest that one of the policies proposed might be counterproductive. Realistically, a credit subsidy will relax capital constraints. Removing capital constraints in the discrete time model led to a dramatic increase in deforestation rates, even when accompanied by a reduction in discount rates. Discount rates would have to fall to unrealistically low levels to overcome the impact of increased capital availability.

The option of international funding for the purchase and protection of conservation units is politically feasible and affordable. It would do little to slow deforestation in the short run, but could preserve sufficient forest to reduce the risk of accidentally crossing the ecological threshold beyond which forest could not regenerate.

Political feasibility, effectiveness and affordability undermine the international Pigouvian subsidy option. To be effective, such a policy would require the international community to transfer large sums of money to Brazil, and Brazil would be able to spend that money any way it wished. While Brazil would not get the money unless deforestation was actually reduced, the quantities of money required and the lack of direct accountability means that it is highly unlikely the international community would back such a policy, even if the obstacles of administration and free riding could be overcome.

Effectiveness of the international Pigouvian subsidy depends on the ability of the Brazilian government to implement policies that effectively slow deforestation, and the prospects are not promising. Targeting a credit subsidy option is probably impossible. Credit is too fungible, and one way another it would be diverted to whatever investment offered the highest returns to the investor. As things stand now in the Amazon, the most profitable investments require deforestation. Credit subsidies sufficient to lower discount rates would also be prohibitively expensive. Squatters occupy only a small percentage of the Amazon, so providing secure land tenure would have at best a correspondingly small impact. Tradable deforestation permits would be virtually impossible to monitor and enforce.

Some of the national level policy options do show some promise. Research, development and extension of more environmentally sustainable technologies are slow processes, would therefore not slow deforestation rates in the short run, and would probably not be justified on Brazil’s part simply to earn a Pigouvian subsidy. However, this option is not terribly expensive, and making alternatives to deforestation more profitable than deforestation may be one of the more promising strategies in the long run. To the extent that Brazil is serious about slowing deforestation, international funding for existing legislation should be relatively effective. Ending extensive road construction and charging a Pigouvian tax on deforestation are also promising, and would probably save money.

In summary, little is likely to change without international assistance, yet the international community is unlikely to supply sufficient funding to make a substantial impact in deforestation rates. Even if international assistance were forthcoming, the Brazilian government would probably be unable to significantly slow the rate of deforestation. The two most promising of the feasible policies are probably international funding for enforcement of existing legislation and for the acquisition and protection of conservation units. At the national level, continued research and extension is justified, as is a halt to extensive road building and a deforestation tax imposed when title is awarded or transferred. In the short term however, prospects for slowing deforestation are fairly poor. Perhaps as the international community becomes more concerned with environmental issues, and Brazil develops the institutional capacity to slow deforestation, other policies will become viable. Unfortunately, any delay increases the risk of irreversible loss of rainforest.

In light of these dismal prospects for slowing deforestation, Chapter Six examines the implications of intergenerational justice on the deforestation issue, and arrives at the following conclusions.

Intergenerational justice demands at a minimum sustainability to the extent that it is feasible. Though it is not necessarily required that we save exhaustible resources for the future, we are liable to compensate future generations for overuse or exhaustion of renewable resources and for environmental damages. The problem with liability is the unpredictable uncertainty: we do not know what ecological damage our actions today will cause, nor do we know what future technology may do to compensate. As uncertainty increases the faster the pace of change, and high discount rates typically favor faster exploitation of resources and thus faster ecological change, high discount rates appear to be incompatible with intergenerational justice. A discount rate based on the average opportunity cost of total capital is proposed as an alternative compatible with sustainability. For the current model, such a discount rate is equivalent to the growth rate of the forest in the absence of ecological degradation.

The exhaustion of a renewable resource is ethically distinct from the exhaustion of a non-renewable resource. First, the former is a finite loss for an 'infinite' number of future generations, while the latter is finite loss for a finite number of generations. Second, it is in general relatively simple to develop substitutes for non-renewable resources. Renewable resources in contrast are generally components of an ecosystem. The ecosystem in turn provides valuable functions which depend on its structural components, i.e. the renewable resources question. While the direct uses of renewable resources may be easy to substitute for, their functional role as part of an intact ecosystem may have no feasible technological substitutes. To the extent that the intact Amazonian ecosystem provides life support functions for the human race, its loss is unacceptable.

In conclusion then, this research is pessimistic regarding the international will and national ability to slow deforestation in the

Amazon. The potential loss of the Amazon for future generations may have profound and morally unacceptable consequences. Unfortunately, morally acceptability has rarely been a prime determinant of human actions.

Suggestions for Further Research

Clearly, one of the major shortcomings of this work is the lack of empirical estimation of the model parameters. While it may be impossible to objectively estimate the social valuation of the public good, v(S), with an appropriate data base it may be possible to estimate the parameters for the equation of aggregate agricultural yield and for the equation of motion for forest stock. Eustaquio Reis of IPEA in Rio is adding to perhaps one of the best available data bases on deforestation in the Amazon. It is possible to construct an index of aggregate agricultural yield from his data, but at the time this was written, the data base had inadequate time series data to distinguish between the cumulative impact of deforestation and the current deforestation effect. Reis is adding more data for cumulative deforestation for more recent years, which may make this possible. Unfortunately, much of the data is available only for five-year intervals, which again may obscure the effect of current versus cumulative deforestation. In addition, since relatively little cumulative deforestation has actually occurred in the Amazon, variations in weather, technological change, and random 'noise' may further obscure the relationships being studied in this work. A more effective empirical approach may have to focus on a smaller area having undergone more deforestation, such as Rondônia or Pará, for example.

The complexities and uncertainties of the ecological and economic relationships in the Amazon examined in this dissertation may make accurate empirical quantification of the parameters involved exceedingly difficult. Even if the variables could be accurately quantified, the level of international concern over destruction of the Amazon and institutional weakness in Brazil mean that such information may be of little use. In short, as long as the option is deforestation for private economic gain or conservation for the public good, those who are responsible for deforestation in the Amazon will continue to deforest. Determining the theoretical socially optimal level of deforestation will not affect the rate at which the individual deforests.

A more promising path for future research may instead be to examine alternatives for development of the Amazon in which economic returns and ecological function are more compatible. One such option would be sustainable logging of the region. While logging leads to forest degradation and a partial loss of public goods provided by intact forest, careful logging can preserve much of the ecological function and still provide substantial income. As rainforests are depleted elsewhere, timber prices are likely to rise, and logging may become an increasingly attractive option. The model presented in this dissertation assumes that provision of private goods leads to a complete loss of public goods, and hence does not capture the dynamic of the selective logging option. If the link can be broken between opening up land for logging and the subsequent clearing for agriculture, sustainable timber harvest may be the option which best combines economic returns with ecological function.

APPENDIX A:

THE AMAZON AS A PUBLIC AND PRIVATE GOOD

This appendix briefly examines the geo-physiology of the Amazon region, describing how its intact forests provide public goods and services, and how forest conversion can provide private goods. While the Amazon basin is characterized by tremendous heterogeneity, for simplicity the region is described in general terms.

Geo-physical Characteristics, Ecology and Public Good Benefits of the Amazonian Ecosystem.

There is abundant literature chronicling the beneficial impact that rainforests have on adjacent agricultural land, and the negative impact of deforestation on soil structure, microclimate, hydrological cycles, and fertility.

