ACCOUNTING FOR THE BENEFITS OF FOREST RESOURCES:

CONCEPTS AND EXPERIENCE

Jeffrey R. Vincent and John M. Hartwick

Planning and Statistics Branch
Policy and Planning Division
Forestry Department

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ACRONYMS

GDP	Gross domestic product
NDP	Net domestic product
SEEA	System of Integrated Environmental and Economic Accounts
SNA	System of National Accounts (1993 guidelines)

1. INTRODUCTION

The System of National Accounts (SNA) is an integrated system providing information on various aspects of an economy's performance (Inter-Secretariat Working Group on National Accounts 1993). Most familiar are the current accounts, which present information on gross domestic product (GDP) in three ways: as the sum of value added (revenue minus intermediate consumption) across all industries (the production account),[1] as the sum of final consumption and savings (= gross investment; the use of income account),[2] and as the sum of employee compensation and operating surplus (the distribution of income account). Production — "a physical process, carried out under the responsibility, control and management of an institutional unit, in which labour and assets are used to transform inputs of goods and services into outputs of other goods and services" (Inter-Secretariat Working Group 1993, p. 4) — is the fundamental concept determining which economic activities the SNA includes. By design, the SNA does not include all economic activities, or all goods and services that contribute to human well-being. With few exceptions, it focuses on goods and services that are produced using human labor and other factors of production and are bought and sold in markets.

The consequence of this production orientation is that macroeconomic indicators in the SNA, such as GDP, are not reliable measures of aggregate economic welfare.[3] Documents on the SNA recognize this, emphasizing that the SNA aims at providing information on production, not welfare. Those documents also point out that GDP is not a measure of sustainable income. That is, GDP does not capture the impact of current production activities on future income, much less welfare.

The exclusion of considerations related to welfare and sustainability helps the SNA achieve its main goal, which is to generate accurate information on production activities regardless of the country applying the system. Moreover, the emphasis on production is understandable when one considers the dominant economic issues during the mid-century period when the accounts were initially designed: recovering from the Great Depression and reconstructing the world following World War II. Since that time, however, issues of welfare and sustainability have gained prominence. The absence of information on these aspects of economic activity within the SNA, and the lack of an alternative, institutionalized system to provide it, hamper the ability of policymakers to address these issues effectively.

In this situation, policymakers often resort to GDP as a proxy measure for national welfare,

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1 More precisely, GDP is the sum of gross value added, plus taxes and minus subsidies on products not included in the value of output (Inter-Secretariat Working Group on National Accounts 1993, p. 6).

2 If trade is not balanced, GDP equals the sum of final consumption, savings, and the net trade balance.

3 By "economic welfare" (hereafter, "welfare"), we refer to the value, to an individual, household, or population (depending on the scale of analysis), of consumption of market and nonmarket, tangible and intangible, private and public goods and services.

despite the warnings by national accountants. This is unlikely to lead to distorted policymaking when few economically significant benefits and costs fall outside the SNA production boundary. Then, GDP offers a reasonable first-order approximation to short-run national welfare, and value added of constituent industries provides a reasonable approximation to those industries' contribution toward the total. Problems are more likely when industries generate important benefits or costs ignored by the SNA. Then, policymakers whose perceptions of the economy are shaped by the SNA can misinterpret the welfare impacts of changes in the economy's performance and the consequences of policies intended to shape that performance.

Forestry is an example of an activity whose contribution to the economy in a welfare sense is unlikely to be measured well by value added in the production account.[4] Forests contribute directly to welfare through the provision of amenity values, which may not satisfy the SNA's definition of "production." They also provide other industries with services, such as watershed protection, whose value the SNA records as part of the operating surplus of recipient industries instead of as services furnished by forests. For these reasons, the SNA likely understates the economic contribution of forests.

For industries unrelated to natural resources, the production account provides information on sustainability through the estimation of net value added, the difference between gross value added and the consumption of fixed (human-made, or physical) capital.[5] The portion of gross value added generated by consuming capital is not sustainable, any more than a personal lifestyle financed by running down one's bank account is sustainable. Even net value added as reported in the SNA does not reflect sustainability in the case of forestry, however, because it ignores the consumption of natural capital that occurs when forests are harvested or converted to other uses. The depreciation of forest capital due to these processes can cause GDP in forest-rich countries to give an exaggerated impression of the increase in a country's income — that is, to understate the long-run costs of such depreciation. Documents on the SNA in fact warn that the neglect of resource depletion effects is one reason GDP is not a measure of sustainable income (Inter-Secretariat Working Group 1993, p. 41).

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4 The distribution of income from forestry production varies from country to country depending on institutional arrangements. In many countries, especially those with government-owned forests, logging companies instead of forest owners capture a significant share of forest rent (stumpage value). Hence, value added in forestry appears unusually low, while value added in logging appears unusually high (operating surplus is inflated by the capture of stumpage value). Combining value added for the forestry and logging industries appears to be the best way to obtain a consistent cross-country measure of forestry production within the framework of the SNA.

5 Even for those industries, net value added is not a perfect indicator of sustainability, as it does not reflect changes in human capital.

This report examines how to formulate better measures of the economic contribution of forests. It takes figures in the current and asset[6] accounts of the SNA as the starting point, and it describes adjustments necessary to convert those figures to welfare terms. The various adjustments presented are surely not implementable in all countries, certainly not immediately. Moreover, they are unlikely to be accepted as standard accounting procedures by national accountants, as some of them violate the SNA definition of the production boundary. Nevertheless, laying out a conceptually sound system is the essential first step toward improved accounting of forest-related benefits. Pilot applications of such a framework should be able to contribute to improved planning and policymaking in countries with forest resources, even if the procedures are not immediately institutionalized and are applied by economic planners and policy analysts rather than by national accountants. We would hope, however, that national accountants would be involved in such applications, to ensure that data from the SNA are used appropriately and to promote a dialogue about the eventual possibility of integrating welfare and sustainability considerations related to forest resources into the SNA, either through a system of satellite accounts or as part of the SNA per se.

The report was commissioned by the Forestry Department of FAO, which intends to use it as one source of information for preparing a handbook on economic accounts for forest resources. That handbook will parallel a recent, similar one for agriculture (FAO 1996). The report has two principal objectives. The first is to present basic concepts that should guide the development of economic accounting procedures for forest resources. The report presents those concepts in two chapters. Chapter 2 identifies the principal adjustments that should be made to the current and asset accounts, and Chapter 3 discusses methods for making them. The second objective is to review empirical experience with such adjustments, with the intention of assessing their feasibility. To this end, we reviewed more than 30 studies from more than 20 countries (more than 100 countries if one includes countries included in regional and global studies). Chapter 4 summarizes the results of that review. The final chapter, Chapter 5, summarizes the findings of the report, compares, the proposed framework to the SNA, and highlights implications for the FAO manual.

We have attempted to structure the report to be accessible, and hopefully useful, to both specialists and nonspecialists. Part I, which consists of the five chapters just described, emphasizes key findings and the intuition behind them. It contains minimal mathematical detail. Only Chapter 3 contains much mathematical analysis, involving net present value calculations of the sort found in introductory forest economics textbooks. Part II contains the technical details supporting the analysis in Part I. It consists of 7 appendices.

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[6] By "asset accounts," we refer collectively to the balance sheets and the accumulation accounts in the SNA. The balance sheets indicate the value of a country's assets at the beginning and end of an accounting period, and the accumulation accounts provide detail on the factors responsible for changes in asset values.

It should be understood that this report focuses on economic accounting, not natural resource accounting. That is, it does not cover accounting systems whose principal goal is to organize ecological information on forests. Such systems are valuable for resource managers and policymakers, and they can facilitate the construction of economic accounts, but they are not our concern here, beyond a few comments we will make when we review existing studies. Readers interested in forestry accounting in the ecological sense may wish to consult OECD (1994, 1995) and a report prepared for the International Tropical Timber Organization by the IIED Forestry and Land Use Programme and The World Conservation Monitoring Centre (1994).

In the remainder of this chapter, we briefly discuss one of the principal rationales for adjusting national accounts for natural resources, i.e. to measure economic sustainability. Then, we review what the SNA and the related System of Integrated Environmental and Economic Accounts (SEEA; United Nations 1993, Bartelmus and van Tongeren 1994) have to say about adjustments for natural resources, in particular forest resources. Perhaps more important, we identify the principal differences in philosophy and purpose between those systems and the system presented in this report. The main point is that the SEEA and the system presented in this report are not two means to the same end, but rather systems that provide different types of information. Viewed this way, the two systems are complementary, not in competition or conflict.

Measuring economic sustainability

The idea of developing improved measures of welfare and sustainability by adjusting macroeconomic aggregates like GDP for changes in the quantity and quality of environmental resources is not new. In the early 1970s, Nordhaus and Tobin (1972) proposed adjusting GDP for the disamenities of urban life. In the early to mid-1980s, several studies examined issues related to natural resource depletion (Ward 1982, Landefeld and Hines 1985, Stauffer 1986). During this same period, academic researchers established the theoretical links between economic sustainability and depletion-adjusted measures of investment and domestic product (Weitzman 1976, Hartwick 1977, Dasgupta and Heal 1979, Solow 1986).

The 1989 publication of *Wasting Assets*, a study of Indonesia by the World Resources Institute (WRI; see Repetto et al. 1989), brought these concerns into mainstream discussions about the national accounts. Since that time, international organizations, in particular the World Bank and the United Nations (especially the United Nations Environment Program and the U.N. Statistical Division), have invested considerable effort in studying the issues involved. Volumes edited by Ahmad et al. (1989) and Lutz (1993) provide useful compilations of key studies related to those efforts.

In the following paragraphs, we discuss two theoretically equivalent procedures for analyzing an economy's sustainability. Both are based on modified components of the SNA.

Testing for sustainability in the asset accounts

There is, of course, no way to predict with certainty the future course of a country's economy. However, the academic work cited above, and subsequent work by Hartwick (1990), Dasgupta and Mäler (1991), Mäler (1991), and others, has established that maintaining the value of a country's total capital stock is a necessary condition for enabling a country's population to be as economically well off in the future as in the current period.[7] The total capital stock includes not just human-made capital (equipment, structures, infrastructure, etc.), but also natural capital (forests, subsoil assets, air and water quality, etc.) and human capital (human skills and ingenuity). Raising welfare over time requires that the value of the total capital stock increase, not merely remain constant.

Maintaining the total capital stock is a necessary condition for sustainability, but it may not be sufficient. It assumes some degree of substitutability among different types of capital, an assumption that has been labeled "weak sustainability." If substitution is not possible, then maintaining minimum stocks of certain types of capital might be necessary to avoid catastrophic losses associated with "threshold effects." Many ecologists have argued that threshold effects are likely in the case of environmental resources. Even if this is the case, however, note that it is not a reason to forgo monitoring the total capital stock. Rather, it suggests that policymakers should pay attention to not just a single number giving the aggregate value of the total capital stock, but also the values of its components.[8] In cases where there is evidence of threshold effects, values of corresponding capital stocks should be interpreted with reference to physical indicators as well, to gain a deeper understanding of prospects for sustainability. Information expressed in both value and physical terms should be considered, rather than just one or the other.

Concerns about threshold effects aside, the sustainability test is therefore to check whether the value of the total capital stock is at least constant over time. Under certain circumstances, direct estimation of the change in value, or net accumulation, might be possible, instead of first calculating the value of the total capital stock at two points in time and then taking the difference between those estimates. The sustainability test is then to check whether net accumulation, broadly defined to include all additions and all subtractions, is nonnegative when summed across all forms of capital. Only if this sum is at least as great as zero does a country maintain the value of its total capital stock, and only if that occurs can the country's future consumption level (broadly defined) match its current consumption level.

The SNA does not furnish sufficient information to check whether the value of the total capital stock is at least constant over time. In practice, asset accounts typically include just financial assets and produced non-financial assets, although in principle they can include non-produced, non-financial assets as well. In Chapter 3, we will look closely at methods for estimating changes in the capital value of forests. Those methods are straightforward in conceptual terms, as they simply involve changes in the present value of future streams of benefits provided by forests. They are less straightforward in practice, as in principle they should reflect all forest-related benefits, not just easily measured commercial products like timber. When they can be applied, however, then the resulting estimates can be combined with estimates for other forms of capital to form an aggregate measure of the change in the value of the total capital stock.

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[7] In the face of population growth, the total capital stock must be maintained on a per capita basis.

[8] See World Bank (1997) for estimates of the value of human-made, human, and natural capital stocks across countries and regions.

Although the greatest value from estimating the capital value of forests probably lies in generating an input for estimating the total capital stock, and thus for analyzing overall sustainability prospects, it does have stand-alone value. It enables one to determine whether a country's forests are becoming more or less valuable as a source of current and future benefits, that is whether their economic contribution can be sustained. It reveals whether a country is becoming more forest-rich or more forest-poor in a quite literal sense.

This economic measure of forest sustainability does not necessarily coincide, however, with a physical measure such as the sustained-yield production level. For example, a country with declining timber stocks might experience an appreciation of its forest capital, if the rate of increase in stumpage values outstrips the decline in physical stocks. From an economic perspective, capital value, which is forward looking and weights goods and services according to their welfare contributions, has more meaning for sustainability than does physical stock, which provides information on current status in ecological terms. We emphasize, however, that estimates of forest capital that leave out important benefits (such as nonmarket ones) and are not interpreted with reference to physical indicators of threshold effects can be highly misleading indicators of sustainability.

Testing for sustainability in the current accounts

Maintaining the value of the total capital stock has a counterpart expression in "flow" terms. That is to check whether net domestic product (NDP), broadly defined to include all forms of capital, remains at least constant over time. NDP is ordinarily defined as the sum of consumption and net investment in human-made capital.[9] To convert it to a measure of economic sustainability, one must include net accumulation instead of net investment (so that it reflects the change in value of capital, not just the value of the change), and include net accumulation for all forms of capital, not just human-made capital.

While this condition might appear different than the first, the two are in fact theoretically equivalent. As we will see in Chapter 2, however, in addition to net accumulation, there are some consumption-related adjustments that should be made to NDP in the case of forest resources. Although the two sustainability conditions remain theoretically equivalent when these additional adjustments are made (because they affect capital values too), analyzing changes in both capital value and NDP is useful if one wishes to shed as much light as possible on an economy's sustainability. Analyzing both is advisable for a more practical reason, too: even though the two conditions are theoretically equivalent, in practice they can yield different predictions about sustainability. This can happen, for example, if high levels of investment in human-made capital cause estimates of net accumulation to be positive, but much of the investment turns out to be unproductive. In that case, NDP might start declining, and thus reveal the unsustainability of the economy, even while net accumulation still appears (incorrectly) to be positive.

[9] This assumes balanced trade.

Industry-specific vs. economy-wide sustainability

While one can certainly calculate capital values and net value added (NDP at the industry level) for just forestry, and should in fact do so to gain a more accurate understanding of forestry's net economic contribution, one must be careful not to misinterpret the implications for sustainability. Considering timber alone, one should expect the economic contribution of forestry to decline from an initial point, when a country's forest estate consists of old-growth forests, to a later point, when it consists of sustainably managed second-growth forests. Old-growth forest stands tend to be more valuable than second-growth stands, due to their higher timber volumes and larger trees. It follows that, even in the absence of deforestation, the conversion of old-growth forests to second-growth forests as logging proceeds in the former should register in adjusted asset accounts as a declining value of forest capital, and in adjusted current accounts as declining net value added for forestry. Incorporating nontimber values would probably strengthen the evidence of unsustainability, as old-growth forests tend to be higher in biodiversity, provide better soil protection, and be more attractive for recreation than second-growth forests.

These indicators correctly signal unsustainability of forestry's economic contribution: forests will not be able to furnish as great a value in the future as at present. Yet, unsustainability of forestry's contribution can coincide with enhanced sustainability of the overall economy — the total capital stock and NDP are rising — if sufficient investment occurs in other industries. Unsustainability of forestry's economic contribution therefore does not necessarily imply that overall economic well-being is unsustainable, any more than sustainability of the latter implies sustainability of the former. For this reason, *we recommend relating forest-related adjustments to not just asset values and net value added for forestry, but to the total capital stock and NDP for the overall economy as well*. Otherwise, the analysis is likely to exaggerate the economic consequences of forest-related unsustainability.

Forest-related aspects of the SNA and SEEA

SNA

Flexibility for making forest-related adjustments in the SNA appears to be greater in the asset accounts than the current accounts. The SNA defines economic assets as "assets over which ownership rights are enforced and which provide economic benefits to their owners" (Bartelmus and van Tongeren 1994, p. 5). These include both produced and non-produced assets. Produced assets can include natural assets, such as livestock for breeding and timber plantations. Non-produced assets include land and natural forests. Depending on the type of asset, asset accounts prepared according to SNA guidelines present information in some or all of the following categories:

- Opening stocks
- Capital formation: gross capital formation (gross fixed capital formation, changes in inventories, acquisition less disposal of non-produced assets), consumption of fixed capital

- Other changes in volume: economic appearance and disappearance of produced and non-produced assets, natural growth of non-cultivated biological resources, catastrophic losses, uncompensated seizures (by the government), other volume changes in non-financial assets n.e.c., changes in classification and structure

- Revaluation (nominal holding gains & losses)

- Closing stocks (= Opening stocks plus the sum of the preceding adjustments)

In principle, asset accounts in the SNA explicitly and implicitly contain information on forest resources. For example, the economic appearance of non-produced assets includes virgin forests being added to economic reserves, economic disappearance includes timber harvesting, catastrophic losses include forest fires, and natural growth includes the annual timber increment in immature trees.

