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Deforestation

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Deforestation

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Deforestation occurs as a result of fire, disease, wind and other natural means, or as a consequence of human activities related to the harvest of timber for commercial purposes and/or clearing of land for agriculture. Throughout history, people have always removed trees for fuel and construction purposes, and to make land available for agriculture. Recently, commercial logging operations in developed countries have become sustainable, although, as we show below, the same may not be true of logging operations in many developing countries.

Global patterns of deforestation are indicated in Table 1. Between 2000 and 2005, the majority of countries in the Caribbean, Europe, North America, Oceania, and Western and Central Asia had no significant changes in forested area, while in Africa nearly all countries lost forestland to agriculture (FAO 2006). The countries with the greatest losses in forest averaged a net loss of 8.2 million ha per year, with Brazil (3.1 mil ha yr^{-1}) and Indonesia (1.9 mil ha yr^{-1}) leading the way. The ten countries with the greatest net gains in forest area averaged gains of 5.1 mil ha yr^{-1}, with China accounting for the most (4.1 mil ha yr^{-1}). In most major industrial wood producing countries (e.g., Finland, Sweden, Canada), forest laws require reforestation of sites after harvest, and evidence indicates that forests in temperate and boreal areas have actually expanded. Thus, we conclude that deforestation is mainly a problem of tropical deforestation, but that rates of deforestation appear to be falling.

Tropical Deforestation

The UN's Food and Agricultural Organisation (FAO) defines tropical forest ecosystems as having a minimum of 10% crown canopy of trees and/or bamboo; they are generally associated with wild flora, fauna and natural soil conditions and not subject to agricultural practices (FAO 1997). Tropical forests cover a large portion of the globe's land surface between 23^{o} north and south of the Equator, and range from open savannahs where precipitation is limited, to dense tropical rainforests. Tropical deforestation is defined to occur when canopy cover is reduced to less than 10%. This implies that significant forest degradation can take place without being considered deforestation. Nonetheless, the FAO definition is generally used because of its consistency and reliability.

In 1995, tropical forests were estimated to cover an area of about 1,733.9 million ha or about 13.4% of the globe's land area, excluding Antarctica and Greenland. This was down from an estimated 1,756.3 million ha in 1990 and 1,910.4 million ha in 1981. During the 1990s, some 5.8 million ha of humid tropical forest were lost each year (or 0.5%), although re-growth reduced this by 1 million ha (Mayaux et al. 2005). However, rates of deforestation have varied substantially throughout the tropics (Table 1). Perhaps surprisingly, the tropical rainforest, which is the forest type of most concern to the international community, experiences relatively slower rates of deforestation than other tropical forests (FAO 1993). Indeed, the highest rates of deforestation in tropical regions appear to occur in (moist or dry) upland forests.

Table1: Forest Area and Rates of Deforestation, 1981–2005

		Average annual change in forest cover							
	Forest cover, 2000	1981–90		1990–95		1990–2000		2000-2005[a]	
Region/country	(10^6 ha)	Area (10^3 ha)	Rate (%)	Area (10^3 ha)	Rate (%)	Area (10^3 ha)	Rate (%)	Area (10^3 ha)	Rate (%)
Africa	*649.9*	*-4,100*	*-0.7*	*-3,748*	*-0.7*	*-5,264*	*-0.7*	*-2,898*	*-0.4*
Tropical	634.2	n.a.	-0.7	-3,695	-0.7	-5,295	-0.8	-2,299	-0.4
Nontropical	15.7	n.a.	-0.8	-53	-0.3	31	0.2	-120	-0.8
Asia	*524.1*	*n.a.*	*n.a.*	*-3,328*	*-0.7*	*-651*	*-0.1*	*n.a.*	*n.a.*
Tropical	288.6	-3,791	-1.2	-3,055	-1.1	-2,427	-0.8	-1,599	-0.6
- South Asia	76.7	-551	-0.8	-141	-0.2	-98	-0.1	+41	0.1
- SE Asia	211.9	-3,240	-1.4	-2,914	-1.3	-2,329	-1.0	-1,640	-0.8
Europe	*998.1*	*n.a.*	*n.a.*	*+389*	*+0.3*	*+424*	*+0.3*	*+661*	*+0.1*
- Northern	70.3	n.a.	n.a.	+8	+0.0	+40	+0.1	+95	+0.1
- Western	32.6	n.a.	n.a.	+358	+0.6	+311	+0.5	+51	+0.1
- Eastern	848.8	n.a.	n.a.	+23	+0.1	+73	+0.2	-28	≈0
Former USSR	*901.4*	*n.a.*	*n.a.*	*+557*	*+0.1*	*+739*	*+0.1*	*-3,704*	*-0.4*
Canada	*244.6*	*n.a.*	*n.a.*	*+175*	*+0.1*	*0*	*0.0*	*+2,621*	*+1.1*
USA.	*226.0*	*n.a.*	*n.a.*	*+589*	*+0.3*	*+388*	*+0.2*	*+3,084*	*+1.3*
Central Am. & Mexico	*73.0*	*-1,112*	*-1.5*	*-959*	*-1.2*	*-971*	*-1.2*	*+546*	*+0.7*
Caribbean	*5.7*	*-122*	*-0.3*	*-78*	*-1.7*	*+13*	*+0.2*	*+11*	*+0.2*
South America	*885.6*	*n.a.*	*n.a.*	*-4,774*	*-0.5*	*-3,711*	*-0.4*	*-4,513*	*-0.5*
Tropical	834.1	-6,173	-0.7	-4,655	-0.6	-3,456	-0.4	-4,251	-0.5
- Brazil	543.9	-3,671	-0.6	-2,554	-0.5	-2,309	-0.4	-3,103	-0.6
Temperate	51.5	n.a.	n.a.	-119	-0.3	-255	-0.5	n.a.	n.a.
Oceania	*197.6*	*n.a.*	*n.a.*	*-91*	*-0.1*	*-365*	*-0.2*	*+346*	*+0.2*
Tropical	35.1	-113	-0.3	-151	-0.4	-122	-0.3	n.a.	n.a.
Temperate	162.5	n.a.	n.a.	+60	+0.1	-243	-0.1	n.a.	n.a.
Global total[b]	**3,869.5**	n.a.	n.a.	**-11,269**	**-0.3**	**-9,397**	**-0.2**	**-7,317**	**-0.2**