Soils

The Amazon basin has the oldest soils in South America, much of which has been made very infertile by millennia of physical and chemical erosion (Toledo and Navas ,1986). The dominant soils have low pH, low effective cation exchange capacity, are deficient in major nutrients, and often show toxic levels of aluminum (Al) and Manganese (Mn) (Nortcliff, 1989). Most regional soils are particularly low in phosphates. While in temperate climates, organic residues and nutrients can accumulate in the soil, this rarely occurs in the Amazon-most nutrients are instead found in the biomass and top few centimeters of soil (Lal, 1986).

Nutrient Recycling

The intense biological productivity of the system in the presence of such poor soils depends on a number of interconnected factors. Shallow and wide root systems enable extremely efficient nutrient recycling, aided by soil micro-fauna which rapidly decompose organic matter. Organic matter decomposes in about six weeks, compared to around one year in temperate forests and several years in northern forests. Nitrogen fixing micro-organisms associated with root systems increase available nitrogen (Toledo and Navas, 1986). Soil microfauna, highly productive in the tropical heat and humidity, accelerate the decay of organic matter and make the nutrients available for plants. Recycling of nutrients is so rapid that soil serves more for mechanical fixation of the vegetation than as a source of nutrients. The loss of nutrients through runoff is matched by the minute amount added to the system by rainfall (Sioli, 1991).

Micro-climate

The Amazonian jungle forms a dense ground cover, creating a stable micro-climate extremely hospitable to life. Torrential tropical storms break on upper story foliage, while the ground level receives only fine water drops and little turbulence. The foliage filters out up to 98% of sunlight at ground level. Much rain evaporates while in the canopy, reducing run-off to rivers. Evaporation cools the air, so temperature and humidity vary little. The moisture returned to the air via evapo-transpiration is responsible for some 50% or more of the rainfall necessary to sustain the forest. As a result, the Amazon is characterized by heavy rainfall for most of the year, with only a short dry season Sioli (1991).

Soil temperature and moisture in the forest are fairly constant as well. High humidity and no wind means little evaporation. Roots keep the soil porosity high, increasing water absorption and retention (Salati and Vose, 1984).The stable temperature (differences between night and day are typically greater than seasonal differences) and steady rainfall are very favorable to plant and animal life.

Geo-physical Impact of Deforestation

Deforestation has a significant impact on the Amazonian ecosystem, evident at several levels.

Impact on Soil

Deforestation in the Amazon is primarily slash and burn by hand, with larger clearings frequently done by machine. Burning returns to the soil some of the nutrients locked up in the vegetation, which, judging from results of a study in one area in Venezuela, is about the amount required by one crop of rice (Lal, 1986). Another study in Brazil found that the market value of fertilizer with the same nutrient content as the ash from burning is about $680 per hectare deforested (Cunha, 1988). Weighing against this benefit, clearing removes the source of new organic matter, while cultivation speeds up organic decay (Greenland, Wild and Adams, 1992). Loss of organic matter decreases water retention and degrades soil structure. Deforestation also leads to changes in pore space distribution, which affects water content of soil and water availability for plants, and may be even more important than fertility in its effect on plant growth (Chauvel, Grimauldi and Tessier, 1991). Most nutrient retention capacity is in the humus, which degrades rapidly with deforestation.

Soil is as much influenced by vegetative covering as it influences vegetation (Lal, 1986). Without the protective cover of vegetation, heavy rains rapidly leach nutrients from the ash and top layers of the soil where they are found. Soil compaction and decreased percolation following deforestation increase water runoff from cleared soils dramatically which is associated with increased erosion and changes in river regimes.[88] Erosion leads to 'sandification' of soils, as lighter organic matter is carried away. No longer reflected by the foliage, direct sunlight (which may be 5000% greater at ground level in cleared than in forested areas) increases soil temperature and decreases soil moisture, while the air becomes hotter and less humid. Temperature variability increases as well (Sioli, 1991).

Studies indicate that how forest is cleared is important in determining the resulting soil quality. Mechanical clearing with bulldozers compacts and scrapes away soil, leading to lower yields than manual slash and burn clearing, and is more expensive. With a tree shredder, mechanical clearing is fast and efficient, but only for very large clearings. Yields are still lower than from manual clearing. In Peru, mechanical clearing of any kind was associated with soil compaction and increased runoff (Salati and Vose, 1983).

Impact on Surface Water

Erosion increases sediment loads in rivers, which in conjunction with increased runoff is associated with flooding in rivers and streams. This has potentially serious economic consequences, since most

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[88] One study in Ghana, referred to in Salati and Vose (1983) found that soil loss on cultivated fields reached 6300 times that from forested areas, and was even greater on bare fields.

Amazonian populations live alongside rivers (Salati and Vose, 1984; Smith, 1982). Increased river sediments change the ecology of the highly productive Varzea, which is flooded and covered with sediments every year. Riverbeds may change, and higher sediment loads may alter river biology. The Amazon river has more species of fish than the Atlantic ocean, and is considered one of the last under-exploited fisheries in the world. Damage caused by deforestation may pose a serious threat to the health of fish populations (Plamondon et. al., 1991). As sediment increases, and rains decrease, rivers may become less navigable, especially during the dry season (Sioli, 1991). Increased siltation rates from higher sediment loads shortens the life of hydroelectric projects.

There is also likely to be an impact on Atlantic ocean fish populations in the vicinity of the mouth of the Amazon. The Amazon spews 200,000 m^3 of water into the ocean every second (enough water to fill all 5 great lakes in less than 1.5 days) and some 400 million tons of sediment per year. Increasing this sediment load could overwhelm marine habitats crucial to fish breeding and growth (Cousteau, et. al., 1980).[89]

Models indicate that contamination of surface water is another result of deforestation. Besides the problems of siltation, concentrations of minerals and nitrogen increase, leading to a decrease in oxygen levels. Water temperatures also increase (Neal, 1992). Empirical studies

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[89] The Yellow River in China drains slightly more than 1/10 the area drained by the Amazon, but the area is heavily cleared. Sediment flows are 4 times those from the Amazon (Cousteau, et. al., 1980). If deforestation in the Amazon led to proportional sediment loads, the Atlantic ocean would receive nearly 40 times the sediment load it now receives from the river. The effect could be catastrophic on coral reefs and near shore ecosystems essential for the reproduction of economically valuable marine species.

support these results. One study found that water quality deteriorates, becoming unacceptable for drinking following conversion of surrounding forests to pasture or crops. Water temperature increases, with greater variation between highs and lows. Dissolved oxygen may decrease to levels that are unfavorable for fish growth and reproduction (Plamondon et. al., 1991).

Impact on Forest Fires

Deforestation also increases the likelihood of fire. Pastures are the most susceptible to fire, followed by logged areas then second growth. The chance of fire in virgin forest is virtually non-existent, even following prolonged droughts. Differences are due to accumulation of combustible material and micro-climate changes. Temperatures in one study site were on average 10 degrees C higher in pastures than in bordering virgin forests at midday, and humidity 30% less. Rainforest trees were found to be highly susceptible to damage by forest fires. Partially logged areas are similar to the areas in Kalimantan, Indonesia, that suffered catastrophic forest fires after being logged (Uhl and Kauffman, 1990).

Impact on Local Climate

Empirical evidence indicates that deforestation in the Amazon changes climates at the local level, and models suggest the potential for climate change at the regional and global levels as well.