SEEA

The SEEA proposes a multi-step process for creating satellite environmental accounts. As a first step, it proposes making existing environmental and resource-related information in the SNA more apparent by disaggregating the current and asset accounts, without changing their basic structure. Regarding the current accounts, it proposes splitting intermediate and final consumption transactions between expenditures on environmental protection and all other expenditures. Similarly, it proposes splitting gross capital formation and consumption of fixed capital between produced assets for environmental protection and all other produced assets. It presents a draft Classification of Environmental Protection Activities, which includes, among others, the forest-related "Protection of nature and landscape (protection of species, habitats; erosion, fire and avalanche protection, etc.)" (Bartelmus and van Tongeren 1994, Box 5).

Regarding the asset accounts, the SEEA proposes reclassifying the information on "Other changes in volume" for non-produced economic assets into four categories (Bartelmus and van Tongeren 1994, p. 7):

- Depletion: reductions in the quantity of assets, due to economic use (e.g., timber harvesting)

- Degradation: positive or negative changes in the quality of assets, due to economic use or discharge of residuals (e.g., damage to commercial timber stands by acid rain)

- Other accumulation: additions to the quantity of assets, due to economic decisions (e.g., transfer of virgin forests to the commercial timberland base)

- Other volume changes: quantitative or qualitative changes in assets not caused by economic decisions (e.g., destruction of forests by natural fires)

These modifications simply involve repackaging existing information in the SNA, without modifying the links between the current and asset accounts or expanding the amount of information they contain.

As a second step, the SEEA proposes shifting “Depletion,” “Degradation,” and “Other accumulation” within the asset accounts, and also including information on them in the current accounts. In the asset accounts, it proposes adjusting “Gross capital formation” of non-produced economic assets for “Depletion,” “Degradation,” and “Other accumulation,” to yield “Net capital accumulation.” In the current accounts, it proposes subtracting “Depletion” and “Degradation” from NDP to yield an adjusted estimate of NDP. It defines “Depletion” as the amount of production of a natural resource above the sustained-yield level.

As third step, the SEEA proposes introducing nonmarket environmental costs and assets, such as those associated with air and water quality and biodiversity. In the asset accounts, it proposes adding a third asset type, non-produced environmental assets. In the current accounts, it proposes subtracting “Depletion” and “Degradation” of non-produced environmental assets, as well as non-produced economic assets, from conventional NDP to yield “Environmentally adjusted NDP” (EDP). It also proposes including transboundary environmental impacts by following the principles that distinguish GDP and GNP. For example, damage caused to another country by transboundary pollution would be deducted from the polluting country’s GNP but not its GDP.

Implementing the second and third steps requires valuing natural and environmental assets. The SEEA proposes several methods for valuing stocks of depletable natural resources. In their operational guide to the SEEA, Bartelmus and van Tongeren (1994) review the net price method in the most detail, although they also mention two other methods, the present value method and El Serafy methods (we will discuss and evaluate all three methods in Chapter 3). Following Repetto et al. (1989), they suggest first establishing physical accounts that contain information on:

- Opening stocks
- Depletion
- Degradation
- Discharge and treatment of residuals
- Other volume changes
- Closing stocks

They note that the structure of physical accounts will vary from resource to resource. Again following Repetto et al., they suggest valuing “Opening stocks” by multiplying them by the net price of the resource at the beginning of the period, where net price is defined as market price of the extracted resource minus average total extraction cost (including a normal return to capital). Similarly, they suggest multiplying “Depletion” and “Other volume changes” by average net price during the period, and “Closing stocks” by net price at the end of the period. They suggest valuing “Degradation” and “Discharge and treatment of residuals” by directly observing changes in market values, to the extent that is possible. Finally, they suggest calculating a “Revaluation” term as the residual difference between the value of the closing stock on the one hand and the sum of the values of the opening stock and the four intervening terms on the other.

For valuing degradation of nonmarket environmental assets, the SEEA advocates using “maintenance costs”: “the costs … which *would* have been incurred if the environment had been used in such a way that its future use would not have been affected” (Bartelmus and van Tongeren, p. 16). For example, if acid deposition from airborne pollutants changes the chemistry of forest soils, the maintenance cost approach involves estimating the abatement costs the polluting industries would incur if they reduced their pollution to levels that did not cause such damage. The SEEA refers to this as a “cost-caused” valuation approach, as opposed to “cost-borne” approaches that value pollution damages in affected industries or sectors.

This report vis-à-vis SEEA

The analysis in this report confirms the main thrust of the SEEA, namely that nonmarket environmental values and the depletion of forest-related assets should be reflected in national accounts. The accounting system presented in this report is not linked, however, provision-by-provision to the SEEA in the way that, say, the report of the Eurostat Task Force on Forest Accounting is (Newson and Gie 1996). In fact, doing so would be inappropriate, as its philosophy and purpose are fundamentally different from those of the SEEA.

The SEEA maintains the production focus of the SNA. Hence, the only forestry benefits it includes are ones related to forestry output within the SNA production boundary. Its primary purpose is to provide expanded information on the impacts of production on the environment, not the reverse. So, for example, it aims more at identifying the sources of industrial pollution than at quantifying how pollution deposition, regardless of the source, affects forestry production. Similarly, in the asset accounts, it is more concerned with identifying how production affects the values of environmental assets (with respect to "Depletion," "Degradation," etc.), than in quantifying the overall change in asset value for purposes of analyzing sustainability.

The production focus, coupled with the assumption of "strong" sustainability (stocks of environmental capital, not just the value of the total capital stock, must be maintained), helps explain the SEEA's preference for the maintenance cost valuation approach. This approach estimates the additional costs to producers (polluting industries) of using the environment in such a way that it is not degraded. It also helps explain the definition of "depletion" as production of a natural resource in excess of its sustained-yield level.

In contrast, the accounting framework presented in this report focuses on welfare. It considers all forestry benefits, regardless of the nature of the production process generating them, as long as they affect human welfare and are scarce (i.e., have value in an economic sense).[10] It is concerned with the impacts of environmental changes on welfare, not the impacts of production on the environment, except insofar as the latter impacts have welfare implications. With welfare as the focus, identifying the industrial causes of certain forms of environmental degradation (e.g., the industrial sources of pollution that damages forests), or the causes of changes in the value of environmental assets (e.g., how harvest, growth, etc. affect the value of a timber production forest), is less important than expressing flow and stock effects consistently and correctly in economic terms.

For this reason, we propose benefits-based ("cost-borne"), not costs-based, valuation methods. Maintenance costs bear no necessary relationship to the welfare consequences of protecting the environment. The costs of maintaining environmental quality might well exceed the benefits of doing so. Under an assumption of strong sustainability, the cost of environmental protection estimated by "cost-caused" methods is implicitly assumed to be a justified expense for maintaining natural capital. For similar reasons, we value dynamic aspects of forest resources like depletion by changes in the present value of benefits, not by the costs of preventing depletion.

In sum, the SEEA is therefore quite consistent in following through on the implications of the SNA's production emphasis and the strong sustainability assumption. These characteristics, however, diminish its value for measuring the economic contribution of forest resources — which, in fairness, it does not purport to do. Our system is designed with the latter purpose in mind. Hence, it emphasizes welfare over production, and benefits-based valuation over cost-based valuation. It also assumes weak, not strong, sustainability. As both production and welfare are important for sound policymaking, as are both the costs and benefits of protecting the environment, and as the degree to which strong or weak sustainability concepts apply will always be a matter of considerable debate, we conclude that both systems can potentially make important contributions to improved forestry policymaking.

[10] Hence, our framework does not include the oxygen-producing function of forests, as oxygen is not in scarce supply.

2. AN ECONOMIC ACCOUNTING FRAMEWORK

Forests interact with the economy in more ways than any other resource. This means that a system of economic accounts taking the SNA as its starting point must make multiple adjustments related to them. It also means that there is a significant risk of double-counting if those adjustments are not made carefully.

The appropriate starting point for considering how to account for the benefits of forest resources is therefore at a conceptual level. One must: (i) identify the broad classes of adjustments that need to be made, and (ii) determine whether those adjustments represent adjustments to the current accounts or the asset accounts and, if the former, whether they are adjustments to gross or net value added (GDP or NDP if the adjustments are made for the entire economy instead of just forestry). This process must be grounded in economic theory, to ensure internal consistency and coherence. Intuition might not be a reliable guide in such a complex undertaking.

We expect that the economic backgrounds of readers of this report will vary considerably. Consequently, we will keep the details of economic theory to a minimum in the main body of the report, concentrating on rationale and results instead. We present full details in the appendices. The models presented in the appendices draw upon models in the literature by Mäler (1991), Hartwick (1990, 1992, 1993, 1997), Hamilton (1997), and Vincent (1997), as well as upon our own original research conducted for this report.

Economic contributions of forest resources

We develop a model to make our assumptions about forest/economy interactions explicit. The model includes the following aspects of forest resources:

(i) Forests as a source of *timber* harvested by logging companies and used as a production input by wood-processing industries.

(ii) Forests as a source of tangible *nonmarket forest products* collected and consumed by households but not bought and sold in markets, for example fuelwood, poles, bamboo, fruit, game, medicinals, and perhaps some portion of the timber harvest.

(iii) Forests as a source of less tangible *forest amenities* consumed by households. These values include such things as existence values associated with biodiversity and the pleasure gained from scenic vistas.

(iv) Forests as a source of *environmental services* (ecological functions) that benefit other industries in the economy. The prime example is watershed protection, which benefits downstream agriculture (among other industries).

(v) Forests as a disposal site for *airborne pollutants* damaging to forest health (e.g., acid deposition).

(vi) Forests as a sink for and a source of *carbon dioxide*, which potentially damages other industries through global climate change. If CO_2 concentration affects forests themselves, either directly through "CO_2 fertilization" or indirectly through climate changes that alter species composition, such impacts are equivalent to the one described in (v).

(vii) Forests as a source of *land* for other purposes, in particular agriculture. The flip side of this benefit is, of course, deforestation, which results in the long-term loss of forest-related benefits.

(viii) *Forest management* as an activity involving the use of both variable inputs (labor, materials) and fixed factors (human-made capital).

Although other contributions can be imagined, this is a quite comprehensive list. It spans the full range of adjustments that existing studies have tried to make. Although it might appear to omit one aspect of forest resources that (appropriately) receives much attention, i.e. biodiversity, in fact it includes biodiversity values, implicitly if not explicitly, in categories (ii)-(iv).

Adjustments to current accounts

Adjustments to the level of GDP

In a model containing these elements, several forest-related adjustments to the national accounts are theoretically justified if one wishes to convert production measures to welfare measures. Before presenting details of the model, let us summarize the main findings. Consider the current accounts, GDP specifically, first. As noted in the introduction, GDP can be calculated either by adding up value added across all industries, by adding up expenditure on final uses (final consumption and savings) of goods and services, or by adding up primary incomes from production activities. The same adjustments to the level of GDP must be made in all three cases. These adjustments relate to the consumption-related nonmarket benefits of forests described in (ii) and (iii) above. Specifically, one must add to GDP the value of household consumption of tangible, but nonmarket, forest products like fuelwood and less tangible forest amenities. Consumption of these types of goods contributes to welfare, but it is not ordinarily recorded in GDP because the goods are not bought and sold in markets (in the first instance) and fall outside the production boundary (in the second).[11]

Although adjustments to the overall level of GDP are required for the consumption values described in (ii) and (iii), they are *not* required for current production values of the types described in (iv) and (v). That is, even though forests provide beneficial environmental services to other industries and suffer damage from pollution discharged by other industries, no adjustments must be made to GDP to reflect these current production linkages. The reason is simple: GDP *already* reflects the impacts. For example, if watershed protection services provided by forests positively influence current output of agriculture (due, for example, to reduced flooding), and forest cover declines, then agricultural output will also decline. GDP will be lower as a consequence. Similarly, if pollution damages the current stock of commercial timber, then

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[11] The national accounts contain a provision for imputing the value of consumption of goods of the sort included in (ii), but this provision is often not implemented.

timber production, and thus GDP, will be automatically lower.

Of course, the impacts of forest degradation might persist beyond a single period or might not be felt immediately. Reduced harvests from lower timber growth might not be observed until several decades after the initial pollution damage occurs, and increased flooding might not occur until several years after significant amounts of forest cover are lost. Adjustments for such future impacts must be made, but they should be made to NDP, not GDP. For the same reason, we do not need to adjust GDP for the depletion of timber (item (i)), for net sequestration of carbon in forests (item (vi)), or for deforestation (item (vii)), even though all have persistent economic consequences. We will discuss adjustments for these long-lasting impacts later.

In sum, just two adjustments, both related to nonmarket household consumption values, must be made to GDP: one should add the value of household consumption of tangible nonmarket forest products, and also add the value of household consumption of less tangible forest amenities. In effect, one must add the value of direct consumption of private and public goods that do not pass through markets. One does *not* need to adjust GDP for current production-related links between forestry and other industries in the economy, even when those links involve nonmarket impacts (as they usually do). Hence, we have:

Adjusted GDP = Conventional GDP
+ Final consumption of nonmarket forest products
+ Final consumption of forest amenities.

Reallocation of value added within GDP

The foregoing discussion pertained to economy wide GDP. Although adjustments for current production-related impacts are not justified at that level, they are for GDP at the industry level, i.e. for industry-specific value added. What is needed is to reallocate some value added from other industries to forestry in the case of environmental and pollution disposal services provided by forests. As this is simply a matter of reallocation, the level of overall GDP does not change.

The reallocation is most easily understood by working with GDP as defined by the sum of value added across industries (i.e., GDP from the production account). Assuming a four-industry economy with balanced trade, conventional GDP is given by:

Conventional GDP = Value added in manufacturing
+ Value added in agriculture
+ Value added in logging
+ Value added in forestry

Ignoring taxes and subsidies, value added is the sum of employee compensation and operating surplus, with the latter defined as the value of output minus employee compensation minus expenditure on intermediate inputs. From a social standpoint, operating surplus in manufacturing is overstated because that industry receives free pollution disposal services from forests.

Similarly, operating surplus in agriculture is overstated because agriculture receives free watershed services from forests. For both reasons, operating surplus, and therefore value added, in forestry is *under*stated.

The necessary adjustments are as follows:

Adjusted value added in mfrg	= Conventional value added in manufacturing - Value of pollution damage to forests
Adjusted value added in agriculture	= Conventional value added in agriculture - Value of environmental services provided by forests
Adjusted value added in forestry	= Conventional value added in forestry + Value of pollution damage to forests + Value of environmental services provided by forests

No adjustment is needed for the logging industry.

Additional adjustments to NDP

NDP, the sum of final consumption and net investment, provides a truer measure of income than GDP, the sum of final consumption and gross investment, because it deducts the consumption of capital. That is, it deducts depreciation. Conventional NDP includes net investment in just human-made capital. As demonstrated in Appendix 1, NDP should also include net investment in forest capital (and other forms of natural capital, and human capital as well, for that matter).

But net investment is not necessarily adequate for analyzing economic sustainability. Net investment is the value of the change in quantity of capital. It equals the change in value of capital — which is what matters for sustainability — only if no holding gains/losses occur. In the presence of holding gains/losses, net investment does not equal the change in value of capital. Then, NDP defined as the sum of final consumption and net investment does not provide an accurate long-run welfare measure, even if final consumption includes nonmarket goods and even if net investment is defined across all forms of capital. For example, if the value of the timber stock falls due to a permanent decrease in log prices, then long-run welfare prospects fall as well. Excluding this holding loss from NDP would cause NDP to overstate long-run welfare prospects (Asheim 1997).

There are two ways of addressing this problem. One is to continue to define NDP as the sum of final consumption and net investment, and to define a new measure that is the sum of NDP and holding gains/losses. The alternative is to broaden the definition of NDP to include holding gains/losses. Which approach is chosen is purely a matter of convention. In the end, the sum of final consumption plus net investment plus holding gains/losses is what matters, regardless of what we call it. For the sake of simplicity, we will define "adjusted NDP" as including not just the sum of conventional NDP and net investment in natural capital, but also holding gains/losses. That is, we define adjusted NDP as final consumption (including consumption of nonmarket goods) plus the change in value (not just the value of the change) of the total capital stock. In keeping with national accounts terminology, we refer to the change in value as net accumulation.