Notes:
n.a. implies not available or not applicable.
[a] Preliminary and based on authors' calculations
[b] Totals may not tally due to rounding.
Source: FAO (1993, 1997, 2001, 2006); http://www.mongabay.com/forest_types_table.htm

It is estimated that 90% of (modern) tropical deforestation occurred between 1970 and 1990 (Skole et al. 1994). Although reduced in size, the world's tropical forests still constitute an area equal to the whole of South America. Even at the current rate of tropical deforestation, the world's tropical forests would continue to exist through the entire 21st century and well into the 22nd century. Of course, the current rate of tropical deforestation will almost surely change over time.

In many respects, tropical deforestation today is not dramatically different from temperate deforestation that occurred centuries earlier. In the past, expanding populations led to greater use of wood for fuel and construction and an expansion of agricultural land, resulting in large-scale deforestation in many regions of Europe and North America. The denuding of the forest landscape was often the result of spontaneous actions, but also reflected government policies. In the U.S., for example, the Homestead Act required land clearing as a prerequisite for obtaining land title. A similar policy existed in Brazil until recently. For North America and Europe much of the early land clearing has subsequently been offset by forest renewal, largely through natural processes.

It has sometimes been claimed that it is difficult to renew tropical forests, but evidence suggests otherwise. For example, it is believed that large areas of the American tropics had been in terraces, irrigated agriculture and agro-forestry in the pre-European settlement period, but reverted to forests as disruptions and disease decimated local populations (Pyne 1997). These areas then returned to tropical forest. Deforestation is generally a reversible process, but appears irreversible because of the long time required to restore forests to their original state.

Economic Benefits of Tropical Forests

Forests provide many values to humans. We distinguish between production functions (production of timber and non-timber forest products), regulatory functions (e.g., carbon sink, watershed protection) and wildlife habitat/biodiversity functions, where the latter include non-use values associated with preservation. Preservation values are associated with the knowledge that tropical forests exist now (existence value) and in the future (option and bequest value).

Production Functions of Tropical Forests

Tropical forests produce tangible products such as timber, fuelwood and non-timber forest products (e.g., rattan, oils, fruits, nuts, ornamental flowers, bush meat), plus less tangible assets such as opportunities for eco-tourism.

Tropical stands contain some 200 m^3 to 400 m^3 of timber per ha (Thiele and Wiebelt 1993; Pearce and Warford 1993, p.130), but much of this consists of non-commercial species, so clear felling does not usually occur. Nonetheless, if 30% to 40% of the harvest is usable and assuming total rents of US\$30 m^{-3}, clear felling yields a rent (or social surplus) of \$1,800-\$4,800 per ha, not including returns from subsequent land uses. Subsequent use of the land in forestry yields a positive but small return (less than US\$1 ha^{-1} yr^{-1} for artificially regenerated stands), while managed plantations frequently yield negative returns and proceed only with government subsidies (Sedjo 1992).