Though internationally the public seems to be concerned with the global warming impact of Amazonian deforestation, the local climate impact promises to be far more severe. By interfering with the recycling which characterizes the hydrological cycle, continued clearing is expected to lead to a significant decrease in cloud cover, rainfall and total water in the ecosystem[90]. Reduced rainfall will lead to an increase in soil and air temperature, and reduce moisture content. More important than the simple decrease in rainfall is the expected extension of the dry season. The length of the dry season is the limiting factor in cattle yields and certain crop yields, and an increase in duration may also be destructive to existing forest and prevent regrowth. Forested areas may be negatively affected, if they depend on rainfall from evapo-transpiration occurring in neighboring deforested areas (Salati and Vose; 1984; Fearnside, 1991).

Air and soil temperatures are known to increase with deforestation, as does their variability. Though overall rainfall may decrease, surface runoff and hence erosion would probably increase during the rainy season (Sioli, 1991).

Impact on Regional Climate

The Amazon is continental in size, and probably serves to moderate the continental climate effect in nearby regions, much as oceans moderate coastal climates. The climate effect of deforestation is thus likely to have large impacts on weather and agriculture throughout South America. The Chaco and Bolivian Altiplano are known to be influenced by the Amazonian hydrological cycle, and severe deforestation will probably influence weather patterns world-wide, even ignoring the increase in green house gasses (Salati and Vose, 1983).

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[90] Walker et. al. (1995) suggest that deforestation of 50% of the Amazon may lead to no rainfall at all during much of the year. Salati and Vose (1983) note that the once major Motagua river in Guatemala lost 50% of its water volume following te loss of 65% of the surrounding natural forests over the last 50 years.

Even if net regional impact was neutral with respect to agricultural production, local changes could be very costly to adapt to.

Impact on Global Climate

The Biomass and soil of the Amazon rainforest is a tremendous storehouse of CO_2. Estimates of biomass in the Amazon range from 354 to 507.5 tons of dry matter per hectare, of which some 50% is carbon.[91] When deforested, the forest is replaced by crops or pastures which sequester only 1-5% of the carbon found in the original biomass. Decay of organic matter in the soil also accelerates. Pastures from cleared forests give off three times more N_2O than the forest, which increases the greenhouse effect of deforestation by up to 35%. Cattle and rice both contribute to the greenhouse effect through methane production, as do termites, whose populations increase in the deforested areas (though these effects are likely to be minor) (Fearnside, 1985; Luizao et. al., 1989).

The amount of CO_2 released to the atmosphere by burning depends on the efficiency of the burn, the rate of decay of the organic matter left in the soil and the biomass of the vegetation which replaces the forest. While often burning of vegetation in the Amazon is not that efficient, the remaining biomass decays over the next 10-20 years, a short time span in relation to the global warming problem (Bueno and Marcondes Helene 1991). Conservatively we can assume that the replacement vegetation has 5% of the biomass of the original forest.[92]

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[91] Bueno and Marcondes Helene (1991). There is significant variation in biomass between regions of the Amazon, and studies provide different estimates depending on the methodology used. Other authors provide higher figures (eg. Salati and Vose (1983) claim 500-1000 ton/ha) but do not say whether this is dry weight.

[92] The literature at times refers to carbon content, and at others refers to CO_2 output.

(For details on the wide variety of estimates of the carbon output to the atmosphere from deforestation, see Bueno and Marcondes Helene (1991))

What is the value of sequestering this CO_2? First of all, global warming is expected to affect the tropical countries less than the temperate countries, so the costs of global warming may be different for tropical and temperate countries. However, it is quite likely that global weather patterns may shift, and even if the temperature remains fairly constant, rainfall patterns might change and have a serious impact. Rainfall in the Amazon basin is expected to decrease as a result of global warming. Also, if ocean levels rise, Brazil will be seriously affected. Most of Brazil's big cities, with the exceptions of São Paulo and Brasília, are on the coast. At any rate, it is virtually impossible, given the present state of knowledge, to convincingly determine first the impact on global warming from this level of CO_2 emissions then second determine the economic impact from the warming. A simple alternative is to determine the cost of reducing other CO_2 emissions by this much. These costs should be increasing with respect to quantity, as the least expensive reductions are carried out first.

Global warming however is not the only global climatic effect of deforestation in the Amazon, and indeed may not be the most important. Of the solar energy reaching the Amazon, some 90% is absorbed by the forest, the rest reflecting back into the atmosphere. In contrast, of solar energy reaching the Sahara, only 60% is retained. Yet the temperature in the Sahara is much higher than in the Amazon,

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whether carbon content is used as the standard reference. The molecular weight of $C0_2$ is 44, and that of C only 12, so the conversion factor for tons of C to tons of $C0_2$ is 44/12 = 3.66

indicating that although less energy is absorbed, more remains in the area. In the forest, much of the heat is absorbed by evapo-transpiration, and is carried high up into the atmosphere, raising the temperature 5-10 km above the earth by as much as 28 degrees C each day. This is a tremendous amount of energy, and winds and rain spread this energy into the temperate zones, increasing the average temperatures there. Deforestation will lead to less energy being absorbed by the Amazon, and much less energy being transported to temperate and polar zones. This effect could increase the temperature differential between tropical and temperate zones, shortening the growing season in temperate zones and possibly even accelerating the onset of another ice-age (Molion, 1990). The green house effect and the increased temperature differential between tropical and temperate zones may lead to opposite effects in the temperate countries. Rather than cancel each other out however, the two effects may interact to wreak havoc with global weather patterns. Such changes would inevitably prove very costly, even if on average worldwide conditions for agriculture were not negatively affected.

Irreversibility

Accumulating evidence suggests that extensive deforestation in the Amazon is for all practical purposes irreversible. Small clearings typical of slash and burn farming with low population densities mimic natural events, and regrowth is rapid. In larger clearings, however, microclimate change is greater, and seed sources are more distant. Though regeneration does occur in large cleared areas, and may become structurally similar to the old growth given time, it is with different vegetation than was initially cleared. Species loss still occurs (Lisboa and Prance, 1991). New computer models suggest that regional climate change following extensive deforestation will prevent re-growth of rainforest (Monastersky, 1990).

Biodiversity and its Economic Value

The Amazon stands out for its tremendous biodiversity, perhaps greater than any other region on earth. Until fairly recently, an accepted figure for the number of species on the planet was 5-10 million. Some researchers now estimate the number of species in the Amazon alone as 30 million. Regardless of the actual numbers, the earth's rainforests, covering 7% of the land area, harbor over half of all species. Off the cuff estimates of extinction rates for tropical rainforests are some 17,500/yr., which is perhaps 1,000-10,000 times greater than natural extinction rates for the whole planet (Wilson, 1988).

All ethical issues aside, what is the economic value of biodiversity? First, many plants and animals of the rainforests may become important food sources. Various important food sources already come from the rainforests, such as cassava, cacau, pineapple, etc. (Schultes 1979). Many other Amazonian fruits are developing commercial markets. The people of Iquitos consume at least 193 different kinds of fruit, 139 of which are native and 57 of these are harvested in the wild and sold in the market place. Some of these fruit species are just now being brought under cultivation (Gentry, 1992). Another study documents at least 121 wild harvested fruits from the Brazilian Amazon, of which only one quarter are among the fruits consumed in Iquitos. New species of edible fruits are still being discovered. Indians in Peru alone use at least 526 species of edible plants (Brack, 1992). To quote Thomas Jefferson, "the greatest service which can be rendered any country is to add a useful plant to its culture."[93]

Second, many plants and plant extracts have commercial utility for industry, and others are being discovered. Rubber accounts for billions of dollars in commerce per year. Rubber has been known for thousands of years, yet only with the growth of the car industry did it acquire its present international importance. Some future discovery may confer enormous value upon some other seemingly worthless rainforest plant. There are many species of rubber trees which produce latex of various qualities with no current commercial use, anyone of which could prove complementary to some future technology. Other examples of species with high potential economic value are a tree whose sap is a hydrocarbon capable of running a diesel engine without processing, and various known waxes, oils, resins and gums (Schultes, 1979).