Assuming that the economically most significant aspects of forest resources are the ones listed at the start of this chapter, net accumulation of forest capital can be decomposed into four elements. The first is *net accumulation of timber*. In the absence of holding gains/losses, the change in the value of the timber stock depends on the balance between timber growth on the one hand and harvest and other factors reducing the stock on the other. The second element is *net accumulation of carbon*. If we assume that sequestered carbon is proportional to the standing timber volume, then, in the absence of holding gains/losses for either, net accumulation of carbon is proportional to net accumulation of timber. This does not imply double-counting, as the timber and carbon stocks are valued by different procedures (discounted flows of stumpage value in the case of timber, and discounted flows of avoided economic damages in the case of carbon).

The third and fourth elements are also closely related. The third is *net accumulation of forestland*. Deforestation reduces the stream of future benefits provided by forests: timber harvests, consumption of nontimber products and forest amenities, environmental services, and carbon sequestration will all be less. On the other hand, expansion of forest area increases the future provision of those benefits, so the capital value of forestland can appreciate as well as depreciate.

The fourth element is the *net accumulation of converted land.* One must not simply subtract the loss of forest capital due to deforestation from conventional NDP; one must also *add* the capital value of that land in its new use. Otherwise, the accounts will overstate the negative economic impacts of deforestation. If markets function perfectly, then the appreciation of developed land due to forest conversion should at least offset the depreciation of forestland due to deforestation. If, in addition, land conversion is costly, as it typically is (one must not only harvest all the commercial trees but also fell and dispose smaller trees, remove stumps, etc.), then the former will exceed the latter. That is, deforestation should result in a net increase in land-related capital values. Because markets do not work perfectly in practice, however, some of the costs of deforestation are typically ignored when land-use decisions are made by either private parties or the government. Hence, the decumulation of forestland could well exceed the accumulation of converted land. Whether it does or not is an empirical question, whose answer depends on the magnitude of nonmarket forest values and on the characteristics of property rights and other institutional factors.

In effect, the first two elements, net accumulation of timber and carbon, reflect changes in the value of the land area that remains under forest cover during the accounting period, while the second two elements, net accumulation of forestland and converted land, reflect changes in value due to changes in forest area that occur during the accounting period. This observation raises two issues. The first is the issue of how to account for changes in timber and carbon stocks on areas deforested during the accounting period. Should they be included in net accumulation of timber and carbon, or in net accumulation of forestland? There is an obvious risk of double-counting. We recommend the following. Begin by calculating the present value of future timber production (the discounted sum of stumpage value from future harvests; more on this in the next chapter) from the deforested area at the beginning of the accounting period (before it is deforested) and at the end (after it is deforested). These present values equal the asset value of the timber stock. In making these calculations, assume (hypothetically, obviously) that the area will remain under forest cover, i.e. that it will indeed produce future timber harvests and not be deforested. The difference between the two present values, ending value minus beginning value, is by definition net accumulation. Include it in net accumulation of timber. It gives the change in the value of the beginning timber stock, on the assumption that the land stays in timber production. Include the *negative* of the ending value in net accumulation of forestland. It gives the change in value of forestland due to the loss in future timber harvests caused by the deforestation that actually occurs. Calculations for the carbon stock are analogous.

The second issue has to do with forest degradation, i.e. changes in quality as opposed to changes in quantity or holding gains/losses. The four-element framework includes degradation related to timber and carbon, in that pollution and other forms of degradation (e.g., improper logging) damage timber growth and thus future values associated with timber and carbon. All other values of forests are assumed to be simply proportional to forest area and not subject to degradation. This is obviously unrealistic. This shortcoming can easily be rectified in theory: one simply adds a fifth form of net accumulation, for changes in the value of forests as a source of nontimber, noncarbon values. This fifth item would be calculated as the difference between the present value of future values of forest-related benefits, *other than timber and carbon* (which are already accounted for separately), at the end of the period, minus the present value at the beginning of the period. This calculation could be done for the forest as a whole, or, if data permit, for individual values (several additional net accumulation entries). Developing a separate net accumulation entry is probably most important to consider for the case of fuelwood, which is the most important nonmarket product of forests in most developing countries and an important cause of degradation (through over harvesting). As in the case of timber and carbon, net accumulation calculations for forest degradation must be done carefully to avoid double-counting when deforestation is also occurring.

The four-element decomposition of net accumulation is therefore meant to be illustrative, not definitive. Alternative decompositions are possible and probably desirable in many countries. Whatever decomposition format is selected, three points are critical. First, asset values should equal present values of future returns. The present values should reflect quantity and quality changes and holding gains/losses. Second, net accumulation should equal the present value at the end of the accounting period minus the present value at the beginning of the period. Third, in the presence of changes in forest area, net accumulation of elements of the forest capital stock that are treated as separate assets must be accounted for carefully to avoid double-counting.

Assuming that the four-element decomposition is appropriate, the following four adjustments must be made to conventional NDP:

Conventional NDP
+ Net accumulation of timber
+ Net accumulation of carbon
+ Net accumulation of forestland
+ Net accumulation of converted land
= Adjusted NDP

Written out in full, we have:

Conventional GDP
+ Final consumption of non market forestry products
+ Final consumption of forest amenities
= Adjusted GDP
+ Net investment in human-made capital
= Conventional NDP
+ Net accumulation of timber
+ Net accumulation of carbon
+ Net accumulation of forestland
+ Net accumulation of converted land
= Adjusted NDP[12]

This may be viewed as the master relationship between conventional current accounts and accounts adjusted for current and future economic contributions of forestry. To recap, GDP needs to be adjusted for economic benefits associated with two items, which carry over into NDP. NDP needs to be adjusted for changes in value (net accumulation) of four categories of natural capital associated with forests. Current values of environmental services provided by forests as inputs into other industries do not require any adjustments to GDP, but they do require offsetting adjustments to value added in forestry and the receiving industries if one wishes to measure social value added accurately at the industry level. The present value of future services should, however, be reflected in adjusted NDP through the net accumulation terms. For example, watershed services are one component of the value of forestland, so net accumulation of forestland should reflect the loss in future value of such services when deforestation occurs.

Forest management expenditures

So far, we have not mentioned any adjustments to either GDP or NDP related to item (viii), forest management activities. That is because no adjustments are needed. In the production account, GDP already includes value added in forestry (employee compensation plus operating surplus); in the use of income account, it already includes forestry-related investments in fixed capital (e.g., construction of forest roads). These accounts correctly exclude forestry's use of intermediate inputs. As NDP is a forward-looking measure, there is no need to take into account historical expenditures on forest management, despite the fact that the benefits of these expenditures (enhanced timber production) are typically not realized until many years after the expenditures are made. All one needs to do is to account for the depreciation of human-made capital in forestry, as in any industry.

Adjustments to the asset accounts

In simplified form, SNA balance sheets contain three entries:

- Opening value of asset
- Net accumulation (= change in value of asset)

[12] Note: these last four items added together equal the Change in value of forest capital

- Closing value of asset.

Opening and closing values are defined as the present value of future returns generated by the asset. For example, the asset value of a timber production forest equals the discounted sum of total resource rent (volume harvested times average net price, or stumpage value) associated with future harvests. If the forest is also an important source of nontimber benefits, then the asset value should also include the discounted sum of net nontimber benefits. Given that discounting is involved, the asset value depends on the discount rate, the frequency between harvests (and production cycles for nontimber benefits, if not annual), and the age of the forest.

If asset markets are efficient, then the market price of an asset should equal the present value of future returns, making it unnecessary to calculate the asset value by the present value method. In practice, the market price of forestland seldom reflects the full asset value, due to the presence of nonmarket benefits like nontimber products, amenity values, and environmental services. Market price usually (though not always) reflects only timber values. Moreover, many countries, especially ones in the developing world, do not allow private ownership of forests, so there is no market price that can be used as even a lower bound on asset value. In such cases, there is no choice but to use the present value method to calculate asset values.

Once the asset values of the opening and closing stocks are determined, through either market-determined asset prices or present values, net accumulation can be calculated by subtracting the value of the opening stock from the value of the closing stock. In theory, net accumulation can also be calculated directly, instead of by taking the difference in asset prices or present values. We review methods for directly calculating net accumulation for timber in the next chapter. Those methods are also applicable to other forest benefits provided on a cyclical basis (e.g., fuelwood). In practice, sometimes one approach is easier, and sometimes the other. Which is the case depends on the type of forest asset under consideration. Direct calculation of net accumulation is likely to be easiest when timber is the principal benefit provided by forests. In that case, however, market prices for the asset (the prices of commercial timberland of various species and various ages) are also more likely to be available. Generally, it seems that when direct calculation of net accumulation is easiest, it is also least essential.

Whether net accumulation can be decomposed into separate elements like the value of increases in the volume of the asset (e.g., timber growth), the value of decreases in volume (e.g., timber harvesting, catastrophic losses related to fires and pest outbreaks, etc.), the value of degradation of the quality of the stock (e.g., reduced growth and excess mortality to pollution damage or a change in species composition due to ecological thresholds being exceeded), and holding gains/losses — that is, whether detailed accumulation accounts can be created — is also an empirical matter. Although such decomposition is not necessary for examining aggregate issues related to the economic contributions of forests, it might provide useful information for policy analysis and planning. For example, if a forestry department wished to assess the potential benefits of an increase in the budget allocation for, say, fire-fighting, a set of accumulation accounts that gave information on current and past losses in timber asset values due to forest fires would facilitate the needed analysis.

In many cases, however, physical indicators from physical forestry accounts or the SEEA might be a more feasible, and perhaps entirely adequate, source of information on the causes of changes in forestry asset values. While recognizing this point, we note here one potentially feasible decomposition for timber production forests that is linked to the methods discussed in the next chapter:

- Decumulation due to timber harvesting in the current period
- Accumulation due to future growth of forests logged in the current period
- Accumulation due to growth of immature forests
- Decumulation due to fires, pest outbreaks, and other losses in mature and immature forests.

A further step would be to divide each of these elements between: (i) estimates based on constant prices (no holding gains/losses), and (ii) the estimated difference in present values due to differences between expected future prices and constant prices (holding gains/losses).

A final point is that, given the multiple benefits provided by forests, and the fact that those benefits have very different characteristics in terms of production cycle (constant flow or cyclical), market status (priced or unpriced), and so on, it is unreasonable to expect that a single format of accumulation accounts can be applied to all types of forest capital. Accumulation accounts need to be tailored to fit the particular types of forest capital that they cover. For example, the structure indicated in the previous paragraph might be perfectly suitable for tracking changes in values of timber stocks, but it is unlikely to be ideal for tracking changes in values of biodiversity stocks (if biodiversity is treated as a separate forest asset). While the lack of a "one size fits all" framework might concern national accountants interested in standardization across assets and countries, it is not a cause of concern when the purpose of the accounting system is to generate accurate and appropriate measurement of forestry asset values and their changes within a specific country.

National accounting matrices

One way to visualize the various adjustments to the current accounts and their relationship to entries in conventional accounts is to construct a social accounting matrix (SAM), which we prefer to call a national accounting matrix (NAM). Rows of a NAM show supplies of inputs (i.e., sources of income), while columns show use of those inputs (i.e., patterns of expenditure). The sum of entries in a given row equals the sum of entries in the corresponding column. That is, a NAM is structured to be in balance in an accounting sense.

Table 1 presents a NAM for a situation in which timber is the only value of forests. There are three primary factors, labor, capital, and forests, and one intermediate input, logs. Labor, capital, and logs are used in the production of consumer goods, investment goods, and logs themselves. There is no deforestation or depreciation of human-made capital. Under these assumptions, NDP according to the income approach is given by the sum of the last row: wages, capital earnings, and total resource rent (so-called Hotelling rent plus inframarginal rent (producer surplus)), minus depreciation of the timber stock. Households own the primary factors, are the source of savings for investment, and consume the consumer goods. We ignore the role of government as a resource owner and saver; in a sense, the "households" category can be thought of as a catch-all category that includes both private and public owners, savers, and consumers. According to the expenditure approach, NDP is the sum of the last column: expenditure on consumer goods and investment goods, minus depreciation. Appendix 3 provides a more detailed analysis.

Table 2 shows additional entries to the NAM when the forest provides amenity values. In the last row, forest-owning households now receive income from selling forest amenities to other households. The expenditure by the receiving households now shows up in the last column. If the amenities are nonmarket, which is the usual case, then monetary transactions do not occur, and these cells need to be filled in using estimates from nonmarket valuation methods. Appendix 4 provides a more detailed analysis of this NAM.

Table 3 presents the final and most complicated NAM. The value of the standing forest is again just for timber, as in 1, but now forestland has an alternative use, agriculture. Hence, there is an additional primary factor of production, agricultural land, which is generated by clearing forestland, a process that requires inputs of labor, capital, and logs. Both the income and expenditure versions of NDP now include additional terms related to deforestation and development of new agricultural land. Note in particular that the last column includes the difference between the price of forestland and the price of agricultural land, not just the former. That is, the NAM reflects both the depreciation of forestland due to deforestation and the appreciation of agricultural land due to development of cleared forestland. Appendix 5 provides a detailed analysis of the NAM in Table 3.

3. CALCULATING ENTRIES IN THE FRAMEWORK

Getting the accounting framework right for forest resources is the easy part. Implementing the framework is considerably more difficult. Implementation raises conceptual issues related to methods for calculating entries in the framework. Once those issues are resolved, one faces the challenge of compiling adequate data for applying the methods. This chapter addresses conceptual issues related to methods, and the next considers the feasibility of implementing the methods as revealed by recent empirical studies.

In the previous chapter, we identified eight basic accounting adjustments related to economic aspects of forests:

To be added to GDP
Final consumption of nonmarket forest products
Final consumption of forest amenities

To be reallocated within GDP
Environmental services of forests
Pollution deposition in forests

To be added to NDP
Net accumulation of timber
Net accumulation of carbon
Net accumulation of forestland
Net accumulation of converted land

Implementing the first four adjustments and the sixth (carbon) is a matter of applying nonmarket valuation techniques. Much experience has been gained with these techniques during the past twenty years. Several book-length treatments are now available (e.g. Boardman *et al.* 1996, Dixon *et al.* 1995, Freeman 1993, and Smith 1996), and literally thousands of articles have been written. Reviewing the range of available techniques, and experience with them, is far beyond the scope of this report, and indeed it was not included in the terms of reference for the report.

For these reasons, this chapter will primarily focus on valuation issues related to timber and land. These aspects of forests pertain to two of the major policy issues related to forests, timber depletion and deforestation. They also involve unique economic features of forests, such as long rotation cycles. The studies reviewed in the next chapter indicate that adjustments related to timber are typically the most feasible ones to implement, and usually the largest.

Before discussing timber and land issues, however, we will offer a few observations related to other adjustments. These observations take advantage of information generated by the model in Appendix 1, and they provide background concepts necessary for evaluating the studies in the next chapter.

Nonmarket values

Three of the adjustments in the above list relate to nonmarket impacts on output in other industries: environmental services, pollution deposition, and CO_2 sequestration. For example, agriculture and hydropower benefit from the free watershed protection services provided by forests. Similarly, manufacturing benefits from pollution deposited in forests because it does not have to pay to abate the pollution. If it did, its profits and output would be lower. Lastly, climate-sensitive industries benefit from carbon sequestered in forests because sequestration reduces the risk of climate change and its deleterious consequences.

For these entries, the most straightforward valuation method to apply, and the one implied by the model in Appendix 1, is the *productivity change method*. For environmental services, application of this method involves calculating the following expression:

Area of forest providing environmental service

× Hypothetical increase in current output of the industry receiving the service if forest area were to increase by one unit
× Unit value (price) of output of industry receiving the service.

The second line gives the marginal product of forests in providing the service; in combination, the second and third lines give the marginal value product of forests as a source of the environmental service. Note that the first line includes only the forest area actually providing the service, not the total forest area. Including total forest area would overstate the value of the service. As discussed in Chapter 2, the estimated amount given by the above expression should be subtracted from value added of the industry receiving the benefits and added to forestry value added.

For pollution deposition, two expressions are possible. The first is similar to the one above:

Amount of pollution deposited in the forest

× Hypothetical increase in current output of the polluting industry if it were allowed to emit one more unit of pollution
× Unit value (price) of output of the polluting industry.

This is equivalent to:

Amount of pollution deposited in the forest

× Cost of abating the last (marginal) unit of pollution.

The second expression is in terms of forest damage:

Amount of pollution deposited in the forest

× Hypothetical decrease in current growth of timber if the polluting industry were allowed to emit one more unit of pollution
× Sum of stumpage and carbon sequestration values of a unit of timber.

As in the case of environmental services, the calculated amount from either expression should be subtracted from value added in the polluting industry and added to forestry value added.

If pollution is at the optimal level, so that the marginal benefit of abating pollution equals the marginal cost, then the two expressions should yield the same calculated amount. When pollution is above or below the optimal level, however, the two expressions yield different amounts. In this case, which is the usual case in practice, the second expression is preferred, as it measures the forgone benefits provided by forests — the opportunity cost of timber output and carbon sequestration services that society sacrifices — and thus indicates the welfare impact of using forests for pollution disposal.