Estimates of the value of sustainable selective logging per ha vary considerably, with differences due to (among other things) discount rates, stumpage prices, management costs, site conditions and productivity (see, e.g., Vincent 1990; Pearce and Warford 1993; Barbier et al. 1995). For instance, for Indonesia, Pearce and Warford (1993) estimate that selective logging yields a discounted net return of US$2,409 ha^{-1} (assuming a 6% discount rate). Other estimates of the value of *sustainable* selective logging vary considerably. Vincent (1990) provides estimates of present value ranging from +US$850 down to -$130 per ha, with the outcome of the most realistic scenario in the vicinity of $250 ha^{-1}.

Small-scale gathering of non-timber forest products (NTFPs) is competitive with commercial logging only in some regions. The values provided by rattan, oils, fruits, nuts and bush meat can be large on occasion (de Beer and McDermott 1989; Peters et al. 1989) and, in some cases, large numbers of forest dwellers depend critically on them for survival. However, one cannot simply extrapolate these high figures to large stretches of tropical forests due to downward sloping demand, uncertainty concerning sustainable supply, and increasing costs of production and transportation.

Likewise, eco-tourism is only locally important. Although tropical rainforests are generally not very attractive to tourists because of the humid climate and their limited scenic value (compared to East African game parks, say), recreation and tourism have the potential to become sources of foreign exchange. However, the role of eco-tourism in the promotion of forest conservation will likely remain small, and per ha values fall as more regions are available for tropical forest recreation.

Regulatory Functions of Tropical Forests

Tropical ecosystem regulatory services consist of watershed protection, waste assimilation, soil conservation, carbon storage, and others. Since these services do not have prices, non-market valuation methods are needed to gain insight into their values. Non-market benefit estimates employ a variety of techniques to estimate environmental damages that deforestation might cause (van Kooten and Folmer 2004). Thus, for example, Postel and Heisse (1988) estimate that deforestation in Costa Rica resulted in revenue losses of $133-$274 million from sedimentation behind one dam, while Ruitenbeek (1989) computes the fishery and agricultural benefits of forest conservation in one region of Costa Rica to amount to some $3/ha/yr, or a present value of US$60 ha^{-1} using a discount rate of 5%. Apart from protection against soil erosion and sedimentation, tropical forests are believed to provide protection against floods and a more balanced supply of water when there are seasonal differences in precipitation because the soil acts as a sponge. Ruitenbeek (1989) estimates the present value of the watershed function to be US$23 ha^{-1} of forest protected in Costa Rica. However, it is important to recognize that it is not deforestation *per se* that leads to the loss of regulatory functions, but rather the nature of the succeeding land use. Agricultural practices that leave soils exposed during the wet season create erosion problems and nutrient losses, but land uses that provide crop cover all year long (e.g., pasture, coffee plantations) experience rates of erosion not much worse than forestland.

Release of carbon is an important cost associated with tropical deforestation, with estimates of the potential damages from deforestation some $25-$175 ha^{-1} yr^{-1} (IPCC 1996). Without knowledge of the shadow price of CO_2 in the atmosphere, however, it is impossible to determine unambiguously this component of the costs of tropical deforestation. Therefore, we employ several estimates of CO_2 prices in the cost-benefit analysis below.

Habitat, Biodiversity and Non-use Values

Tropical forests are home not only to millions of people for whom forests are an integral part of economic, social and religious life, but also to millions of animal and plant species, most of which are endemic to the local forest ecosystem. Tropical deforestation is considered a major contributing factor to loss of species, with claims of annual loss ranging from 14,000 to 40,000 species to as many as 16 million (Hughes et al. 1997). Even under the most optimistic assumptions, the present value of marginal species is small, less than $10,000 at best. As the number of species increases, the value of marginal species falls – from almost $3,000 when there are 250,000 species to a negligible amount when there are more than one million (Simpson, Sedjo and Reid 1996). If the value of marginal species is small, then, by extension, so is the value of a marginal hectare. Consider biodiversity prospecting. Even ecological 'hotspots' such as in Ecuador, favourable assumptions suggest pharmaceutical values of approximately US$20 ha^{-1}, with estimates for other regions much lower. Barbier and Aylward (1996) conclude that "the potential economic returns from pharmaceutical prospecting of biodiversity are on their own insufficient justification for the establishment of protected areas in developing countries". While the economic value of species in biodiversity prospecting may be modest at the margin, ecosystem stability may nonetheless be positively linked to diversity; yet, ecosystem stability and services from ecosystems may not depend on the uniqueness of the species mix (e.g., Hawaii has lost much of its original species but its forest continue to provide services using a mix of invasive and indigenous species).

Non-use values related to biodiversity (species) are likely more important than use values. Based on data from contingent valuation studies cited by Pearce and Warford (1993, pp.131-132), we estimate that the annual existence value for the total tropical forest is approximately $3 per ha, and no more than $6 per ha for the tropical rainforest. These estimates are much higher than estimates of household willingness to pay obtained by Kramer and Mercer (1997). As we show below, whatever value is chosen, it is likely small compared to commercial values. Further, since non-use values decline as the forest stock increases, the marginal preservation value is likely much lower than indicated here.