Third, the genes from wild relatives of rainforest plants already commercialized may be required to protect world-wide production against future blights, just as wild American grape stocks saved Europe's vineyards from blight. Barley, sugar cane and rice are other crops protected from disease by genes from wild species (Plotkin, 1988; Iltis 1988). Species of Cacau have been discovered in the wild which are resistant to various Cacau blights and pests. World wide, rubber trees from outside of Brazil are virtually all descendants of some 26 seedlings raised from seeds smuggled outside of Brazil. If any of the numerous rubber blights were to reach Africa or Malaysia, resistant wild stock might be required to save the industry. Alternatively, genes from wild

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[93] quoted in Plotkin (1988)

plants may be used to improve yield or quality of domestic crops. Many wild trees have higher yields of better quality rubber than plantation trees (Schultes, 1979). As an example of potential values, the recent discovery of a perennial corn variety in Mexico which is immune or resistant to all seven types of diseases which plague commercial corn production could revolutionize corn agriculture, and is expected to be worth million of dollars per year (Iltis, 1988). Virtually everyone consumes rubber, chocolate, pineapples, etc.. Protecting these wild genetic stocks is clearly a case of a global public good; and is also a country specific public good, in that the countries that produce these products have the most to gain from preserving genes that could save their industries from catastrophe.

Fourth, besides using genes to protect against insect blights, insect pests are often best fought with other insects. One example is the Cassava mealy bug, introduced accidentally from South America to Africa, which severely affected cassava production, threatening the livelihoods and even lives of millions of people. Researchers in South America discovered 12 predators on the mealy bug. A parasitoid wasp, e.lopezi, which preyed specifically on this mealy bug, was selected, and when released and subsequently established controlled the mealy bug, increasing cassava yields by an average of 2.48 tons/ha on study sites in Ghana and the Ivory Coast. However, there are hyper-parasites of e. lopezi indigenous to Africa, which may prove a problem in the future (Neuenschwander, 1989; Lohr et. al., 1990). Other predators of the mealy bug may need to be introduced. If pest insects from the Amazon reach areas where native Amazonian crops are grown, the Amazon will likely prove the best place to look for a predator of those pests.

Fifth, plants and animals produce many chemical substances which could have commercial value. The intense competition for niche space forces rainforest species to evolve any number of bizarre and potentially useful chemical compounds. 75 species of plants are employed in making arrow poisons in the Colombian Amazon alone (Schultes, 1992), and at least 334 species of plants are used as toxins by the Amerindians of the Peruvian Amazon. At least 2000 plant species are used for medicine by Peruvian Amerindians (Brack, 1992). Curare and Rotenone are two examples from the Amazon which come readily to mind, and some 25% of medicines sold in the US have active compounds from tropical plants.[94] Only a minute percentage of rainforest species have been tested for desirable chemical compounds. Species are being wiped out just as we are developing technologies to test their chemical properties en masse.

Sixth, the field of biomimetics is only now getting underway. Materials science is studying the structural properties of certain animals and plants for insights into how to improve our own materials. For example, silk is stronger than Kevlar (the material of bullet proof vests), and is made from water soluble materials at room temperature, while Kevlar requires sulfuric acid at high temperature and pressure. Certain beetle shells resemble space age carbon fibers in structure. Hundreds of millions of years of information and experimentation may be stored in each organism, and once lost, it is lost forever.[95]

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[94] Repetto and Gillis (1988). This figure is subject to some doubt. Many authors claim that this is an exaggeration. The number may include drugs like aspirin, which has close relatives found in various plants, and accounts for a large portion of drug sales.

[95] Reports on biomimetics are occasionally found in the popular literature such as the NYT Science Times and Popular Science.

Seventh, as biogenetic engineering and the computer revolution progress, we will improve our ability to 'read' the information in genes then manipulate the genes themselves to potentially produce tremendously valuable new species. Mammals have far fewer genes than most flowering plants. Each individual in a species that propagates by sexual reproduction has unique genetic information (Wilson, 1988). Destruction of many species can be compared to destruction of a library, just as we are learning to read. Some argue that our technology may progress to the point where we could reverse extinction by recreating genes of extinct species. While theoretically possible, the genetic complexity of even the simplest creature makes the likelihood of this accomplishment approach zero. We could also destroy all the books in existence and potentially recreate them using typing monkeys, but it still makes sense to preserve our libraries. To some extent, advances in biotechnology may provide substitutes for genes from rainforest plants, but they are more likely to be complementary to bio-diversity.

Option Value and Quasi-option Value

Paraphrasing Pearce and Turner (1990), if we are certain of our future demand for environmental goods, of our future income (ability to procure environmental goods) and the future supply of environmental goods, the benefit to the consumer of such goods is the difference between the willingness to pay for the good and the actual payment. Since we are dealing with expected values, this benefit is known as expected consumer surplus. If the individual is however unsure of the future availability of the good, and he/she is risk averse, he/she should be willing to pay more than expected consumer surplus to reduce the risk of not having the desired amount of the good in the future. This difference between expected consumer surplus and willingness to pay is known as option value, and it is positive for the risk averse individual. In the absence of risk aversion and with the addition of demand uncertainty, the sign of option value is no longer certain.

Another type of value arises in the presence of uncertainty, irreversibility and additional information forthcoming in the future, and is known as quasi-option value. The value of biodiversity in the Amazon provides an excellent example of this. Land can be converted now to croplands, which have an approximately known value. The value of the plants irreversibly destroyed by conversion will only be known in the future, as they are studied and as biotechnology or industry perhaps 'discovers' a use for them. Quasi-option value is essentially the value of preserving the option to use these plants in the future, and all else equal, will lead to less irreversible development of natural resources (Pearce and Turner, 1990).

Existence Value

Existence value is the value of a good apart from all possible uses of the good. It is basically the mental well-being we obtain from knowing something exists. Clearly, the Amazon has considerable option value, ample evidence being the monetary donations and expressed concern for preserving this ecosystem by people who will never see or benefit from it in any way.[96] There has been a clear trend in Brazil and world-wide towards greater concern for preservation of the Amazon. Some of this concern undoubtedly arises because of increased

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[96] Actually, given the role of the Amazon in world climate regulation, many people may actually derive use value from the existence of the Amazon without being aware of that fact.

awareness of the economic benefits from the region, but part no doubt arises from an increased valuation for its simple existence. This value has arisen as increasing human populations and resource use have had an increasingly noticeable impact on the environment, while increased media coverage and increased access to media have increased awareness of the problem. Existence value of a resource is clearly contingent upon available information, which in Brazil implies media coverage for the vast majority of the population.

Bequest Value

Bequest value is the value of preserving the Amazon for the benefit of future generations, either for their use or simply for the value they might derive from the knowledge of its continued existence. Bequest value is therefore more of an option value than an existence value.