For carbon sequestration, the expression is more complicated, as the adjustment is to NDP, not GDP:

Net sequestration of carbon in the forest (release minus uptake)

× Present value of hypothetical future increases in the value of output of climate-sensitive industries if one more ton of carbon were sequestered.

Note that net sequestration can be either positive or negative. In either case, the product of it and the second term should be added to NDP. Obviously, the most difficult step here is to calculate the second term, which gives the long-run, avoided damages resulting from carbon sequestration in the forest. The most feasible approach is probably to base the value on predictions of economic models of climate change. Nordhaus (1994), for example, estimated a 1995 value of US$5.24 per ton of carbon (at 1989 price levels).

The two entries related to nonmarket consumption require a different valuation approach, as in those cases the economic contribution of forests is not operating through production relationships. For household collection of nonmarket forest products, the model in Appendix 1 implies using the following *opportunity cost method* to calculate a *lower-bound* estimate:

Amount of time spent collecting × Opportunity cost of time.

The calculated amount should be added to GDP. Note that this expression does not include the cost of purchased intermediate inputs (e.g., bags, tools, transportation), as GDP is net of purchases of intermediate inputs (double-counting would occur if they were included in the formula above). If such inputs are made by households rather than purchased, however, then the time spent making them should be included. Nor does the expression include forest fees paid to the government or other forest landowners, as those fees are (or should be) already included in GDP.

This last point, however, gets at the reason why the expression given above yields a lower-bound rather than a complete estimate. In many instances, particularly in developing countries, forest ownership rights are not well-defined or enforced. Consequently, collectors of nonmarket forest products often do not have to pay for the use of forest resources. In a situation of complete open-access, one expects that this will cause forest rent to be completely dissipated: households will collect nonmarket products up to the point where the perceived value of the last unit collected just equals the opportunity cost of labor used to collect it. That is, they will ignore impacts on forest productivity, for example whether collecting less in the current period would make more available in future periods. In this situation, the (suboptimal) value of collection simply equals the opportunity cost of labor involved. If, however, customary rights prevent the complete dissipation of forest rent, then the full value of collection of nonmarket forest products is given by the sum of forest rent and the opportunity cost of labor.

Valuation of nonmarket forest products is easiest when some portion of the amount collected is sold in markets. Then, collection can be valued simply by multiplying the amount collected times the market price, as long as the products consumed and the products sold do not differ appreciably. Similarly, collection can be valued by the price of a substitute product when the degree of substitution is high (and by more advanced valuation methods when it is not).

The last nonmarket value, final consumption of forest amenities, is the most difficult to value. We have defined this as a non-use value: its production does not require any expenditure on market goods or any input of labor or other factors. An example would be the existence value of biodiversity. To estimate such a value, there appears to be little choice but to apply the contingent-valuation method, which involves asking a sample of individuals to state their willingness-to-pay to protect the nonmarket benefit or their willingness-to-accept to forgo it. When consumption of amenities involves the purchase of other goods, for example when one must drive to a park and pay an entrance fee to enjoy the amenities in the park, then other methods, such as the travel-cost and hedonic-pricing methods, can be applied.

Timber values

Understanding the relationship between asset value and direct methods for estimating net accumulation is easier in the case of a nonrenewable resource than in the case of renewable resources like forests. For that reason, in this section we first discuss the nonrenewable case. Then, we examine how the introduction of renew ability (timber growth) and the typically long time period between regeneration and harvest complicates matters in the case of forests.

Asset value and net accumulation for a nonrenewable resource

The asset value of a natural resource, whether nonrenewable or renewable, equals the discounted sum of the net returns (resource rents) it generates over time. For a nonrenewable resource, asset value at time t is therefore given by

$$V(t) = \sum \{(1+i)^{t-s} [pq(s) - C(q(s))]\} ,$$

where the sum is evaluated over the interval $s = t, \ldots, T$. i is the discrete discount rate, p is the price of one unit of the extracted resource (assumed to be constant over time), $q(s)$ is the quantity extracted in period s, $C(q(s))$ is the total extraction cost, and T is the terminal time (the period when the resource is exhausted). The difference, $pq(s) - C(q(s))$, is current resource rent. By separating out resource rent in period t, which is not discounted, from the discounted sum, we can equivalently express asset value as

$$V(t) = pq(t) - C(q(t)) + V(t+1)/(1+i).$$

$V(t+1)$ is simply asset value one period later, in period $t+1$.

Net accumulation equals asset value at the end of a period (i.e., at the beginning of the next period) minus asset value at the beginning of the period:

$$D(t) = V(t+1) - V(t) .$$

Substituting the second expression for V_t into this expression, we obtain

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

This is the fundamental equation of asset equilibrium (Hartwick and Hageman 1993). It indicates that net accumulation is the difference between two opposing forces: the shifting of the discounted stream of future rents toward the present, which increases asset value (net accumulation tends toward a positive value), and the realization of current resource rent, which decreases asset value (net accumulation tends toward a negative value). Hence, net accumulation is *not* equal to the negative of current resource rent, which most applied studies have assumed to be the case. Under the assumptions we have made, net accumulation is indeed negative (the latter force outweighs the former), but it is smaller in absolute value than current resource rent.

In Appendix 2, we demonstrate that if the assumptions underlying the simple model presented above hold — in particular, if the resource is extracted optimally (to maximize the discounted sum of rents), and if prices, the extraction cost schedule, and the discount rate are constant over time — then one can estimate net accumulation *directly*, without needing to calculate the present value of future flows of rents. Two basic approaches, which in theory should yield equivalent results, are available. The first is commonly called the *net price method*. According to this method, one multiplies the *marginal* net price of the resource (price minus marginal cost) times the negative of the amount extracted:

$$D(t) = -[p - C'(q(t)] \, q(t).$$

The use of marginal net price instead of average net price might appear to be a minor detail, but in fact it is crucial: if one uses average net price, then one is calculating the negative of total resource rent, which as noted above overstates net accumulation.

Data on marginal costs are typically hard to obtain or unavailable altogether. If, however, data are available on average cost and the elasticity of the marginal cost curve (percentage change in marginal cost per 1-percent change in quantity extracted), then one can apply the net price method by using the expression,

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

where $C(q(t))/q(t)$ is average extraction cost and β is the elasticity of the marginal cost curve.

The second direct estimation approach also makes use of the marginal cost elasticity. Under this approach, which we refer to as the *El Serafy method*, one multiplies the negative of total resource rent times a conversion factor involving the discount rate, the number of years until the resource is exhausted (T-t), and the elasticity (see Vincent 1997):

$$D(t) = -[pq(t) - C(q(t))]\, (1+\beta) / [1+\beta(1+i)^{T-t}]\ .$$

This is a generalized version of the original El Serafy method (El Serafy 1989), which implicitly assumes that $\beta = \infty$ and thus reduces to

$$D(t) = -[pq(t) - C(q(t))] / (1+i)^{T-t}\ .$$

Note that this simplified version of the formula yields accurate estimates of net accumulation only if the marginal cost elasticity does indeed equal infinity. This is highly unlikely in practice, so one is better off using the version including the marginal cost elasticity. Some authors have referred to the El Serafy method as the user-cost method, but we will eschew this terminology as it creates confusion with the standard meaning of “user cost” among resource economists.[13]

Net accumulation of timber: the net depletion method

As we will see in the next chapter, both the net price and El Serafy methods have been applied to timber resources. The former has been the most popular, and in applications to timber it is perhaps best described as the *net depletion method*. Typically, one calculates the net depletion of the timber stock by subtracting growth (and other additions) from harvest (and other subtractions). Then, one multiplies the negative of the resulting amount times net price:

$$D(t) = -[p - C'(q(t))]\, [q(t) - g(S(t))]\ .$$

$g(S(t))$ is growth of the timber stock in period t. This expression assumes that the cost function is nonlinear, and so it includes marginal net price. Alternatively, if costs are linear ($C(q(t)) = cq(t)$), then one can apply

$$D(t) = (p - c)\, [q(t) - g(S(t))].$$

[13] The discounted future marginal rent that is forgone when a unit of a resource is extracted in the current period.

This expression is really just a special case of the preceding one: when the cost function is linear, marginal cost ($C'(q(t))$) equals average cost (c).

Although the net depletion method might seem to be a reasonable generalization of the net price method, it does not yield accurate estimates of net accumulation of timber. The reasons are easy to see if one separates the expression into its two components, for harvest and for growth. We begin by disaggregating the forest by age class: A_T hectares of mature forest are harvested in a given period, and A_t hectares of immature forests of ages $t = 1, ..., T\text{-}1$ are left to grow. Note that t now refers to age of the forest, not year, and that there are several age classes of immature forests, not just one. Assuming that: (i) forests are even-aged (all trees in a stand are the same age), (ii) all standing timber is harvested at the optimal rotation age T, with no intervening production (e.g., from thinnings), and (iii) $q(T)$ is the standing timber volume per hectare in mature forests, then total harvest equals $A_T q(T)$. Similarly, timber growth for forests in age class t equals $A_t q'(t)$, where $q'(t)$ is the derivative of the timber volume function.

Net accumulation for a forest disaggregated by age class equals

$$A_T D_H(T) + \sum A_t D_H(t) ,$$

where $D_H(T)$ and $D_H(t)$ represent per-hectare net accumulation values of mature and immature forests, respectively. The sum in the second term is evaluated over the interval $t = 1, ..., T\text{-}1$: "immature forests" is not a single category, but rather a shorthand phrase for all forests that are left to grow during the current period rather than being harvested.

On a per-hectare basis, and using our new notation, the net depletion method amounts to applying the following expressions to mature and immature forests:

<u>Net depletion method</u>

$$D_H(T) = -[p - C'(q(T))]\ q(T)$$

$$D_H(t) = [p - C'(q(T))]\ q'(t), \text{ for } t = 1, ..., T\text{-}1.$$

The first expression states that the change in value of one hectare of mature forest equals the product of marginal net price and the negative of volume harvested. This would seem to be analogous to the expression for nonrenewable resources. Of course, renewable and nonrenewable resources differ due to the fact that the former can grow back. For this reason, one should suspect that this expression is incorrect. The change in value of a hectare of mature forest should also reflect the value of future harvests, assuming that the land remains under forest cover.

Grounds for suspicion about the expression for immature forests are even more obvious. The second expression states that the change in value of one hectare of immature forest equals the product of marginal net price and the volume of current growth. Yet, the timber is not yet mature, so it is surprising that it is being valued by the same factor (marginal net price) applied to mature timber. One should expect that the number of years until harvest (the degree of immaturity) somehow needs to be factored in.

Net accumulation of timber: correct methods

In Appendix 2, we demonstrate that these concerns about the net depletion method are valid. We derive two alternative, but equivalent, sets of expressions for calculating the net accumulation of timber. These methods can also be applied to any other forest product produced at intervals of more than one year (i.e., requiring more than a year between regeneration and harvest).

The first set, which is the correct version of the net price method when applied to timber and can therefore be referred to as the *net price variation*, is

Net price variation

$D_H(T) = -[p - C'(q(T))]\ q'(T)\ [1 - (1+i)^{1-T}] / i$

$D_H(t) = [p - C'(q(T))]\ q'(T)\ (1+i)^{t-T}$, for $t = 1, \ldots, T-1$.

Two differences relative to the net depletion method are immediately obvious. First, for mature forests, the net depletion method includes the harvest volume at the optimal rotation age, while the correct expression (the first one above) includes *growth* at the optimal rotation age. Second, for immature forests, the net depletion method includes current growth, while the correct expression (the second one above) includes growth *at the optimal rotation age*. Hence, to calculate net accumulation of timber using the net price variation, one requires data on: the marginal net price of harvested timber (which equals the average net price if the cost function is linear), the growth rate per hectare at the optimal rotation age (the current annual increment, not the mean annual increment), the age of the forest, the optimal rotation age, and the discount rate.

The second set of expressions, which is identical to the first set and is the correct version of the El Serafy method when applied to timber (hence, we dub it the *El Serafy variation*), is

El Serafy variation

$D_H(T) = -[pq(T) - C(q(T))]\ [1 - (1+i)^{1-T}] / [1 - (1+i)^{-T}]$

$D_H(t) = [pq(T) - C(q(T))]\ i\ (1+i)^{t-T} / [1 - (1+i)^{-T}]$, for $t = 1, \ldots, T-1$.

Two obvious differences compared to El Serafy's method for nonrenewable resources are that the marginal cost elasticity does not appear and that the discounting terms are more complex (note that they differ for mature and immature forests). These differences are related: the complexity of the discounting term reflects not only the delay between regeneration and harvest, but also the economic condition for selecting the optimal rotation age. In the case of El Serafy's method for nonrenewable resources, the marginal cost elasticity enters for a reason analogous to the latter, i.e. Hotelling's rule. Although one does not need data on growth increment to apply these expressions, one does need, in addition to data on resource rent (stumpage value) per hectare of harvested forest, data on age of the forest, the optimal rotation age, and the discount rate.

Note that the volume of growth in the first set of expressions ($q'(T)$) and the harvest volume in the second set ($q(T)$) both pertain to merchantable volumes: timber in trees of commercial species, net of defect. Calculating net accumulation on the basis of net growth of wood in trees of all species (in the case of the first set of expressions) or gross harvest volume (in the case of the second) would generate upwardly biased estimates. It is also possible to show (see Vincent 1997) that no downward adjustment to net accumulation needs to be made for normal (strictly speaking, optimal) levels of logging damage.

Both sets of expressions are considerably more complex than their counterparts for nonrenewable resources, and more complex than the expression for the net depletion method. If the values they generate are not appreciably different from the incorrect values generated by the net depletion method, then applying them might not be worth the extra difficulty. In Appendix 2, we demonstrate that the net depletion method tends to overstate the decrease in value when mature forests are harvested, with the degree of error depending on the linearity of the cost function. It also overstates the increase in value of immature forests due to growth, except in very young forests when the volume-age relationship has a logistic (S-shaped) form. Since the biases are in opposite directions (negative for mature forests, positive for immature forests), they are to some extent offsetting at the level of the forest estate, which includes a mix of mature and immature forests.

The net impact of the two biases therefore depends on the relative areas of forests in different age classes. If the forest estate consists primarily of mature and very immature forests, which is more likely to be true in developing countries, then the net depletion method will tend to produce downwardly biased estimates of net accumulation of timber in the forest estate. The asset value of the forest estate will appear to be falling more rapidly than it actually is. In contrast, if the forest estate consists primarily of well-established immature forests, which is more likely to be true in developed countries, then the net depletion method will tend to produce upwardly biased estimates of net accumulation. The value of the forest estate will appear to be rising more rapidly than it is.

Only in the case of the forester's ideal, or "normal" forest, which has equal areas in each age class, does the net depletion method yield an unbiased estimate of net accumulation. In that special case, net accumulation trivially equals zero, because the age-class structure of the forest is stationary from one period to the next. Unfortunately for the net depletion method, "normal" forests are much more common in forestry textbooks than in the real world. Even in the unlikely event that some country's forest estate is indeed "normal," there is no need to apply the net depletion method or any other method for that matter, as one knows *a priori* that net accumulation equals zero.

An empirical comparison of the net depletion method to the correct methods

Table 4 compares the various methods for the same forest at different ages. The data are drawn from dipterocarp forests in Malaysia. The relationship between standing volume per hectare (net of defect) and age is given by

$$q(t) = 0.65 \times 132 \times e^{1-60/t},$$

which has a logistic shape. Log price (p) is RM115/m^3 (1978 price levels), where 1 RM (ringgit Malaysia) ≅ US\$0.40. The logging cost function is linear, with c = RM45/m^3, and the discount rate is 4 percent (real terms). Under these assumptions, the optimal rotation age (*T*) is 33 years. The harvest is 37.9 m^3/ha, and the resource rent associated with that harvest volume is RM2,650/ha, since the marginal (= average) net price is RM70/m^3.

The column headed "Present value" shows net accumulation calculated as the difference between present values. For t = 33, the formula used is $V(1)-V(T)$. As expected, net accumulation is positive (asset value is rising) during the years leading up to harvest, with its level increasing. The columns headed "El Serafy variation" and "Net price variation" show net accumulation calculated using the correct versions of those methods for timber resources. The estimates are exactly the same as those in the "Present value" column. This simply reflects the fact that the El Serafy and net price variations are derived from the difference between present values (see Appendix 2).

The final column shows estimates calculated from the net depletion method. As expected, the estimates differ from those in the previous three columns, especially for older immature forests. Given the logistic volume-age relationship, the net depletion method understates the increase in value of very young forests (up to age 13), but beyond that point it overstates it. It overstates the decrease in value of the mature forest by 1.5 percent, which is small both in absolute terms and relative to the discrepancies for the immature forest.

A couple of simple examples illustrate the potential magnitude of error associated with the net depletion method. If 90 percent of a country's forest estate is mature and 10 percent is immature (say, age 10 years), then the correct estimate of net accumulation on the average hectare is -RM2,343:

= (0.9 × -RM2,610) + (0.1 × RM59).