Summary

A summary of the marginal values of tropical forests is provided in Table 2. For comparison, estimates of the average economic values of tropical forests as calculated by Costanza et al. (1997) are also provided in Table 2. While it is true that tropical forests provide a wide range of ecosystem services and other non-timber amenities, their marginal values are small compared to commercial values of the forest. Nonetheless, as more of the tropical forest is converted to other land uses, it is likely that the costs of further conversion (the value of foregone ecosystem and other non-timber amenities) will increase as well. At some point, the marginal costs of additional land conversion, including the costs of associated risks, will equal or exceed marginal benefits and no further tropical deforestation should occur.

Causes of Tropical Deforestation

The causes of tropical deforestation are complex and not well understood. Identification of causes is influenced by poor-quality data, the approach employed (normative, positive, statistical, structural, etc.), the level of analysis (local, country-level or cross-country comparisons), different definitions of terms such as 'deforestation' and 'shifting cultivation', and failure to distinguish between types of logged areas, Moreover, explanations of tropical deforestation are situation dependent – the forces that bring about deforestation differ by region and country, and over time. Because of these differences, there is often no consensus about the actual causes of deforestation. Nonetheless, we investigate some of the main factors that have been raised – commercial logging, conversion to agriculture, population pressure, poverty, and the role of good governance.

Table 2: Summary of the Economic Values of Tropical Forests (US$/ha/yr)

Item	Marginal [a]	Average [c]
Commercial logging		
-Clear felling	72-192	not calculated
-Natural forest management	≈ 1	315 (all raw materials)
Agriculture[b]	120-140	not calculated
Sustainable land use		
-Selective logging	10-145	not calculated
-Nontimber forest products	≈ 10	32
-Tourism	≈ 1	112 (all outdoor recreation, incl. tourism)
Preservation		
-Watershed protection[b]	≈ 2	8
-Prevention of soil loss	≈ 3	245
-Flood preventation	≈ 1	6
-Other	not calculated	1,024
-Global climate change	2-140	223
-Biodiversity prospecting	1-2	41
-Non-use value	1-4	2

Notes:
[a] Unless otherwise indicated, these data are based on discussion in the text. Values are annualized using a 4% discount rate.
[b] Source: van Soest (1998, p.25).
[c] Source: Costanza et al. (1997). Not all categories correspond to those in the marginal column.

Commercial Logging

A common but simplistic view, now largely rejected by most analysts, is that tropical deforestation is due to commercial timber logging (Kaimowitz and Angelsen 1998, 2001). Commercial logging in the tropics rarely results in significant direct land conversion. Unlike commercial logging in the temperate forest, in the tropics it almost never involves clear felling; because of the high diversity of tree species, only a relatively few of the total trees in a tropical forest are commercially suitable (Panayotou and Sungsuwan 1994). Within the tropical belt there are strong regional differences in logging intensity, with highly selective logging in Africa and Latin America and more intensive timber harvesting in Asia (where sometimes 40% of trees are extracted and clear felling sometimes occurs).

There are two main factors that determine logging intensity: (1) the share of marketable trees per ha (which is typically much lower than in temperate zones) depending on species composition and output demand; and (2) transport costs that depend on the proximity of markets and the mode of transport (river or road) (van Soest 1998). Selective logging is generally conducive to forest regeneration and re-growth. Although selective logging can be damaging in practice (e.g., because of careless logging induced by perverse incentives, or simply because it is too costly to untangle trees that are linked by lianas and vines), in most cases the forest is able to regenerate (Grainger 1993). The most damaging aspect of the harvesting process may be the construction of roads (Myers 1980; Grainger 1993; Panayotou and Ashton 1992). Estimates of the direct contribution of commercial logging to deforestation are therefore modest, typically varying from 2 to 10% (Amelung and Diehl 1992). However, logging often facilitates conversion of forestland to agriculture.

Illegal logging is also important and is estimated to deprive governments of some \$15 billion annually in royalties, and depress timber prices by some 7-16% (The Economist 2006). For instance, the Indonesian government estimates that it loses \$3 billion in royalties each year, not an inconsequential amount when compared to total annual royalties of \$6.5 billion (The Economist 2006; Dauvergne 1997).

Conversion to Agriculture

Deforestation is primarily caused by a desire to convert forests to agriculture, which is particularly true in Africa and Latin America but less so in Asia. A fundamental distinction needs to be made between ‘shifting cultivators’ and ‘forest pioneers’, with numerous possibilities between these extremes (Sunderlin and Resosudarmo 1997). Shifting cultivators clear the forest, cultivate the land for a short period and then leave it fallow for sufficient time to enable the land to revert back to natural forest. Traditional shifting cultivation can be sustainable, with products consisting of low-yield crops and a wide range of timber and non-timber products. Forest pioneers, on the other hand, clear the forest with the intention of establishing permanent or semi-permanent agricultural production. Myers (1991) attributes a relatively higher share of tropical deforestation (degradation) to shifting cultivation (about 60%), with permanent agriculture, mining, etc, accounting for no more than 18%.