Some people question the component of bequest value which arises from assumptions that future generations will derive existence value from the Amazon. We do not know the preferences of future generations, so we cannot know if they will positively value the simple existence of the ecosystem. Recent scientific research is contributing to this debate. According to Iltis (1970) and Wilson (1984), the brain of the human species evolved while man lived in a more natural setting, and we derive significant psychological benefits from continued exposure to wilderness areas. However, if people are raised completely isolated from the wilderness, they may no longer be able to experience these psychological benefits from exposure. Hence, whether or not future generations will value wilderness areas may depend on whether or not we leave them any. The research suggests, however, that if we leave them no wilderness so that they do not value it, they are still deprived of a psychological benefit which they are no longer capable of experiencing.

Amerindian Lives, Culture and Knowledge

A particularly difficult issue is the 'value' of Indian populations and cultures. These cultures are perhaps the greatest storehouse of knowledge of the economic value of rainforest species. Much of this knowledge will be lost with the extinction of the cultures. The more complex ethical issue is the 'value' of the actual people and culture. These cultures may be almost entirely outside of the market economy, with no legal property rights to the land they have resided on for generations. Deforestation not only destroys their ability to survive as a culture, but the accompanying exposure to disease and violence threatens their very existence. Being outside of the market economy, they have virtually no ability to pay for the protection of forest, and hence contribute nothing to a 'willingness to pay' valuation of the rainforest. Many non-Indians even value the existence of the Indians negatively. The nation's willingness to pay for the preservation of Indians and their culture might well be negative. Arguably, if Amerindians understood the impacts of deforestation and development, i.e. possible cultural and genetic genocide, the compensation they would demand for destroying their forests might well be virtually infinite.[97] Hence a 'willingness to accept' valuation of the rainforest might preclude any future development.

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[97] Many would dispute the statement that Amerindians would demand virtually infinite money to allow destruction of the rainforests. After all, they seem to like VCRs, Camcorders, airplanes, etc. Elimination of the rainforest would mean elimination of their way of life, their culture, and even their religion, which is integrally tied to the nature which surrounds them. Throughout history, millions of people have died in defense of their religion, which implies they attach an infinite value to it.

Private Good Benefits

Extracting private good benefits from the Amazon need not interfere with the public good value of the region. In a study by Fearnside (1986a), he found that sustainable forest extraction has only minimal ecological impacts. Pasture, however, was the single most ecologically destructive activity in the region, followed by annual crops.

Cattle and Pasture

As mentioned earlier, pasture is the predominant use of cleared land in the Amazon. The poor soils have very low productivity, and many researchers conclude that production is only profitable under very limited circumstances in the absence of the government subsidies. Most writers argue that large scale cattle ranching has been undertaken more to gain title to land for speculation purposes than to profit from beef production (Hecht, 1985, 1992; Browder, 1988; Fearnside, 1989).

John Browder (1988) examines the social costs of beef production in the Amazon, looking primarily at government subsidies given to cattle farmers and the stumpage value of wasted timber. He comes to the conclusion that 'for every quarter-pound unit of Amazon beef that costs US$ 0.26 to produce, Brazil absorbs at least US$0.46 in social costs', for a total subsidy of US$4,815 billion between 1966 and 1983. This comes to US$511 per acre.

The major component of the social cost is the waste of timber resources, 50% of which Browder estimated could be recovered. The rest was in the form of subsidized credit from SUDAM and the Central Bank. Without these subsidies, cattle production would not be economically feasible. Subsidies on national beef were found to be far higher than the price of imported beef.

Even with subsidies, cattle ranches are often only profitable when over-stocking pastures and cannibalizing ranch assets. Clearly, speculative increases in land prices are a significant incentive for cattle production(Browder, 1988).

Hecht, Norgaard and Possio (1988) construct a model of cattle production in the Amazon on large subsidized ranches and test it under a wide range of conditions chosen to model results of numerous previous studies. The four cases they examine include: traditional technology, traditional technology with overgrazing, improved technology with optimistic assumptions and improved technology with pessimistic assumptions. They investigated various rates of increase in land prices, from 0 to 40% per year. In their model of traditional agriculture, without increases in land prices, virtually all scenarios showed a net loss. Only when factor prices were very low and output prices very high, which occurs rarely and only for short periods, did ranching show a positive NPV. This only occurred when using the relatively low discount rate of 10%, whereas real discount rates (I assume the authors mean actual real interest rates) between 1970 and 1985 ranged from 12% to 70%. With subsidies and land price increases, a positive NPV occurs for many of the scenarios. On the other hand, overgrazing with traditional technologies produced a higher NPV than technically optimal stocking levels, and with subsidies and land price increases led to positive NPVs in 13 of 16 trial cases. Interestingly, returns to all resources are always higher with technically optimal stocking levels, and are positive for only 3 of 16 cases of overgrazing. Improved technologies showed a positive rate of return to all resources even without increases in land prices, but still not as high as the returns to traditional pasture with overgrazing. Under pessimistic assumptions, improved technology only gave a positive NPV when land prices increased by 30% a year. None of the scenarios led to a positive NPV with respect to society, i.e. ignoring increased land prices and in the absence of subsidies. Thus, even ignoring the costs of environmental degradation, cattle ranching is not socially optimal. This work supports the results of other research (eg. Mahar (1979) and Hecht (1982, 1985)).

At least up until 1988, about 30% of forest conversion in the Amazon is attributable to several hundred large scale ranches. By 1983, 450 ranches averaging 23,000 hectares, had absorbed US $500,000,000 in incentives from the Brazilian government. Between 1980-88, four times as much deforestation occurred on assisted as compared to unassisted projects. Repetto (1988) found that initial capital costs are about US $400 per hectare for clearing, planting pasture and stocking, compared with US $60 hectare gross returns. A cost benefit analysis shows losses of 55% of investment costs over a 15 year project with a 5% discount rate and 2% real growth in land prices. Doubling actual cattle prices would have led to marginal profits, and 5% real growth in land prices would have cut losses to 45%. With all government subsidies and incentives included, returns are 249%. This remains positive if interest rate subsidies are removed, but goes highly negative if losses can't be offset against other taxable income. For the typical ranch, the present value of the government's total financial contribution is US $5.6 million, twice the cost the government would have incurred had it undertaken the investment directly. Estimated total fiscal cost of SUDAM ranches alone totaled $2.5 billion as of 1988 (Repetto, 1988).

Cattle do have characteristics that make them a rational investment, particularly for the small farmer in the Amazon. Cattle raised in the Amazon are fairly well adapted to the environment. Further, cattle are not as dependent on seasonal cycles as plant crops, and can be sold when market conditions are favorable or to provide a large lump sum to cushion against crop failure or provide for emergency expenses. There is a good market for cattle in the Amazon (some must be imported from other regions to meet consumption demands) with per kilo prices higher than for almost any crop. Third, cattle provides an excellent way to store value in an inflationary economy, with returns on capital higher than many other options available. Investment and labor costs are low, and cattle are an ideal way to eke out returns from lands without other use. Even if returns per hectare are low, they can be significant for subsistence farmers. In addition to their low risk and opportunity costs (if grazed on worn out land), cattle provide milk, hides and meat to the farmer, as well as growth in capital through calves. Because cattle show productive use of land for the lowest investment possible, they are a favored means of securing tenure on land. There is also a favorable social status tied to cattle ownership. Finally, as cattle can transport themselves to market, there is less dependence on unreliable roads. Clearly, in spite of the negative press cattle ranching in the Amazon receives, a rational colonist is very likely to favor deforestation for conversion to pasture lands (Hecht, 1985).