In contrast, the net depletion method predicts -RM2,383:

= (0.9 × -RM2,650) + (0.1 × RM24),

which overstates the actual loss in value by only a tiny amount, 1.7 percent. If all the forest estate is of medium age (e.g., age = 17 years), however, then the net depletion method overstates the actual gain in value by 27 percent (RM99 per hectare vs. a true value of RM78 per hectare).

Perhaps the most interesting example is the following. Suppose that 5 percent of the forest estate is of age 33 years and 95 percent of age 24 years. With this age class structure, timber growth exactly equals harvest. Hence, the net depletion method yields a value of zero.[14] The actual

[14] Calculating the estimate from the net depletion method by using values in the last column of Table 4, instead of directly by subtracting growth from harvest (both equal to 37.9 m^3) and multiplying by net price (RM70/m^3), yields a value slightly less than zero. This is due to slight differences between growth rates calculated by the derivative of the growth function, $q'(t)$, which is how they are calculated in Table 1, and growth rates calculated by the difference in standing volumes, $q(t+1) - q(t)$. The sum is indeed zero if growth rates are calculated by the latter expression.

weighted-average net accumulation is -RM33 per hectare, however. So, net accumulation does not necessarily equal zero when growth equals harvest. It does so only when there are equal areas in all age classes.

Net accumulation in uneven-aged forests

The net price and El Serafy variations presented above were derived for even-aged forests. These methods can also be applied to uneven-aged forests, as long as harvests are approximately the same each time the forest is harvested. For example, suppose a forest contains three age classes, with the rotation age (chronological age of mature trees at harvest) being 60 years. Then, the forest is harvested every 20 years. This is the cutting cycle. In the expressions for the net price and El Serafy variations, *T*, the optimal rotation age (60 years), should be replaced by the cutting cycle (20 years) whenever it appears in association with the discount rate (e.g., in the term $(1+i)^{t-T}$). $q(T)$ still represents the amount of timber harvested per hectare, but this is now less than the standing volume, since some of the standing volume is in immature age classes. Similarly, $q'(T)$ now represents only growth of mature timber. $t-T$ still represents the negative of the number of years until the next harvest, though T is, as noted above, now the cutting cycle instead of the optimal rotation, and t is the number of years since the most recent harvest, not the chronological age of trees.

Asset values of timber

Expressions presented in the preceding sections can be used to make timber-related adjustments to not only the current accounts but also the asset accounts. We have shown how to decompose net accumulation into reductions in asset value due to harvesting of mature forests (on a hectare basis, $D_H(T)$) and increases due to timber growth in immature forests ($D_H(t)$). Incorporating other types of reductions, such as losses due to pests or forest fires, involves straightforward applications of the same valuation principles. For example, fire loss of a hectare of forest of age t changes an asset with a value of $V_H(t)$ to one with a value of $V_H(0)$. Hence, net accumulation in both the current and asset accounts should include an extra amount, equal to $V_H(0) - V_H(t)$.

These points suggest the following structure for the accumulation accounts for timber:

	Net price variation	El Serafy variation
Additions		
Future harvests in immature forests	$\Sigma A_t (p - c)\, q'(T)\, (1+i)^{t-T}$	$\Sigma A_t (p - c)\, q(T)\, i(1+i)^{t-T} / [1 - (1+i)^{-T}]$

Future harvests in mature forests	$A_T(p - c)\ q'(T)\ (1+i)^{1-T} / i$	$A_T(p - c)\ q(T) / [1 - (1+i)^{-T}]$
<u>Subtractions</u>		
Timber harvest	$-A_T(p - c)\ q'(T) / i$	$-A_T(p - c)\ q(T)\ (1+i)^{1-T} / [1 - (1+i)^{-T}]$
Catastrophic losses	$\sum A_{t*}[V_H(0) - V_H(t)]$ $+ A_{T*}[V_H(0) - V_H(T)]$	$\sum A_{t*}[V_H(0) - V_H(t)]$ $+ A_{T*}[V_H(0) - V_H(T)]$

We have assumed that the cost function is linear and thus use $p - c$ (average stumpage value) to represent marginal net price. Area variables with an asterisk (i.e., A_{t*}, A_{T*}) denote areas suffering from catastrophic losses (fire, pest outbreaks, etc).

For the balance sheets, we need asset values, $V_H(T)$ and $V_H(t)$. We emphasize that the asset value of the timber stock, $A_T V_H(T) + \sum A_t V_H(t)$, is not equal to the simple product of standing timber volume times net price, even when average and marginal net prices are the same. Assuming that the logging cost function is linear, the asset value of one hectare of mature forest is (see Appendix 2)

$$V_H(T) = (p - c)\ q(T) / [1 - (1+i)^{-T}]\ .$$

The discounting term causes this to be larger than the simple product, $(p - c)\ q(T)$. The magnitude of the error in using the latter instead of the former is greater for lower discount rates and shorter rotations. For example, the simple product understates the actual asset value of the mature forest by just 0.3 percent when the discount rate is 10 percent and the rotation age 60 years, but by 45 percent when the discount rate is 4 percent and the rotation age is 30 years.

For one hectare of immature forest, actual asset value is:

$$V_H(t) = (1+i)^{t-T}(p - c)\ q(T) / [1 - (1+i)^{-T}]\ , \text{ for } t = 1,\ \ldots,\ T\text{-}1.$$

This is larger than the simple product, $(p - c)\ q(t)$, because

$$q(t) < (1+i)^{t-T}\ q(T) / [1 - (1+i)^{-T}]\ .$$

$(1+i)^{t-T}\ q(T)$ alone is larger than $q(t)$, because timber growth exceeds the discount rate up to T (otherwise, the forest would be harvested at an even earlier age). Division by the term in brackets makes the right-hand side even larger than the left-hand side.

In sum, the asset value of the forest for timber production is *greater* than the value predicted by the simple product of net price times standing volume. The simple product understates the actual asset value by an even greater amount if one excludes the timber volume in immature forests, which one might be tempted to do considering that trees in those forests might, at the current moment, be too small to have any commercial value.

Holding gains/losses

In deriving both sets of correct methods for estimating net accumulation, we assumed that log prices and the marginal cost function are constant over time. In reality, both prices and costs fluctuate. Vincent, Panayotou, and Hartwick (1997) have demonstrated how to calculate holding gains/losses for nonrenewable resources directly (that is, without calculating the change in present value). The expression they derived is (not surprisingly) a discounted sum involving future price changes and extraction levels.

Price changes create holding gains/losses in the case of timber resources as well. To our knowledge, however, no one has yet derived a direct expression for calculating them. This is not necessarily cause for concern. Given the long time periods involved in timber production, holding gains/losses are not a serious concern if they are ephemeral, i.e. if prices (specifically, net prices) show no persistent trend over time. If this is the case, then a practical solution is to use a moving average of net prices to remove the effects of more extreme transitory fluctuations.

If, on the other hand, net prices show a trend that is expected to continue for one or more rotations, the effect on net accumulation estimates can be roughly approximated by reducing the discount rate. For example, if the discount rate is 10 percent and net prices are rising at 2 percent, one can calculate net accumulation by using a discount rate of 8 percent. Although this will not yield perfectly precise estimates, in most cases it should yield better estimates than ignoring the trends in net prices altogether. It has the added, and not inconsiderable, virtue of being easy to do.

More exactly, when the holding gain/loss is due to a perpetually rising net price that is rising at a constant percentage rate, the asset value of one hectare of forest is given by

$$V_H(T) = (p - c)\, q(T) / [1 - (1+i)^{-T}(1+\delta)^{T}]$$

$$V_H(t) = (1+i)^{t-T}(1+\delta)^{T-t}(p - c)\, q(T) / [1 - (1+i)^{-T}(1+\delta)^{T}] \text{, for } t = 1, \ldots, T-1,$$

where $(p - c)$ is current net price (stumpage value) and δ is the annual percentage increase in net price. Note that setting $\delta = 0$ yields the expression for asset values given in Chapter 3. Net accumulation *inclusive of holding gains/losses* is now given by

$$D_H(T) = V_H(1) - V_H(T)$$

$$D_H(t) = V_H(t+1) - V_H(t) \text{, for } t = 1, \ldots, T-1.$$

These differ from the expressions given earlier in this chapter, $D_H(T)$ and $D_H(t)$, which assumed constant net price.

We can use those earlier expressions, however, to isolate holding gains/losses. For a mature forest, the holding gain/loss is given by the difference, $D_H(T)$ - $D_H(T)$. This just equals zero if $\delta = 0$. The expression for immature forests is analogous. To include the resulting estimates of holding gains/losses in the proposed structure for timber accumulation accounts given above without double-counting, one should calculate other entries in the accounts (i.e., additions due timber growth in mature and immature forests, subtractions due to timber harvest, etc.) under an assumption of constant net prices.

If the gains/losses do not derive from a constant, perpetual percentage increase in net price, the formulation will necessarily be more complex. However, it will always have the general form, holding gains/losses equal actual net accumulation minus hypothetical net accumulation assuming constant net price.

Deforestation

In the notation of the previous section, the asset value of one hectare of forestland for timber production is $V_H(t)$ for a forest of age *t.* If timber is the only benefit provided by forests, then the reduction in asset value due to deforestation is given by the product of area deforested and per-hectare asset value:

-Area deforested $\times$ $V_H(t)$.

If all commercial timber is felled and sold before deforestation occurs, then the second term is the asset value of bare-land, $V_H(0)$. In that case, the only loss of timber production is from future rotations, not from the current standing volume. As mentioned in Chapter 2, we recommend including deforestation-induced losses in current standing volume in the net accumulation of timber, not in the net accumulation of forestland.

More generally, of course, forests provide nontimber benefits as well as timber. The decrease in asset value due to deforestation then equals the sum of decreases related to both timber and nontimber benefits. If nontimber benefits are, like timber, provided on a harvest cycle spanning more than one year from regeneration to harvest, then the expression for $V_H(t)$ given in the previous section can be applied to calculate their contribution to the value of deforested land. If instead they are provided at a constant annual value per hectare, regardless of the forest's age, then the loss in value of nontimber benefits due to deforestation is given by the annuity value,

-Area deforested × Annual per-hectare value of nontimber benefits / i .

This expression should be calculated for the full range of nontimber benefits, even those that do not affect the overall level of GDP or NDP: nontimber forest products, forest amenities, environmental services, and carbon sequestration.

If the annual value is not constant—for example, if it rises with the age of the forest—then one needs to perform more complex calculations. If $VN_H(t)$ is the annual per-hectare value of nontimber benefits provided by a forest of age t, then the correct expression is:

$$\text{-Area deforested} \times \{\sum [VN_H(s)/(1+i)^s] + (1+i)^{t-T}[\sum VN_H(s)/(1+i)^s] / [1-(1+i)^{-T}]\},$$

where s in the first summation (which denotes nontimber values during the remainder of the current rotation) is evaluated from t to T and in the second (which denotes nontimber values during future rotations) is evaluated from 1 to T.

Asset accounts must also include the net accumulation of converted (developed) land. Calculation of this entry depends, of course, on the nature of the use. If the land yields a constant annual per-hectare flow of rent (e.g., annual crop agriculture), then the simple annuity formula applies.

Although the value of developed land is necessarily at least as great as the value of forestland under perfectly efficient markets, with the difference given by land clearing costs (Chapter 2 and Appendix 1), the ubiquity of imperfections in forestland markets due to incomplete property rights and the presence of nonmarket values indicates that one should not automatically set the value of forestland equal to the value of converted land in its new use minus land conversion costs. If one has no choice but to use this formula, then one should be sure to use the value of developed land that actually competes with forestland. For example, if deforestation is occurring in the uplands, one should use the value of agricultural land in the uplands, not an average value, which implicitly includes the value of agriculture in more fertile lowlands.

In Appendices 5 and 6, we provide further analysis of the relative values of forested and converted land.

4. REVIEW OF EMPIRICAL STUDIES

Researchers have conducted empirical studies aimed at incorporating forest resources into the national accounts of more than 20 countries since the late 1980s. We obtained and reviewed more than 30 studies. We define a study as a discrete research project. A single "study" might generate several publications, as indeed several have.

Appendix 7 provides details of the studies. In this chapter, we highlight the main characteristics of the studies and what they tell us about the feasibility of improved accounting for the economic benefits of forest resources. We take as points of reference the accounting framework presented in Chapter 2 and the valuation principles presented in Chapter 3. Country and region names in bold-faced type indicate headings in the appendix, to make it easier to look up additional information on the studies.

Our review is more focused on forest resources than some previous ones (e.g., Sheng 1995, Hamilton and Lutz 1996), and more comprehensive than others (e.g., Hartwick 1993, Newson and Gie 1996). Nevertheless, we encourage readers to consult those and other reviews.

General characteristics

The earliest study in our sample is the well-known study of **Indonesia** by the World Resources Institute (WRI; Repetto et al. 1989). This is the most frequently cited study on natural resources (including forest resources) and the national accounts. A study for the World Bank by Peskin (1989), which commented on the WRI study and contained additional estimates for **Tanzania**, came next. The number of studies increased more or less steadily during the 1990s, with the greatest number, nearly a dozen, being published or otherwise made available in 1996. We are aware of at least three studies having been published so far in 1997. Several more are in preparation under the auspices of the U.N. Statistical Division.

The greatest number of studies pertains to countries in Asia, and the least to countries in Africa. By region, the countries covered are:

Asia (8 studies): Indonesia, China, Malaysia (2), Nepal, Philippines (2), Thailand

Central and South America (5 studies): Chile, Costa Rica (2), Ecuador, Venezuela

Europe (5 studies): Austria, Finland (2), Sweden (2)

North America (4 studies): Canada (2), Mexico, U.S.

Oceania (4 studies): Australia (2), New Zealand, Papua New Guinea

Africa (2 studies): Tanzania, Zimbabwe

Numbers in parentheses indicate the number of studies in individual countries where more than one study was conducted. We considered as separate studies ones conducted by different research teams, as well as ones conducted by the same team at different points in time but which differed substantially in their approach or coverage.

In addition to the 28 studies in the 21 countries listed above, the sample included one pan-Asian study (**Asia**) and one global study (**Global**). These expand the country coverage considerably. The latter, for example, included more than one hundred countries. Not surprisingly, these multi-country studies tend to include less detail than the country-specific studies. They also tend to assume many similarities across countries (e.g., that per-hectare values of forests for nontimber benefits are identical).

Most of the studies covered one or more resources in addition to forests. That is, they did not focus exclusively on forests. They were less forestry accounting studies than broader resource accounting studies. More than half covered subsoil assets (minerals) in addition to forests. Other non-forest resources included agricultural soils, rangeland, fisheries, and, in a few instances, air and water pollution. On the positive side, placing the analysis of forest resources in the context of studies with broader coverage of natural resources creates an opportunity to assess the importance of adjustments for forest resources relative to adjustments for other resources. More negatively, however, the goal of being comprehensive appears to have forced some researchers to sacrifice a certain amount of depth and breadth in analyzing forest resources. The forestry-specific studies tend to cover a broader range of aspects of forest resources (e.g., nontimber aspects as well as timber) and to marshall more data in making adjustments to the accounts.

The forestry-specific studies tend to be the more recent ones. In part because of this, they tend to be the ones covering the longest time periods. The **Canada** (I) and (II) studies analyzed the longest period, from the early 1960s to the early 1990s. A few studies, generally (but not solely) those that addressed a broad range of resources, analyzed just a single year. Most studies, whether forestry-specific or more comprehensive, covered at least 1 decade.

An implication of these points is that experience with the nuances of forestry accounting is more fresh, and thus more in need of review and discussion, than the total number of studies and their distribution over time (going back nearly a decade) suggests. Unfortunately in this regard, very few reports on the studies were published in academic (refereed) journals. Most were "published" as chapters in conference proceedings, as working papers, as part of organizations' own report series, or as draft manuscripts. This has three implications. First, identifying and obtaining the reports is difficult. Hence, it is not surprising that later studies do not always appear to draw fully on the results of earlier studies, even when the studies occur in the same country. This also leads us to conclude that Appendix 7 and the "Literature cited" section of this report might be of greater value than we originally expected them to be.

Second, the fact that most material has been published in outlets other than refereed journals means that it has probably been subjected to a less intensive review process. This raises the risk of inappropriate application of accounting procedures and valuation techniques. In a well-established field, this would not be a great concern. In the accounting field, however, there remains considerable controversy about the most appropriate ways of creating economic accounts for natural resources. To be sure, reports of some organizations, for example the World Bank and the World Resources Institute, do undergo internal (and in many cases) external reviews before publication. And the authors of papers presented at conferences and published in proceedings volumes do receive feedback from other conference participants. Nevertheless, in the absence of peer review, one should not be surprised if procedures in some studies are less sound than they could be.

Third, the infrequent publication of studies in the academic literature means that more theoretically-inclined researchers who read and publish predominantly in that literature are less likely to be aware of the issues that applied researchers face in attempting to create economic accounts for forest resources. For example, the long time period between forest regeneration and maturity of the timber crop might appear to theoreticians to be a minor detail that can be glossed over. As we have seen in Chapter 3, however, ignoring the rotation length can lead to severely biased estimates of the net accumulation of timber. Conversely, the fact that minimal dialogue between theorists and practitioners has occurred suggests that practitioners might not be taking full advantage of the implementable results of theoretical research.