Forests are converted to both permanent and shifting agriculture as a result of various factors, such as high agricultural prices, conversion subsidies, access roads, population pressure, and lack of tenure security, but the significance of these factors varies. Thus, increasing integration in the (inter)national economy and increasing population pressure (especially brought about by regional migration of landless or otherwise displaced peasants) results in the abandonment of traditional cultivation patterns and their replacement by less sustainable production techniques.

Income and Deforestation

The relation between income and deforestation is complex and ambiguous, having direct and indirect effects (Palo 1994). The environmental Kuznets curve (EKC) hypothesis suggests that deforestation is positively correlated with low income levels, but negatively correlated with high levels of income. One explanation for this relationship is that initially deforestation is viewed as an engine for economic growth, but, as income rises, people demand more of the amenities associated with natural forests in addition to wood products. As a country’s citizens become better off, there comes a point where the demand for natural forest amenities exceeds a desire to permit further deforestation for economic development. The main reasons for this are as follows: Associated with increases in per capita income are higher education levels (and potentially less corruption in resource management), improved land tenure arrangements, fewer individuals engaged in primary production (agriculture and forestry) as a proportion of the population, and general improvements in the economy as a result of technical changes (e.g., Cropper and Griffiths 1994; Naidoo 2004).

Empirical evidence for an EKC in the case of tropical deforestation is mixed, partly due to the way empirical models are specified but also because deforestation itself is defined differently in different studies and because only poor tropical countries are investigated. For studies where an inverted-U relation is found, turning points vary among studies from annual incomes of US$500 to $3,500 to $5,000 (Kaimowitz and Angelsen 1998, 2001; Meyer, van Kooten and Wang 2003; Scrieciu 2006).

Population and Deforestation

The effect of population growth and population density on rates of deforestation is also ill understood, partly because there are two views about this. Those subscribing to the neo-Malthusian view generally find evidence of a positive relation between population and deforestation (Scrieciu 2006; Saxena et al. 1997; Southgate 1994; Repetto and Gillis 1988). Studies of population change that take a more optimistic view find that increased population density leads to less erosion and more forests (Tiffen and Mortimore 1994), and that accompanying wood scarcity leads to increased tree planting (Hyde and Seve 1991). Many studies find that neither population density nor growth has any effect on deforestation (Palo 1994; Cropper and Griffiths 1994). The overall picture remains unclear, primarily because the direction of causality has not been identified (Kaimowitz and Angelsen 1998; Sunderlin and Resosudarmo 1997; Brown and Pearce 1994; Kummar and Sham 1994), although Scrieciu (2006) finds population pressure to be the driver of agricultural expansion, which he equates (probably erroneously) to deforestation. Nonetheless, a cursory examination of Ethiopia, which has a high and growing population, indicates that population must play a role – its rate of deforestation is some 37% with fuelwood needs and not agricultural expansion the primary cause.

Ultimate Causes

Policy or government failure is usually a more important driver of tropical deforestation than market failure. Repetto and Gillis (1988), Panayotou (1993) and Mendelsohn (1994), among others, demonstrate that government policies, whether deliberate or inadvertent, can result in deforestation at the cost of reducing society's welfare. Major forms of policy failure include (Sunderlin and Resosudarmo 1997; Repetto 1997; Repetto and Gillis 1988; Binswanger 1989): (1) direct subsidies to cut down forests; (2) indirect subsidies to forest companies through forest concessions that fail to capture all of the available rents and encourage excessive harvesting and wasteful rent seeking; (3) creation and protection of an inefficient ('log wasting') domestic forest industry; (4) direct subsidies to cattle ranchers to generate foreign exchange; (5) generous investment tax credits; (6) exemption of agricultural income from taxation; (7) subsidized credit for agriculture; (8) rules on public land allocation that favour large land holders or require 'development' of land to demonstrate ownership; (9) development of public infrastructure (e.g., access roads); and (10) overpopulation and migration policies (sometimes rooted in ethnic politics).

Reasons why governments may choose to promote deforestation include:

- Governments overstate the value of forests for timber and understate the value of non-timber products, and their regulatory and habitat functions.
- The value of forest soils for agriculture is often overstated, with soils quickly depleted by cropping.
- Forest regions sometimes serve as an outlet for crowded populations, with peasants encouraged to move into forested regions rather than the cities, thereby avoiding social unrest (Reed 1992).
- Investment in the forestry sector may be promoted to secure doubtful employment and other benefits (Osgood 1994).
- The value of minor forest products is systematically ignored because the majority of economic benefits accrue to powerless social groups (de Beer and McDermott 1989).
- Forests are not considered essential for economic development, more or less consistent with experience in the Western world. Forests may even be viewed as an asset to be liquidated in order to diversify the economy. Sometimes resource prices are kept artificially low to encourage industrial and agricultural activity, and economic growth.