Recent research also suggests that cattle ranching can be economical without subsidies. Much of previous pasture degradation was the result of over-stocking encouraged by government policy. New pasture grasses offer hope, and in some areas recuperation has occurred without subsidies. With the end of fiscal incentives, new ranches are typically logged first to clear pasture land. Since it is easier to get concessions for cattle than lumber, many ranchers used ranching as an excuse to lumber. Some ranchers use returns from timber sales to renovate pasture, indicating cattle are seen by some as economically viable. Pasture management is the problem with successful cattle ranching. The animals themselves are well suited. Initially pasture grasses were poorly chosen, but more promising ones are available. At least half of ranches created in the 60s and 70s suffered serious degradation, though of these some 10% have been renovated (Schneider, 1990).

Another recent study of ranching in Eastern Amazonia is optimistic towards its potential economic success. The authors found that many ranchers were restoring pasture land, at a cost of some $260 per ha. Returns to restored land were estimated at $51 per ha in a 15 year simulation with additional fertilizer applications every 5 years. The study suggests an NPV of $155/ha, with stocking rates of 1 animal unit/ha (au/ha) and a discount rate of 12%.[98] However, $260/ha initial cost is prohibitively expensive for most ranchers, and is often financed by selling timber rights on forested land. Up to 3.5 hectares must be logged to pay for one ha of pasture renovation, so the net returns to society must subtract the value of this forest. Another problem is that

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[98] The assumption that the pasture will maintain such high productivity with fertilizer applications at 5 year intervals seems totally unwarranted. Other researchers have documented rapid declines in pasture carrying capacity due to weed invasion and soil compaction, in addition to fertility loss. Capital markets in Brazil are such that a 12% discount rate is very low. Hecht, Norgaard and Possio (1988) claim discount rates (by which I assume they mean real interest rates) ranged from 12 to 70% between 1970-1985. Also, there may be flaws in the authors' calculations. If pasture renovation led to permanent improvement, and no future maintenance was ever required, NPV would only be $165. The authors claim to have included initial land and cattle purchase, with sale at the end of 25 years for the same price paid, except in the case of improved pasture, which increased in value.

typically a single species of grass is used to renovate pastures, and this species is subject to insect infestations. Other capital intensive production options, dairy/calf production and specialization in range fattening, showed NPVs of $20 and $6 per ha, respectively. These three cases were the most profitable ones analyzed.

Extensive ranching on large and medium ranches has low investment costs, but net returns of only $6 to $20 per hectare per year. The NPV of cattle production on these ranches was negative at a 12% discount rate (Mattos and Uhl, 1993).

Agriculture

Most agriculture in the Amazon is carried out by small scale producers. Typical production technology involves clear cutting then burning forests (which requires approximately 29 man-days labor/ha (Fearnside, 1986)), followed by two to three years of annual crops with rapidly declining yields. When yields fall too low, the cycle is repeated. Fertilizer is rarely applied. At a typical daily wage of $2.50 for manual labor[99], the cost of clearing one ha of forest is about $72.00[100], and one study estimates the nutrient content of the ash is equivalent to about $680.00 of fertilizer inputs (Cunha and Sawyer, 1991). Farmers naturally substitute abundant forest resources for scarce capital. When

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[99] It is difficult to calculate wages in Brazil. The nationally legislated minimum wage changes every several months, the frequency depending, among other things, on the rate of inflation. An overnight increase in the minimum wage of %250 is not uncommon. For example, the minimum wage increased from some $36 per month to about $100 per month in January, 1993. Fearnside (1986c) and Lisansky (1991) site figures of $2.50 per day for manual labor, whereas Uhl and Vieira cite a figure of $1.50/day.

[100] Hecht, Norgaard, and Possio (1988) estimate the cost of deforesting one hectare at $87-130, Browder (1984) provides a figure of $55, and Kitamura and Serrao (1982) claim $150. [All cited in Hecht et. al. (1988)] The figure I calculate is on the low side of this range.

nearby forests and soils are exhausted, settlers will typically move on (Almeida 1992a).

There is also significant production of permanent crops, such as coffee, cacao or pepper. These require larger initial investments, are dependent on world prices, which can vary significantly from year to year, and have a long lag between planting and harvesting. In addition, these crops are highly subject to destruction by insects and disease.

Crop production in the Amazon is a risky venture. Crop prices are notoriously volatile and beyond the control of the squatter.[101] This is especially problematic because of the lag between planting and harvesting, especially for permanent crops such as coffee or cacao. Colonists can hardly use current prices as indicators of next season's price.[102] Natural risks are abundant as well. Weather is unpredictable, and the hot, humid climate of the Amazon is ideally suited for insect pests and plant diseases. Insect species vary greatly between regions quite close together, and many are highly opportunistic, quickly learning to utilize a new food source. This means that one farmer's crops may be decimated by pests and another's nearby left relatively untouched. Insecurity of land tenure means investments in crops may be lost if the land is lost before harvest. Changes in state policy (e.g.

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[101] For a graph showing the considerable variation in rice prices on the national market over the period 1960-1980, see Costa (1991).

[102] Lisansky (1991) states that one season's prices often bear a negative correlation with the next season's. When rice prices were high, farmers would expand production, and drive down prices. When low, farmers would cease to produce rice, and price increases occurred. The only example she gives is for 1978, when producer prices at harvest time were $2.50 for a 60k bag, while in 1979, prices were $7.00 for the same amount. Prices also vary tremendously depending on availability during the year. In 1979, merchants were selling rice at harvest time for $15.00 per bag, while later in the year prices reached $40.00 for the same quantity.

ending price guarantees) can also add to the degree of uncertainty (Ellis, 1988).

Though highly variable from region to region within the Amazon, transport costs from the producing site to markets tend to be much higher than in the rest of the country, both because of distance and poor infrastructure. There are typically few options available for selling produce, and frequently buyers have monopsony power, which is aggravated by the fact that by nature most crops come on the market at the same time, and storage facilities are scarce (Almeida, 1992a).

Comparative Disadvantage

Almost any crop which can be produced in the Amazon can be produced with higher quality and lower price in the south, much closer to the markets. Improving trunk roads has served more to bring southern produce to the north than vice-versa. Nationally, increased yields and development of new production areas increasingly marginalizes the Amazon for crop production, as lower prices means transportation costs are felt more.

To make matters worse, extension services have been declining in the Amazon since 1987 when responsibility was turned over to the states. Farmers have largely ignored extension service advice with respect to input packages, either through ignorance, lack of credit, or inappropriateness of the packages (Schneider, 1990).

Prospects for Sustainable Agriculture

While technologies exist for continued sustainable production on some Amazonian soils, the current methods are highly input and information intensive, two factors of production conspicuously absent in the Amazon. Under virtually ideal conditions in Yurimaguas, in the Peruvian Amazon, it is possible to produce two to three crops per year with high yields for at least 10 years by using crop rotations and chemical inputs (Nicolaides III et. al., 1983a & b). There are serious problems with adapting this technology to large areas however. Three different plots at the study site, with the same original vegetation in the same area, require different fertilizer applications, which can only be determined by soil analysis. After ten years, soils were deficient in 10 nutrients, so soil analysis required great precision and was difficult even for the highly trained researchers. Even with skilled technicians, after three years yields fell rapidly at the test site when some trace elements were neglected.