The infrequency of publication in academic journals is not a consequence of the studies being conducted primarily by government agencies. In fact, more than half the studies were conducted by researchers with universities, research institutes, or international organizations. Only twelve of the studies appear to have involved government agencies responsible for the preparation of national accounts: **Australia** (I), **Austria**, **Canada** (I) and (II), **Chile**, **Finland** (I) and (II), **Malaysia** (I), **Mexico**, **New Zealand**, **Philippines** (I)**,** and **U.S.**

Links to national accounts

Virtually all the studies included timber, and nearly half covered one or more nontimber aspects of forest resources. The list includes nonmarket production of fuelwood, berries, mushrooms, game, rattan, and peat; amenity values associated with protected areas and biodiversity; environmental services like watershed protection and soil protection; carbon sequestration; and acid deposition. The **Tanzania** study was the first to consider a nontimber value, fuelwood. The **Sweden** (I) study, and two modeled after it, **Finland** (II) and **Sweden** (II), covered the greatest range of nontimber values, more than half a dozen in each case.

The studies therefore contain examples of all the types of adjustments discussed in Chapter 2. In many cases, however, they do not indicate clearly the accounting framework guiding the adjustments they make. Most tend to be rather imprecise about adjustments to GDP vs. NDP. Some talk of calculating “green GDP,” when the adjustments they make involve net accumulation and thus pertain to NDP. Generally speaking, the more ambitious the study in terms of the number of aspects of forest resources it covered, the more likely it was to be lax in terms of its conceptual framework, although the **Sweden** (I) study was quite careful in this regard.

These comments point to our principal conclusion: *empirical efforts to incorporate forest resources into the national accounts must be guided by economic theory more than they have been*. In the absence of a transparent and internally consistent conceptual framework, adjustments to the national accounts become ad hoc and unreliable. The only way to avoid this problem is to develop a framework based on sound economic principles. The framework in Chapter 2 represents our attempt to do this.

Some studies made adjustments to both current and asset accounts, while others made adjustments to just one or the other. Of those that made adjustments to current accounts, about two-thirds made adjustments for net accumulation. In most cases, the net accumulation estimates were for timber, although a few studies included nontimber values in calculations of net accumulation of forestland. Five studies estimated the value of nonmarket production of forest goods, which is an adjustment to GDP (and consequently to NDP, too).

One study, **Finland** (I), investigated a specific SNA recommendation, that timber growth in "cultivated" forests be valued and added to GDP. **New Zealand** already implements this recommendation, and has for some time. If this recommendation is implemented, then one must remember to exclude growth from estimates of net accumulation. The **China** study double-counted the value of timber growth in NDP by both adding it to GDP and using the net depletion method to calculate net accumulation.

About a third of the studies made adjustments related to asset accounts. In most cases, they simply calculated the value of the standing forest, without formally linking the estimates to the accounts. A few did, however, and compared the asset value of forest resources to the value of other assets in the economy.

With two exceptions, the studies all focused on adjustments at the national level. In addition to doing this, the **Malaysia** (I) and (II) studies also adjusted income accounts at the subnational level. They found that the impacts of net accumulation adjustments varied greatly within the country, with important implications for regional sustainability.

Valuation

Physical accounts

In most studies, making the adjustments was a two-stage process: first, the authors compiled physical information (e.g., area deforested, cubic meters harvested, etc.), and second, they converted physical impacts into monetary terms. The studies varied greatly in terms of the physical information they compiled and used. At one extreme were studies whose physical accounts consisted of just a single number. For example, in valuing the loss of habitat in Australia during 1980-89, Young (1993) assumed that the area of native forest cleared each year was 230,000 ha (**Australia** (I)). At the other extreme were studies that constructed elaborate GIS databases for analyzing changes in forest cover by forest type (**Costa Rica** (I)), or used detailed data on forest areas and growing stock by forest type, age class, and ownership category to calculate the forests' asset value (**Australia** (II), **Canada** (II)).

Almost half the studies constructed aggregate growth/drain accounts for estimating the net depletion of timber. The prototype for this approach was the WRI study of **Indonesia**. That study applied the physical accounting identity,

Closing stock = Opening stock + Additions - Subtractions,

to standing timber volumes. Net depletion equals the difference between subtractions and additions. Additions include growth of existing forests and reforestation, while subtractions include harvest, fire and pest damage, and so on. Studies varied in their implementation of this approach. Some accounted for just timber stocks, while others accounted for forest areas as well.

Some grouped all forests together, while others distinguished between old-growth and second-growth forests or mature and immature timber stocks. A few distinguished forests by dominant species.

Variation in physical accounting approaches is unavoidable. Physical accounts need to be tailored to the particular aspects of forest resources being emphasized, which necessarily vary across countries. The tailoring must be done within the constraints imposed by data availability, which also vary. Hence, we do not advocate any single physical accounting scheme. What we emphasize is that *creators of economic accounts for forest resources should have a clear idea of the uses of the accounts and the physical information necessary to create the accounts, and they should take full advantage of whatever data are available.*

Net accumulation of timber

We break down the valuation of timber into two components: net accumulation, which is needed for adjusting NDP in the current accounts, and asset valuation, which is needed along with net accumulation to bring timber into the asset accounts. We deal with the former in this section and the latter in the next section.

Most studies used the net depletion method to estimate net accumulation. That is, they multiplied the negative of net depletion of the physical timber stock times net price. The popularity of this method appears to be due to its simplicity — it does not require information on the discount rate or the age of forests — and the example set by WRI's **Indonesia** study. One study (**Malaysia** (I)) used smoothed values of net prices in applying this method, on the assumption that smoothed values, which exclude fluctuations due to short-run market events, provide a closer approximation to long-run user costs. Two studies (**Nepal**, **Philippines** (I)) intended to, or actually did, adjust net accumulation for "revaluation" (holding gains/losses) calculated by the residual method outlined in the WRI study: value of closing stock minus value of opening stock minus net accumulation as calculated by the net depletion method. In doing so they followed a suggestion by Peskin (1989). Three others (**Finland** (II), **Sweden** (I) and (II)) deducted current silvicultural expenditures (both fixed and variable) from their estimates of net accumulation.

No study applied the correct version of the net price method (the net price variation) presented in Chapter 3. Hence, *all the estimates of net accumulation in existing studies based on the net depletion method are biased, with the direction of the bias not clear* (because the studies do not provide information on the age class structure of the forests). Most likely, the estimates overstate the decrease in asset value in developing countries, and overstate the increase in developed countries (in view of the discussion about this bias in Chapter 3). Problems with the estimates are compounded by some of the additional adjustments made by certain studies. While holding gains/losses belong in net accumulation, the "revaluation" approach does not yield accurate estimates of holding gains/losses when closing and opening stocks are incorrectly valued by multiplying timber stocks times net price (Chapter 3). This is how the **Nepal** and **Philippines** (I) studies valued the stocks. Nor should one deduct silvicultural expenditures from net accumulation (Chapter 2).

A few studies applied other methods. Three (**Asia**, **Malaysia** (II), **Mexico**) applied El Serafy's method, the first two in its generalized form (i.e., with the marginal cost elasticity not equal to infinity) and the third in the original form (marginal cost elasticity equals infinity). All applied the version for nonrenewable resources, not the correct versions for timber presented in Chapter 3. If timber depletion is primarily a matter of the draw-down of old-growth timber stocks — either because all forestland is converted to other uses following logging, or because second-growth forests have a "normal" age-class structure (i.e., equal areas in each age class up to the rotation age) — then net accumulation of timber is analogous to net accumulation of a nonrenewable resource. Under these circumstances, application of El Serafy's method to the harvest of old-growth timber should yield accurate estimates of net accumulation, as long as the correct value of the marginal cost elasticity is used. The **Malaysia** (II) study used this rationale for applying El Serafy's method, but its assumption that Malaysia's second-growth forests are "normal" is heroic. The other two studies applied El Serafy's method to all timber, not just old-growth. For these reasons, *net accumulation estimates in studies applying El Serafy's method are of dubious accuracy*.

Two studies (**Ecuador**, **Thailand**) applied the replacement cost method, which they somewhat confusing referred to as the user-cost method. In effect, these studies calculated the present value of the hypothetical costs of establishing timber plantations to offset the volume (**Thailand**) or value (**Ecuador**) of harvestable timber in natural forests lost due to deforestation. There is no theoretical reason to expect this method to yield estimates of net accumulation bearing any relationship to true values, because the long-run costs of plantation timber could be either greater than or less than the long-run net benefits of timber production in natural forests. For this reason, *the replacement cost method is not a sound method for estimating the net accumulation of timber*. The **Ecuador** study attempted to deal with this problem by calculating replacement costs linked to value rather than volume of forgone timber, but it based its value estimates on the net depletion method, which as noted above yields biased estimates.

Two studies (**Costa Rica** (I), **Philippines** (I)) calculated net accumulation by applying the basic definition: net accumulation equals change in asset value. They calculated asset value as the present value of future flows of resource rents. *The **Costa Rica** (I) and **Philippines** (I) studies probably provide the most accurate estimates of net accumulation of timber.*

Four studies compared estimates from different methods. The **Philippines** (I) study compared the net price and present value methods. The former yielded estimates larger (in absolute value) than those of the latter. Assuming that the latter estimates are more accurate, the direction of the bias is what we would expect in a developing country (Chapter 3). The magnitude of the bias was enormous: estimates from the net price method exceeded those from the present value method by a factor of 30 times. The **Mexico** study compared the net price and El Serafy methods, finding that the former yielded estimates 15 times greater than the latter. Because both methods are problematic when applied to timber, interpreting this discrepancy is difficult. For similar reasons, it is difficult to interpret the comparison of the net price and replacement cost methods in the **Ecuador** and **Thailand** studies.

Asset value of timber

More than half the studies calculating the asset value of timber did so by multiplying the standing stock times the net price. As noted in Chapter 3, this does not yield accurate estimates. It understates the value of both mature forests and immature forests. Three studies attempted to avoid the bias for immature forests by multiplying net price times only the stock of mature timber, but, as immature forests do have a positive asset value, this compounds the downward bias.

Six studies (**Global**, **Australia** (I), **Austria**, **Canada** (II), **Costa Rica** (I), **Philippines** (I)) applied the theoretically correct present value method: they set asset value equal to the discounted sum of future rents. Two studies (**Global**, **Canada** (II)) assumed that forests were managed on an even-flow basis and that future annual flows of rents would therefore equal current flows. Hence, they simply divided current annual rent by the discount rate to estimate the asset value. (For unsustainably managed forests, the **Global** study capitalized the flow up to the projected year of complete depletion of timber stocks.) While this simplification is understandable for the **Global** study, whose objective was to calculate "ballpark" estimates for over one hundred countries, it is less understandable for the **Canada** (II) study, which apparently had access to detailed data on forests by age class. That study perhaps could have calculated more accurate estimates.

The remaining four studies took forest age into account in calculating asset values. The **Austria** study applied "age constants," which are implicit discount factors; the other three applied conventional discounting techniques. As in the case of net accumulation, *the **Costa Rica** (I) and **Philippines** (I) studies, along with the **Australia** (II) study, applied the most appropriate procedures for estimating timber asset values*. For countries that wish to incorporate forest resources in the asset accounts, *we advise calculating asset values by using the present value method instead of by multiplying standing timber volume times net price*.

Studies employing the present value method used discount rates ranging from 2 to 15 percent. The studies did not always make clear the rationale for the discount rates chosen. The benefit-cost analysis literature contains well-established procedures for selecting the discount rate (Boardman et al. 1996). As the choice of discount rate has a critical impact on estimates from the present value method, *studies should make clear the criteria used in selecting the discount rate and should calculate asset values using a set of discount rates believed to span the range of plausible rates for the country in question*.

At least three studies (**Indonesia**, **Philippines** (II), **U.S.**), and maybe more (details are not clear), calculated a residual "revaluation" term of the type described earlier, by subtracting opening asset value and net investment (value of change) from closing asset value. We have already given one reason why this procedure is flawed: multiplying standing timber volume times net price yields inaccurate estimates of the asset value of timber stocks, and therefore inaccurate residual estimates of holding gains/losses. A second reason has to do with the fact that gains/losses under this procedure come from changes in net price between the beginning and end of the accounting period. Such short-term fluctuations do not necessarily affect the value of timber when it is actually harvested several years (or decades) hence. Even a large increase in timber price during the current period has no impact on the asset value of immature forests unless it persists until the forests are harvested. The implication is that *in calculating timber asset values, analysts should* *use projections of net prices expected to apply when forests are actually harvested, not current net prices*. The simplest, but not necessarily most accurate, way to do this is to determine trend values by either taking a moving average or by applying regression techniques to several recent years of data. The **Canada** (II) and **U.S.** studies did the former, while the **Malaysia** (I) study did the latter.

Deforestation

We noted above that several studies included the volume of standing timber lost during deforestation in their estimates of net accumulation of timber. This procedure is consistent with our recommendation in Chapter 3, as long as the volume refers to merchantable timber (trees of commercial size and species in accessible areas) and is net of defect and normal rates of logging damage. The **Costa Rica** (I), **Ecuador**, **Malaysia** (I) and (II), and **Thailand** studies stated that they took into account some or all of these considerations. Several other studies instead assumed that *all* standing timber in deforested areas represented a commercial loss. Those studies overstated the loss in asset value.

A more fundamental issue related to deforestation is how to account for the change in land use from forest to other uses. As noted in Chapter 2, not only should the loss in value associated with the reduction in forest area be deducted in the current and asset accounts, but the gain in value associated with land in its new use should also be added. Only two studies (**Mexico**, **U.S.**) included both adjustments, although the **Nepal** study noted its necessity. This small number partly reflects the fact that many of the studies covered only forestry, but even some of the studies that were more comprehensive ignored the addition for converted land (e.g., **Costa Rica** (I)). If land markets work perfectly, then as noted earlier the value of converted land should always be greater than or equal to the value of forestland, but land markets are rarely perfectly efficient, especially in the face of nonmarket values and attenuated property rights. Hence, *it is important to investigate how the asset value of land in forest use, for the full range of forest-related benefits, compares to the asset value of land in alternative uses, and not simply assume that the latter is at least as large as the former.* The **Mexico** study concluded that the asset value of forestland for timber production exceeded the asset value for agriculture, and therefore deforestation reduced the country's wealth. The **U.S.** study, on the other hand, simply assumed that the two were equal.

A comprehensive investigation of the asset value of forestland will always be hindered to a greater or lesser degree by limited data on nonmarket benefits. We discuss nonmarket valuation issues more in the next section. Here, we note the unsurprising consequence, which is that most of the studies focused on a small set of benefits in valuing forestland. Three of the studies (**Costa Rica** (I), **Mexico**, **Thailand**) equated the loss in value associated with deforestation to just the value of forgone timber production. This is not a problem when the only benefit is timber, as the asset value of the forest then simply equals the present value of rents from future timber harvests. That is, *when forests provide only timber, asset values for timber and forestland coincide.* They cannot be accounted for separately (Chapter 3), unless one introduces some artificial distinction, such as that the latter equals "bare land" timber value (asset value of a forest of age 0) and the former equals the difference between actual asset value and bare land value.

At least one study (**U.S.**) double-counted by including both the asset value of timber and the asset value of forestland in the asset accounts, without deducting the former from the latter. That study further overestimated the asset value of forestland by setting it equal to the average value of agricultural land, the presumed alternative land use, instead of the marginal value. The margin of competition between forests and agriculture typically occurs on poorer soils and at higher elevations, not in the middle of agricultural land that is already developed and in prime locations.

Because forests offer benefits beyond timber, the total asset value of forestland usually exceeds the timber asset value. Four studies (**Australia** (I), **Costa Rica** (II), **Malaysia** (I), **Papua New Guinea**) equated the loss in value associated with deforestation to the forgone value of one or more nontimber benefits. They did so by multiplying per-hectare values drawn from the literature, which were assumed to apply to all forestland, times the area deforested. There is nothing wrong with this procedure, as long as the values do indeed apply to all forestland and are asset values (Chapter 3), not simply values of current production. All but the **Costa Rica** (II) study appear to have used asset values.