For a democratic market economy to function properly, or for market-oriented economic policies to have effect, at least two criteria beyond well-functioning markets and well-defined property rights are required (Fukuyama 2002). First, a country must have institutions within which policy change can occur. Second, public economic policies can only be carried out by the state, but the state must be limited in scope and yet able to enforce the rule of law, competent and sufficiently transparent in formulating policy, and with enough legitimacy to be able to make painful decisions. Good governments protect property rights and individual freedoms, keep regulations on businesses to an optimum, provide an adequate (efficient) level of public goods (e.g., infrastructure, schools, health care, police protection, court system), and are run by bureaucrats who are generally competent and not corrupt (La Porta et al. 1999; De Soto 2000). Unfortunately, in developing countries regulatory agencies often prevent market entry, courts resolve disputes arbitrarily and sometimes dishonestly, and politicians use government property to benefit their supporters rather than the population at large (Shleifer and Vishny 1998, p.8). Consequently, illegal logging is often rampant in developing countries.

Is Tropical Deforestation Excessive?

As a result of market and government failures, it is often assumed that current rates of deforestation must be excessive (Barbier and Burgess 1997). But conservation of tropical forests involves considerable opportunity costs – the foregone benefits from log sales and subsequent returns to agriculture. What then is the optimal stock of tropical forest that a country (global community) should protect?

In one of only a few studies, Ehui and Hertel (1989) compute an optimal tropical forest stock for Côte d'Ivoire, which had the highest rate of deforestation of any nation during the 1980s but also achieved the fastest agricultural growth in sub-Saharan Africa. They found that the optimal forest stock ranged from 5.4 million hectares (for a discount rate of 3%) to 1.9 million hectares (discount rate of 11%). Their estimates of the optimal forest stock exceeded the actual 1990 forest stock of approximately 3.2 million ha for discount rates below 8%. However, the optimal stock of forests in Côte d'Ivoire and elsewhere depends on the discount rate, with further deforestation optimal when discount rates exceed about 10%

(if one leaves some room for uncertainty). Whether this is the case is an open question, but extant real rates of discount exceed 20% in most developing countries.

Ehui and Hertel conclude that their estimates of optimal forest stock are under-estimates of the true optimal stock, since positive externalities like preservation and ecosystem benefits are not taken into account. Also excluded are the values of non-timber forest products, possibilities for eco-tourism and existence values, although one would suspect that their inclusion would lead to higher optimal forest stocks. But, as we saw above, these values are generally quite small at the margin.

Empirical research by Bulte et al. (1997) for the Atlantic Zone of Costa Rica, where the opportunity costs of sustainable timber management are likely higher because multinational firms are willing to invest in highly profitable plantations of fruits and vegetables, provides support for the conclusions about forestry in Côte d'Ivoire. The authors conclude that the optimal forest stock is below the current stock, and that this is the case even when non-use values are taken into account and the value of non-timber forest products is increased to a value that is five times the authors' optimistic estimate of its true value.

Our own benefit-cost analysis (reported in Table 3) yields an ambiguous conclusion. Using the most recent information on global forest resources (FAO 2006a), we calculated the annual benefits and costs of logging activities and fuelwood acquisition activities for the period 2000-2005. Benefits are given by the value of harvested logs plus the net discounted value of the deforested areas in agriculture, while costs are measured by the discounted loss of non-market amenities (including ecosystem services) and shadow damage caused by emissions of CO_2 from land use change. (Note that net revenues from logging are assumed to be consumed rather than invested in productive activities.) The results indicate that the worldwide net benefits of logging activities might have amounted to some \$22.1 billion per year. In that case, global society is actually better off when countries deforest forestlands at the margin. However, our calculations indicate that, if damages from release of CO_2 and losses of other ecosystem services are sufficiently high, deforestation is an inefficient activity, with the potential to damage global welfare by as much as \$126.4 billion. Similar results hold for the regional level.

There are three important qualifiers. First, it is assumed that deforestation releases all of the CO_2 stored in harvested timber. Some of the carbon might remain sequestered in products. Further, the subsequent land use (e.g., coffee plantation, high-yielding forest plantation, agroforestry) might result in the sequestration of carbon to offset that released by deforestation. Second, the cost benefit analysis presented in Table 3 relates to the period 2000-2005 for forest covers as presented in the two last columns of Table 2. For further deforestation, the costs are likely to increase and the benefit-cost ratio of logging is going to fall. Third, in making decisions about how much deforestation to permit, developing countries are usually not provided compensation, or provided inadequate compensation, for CO_2 released to the atmosphere by deforestation activities. Hence, release of CO_2 does not enter into the decision calculus. The problem is that people need timber for fuelwood, construction, paper and other products, and foreign exchange, and that, at the margin and from their perspective, these values exceed the foregone environmental amenities.