Fertilizer applications require more capital than most farmers have, and increase risk. Occasional heavy rains can wash off fertilizer applications, as happened at least twice at the study site, and new fertilizer applications are then required. The technology is also only recommended when slope is 8% or less. Maps at 1:1,000,000 show that 50% of the Amazon might be suitable, but ground level studies suggest much less. Only some 6% of Amazonian soils do not offer serious limitations to agriculture, and more fertile soils tend to occur on greater slopes, where erosion is a greater threat (Fearnside ,1990).

Diseases and pests increase greatly as cultivated area expands. Pests tend to be recruited locally, and numbers rise asymptotically over time. Only 1.5% of pests on cacao and sugar cane are geographically widespread. The size of a mono-crop is the best indicator of the number of pest species present. Pest communities change rapidly with time and cultivation techniques. Weeds show similar characteristics, with only a 10% overlap between the average two sites on the varzea study area

Only 20% of weeds were common to more than one of three sites in study. In the Amazon, pest diversity is greater than in other ecosystems, and pests are largely endemic, therefore hard to predict. Control techniques must be site specific, and other pests are ready to replace those eliminated (Hecht, 1982). Pesticide applications are very high at Yurimaguas. Insects acquire immunity rapidly, there are innumerable opportunistic insect varieties, different insects attack different areas, and pesticides have serious negative environmental consequences. Weeds are also a serious problem, and many fail to respond to herbicides. Chemicals are required throughout the year, but currently availability is a serious problem throughout much of the Amazon. Inputs and outputs were available in Yurimaguas at the same prices as in Lima, i.e. heavily subsidized. The military brought supplies when roads were out. Machines were also supplied by the researchers. Maintenance and repair of machinery is very difficult in the Amazon. Without machinery, hand preparation of soil is extremely difficult because of soil compaction under continuous cultivation (Fearnside 1990).

The Yurimaguas experiments have shown that while sustainable agriculture is possible, it is a technology not easily disseminated. There are considerable differences between soils in different areas of the Amazon and even on the same plot, with vastly different requirements for maintaining soil productivity. One cannot simply transfer the technology appropriate for one site to another (Eswaran, 1992). Sustainable cropping requires not only fertilizer, but a means to restore soil structure and soil-water relationships in addition to a continuous supply of organic matter Lal(1986). Soil conditions seriously impede the rational use of fertilizers because of clay content and the compaction which follows deforestation, hence soil nutrient loss may be permanent and mineral fertilizers are not a perfect substitute. Even 'almost ideal well managed pasture areas' suffer serious loss of soil fertility (Cerri et. al. 1991).

Sustainable Extractive Production

Commercial extractive activities employed 100,000 people in the Amazon, some 14% of the economically active population, as recently as 1980. This number does not account for extractive production for home consumption or barter, which is practiced to some extent by virtually every rural household in the region (Homma, 1989).

There is abundant literature discussing sustainable extraction in the Amazon, much of which indicates that potentially it could render higher yields per acre than agriculture, even ignoring the fact that agricultural lands degrade. One study of the economic value of rainforest extraction documented the net present value of sustainable extractive production from a one hectare plot of sandy soil near Iquitos, Peru. The plot included 11 species of edible fruits, 60 commercial timber species, and rubber. The net present value was calculated conservatively as $6,330, using a 6% discount rate. In comparison, the net present value of the land used for cattle ranching was less than $3000, and for managed plantations just over $3000. This study ignored the value of medicinal species, psychoactive species and thatch and fiber species (Peters, Gentry and Mendelsohn, 1989). Another study found that river dwellers near Iquitos earn some $1700 per hectare/yr from extractive production (Brack, 1992).

Many of the trees suitable for commercial extraction, especially palms, occur naturally in dense concentrations on areas unsuited for agriculture. M. flexuosa, a palm with many economic uses (fruit high in vitamin C, oils high in vitamin A, useful fibers, cork substitute, wine and timber) reaches densities in natural stands 1-2 times greater than African oil palm plantations (Kahn, 1991). Dense stands of the vitamin C rich Camu Camu palms are able to produce an estimated $5000-$6000 in fruit per hectare per year, and an actual test site of 10 ha produced $10000 worth in one year. Many of these species are already exploited, but could be exploited at much higher levels with minimal environmental impact (Balick, Kahn and Anderson, 1991).

In 1980, over half of Para`s exports came from extractive production, yet extractive resources were underexploited. The three tree species which comprise the majority of timber harvested could be managed for sustained yield, yet are not. In Acre, rubber trees were cleared for pasture, and in both Mahogany and Brazil nuts are cut and burned to make pasture (Hecht, 1982).

In parts of Maranhão where the Babassu palm is abundant, extractive activities provide significant income, and in poor rural households as much as wage labor or agriculture. The importance of extraction is more pronounced amongst the poorest. In particular, extraction is a major cash source for women. Current rural development programs undermine this income source, and extractive income is often ignored (May, 1986).

Timber

Timber production in the Amazon is growing rapidly. Traditionally, only river floodplains were available for timber harvest, but the opening of roads has allowed access to much greater areas. The Amazon contributed only 14% of Brazil's wood harvest in 1976, while 10 years later this had increased to 44%. Logging in the Amazon is typically highly selective, though the number of commercial species is increasing.

A case study in the Paragominas region of Pará found that logging could be lucrative, but had large environmental costs. While only an average of 8 trees per hectare were harvested in the study sites, this was 16% of basal area, since selected trees are typically the largest. Harvesting also damaged or destroyed an additional 28% of the basal area, and reduced canopy cover by nearly 50%. In addition, micro-climate changed in logged forests, becoming hotter and dryer, which in combination with the slash left from logging greatly contributed to fire hazards. Eight of fifteen logging sites studied suffered from forest fires. Selective logging threatens extinction of certain trees. Some trees selected provide fruit for wildlife, and their elimination may threaten animal populations as well. Remaining trees in logged forests are more susceptible to uprooting by wind. An additional threat is posed by farmers and ranchers who often follow behind logging operations. Logged areas are unlikely to return to their previous state.

Rights to logging on land sell for $25 to $50 per hectare, a small cost in comparison to returns for vertically integrated logging/sawmill operations. There is thus little incentive to log carefully. Landowners can earn some $175 per hectare if they carry out the logging operations themselves and sell the wood to sawmills. The authors calculate that at current cutting rates, the Amazon will be mostly logged within 80 years. Logging is currently increasing exponentially, however. The rotation period in unmanaged forests is estimated at 75-100 years. While there are technologies available which might allow sustainable logging, the ratio of unmanaged to managed logging operations is 35,000 to 1 in tropical America (Uhl and Vieira, 1989).

The government has subsidized logging operations just as it subsidized large agro-pastoral projects. From 1965 to 1983, 35% of tax credit funds went into lumber processing. Projects enjoyed 15 year tax holidays, liberal export financing and other advantages. Once mills are built, there is considerable pressure to maintain them open. Generous government incentives encourage inefficient and wasteful plants (Reppetto and Gillis, 1988).