Nontimber values

Thirteen of the studies included values related to one or more nontimber aspects of forests. Using the terms in the framework in Chapter 2, we can summarize the coverage as follows:

Nonmarket forest products
Fuelwood: **Asia**, **Nepal**, **Sweden** (I) and (II), **Tanzania**, **Zimbabwe**
Fodder: **Finland** (II), **Nepal**, **Sweden** (I) and (II)
Game: **Malaysia** (I), **Finland** (II), **Sweden** (I) and (II)
Other (e.g., mushrooms, berries): **Finland** (II), **Sweden** (I) and (II)

Forest amenities
Biodiversity: **Australia** (I), **Global**, **Malaysia** (I), **Finland** (II), **Sweden** (I) and (II)
Social and spiritual values: **Papua New Guinea**
Recreation (inc. tourism): **Costa Rica** (II), **Finland** (II)

Environmental services
Watershed protection: **Costa Rica** (II)
On-site soil erosion: **Mexico**
Not specified: **Papua New Guinea**

Airborne pollutants
Acid deposition: **Finland** (II), **Sweden** (I) and (II)

Carbon sequestration
Canada (I), **Costa Rica** (II), **Finland** (II), **Malaysia** (I), **Sweden** (I) and (II)

Aggregate nontimber values
Global

One of the studies (**Global**) calculated asset values. For forests outside protected areas, it assumed that the annual value of nontimber benefits was constant across forest types, though different in developing and developed countries. It multiplied aggregate per-hectare estimates of the value of those benefits, drawn from the literature, times forest area. It divided the result by ten, on the assumption that one-tenth of total forest area generated appreciable nontimber benefits, and divided again by 4 percent to capitalize the values. For forests within protected areas (mainly biodiversity values), it applied the opportunity cost method: it assumed that the asset value of nontimber benefits was at least as large as the asset value of land in its alternative use, which it assumed to be pasture land. Obviously, the validity of this method depends on the rationality of governments in deciding which areas to protect, and on the opportunity cost indeed being the forgone value of pasture land rather than other alternative uses (e.g., timber production or crops). Even if these conditions are satisfied, one should bear in mind that the method gives lower-bound estimates.

The remaining studies valued flows rather than stocks. For nontimber products, they used two principal valuation methods, both of which were described in Chapter 3. If some portion of production was marketed, several of the studies valued the remaining portion by multiplying times market price. The **Asia** and **Zimbabwe** studies, and implicitly the **Sweden** (I) and (II) studies, used this method for fuelwood. The second method was based on the opportunity cost of labor used in the collection of nontimber products. The **Nepal** and **Tanzania** studies used this method for fuelwood. As noted in Chapter 3, this method understates the value of production, except when forest resources are in a state of complete open-access (in which case they generate no rent). Most of the studies used one or the other of these two methods for valuing nonmarket production of nontimber products other than fuelwood.

The studies used a broader range of methods for valuing forest amenities. As noted above, the **Global** study used the opportunity cost of land to value protected areas. The **Finland** (II), **Sweden** (I) and (II), and **Papua New Guinea** studies also used this method. The first three set the opportunity cost equal to forgone timber rents instead of forgone rents from grazing, while the fourth set the opportunity cost equal to the official compensation rates that tribes are legally entitled to claim when the government appropriates their land. As noted in the previous section, the **Australia** (I) study set the per-hectare value of habitat protection equal to an estimate drawn from the literature. It did not provide details on the derivation of this estimate. The **Costa Rica** (II) study set the per-hectare value equal to the estimated net expenditure by international ecotourists. The **Finland** (II) study used number of recreational visitors instead of forest area as the basis of its estimate, multiplying the former times a literature estimate of the value per visit based on contingent valuation studies. Lastly, the **Malaysia** (I) study related forest area to number of species, and developed a range of estimates for the value of an individual species, including government expenditure to protected a locally endangered species and government expenditure to reintroduce locally extinct species.

The **Papua New Guinea** study assumed that compensation rates included unspecified "ecological services." While the asset value of such services is indeed part of the loss in value associated with deforestation, the annual value of the services should *not* be added to GDP (Chapter 2). As the study only estimated net accumulation, it did not commit this mistake. Likewise, the **Costa Rica** (II) study was correct in including the value of watershed services in its net accumulation estimates for deforestation. Its estimate of this value is implausible, however, as it set the unit value of water equal to the rate paid by urban consumers, which includes the costs of water treatment and distribution as well as the services provided by forests in providing the raw water. It also multiplied the rate times runoff from all forests, not just municipal watersheds, and it did not capitalize the value.

The **Finland** (II) and **Sweden** (I) and (II) studies included values related to airborne pollutants other than CO_2. They correctly included losses in forest productivity due to acid deposition in their estimates of net accumulation. The **Finland** (II) study valued the loss by the productivity change method: forgone timber growth times average stumpage value. The **Sweden** (I) and (II) studies used instead the replacement cost method: they estimated the cost of limestone and magnesium needed to offset acid deposition. The **Mexico** study also used this method to value long-run losses in forest productivity due to on-site soil erosion. We discussed the shortcomings of the replacement cost method in the section on *Net accumulation of timber*, in reference to the **Ecuador** and **Thailand** studies.

The **Finland** (II) study was the only one to value the disposal services provided by forests for air pollutants other than CO_2. It did the valuation correctly, multiplying the amount of nitrogen oxides and sulfur dioxide deposited in forests times the estimated abatement costs for the polluting industries. However, it subtracted the resulting estimate from forestry value added instead of adding it (Chapter 2). Moreover, as it was a forestry-specific study, it did not make the required offsetting adjustment by subtracting the estimate from value added in the polluting industries.

The studies that covered carbon sequestration all used the same method. First, they multiplied the net depletion of the timber stock times a parameter to convert from cubic meters of wood to tons of carbon. They then multiplied the resulting quantity times either the local carbon tax (**Sweden** (I) and (II)) or proposed global carbon taxes (the other studies). This is the method discussed in Chapter 3, although to obtain accurate estimates one should also account for changes in carbon storage in the soil and other parts of the forest ecosystem besides just standing timber. Hoen (1993) provides a useful discussion of this issue, in reference to the **Sweden** (I) study.

This is not the place for an extended discussion of the pros and cons of the different valuation methods applied to these widely varying nontimber aspects of forests, as many books and articles already provide extended treatments of valuation principles and methods. We highlight just three points of particular relevance for economic accounting. *First, most of the estimates are very rough, and rougher than they need to be.* While drawing existing estimates from the literature is perfectly acceptable, and often the only option (especially in countries with limited financial and human resources to conduct valuation studies), studies should consider and evaluate a range of estimates, and select the ones that correspond most closely to the situation in the country where the study is being conducted. Studies that calculated original estimates instead of drawing from the literature apparently often did not apply valuation methods correctly (e.g., in setting unit water values equal to municipal water rates). These mistakes were avoidable. *Second, some studies apply per-hectare value estimates to the entire forest, when only part of the forest provides the benefits being valued*. This leads to an upward bias in estimates of nonmarket values. The bias could be enormous if the one-tenth assumption in the **Global** study gives the correct order of magnitude. *Third, some studies value benefits that might already be included in the accounts, thus running the risk of double-counting*. For example, it is likely that final consumption expenditures in ordinary GDP already include some of the recreational and tourism expenditures estimated by the **Costa Rica** (II) and **Finland** (II) studies. Moreover, as emphasized in Chapter 2, overall GDP does not need to be adjusted for the current value of environmental services that forests provide to other industries.

Magnitude of the adjustments

The priority placed on adjusting national accounts for forest resources should depend on how much the adjustments improve macroeconomic aggregates like GDP, NDP, and net investment as indicators of welfare and sustainability. If other prospective adjustments yield greater improvements, then analysts should give them precedence over forest-related adjustments. The studies provide some information on this issue, particularly those studies that cover other resources in addition to forests. We emphasize, however, that this information should be regarded as no more than suggestive, and perhaps even misleading. The sample of studies is small, the countries they cover were not selected randomly, and the accounting approaches and valuation techniques used in them vary considerably, with some suffering from severe biases.

Consider first the magnitude of adjustments to the current accounts. Forest-related net accumulation was large relative to net value added in forestry in some studies, but it was generally smaller than net accumulation of subsoil assets. It was also small relative to NDP and net investment. It tended to be larger in developing countries than in developed countries. These same tendencies were generally true of estimates of final consumption of nonmarket forest products.

In many developed countries, net accumulation of timber was positive: the value of timber resources rose, due to rising timber stocks and capital gains. Even in developing countries, overall net investment tended to be positive after adjusting for changes in the value of forest capital, indicating that investment in human-made capital more than offset disinvestment of forest capital (although whether it outweighed the total depreciation of all forms of natural capital is not always clear, certainly not in the forest-specific studies). Moreover, the actual relative importance of net accumulation and nonmarket production was even less than it seemed in studies that applied the net price method, that included net accumulation of forestland but not net accumulation of converted land, and that assumed the entire forest produced appreciable amounts of nontimber products.

We emphasize that adjustments for net accumulation and nonmarket forest products are theoretically justified and should in principle be made, even if they have a minimal impact on the accounts. Furthermore, small values at the national level do not necessarily imply small values within a country. The **Malaysia** (II) study found that the loss in value of timber assets was large relative to NDP and net investment in Sabah and Sarawak, though not in Peninsular Malaysia nor at the national level. Given that the abundance of natural resources usually varies considerably within a country, income accounts adjusted for forest resources may be more valuable for provincial policymakers than for national policymakers.

Findings are similar for the asset accounts. Forests account for a much smaller (in many cases, a virtually insignificant) share of total capital than does human-made capital, especially in (not surprisingly) developed countries. They usually account for a smaller share of countries' natural wealth than do subsoil assets and often cropland. Within the category of forest capital, the asset value of timber resources tends to be larger than the asset value of nontimber resources.

Conclusions for asset accounts are even more tenuous than for product accounts, as considerably fewer studies analyzed the former than the latter. Nevertheless, the findings just noted point in the same direction as those for product accounts: that *economic accounting of forest resources is likely to be more important in developing than developed countries, at the subnational than the national level, in mineral-poor than mineral-rich countries, and for timber than for nontimber values*.

5. SUMMARY AND IMPLICATIONS FOR FAO HANDBOOK

Summary

This report has argued that national income accounts, which are aimed at measuring production, suffer several shortcomings as a system for recording the aggregate welfare impacts of human use of forest resources. In Chapter 2 we summarized the principal adjustments that need to be made to the current accounts to convert them to a system that more accurately depicts the economic contributions of forest resources. Those adjustments were based on the list of economic aspects of forests listed at the start of that chapter. Other aspects could certainly be added.

Adjustments to the asset accounts parallel the adjustments to the current accounts. Given the list of economic aspects at the start of Chapter 2, there should be four balance sheets, for timber, carbon, forestland, and converted land. (The number would differ if forest-related assets were classified differently.) Opening and closing asset values equal the present value of future returns, broadly defined, generated by the assets. Asset values for forestland must exclude timber and carbon if, as proposed, timber and carbon are treated as separate assets. Net accumulation should be the same in the current accounts (as an adjustment to NDP) and the accumulation accounts. It equals the total change in value of the asset in question, not just the value of the change in the volume of the asset. In principle, it can be decomposed into increases in the volume, decreases in the volume, changes in quality, and holding gains/losses, but this is likely to be difficult in practice, especially for assets other than timber.

Empirical studies indicate that many of these adjustments are feasible, although they will be highly inaccurate if valuation techniques are not applied properly. Even when techniques are applied properly, the resulting estimates will often not be terribly precise. For this reason, we suggest that the adjustments proposed in this report be implemented as a satellite accounting system. Their implementation will most likely require a joint effort by national accountants and economists in planning or forestry agencies.

Consistency with SNA and SEEA

Implementation as a satellite system is in fact necessary in view of SNA accounting rules. Several of the proposed adjustments violate those rules. An evaluation of the proposed adjustments relative to the SNA yields the following:

> *Final consumption of nonmarket forests products* — The SNA permits imputation of the value of such consumption in the current accounts. It appropriately requires, however, that imputed income associated with production of such products also be included, to ensure that the accounts are in balance. In practice, these imputations are seldom made. Moreover, the SNA only permits such imputations for forests within the production boundary (i.e., cultivated forests), not for all forests as proposed in our framework.
>
> *Final consumption of forest amenities* — This falls outside the SNA production boundary, at least when it pertains to unpriced public goods.

Reallocation of value added — The SNA does not explicitly permit this. Discussions with some national accountants indicated that such adjustments might be interpreted as being consistent with the SNA definition of production, even though the environmental services involved are not bought and sold in markets. Such adjustments would surely be controversial, at the very least, to most national accountants.

Net accumulation — The SNA permits including in NDP only net investment (the value of the change, not the change in value), and then only for fixed (human-made) capital. It recommends including the imputed value of growth of timber in cultivated forests in GDP, and thus in NDP. We recommend including this in NDP, but not GDP, and including it for all timber production forests, natural as well as cultivated. We also recommend subtracting from NDP the value of the reduction in timber stocks when timber is harvested; due to its focus on fixed capital, the SNA does not permit this, though it does include the reduction in the asset accounts (for cultivated forests only), as a change in inventories. Moreover, we recommend also including other factors affecting asset values (e.g., holding gains/losses), so that NDP includes the full value of net accumulation, not just net investment narrowly defined.

Comparison to the SEEA yields similar results. The adjustments we recommend differ from those in the SEEA because ours do not stay strictly within the SNA production boundary, and because we use benefits-based, not costs-based, valuation methods. For example, although some versions of the SEEA propose a "depletion" adjustment for forest resources in NDP, this adjustment applies only to cultivated forests. Moreover, the SEEA defines the adjustment as the discrepancy in production value between actual harvests and sustainable harvests, not as net accumulation.

These differences indicate the fundamental difference in purpose between our proposed accounting system (measuring economic contributions in a welfare sense) and the SNA/SEEA (measuring production). The systems are different means to different ends.

Suggestions for the FAO handbook

In light of these differences, the first chapter of the FAO handbook should communicate clearly the rationale for the proposed system. The main point is that the proposed system is not a competitor to SNA/SEEA, but rather a system with a fundamentally different purpose.

The second chapter should briefly review the structure of the SNA, as the proposed system takes elements of the SNA as its starting point. The first chapter of Inter-Secretariat Working Group on National Accounts (1993) provides an overview of the SNA and should be the main source of information for this section of the report.

The third chapter should describe the proposed adjustments to the asset accounts. It should emphasize the present value method for calculating asset values, but also consider whether, in some countries at least, market prices for forestland can be used as proxies for the asset value of forests. It should illustrate applications of the present value method for nontimber as well as timber values, and include examples showing how to isolate holding gains/losses from net accumulation. It must pay attention to the issues of double-counting when forestland and timber stocks are treated as separate assets. Variants on the four-asset framework presented in this report should be considered.

The fourth chapter should describe the proposed adjustments to current accounts (GDP, industry value added, NDP). The discussion of net accumulation in the third chapter will have covered the principal adjustments required for NDP. Implementation of the other adjustments is basically a matter of estimating nonmarket values at the national level. The chapter should provide several examples for each category of nonmarket value.

The final chapter should discuss the use of information generated by the accounting system. It should include discussion on the value of the information for measuring sustainability, for both forestry and the national economy.

APPENDIX 1 - BASIC MODEL WITH TIMBER, NONTIMBER VALUES AND DEFORESTATION

In this and several subsequent appendices, we construct and analyze models using optimal control techniques, which permit a rigorous derivation of national accounting relationships. The appendices contain a considerable amount of technical detail. They are intended for the specialist, not the general reader. The main text presents the principal results in a non-technical manner.

Structure of the model

The basic model is similar to one presented in Mäler (1991), although with more of a forestry focus. It contains five production activities:

F	=	forestry
W	=	wood production (logging)
N	=	household collection of nontimber products
D	=	deforestation (land conversion)
Q	=	rest of the economy

The letters will be used as subscripts on variables and superscripts on functions. Among the variables are five factors of production:

L	=	labor
K	=	capital
A	=	agricultural land
F	=	forest land
P	=	pollution (other than CO_2)

Pollution is a production factor in the sense that it represents use by industry of the disposal services of the environment. These factors are used to produce four goods:

Q	=	a homogeneous good that can be consumed, invested, or used as an intermediate input
Z_W	=	wood (logs)
Z_N	=	nontimber products
Z_D	=	newly cleared land.

These are produced according to the following production functions:

$$Q = f^{Q}(L_Q, K_Q, Z_W, A, F, P, C)$$
$$Z_W = f^{W}(L_W, Q_W, S)$$
$$Z_N = f^{N}(L_N, F)$$
$$Z_D = f^{D}(L_D)$$

$f^{Q}(\cdot)$, $f^{W}(\cdot)$, $f^{N}(\cdot)$, $f^{D}(\cdot)$ are functions. L_Q is labor used in the production of Q, etc. C is the concentration of atmospheric CO_2 (not the emissions of CO_2, in contrast to P, the emissions of other pollutants). S is the standing volume of timber. The signs on all variables except C are positive. The negative sign on C indicates that higher CO_2 concentrations reduce economic output, for given levels of other inputs. The inclusion of Z_W and A in $f^Q(\cdot)$ represents the use of logs and agricultural land, respectively, as production inputs. The inclusion of F represents environmental services provided by forest to the rest of the economy (e.g. watershed protection). The inclusion of S in $f^W(\cdot)$ indicates that logging costs are lower when the timber stock is higher. Similarly, the inclusion of F in $f^N(\cdot)$ indicates that collection costs for nontimber products are lower when forest area is greater (e.g. people do not need to walk as far to reach the forest).