Table 3: Cost-benefit Analysis of Deforestation in Developing Regions (2000-2005)

Region	Annual Change in forest area, 2000-2005[a]	Estimated carbon removed[a]	Estimated cost of CO_2 emssions for offset prices[b]		Net value of logs removed[a]	Value of land in agriculture[c]		Estimated value of marginal non-market plus non-timber benefits[d]		Estimated annual net benefits of logging[e]		Benefit-cost ratio of deforestation	
			$5/tCO_2	$30/tCO_2		$120/ha/yr	$140/ha/yr	$10/ha/yr	$20/ha/yr	High	Low	High	Low
	million ha	tC/ha	US$ millions									ratio	
Eastern & Southern Africa	-1.702	86	2675.1	16050.6	488.3	4084.8	4765.6	340.4	680.8	2238.4	-12158.3	1.74	0.27
Northern Africa	-0.982	36	650.2	3901.3	1461.0	2356.8	2749.6	196.4	392.8	3364.0	-476.3	4.97	0.89
West & Central Africa	-1.356	193	4799.1	28794.3	2644.4	3254.4	3796.8	271.2	542.4	1370.9	-23437.9	1.27	0.20
East Asia	3.840	43	-3051.6	-18309.7	0.0	-9216.0	-10752.0	-768.0	-1536.0	n.a.	n.a.	n.a.	n.a.
South & Southeast Asia	-2.851	119	6200.9	37205.4	7321.9	6842.4	7982.8	570.2	1140.4	8533.6	-24181.5	2.26	0.37
Western & Central Asia	0.014	56	-14.3	-85.6	0.0	-33.6	-39.2	-2.8	-5.6	n.a.	n.a.	n.a.	n.a.
Carribean	0.054	136	-134.9	-809.4	0.0	-129.6	-151.2	-10.8	-21.6	n.a.	n.a.	n.a.	n.a.
Central America	-0.285	119	622.0	3732.2	427.6	684.0	798.0	57.0	114.0	546.6	-2734.6	1.80	0.29
Oceania[f]	-0.356	52	336.4	2018.6	1838.8	854.4	996.8	71.2	142.4	2428.0	532.2	6.96	1.25
South America	-4.251	167	13019.0	78113.8	5628.3	10202.4	11902.8	850.2	1700.4	3661.9	-63983.5	1.26	0.20
WORLD	**-7.875**	**1006.342**	**25101.9**	**150611.5**	**19810.3**	**18900.0**	**22050.0**	**1575.0**	**3150.0**	**22143.4**	**-126439.9**	**1.57**	**0.25**

Notes:
[a] Source: FAO (2006)
[b] CO_2 offset values obtained from (as viewed 18 October 2006): http://www.ecobusinesslinks.com/carbon_offset_wind_credits_carbon_reduction.htm. Annual value = price ($/t$CO_2$) × carbon released (tC/ha) × area deforested (ha) × conversion of carbon to CO_2 (44 tCO_2/12 tC). Negative values indicate possible gain from afforestation.
[c] Annual land value from Table 2, discounted at a social rate of 5% to obtain discounted value.
[d] Marginal values range from Table 2, discounted at 5% rate. Negative values indicate possible gain to afforestation.
[e] Negative values indicate that deforestation provides negative benefits to society; n.a. = not applicable since afforestation occurs.
[f] Includes New Zealand and Australia, but also many developing countries.

International Forest Conservation Measures

Roughly speaking, two types of trade measures are possible – those that reduce the level of logging (demand-reducing measures such as trade bans and import levies) and those that affect the way exploitation takes place, namely, certification of forest management practices. The effects of trade measures on deforestation are probably modest. Barbier et al. (1994, p.8) argue that the share of trade in total tropical roundwood production is small: only 17% of the tropical wood is used for industrial purposes, with the majority of the remainder consumed as fuelwood. Of the industrial amount, no more than 31% is subsequently exported (with an increasing share involved in South-South trade), so exports account for only about 6% of total tropical roundwood production. Also recall that commercial logging accounts for only a small proportion of deforestation, and it is evident that the direct effects of trade measures are relatively modest for most countries. Yet trade measures have some impact because they signal concern.