Economics of Extractive Production

In spite of the potential commercial value of extractive production, the participation of sustainable extraction in total economic product from the Amazon has steadily declined over the past years. Given the market institutions of the extractive economy in the Amazon, this apparent paradox is easily explained. Extractive producers must market their goods, and access to markets is very limited. In the Amazon, the tradition has been for a wealthy and powerful 'patrono' to purchase all the extractive output from a given area. Extractive workers typically have no choice but to sell to the patrono at the price he sets. Often, they obtain initial supplies from the patrono, are never able to work off the original debt, and work thereafter in a state of debt peonage. The patrono may profit handsomely upon selling the goods at the next level, but this does not benefit the producer. The peasant farmer is typically more independent with respect to subsistence needs, and does not depend on a single purchaser.

Rubber producers, or seringueiros, are a good example. Before the advent of seringueiro cooperatives, the seringueiro typically sold all his production to the seringalista. The producer often received half of the market value or less. The seringalista was typically the sole source of market goods for the seringueiro, often sold at mark-ups of 70-100%. Frequently the seringueiro was unable to pay the initial debt in a given year and was forced to continue working for the seringalista. Alternatively, large corporations might buy enormous tracts of land, then lease the use-rights to a local corporation. This corporation would then charge the seringueiros a share of their rubber in exchange for access to the land (Ripper, 1991).

Other reasons for the apparent under-exploitation of extractable resources include the difficulty of access to both the resources and the market, the lack of knowledge of what to extract and the lack of markets for unfamiliar extracted goods. Much of the knowledge of economically valuable species is local, and of the information gathered in various research projects in Peru, for example, some 90% of it is inaccessible within Peru (Brack , 1992).

Extractive production plays a far more important role than what is apparent from commercial records. Most rural Amazonian residents rely on the forest for food, fuel and building materials. An estimated one tenth of the campesino diet near Iquitos comes from wild harvested fruits (Gentry, 1992). Fish is the main source of protein especially for the poorest portion of the population.

The Amerindians in particular rely on extractive activities for most of their needs. Extractive production is characterized by a fixed supply. After a new extractive product is introduced, demand may grow. The increase in demand is met by expanding production to untapped areas, and the industry undergoes a phase of expansion. Eventually, there are no more untapped areas. In the stabilization phase, continued growth in demand only leads to higher prices. This may lead to the resource being extracted in an unsustainable manner, as has happened, for example, to rose-wood and mahogany. Extinction is then a distinct possibility. Efforts to meet growing demand are now met by research into synthetic alternatives and the establishment of plantations. The extractive industry begins to decline. Finally, synthetic or plantation alternatives completely dominate the market, and the extractive production virtually ceases. If it were not for price supports on natural rubber, there might no longer be an extractive rubber industry. In addition, extractive production declines in the Amazon as waves of agropastoralist immigrants destroy the extractive resource base, independent of the value of extractive activities (Homma, 1989).

APPENDIX B:

DEVELOPMENT OPTIONS IN THE AMAZON

A discussion of optimal deforestation of the Amazon is incomplete without an examination of the options for development in the Amazon, and their likely impacts. Fearnside (1986a) presents 14 possible options for development, and ranks them according to ten criteria, which are:

1) Productive sustainability. This includes energy and nutrient balance, maintenance of geophysical characteristics necessary for production, and consideration of biological factors (insects, disease, etc.). This is of primary importance in the long run.
2) Social sustainability. This means that yield and price fluctuations cannot be so great as to threaten social survival in hard times, and population growth and excessive income disparities cannot place undue stress on the system.
3) Competitiveness without subsidies in the short term.
4) Competitiveness without subsidies in the long-term. Though not mentioned by Fearnside, potential transfers of wealth from the rest of the world to protect the rainforest would not be subsidies, but rather payments for services.
5) Maximum self-sufficiency. The idea is that reliance on outside energy or food imports will make the system more vulnerable to extra-regional fluctuations in prices and supplies.
6) Achieving social goals. Examples include minimal acceptable living standards, employment, and income distribution. It is worth noting that the geo-political goal of settling the frontiers requires, in the long term, either subsidies or some sort of sustainable and profitable economic activity.

7) Compatibility with maintaining areas for other uses, such as ecological or Amerindian reserves.

8) Retaining options for the future. This is especially important in the face of uncertainty, irreversibility of deforestation and increasing knowledge about the region.

9) Minimum effects on other resources, such as fish productivity of the rivers and ocean.

10) Macro-ecological effects, such as loss of biodiversity and climate change.

The options considered, in order of increasing environmental disturbance (and therefore in order of decreasing supply of public benefits) are:

35) Intact forest. This maintains the full public good value of the forest, but in the short run is not competitive with other options.

36) Extraction of forest products (such as rubber, Brazil nuts, medicinal plants, etc.). Currently this provides low standards of living, which may increase as more valuable biological products are discovered;

37) 'Shelterwood' silviculture.

38) Selective extraction (high-grading) with replanting (primarily of trees). Replanting can be costly, and delays in harvest rotations very lengthy.

39) Selective extraction without replanting or regulation (which is how timber is currently extracted).

40) Selective enrichment or poisoning, where high value plants are selectively planted, and low value ones girdled or poisoned, so they die slowly while the high value plants mature. This is labor intensive, and slow.

41) Silvicultural plantations. This involves clearing virgin forest to replant with economically valuable species, as was done in Jarí. If done in monocrops, which is typical, disease is a problem.

42) Clear-cutting without replanting. This may currently not be economically viable unless land is converted to some other use. The government could not find anyone to do this for some of the areas flooded by hydroelectric dams.

43) plantations of perennials. Among other problems, perennials often suffer from insects or disease, few soils are adequate in the Amazon, and if adopted on a large scale international prices of goods produced would fall.

44) Taungya. This is a system of agro-silviculture from Burma where tree crops are planted consecutively with annual crops.

45) Annual crops with fallows.

46) Continuous annual crops.

47) Pasture with fertilizers.

48) Pastures without fertilizers.

The following table sums up the results of Fearnide's analysis.

Table 9: Development options in the Brazilian Amazon, ranked according to ten criteria. The numbers in the top row correspond to the list of ten criteria listed above. From Fearnside (1986a).

	1	2	3	4	5	6	7	8	9	10
intact forest	1	3	3	?	-	1-3	1	1	1	1
extraction	1	?	3	1	3	3	1	1	1	1
shelter-wood	1	?	3	1	3	1-3	1	1	1	1
Selective extraction w/o replanting	1	?	2	1	3	1-3	1	1	1	1
Selective logging w/ replanting	2	?	1	3	3	1-3	1	1	1	1
enrichment /poisoning	1	?	2	1	3	1-3	1-2	1	1	1
silviculture plantation	2	?	2	2	3	1-3	2	3	2	2
clear cut	3	3	1	3	3	1-3	3	3	2	2
perennial crops	2	1	1	1	2-3	1-3	2	3	2	2
Taungya	2	1	2	1	1	1	2	3	2	2
shifting annual crop	1-3	1-3	2	2	1	1-3	3	3	2	2
continuous annual crop	?	1	3	2	1-3	1-3	2	3	3	3
pasture w/ fertilizer	2	3	3	3	3	3	3	3	3	3
pasture w/o fertilizer	3	3	3	3	3	3	3	3	3	3

where 1=good 2=average 3=poor ?=unknown

Fearnside points out that no system is a panacea for the problems of development in the Amazon, and each may be more or less suitable in different areas. While each system has some advantages, some clearly have fewer advantages than others. Unfortunately, government policies and free market forces have not tended to promote the most desirable options.

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