Trade measures aimed at affecting harvesting practices, specifically to promote sustainable harvesting by preferential treatment, may also impact land allocation decisions of governments. Certification of tropical forestry management practices by the Forest Stewardship Council (FSC), an independent, third-part non-governmental certifier, could reduce deforestation. Certification may increase or reduce the competitiveness of forestry as a land-use option. When selective trade measures reduce the profitability of forest management practices, it is possible that conversion of forests for alternative land-use options is accelerated.

Since illegal logging is a big business and wood products from illegal logs enter legal channels (often with the complicity of corrupt government officials), the only way to prevent it is to ensure that any product sold is certified by a third-party. Unfortunately, while timberland area certified outside of developing countries has grown phenomenally since the FSC was formed in 1994, certification of forests in developing countries lags behind.

The preferred approach for controlling tropical deforestation is to provide direct subsidies that cause forestland owners to take into account the non-use benefits of tropical forests (Barbier and Rauscher 1994). International transfers to protect tropical forests are currently going on through, for example, the Global Environmental Facility (a joint agency of the United Nations and the World Bank) and the World Heritage Program. They may also increase with efforts to increase carbon storage in terrestrial carbon sinks. Such transfers should take the form of lump-sum payments to prevent development of a resource, technical assistance and/or loans for environmentally benign projects, or debt relief in return for sustainable resource management. In theory, a direct international transfer should unambiguously increase the long-run equilibrium forest stock. The reason is that imports must be paid for with foreign exchange, which can be earned by selling tropical timber (among other products). Transfers will ease the stringency of the foreign exchange constraint, which implies that more imports can be purchased. As a result, the marginal value of these imports falls. The marginal value of owning forests should also fall, and thus the steady-state forest cover should increase. However, it is an open question to what extent this is the case in the real world.

When transfers are directly coupled to the size of the conserved forest stock (i.e., a greater forest stock implies more funding), the expectation is that funding unambiguously increases the forest stock in developing countries. However, Stahler (1996) has demonstrated that this may not be the case, due to strategic behaviour by governments in developing countries. As marginal external benefits are probably declining in stock size (so that the demand curve for forest conservation is downward sloping), governments of some recipient countries are in a position to increase the compensation per hectare (and thereby their total revenues) by reducing their forest stock. Thus, it is possible that compensating for external benefits will produce the adverse result of smaller stocks and high compensation per hectare. Further, as our calculations in Table 3 demonstrate, failure to make transfer payments for not releasing CO_2 from logging activities results in inadequate incentives to protect forests in developing countries, although this conclusion is case specific and may not always hold.

Finally, a word of caution is necessary for the debt-relief option. Despite some well-publicized successes in the past, debt relief may not be a very good mechanism for attaining the desired aims of the international community. The reason is that money markets are trading the debt of developing countries at a discount that takes into account expected ability to repay. The problem of debt-for-nature swaps is that, while they protect vulnerable ecosystems in some cases, the large nominal reductions in debt barely touch nations' real burdens, and may even increase expected repayments. The same might also be true for other types of transfers, such as lump sum payments and other compensation.

Conclusions

There is no consensus on what causes tropical deforestation, although change in land use is its identifying characteristic. Reasons are situation and country specific. While logging is not the major factor, it is certainly a catalyst as it opens up natural forests to peasants seeking land for growing agricultural crops. Countries with tropical forests might well be reducing their stocks of forests because they are going through development stages similar to those experienced by developed countries. For the period 2000-2005 our crude analysis indicates the benefit-cost ratio of deforestation on a global scale can be as low as 0.25 (a ratio smaller than 1 means it is better not to deforest land) if the value of CO_2 offsets is high, marginal non-market plus non-timber values of deforested land are also high, but the value of land converted to agriculture is low. For the case of low CO2-offset prices, low ecosystem values and high agricultural opportunities, the global benefit-cost ratio is 1.57. Regionally, the benefit-cost ratio varies from a low of 0.20 to a high of 6.96 (there are large payoffs to harvesting trees), suggesting that decisions to continue deforestation are dependent on local conditions. If deforestation continues, however, benefit-cost ratios will inevitably decline, perhaps slowing or halting deforestation in the process. It is important to note that conclusions about the social desirability or feasibility of further deforestation are based to a large extent on the potential contribution that the release of CO_2 makes towards global climate change. But it is clear that, in the absence of massive global transfers to tropical nations to encourage them to preserve forests (e.g., via Kyoto's Clean Development Mechanism), deforestation will likely continue.

We also pointed out that market failure may be less of a factor in deforestation than policy failure. Government policies in many developing countries encourage deforestation for development and revenue purposes, and for political reasons (e.g., as an outlet for expanding populations). Sound economic policy, including much less of the types of intervention by governments that encourage deforestation, may enable humans to protect tropical forest ecosystems and the amenities associated with them. The benefits of this change of policy definitely outweigh its costs. The main problem, however, is to induce countries to adopt such a transition path. International institutions like the World Bank, and international community in general could play an important role.

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