The model contains six state equations:

$$dA/dt = + Z_D$$
$$dF/dt = - Z_D$$
$$dS/dt = g(L_F, K_F, Q_F, S, F, P) - Z_W$$
$$dC/dt = dC_{ROW}/dt - \alpha\, dS/dt$$
$$dK_Q/dt = I_Q - \delta K_Q$$
$$dK_F/dt = I_F - \delta K_F$$

The first two equations indicate that agricultural area increases, and forest area decreases, according to the amount of newly cleared land. The third indicates that the change in the timber stock equals the difference between growth (the function $g(\cdot)$) and harvest (Z_W). Growth responds positively to forest management expenditures (L_F, K_F, Q_F), negatively to pollution (P), and in a presumably nonlinear and not necessarily monotonic way to forest area and the stock of timber (F, S). The fourth equation indicates that the change in the stock of atmospheric CO_2 equals the difference between net emissions occurring in the rest of the world and net sequestration in the country's forests, which is proportional to the change in timber stock. For simplicity, we assume that the country does not emit any CO_2 itself, except from forests if the timber stock declines. The last two equations indicate that human-made capital employed in production of the homogeneous good and forest management changes according to the balance between investment and depreciation (δ is the depreciation rate).

Production and consumption are subject to the following constraints:

$$Q = Q_C + Q_W + Q_F + I_Q + I_F$$
$$L = L_Q + L_W + L_N + L_D + L_F$$
$$A = F_0 - F$$

The first constraint says that output of the homogeneous good is allocated among household consumption (Q_C), intermediate inputs in logging (Q_W) and forestry (Q_F), and investment (I_Q, I_F). The second says that labor is allocated among the five production sectors. Finally, the third says that the area of agricultural land is the difference between total land area (assumed to be entirely in forest initially, F_0) and area of forest land (F).

The objective in this model is to maximize welfare, which is a function of three variables:

$$u \quad = \quad u\,(Q_C\,,\, Z_N\,,\, F).$$

Households consume two tangible goods, the homogeneous good and nontimber products, and one less tangible good, amenities associated with forests. The signs on all three variables are positive. As the purpose of the model is to examine national accounting relationships related to forest resources, we ignore disamenities associated with pollution. The objective is to be maximized with respect to the allocation of the homogenous good (Q_C , Q_W , Q_F , I_Q , I_F), labor (L_Q, L_W , L_N , L_D , L_F), the intermediate goods (Z_W , Z_N , Z_D), and pollution (P). That is, there are fourteen control variables. The current-value Hamiltonian for this problem is:

$$\begin{aligned} H \quad = \quad & u\,(Q_C\,,\, Z_N\,,\, F) \\ & + p_Q\,[f^Q(L_Q\,,\, K_Q\,,\, Z_W\,,\, F_0 - F\,,\, F\,,\, P\,,\, C) - Q_C - Q_W - Q_F - I_Q - I_F] \\ & + w\,[\,L - L_Q - L_W - L_N - L_D - L_F] \\ & + r_Q\,[I_Q - \delta K_Q] + r_F\,[I_F - \delta K_F] \\ & + p_W\,[\,f^W\,(L_W\,,\, Q_W\,,\, S) - Z_W] + p_N\,[\,f^N\,(L_N\,,\, F) - Z_N] + p_D\,[\,f^D\,(L_D) - Z_D] \\ & + \lambda_A\,[Z_D] + \lambda_F[-Z_D] \\ & + \lambda_S\,[g(L_F\,,\, K_F\,,\, Q_F\,,\, S\,,\, F\,,\, P) - Z_W] \\ & + \lambda_C\,[dC_{ROW}/dt - \alpha\{g(L_F\,,\, K_F\,,\, Q_F,\, S\,,\, F\,,\, P) - Z_W\}] \end{aligned}$$

p_Q, p_W, p_N, p_D, and w are prices, and r_Q, r_F, λ_A, λ_F, λ_S, λ_C are adjoint variables (shadow prices).

The model contains no separate variable for biodiversity, which is assumed to be implicitly captured by forest area (in accordance with island biogeography theory). Incorporating biodiversity more explicitly would be straightforward, as long as one is content with a fairly crude representation. One could model the stock of biodiversity, B, as a nonrenewable resource. Decreases in the area of forest (F) and the stock of timber relative to forest area (S/F, a proxy for forest age) reduce B. Since biodiversity is nonrenewable, however, increases in the two variables do not increase B. That is, there is an asymmetry in the model. Biodiversity could then be added as a fourth variable in the welfare function (to represent, say, existence values) and as an eighth variable in the production function for Q (to represent the contribution of genetic resources).

Derivation of adjusted NDP

Following Mäler (1991), we set NDP equal to the linearized Hamiltonian. In combination with results of the fourteen first-order conditions, this yields:

Adjusted NDP	=	$p_Q\,(Q_C + I_Q + I_F)$	} Conventional GDP
		$+ u_N Z_n + u_F F$	} Nonmarket values to be added to GDP
		$- p_Q \delta K_Q - p_Q \delta K_F$	} Depreciation of human-made capital

$$+ \lambda_A Z_D - \lambda_F Z_D$$
$$+ \lambda_S [g(\cdot) - Z_W]$$
$$+ \lambda_C [dC_{ROW}/dt - \alpha\{ g(\cdot) - Z_W\}]$$

Conventional GDP is the sum of expenditures on consumption and investment in human-made capital. GDP, and therefore NDP, ought to include as well the nonmarket value of household consumption of nontimber products and forest amenities (u_N , u_F are marginal utilities). Conventional NDP is the difference between GDP and depreciation of human-made capital. NDP ought to include as well the net accumulation of natural resources, given by the last three lines.

Adding nonmarket values to GDP and net accumulation of natural resources to NDP requires information beyond that provided by market prices. From the first-order conditions and the adjoint equations, we can show:

$$u_N Z_N = wL_N + u_N f_F^N F = wL_N \cdot \frac{Z_N}{Z_N - f_F^N F}$$

$$\lambda_A = \int_t^\infty e^{-r(s-t)} p_Q f_A^Q ds$$

$$\lambda_F = \lambda_A - p_D$$

$$\lambda_S = p_Q f_W^Q - p_W + \alpha\lambda_C$$

$$\lambda_C = \int_t^\infty e^{-r(s-t)} p_Q f_C^Q ds$$

The value of household consumption of nontimber products, $u_N Z_N$, is related to the value of labor used in collection: the wage rate, w, times the amount of labor, L_N. The two are exactly equal only if forests are used for collection up to the point where the marginal product of the forest for collection (i.e., f_F^N) equals zero. This occurs when households have free access to the forest. When access is restricted, due to formal or informal property rights or fees levied on the products collected, the value is larger than the opportunity cost of labor.

The marginal value of land converted to agriculture, λ_A, equals the discounted sum of future returns to agriculture, where returns equal the marginal product of agricultural land, f_A^Q , times the price of output. The marginal value of forestland, λ_F, equals the difference between price of agricultural land (λ_A) and cost of land clearing (p_D). The marginal value of the timber stock, λ_S, equals marginal net price (stumpage value) adjusted for marginal carbon sequestration value: the marginal value of logs as a production input ($p_Q f_W^Q$) minus the sum of logging cost (p_W) and the damage caused by CO_2 released due to logging ($\alpha\lambda_C$; λ_C is negative). Damage caused by CO_2, λ_c, equals the discounted sum of the value of reduced economic output; f_C^Q is the marginal impact of CO_2 on output and p_Q is the price of output.

Environmental services and related matters

These expressions indicate that we can use information on marketed products and inputs to value nonmarket elements of NDP. The same is not true for forest amenities, however, at least in the model as we have constructed it. To value $u_F F$, one needs to use a direct valuation technique like contingent valuation.

The apparent exclusion of environmental services of forests from NDP is perhaps surprising. But in fact, NDP, and GDP as well, already reflect these services. First, NDP reflects these services in the expression for the net accumulation of forestland. The adjoint equation for λ_F implies:

$$\lambda_F = \int_t^{\infty} e^{-r(s-t)} \left\{ u_F + p_Q\left(f_F^Q - f_A^Q\right) + p_N f_F^N + (\lambda_S - \alpha\lambda_C) g_F \right\} ds$$

The marginal value of forestland equals the discounted sum of benefits provided by forestland. These benefits include: forest amenities (u_F); environmental services ($p_Q f_F^Q$), net of the opportunity cost of retaining land as forest instead of converting it to agriculture ($p_Q f_A^Q$); nontimber products ($p_N f_F^N$); and growth of timber ($\lambda_S\ g_F$; g_F is wood increment) plus the value of sequestered carbon ($\alpha\lambda_C\ S_F$). Note that g_F implicitly reflects the effects of pollution on timber growth; there is no need to make a separate accounting.

If markets work perfectly, then λ_F defined by this expression and λ_F defined as the difference between price of agricultural land and cost of land conversion will be exactly equal. In the absence of perfect markets, however, we expect the latter expression (i.e. λ_A - p_D) to understate the value of forestland. For the national accounts, the former expression gives the more accurate indication of the value of changes in forestland, but it is of course more difficult to apply.

Second, conventional GDP already reflects environmental services of forests, and therefore NDP does too. From above, the expression for conventional GDP is:

$$\text{Conventional GDP} = p_Q\,(Q_C + I_Q + I_F)$$

If we substitute $f^Q(\cdot)$ - Q_W - Q_F - I_Q - I_F for Q_C, and linearize $f^Q(\cdot)$, we obtain

$$\begin{aligned} \text{Conventional GDP} &= wL_Q + (p_Q f_K^Q K_Q + p_Q f_P^Q P) && \}\text{VA in manufacturing} \\ &\quad + p_Q f_A^Q A + p_Q f_F^Q F && \}\text{VA in agriculture} \\ &\quad + p_W Z_W - p_Q Q_W && \}\text{VA in logging} \\ &\quad + \lambda_S Z_W - p_Q Q_F && \}\text{VA in forestry} \end{aligned}$$

VA denotes value added. This is the income approach to GDP. For heuristic reasons, we have separated production of the homogeneous good into manufacturing and agricultural components.

We assume here that it is the manufacturing component that generates pollution, and the agricultural component that benefits from the environmental services provided by forests.

Value added in manufacturing equals the payments to labor (wL_Q) plus profits (the term in parentheses). Profits include not just the marginal value product of capital ($p_Q f_K^Q K_Q$), but also the free pollution disposal services that the environment provides ($p_Q f_P^Q P$). Value added in agriculture equals just profits, as we did not distinguish in the model between manufacturing and agricultural labor. As in the case of manufacturing, profits include not just the marginal value product of the fixed factor, in this case agricultural land ($p_Q f_A^Q A$), but also a free environmental service, in this case environmental services provided by forests ($p_Q f_F^Q F$). A portion of agricultural profits is therefore attributable to the forest. Hence, conventional GDP already reflects forest-related environmental services that affect production, although it does not identify them as such.

The last two lines show that value added in logging and forestry is given by the difference between value of output (of logging services in the case of logging, of stumpage in the case of forestry) and use of intermediate inputs. The expression for forestry value added indicates that one should deduct only the value of intermediate inputs, not inputs of labor (L_F) or investment in forestry capital (I_F).

APPENDIX 2 - NET ACCUMULATION OF TIMBER

Introduction

This appendix examines the analytical foundations of methods for estimating the net accumulation of timber. It begins by reviewing estimation methods for nonrenewable resources. It then reviews the standard "net depletion" method for timber resources, which generalizes methods for nonrenewable resources without taking into account the time lags that occur in the real world between timber harvests. This omission tends to cause the net depletion method to overstate both the decrease in capitalized forest value that occurs when mature forests are logged and the increase that occurs as immature forests regenerate. The appendix concludes by presenting alternative methods, based on the familiar Faustmann model of optimal forest management, that avoid these biases.

In certain respects, the analysis in this appendix parallels one by Newson and Gie (1996). We push the analysis further, however, and draw a closer comparison to estimation methods like the net price method and El Serafy's method.

Net accumulation of a nonrenewable resource

The asset value of a natural resource equals the discounted sum of the net returns (resource rents) it generates over time. Net accumulation refers to the change in asset value from one period to the next. It could well be positive, especially in the case of rapidly growing renewable resources. Positive net accumulation can occur even in the case of nonrenewable resources, if for example prices of the extracted resource rise significantly and generate holding gains.

For a nonrenewable resource, asset value at time t is therefore

$$V(t) = \sum\{(1+i)^{t-s} [pq(s) - C(q(s))]\} , \quad (1)$$

where the sum is evaluated over the interval $s = t, ..., T$. i is the discrete discount rate, p is the price of one unit of the extracted resource (assumed to be constant over time), $q(s)$ is the quantity extracted in period s, $C(q(s))$ is the total extraction cost, and T is the terminal time (the period when the resource is exhausted). We can also write (1) as

$$V(t) = pq(t) - C(q(t)) + V(t+1)/(1+i) . \quad (2)$$

We define net accumulation as

$$D(t) = V(t+1) - V(t) . \quad (3)$$

Substituting (2) for V_t in this expression, we obtain

$$D(t) = iV(t+1)/(1+i) - [pq(t) - C(q(t))] \; . \qquad (4)$$

Note that the absolute value of net accumulation is less than current resource rent.

Hartwick (1997) refers to the difference in discounted sums given by (3) as the *indirect method* for estimating net accumulation. Implementing this method requires projections of the future flow of rents, even if one applies (4) instead of (3). In earlier work, Hartwick (1977, 1990) derived a simpler, *direct method*. Deriving this method is easier if we switch from discrete to continuous time. Then, the asset value of the resource is

$$V(t) = \int e^{-r(s-t)} [pq(s) - C(q(s))] \, ds, \qquad (5)$$

where the integral is evaluated from t to T, and r is the continuous discount rate. Net accumulation is given by

$$D(t) = dV(t)/dt \; . \qquad (6)$$

r is the continuous discount rate. Applying (6) to (5), we obtain

$$D(t) = rV(t) - [pq(t) - C(q(t))] \; . \qquad (7)$$

This is the continuous-time analogue to (4). Under an optimal extraction program (Hotelling's *r*-percent rule holds; see Hartwick and Hagemann 1993), dynamic programming implies that this simplifies to

$$D(t) = -[p - C'(q(t)] \, q(t) \; . \qquad (8)$$

Net accumulation equals the negative of the product of quantity extracted times marginal — not average — rent. Hartwick refers to this product as Hotelling rent. Under the assumptions we have made, the product is unambiguously negative: asset value declines. The decrease in asset value due to the realization of current resource rent outweighs the increase due to the shifting of the stream of future rents toward the present. If the assumptions underlying this result hold — in particular, if price, the marginal cost schedule, and the discount rate are constant, and the resource is exploited optimally — then one can estimate net accumulation of a nonrenewable resource with only current data on price, marginal extraction cost, and quantity extracted. One does not need projections of future rents.

Optimal control techniques yield the same result. The manager of the nonrenewable resource seeks to identify the extraction program that maximizes (5), subject to the state equation

$$dS(t)/dt = -q(t) \tag{9}$$

and the stock constraint

$$S(t) = \int q(s)\, ds \,. \tag{10}$$

The integral is again evaluated from *t* to *T*. The current-value Hamiltonian for this problem is

$$H(t) = pq(t) - C(q(t)) + \lambda(t)\, dS(t)/dt \,. \tag{11}$$

$\lambda(t)$, the adjoint (co-state) variable or user cost, gives the capital value of a unit change in the resource. Hence, the second term in (11) equals net accumulation. The first-order condition, $\partial H(t)/\partial q(t) = 0$, yields

$$\lambda(t) = p - C'(q(t)) \,. \tag{12}$$

Multiplying this times $-q(t)$ (= $dS(t)/dt$) yields the same result as in (8).

In practice, obtaining data on marginal extraction costs is usually difficult. Direct estimation methods are still available in the absence of such data, however, if the marginal cost curve is elastic in quantity extracted. If one has data on average extraction cost (= $C(q(t))/q(t)$), then (8) can be written as

$$D(t) = [p - (1+\beta)C(q(t))/q(t)]\, q(t) \,, \tag{13}$$

where β is the elasticity of the marginal cost curve with respect to quantity extracted. Alternatively, if one has data on resource rent, Vincent (1997) has demonstrated that (8) equals

$$D(t) = [pq(t) - C(q(t))]\, (1+\beta)/(1+\beta e^{r(T-t)}) \,. \tag{14}$$

For the special (but unlikely) case when $\beta = \infty$, this simplifies to

$$D(t) = [pq(t) - C(q(t))] e^{-r(T-t)} \,. \tag{15}$$

El Serafy (1989; see also Hartwick and Hagemann 1993) proposed using the discrete-time counterpart of this formula to estimate net accumulation.

The net depletion method for timber

The obvious way to generalize the nonrenewable resource model in the preceding section to the case of renewable resources is to modify the state equation, (9), to include growth of the resource stock:

$$dS(t)/dt = g(S(t)) - q(t). \quad (16)$$

Now, the Hamiltonian in (11) indicates that net accumulation is given by

$$D(t) = [p - C'(q(t))]\ [\ g(S(t)) - q(t)]\ . \quad (17)$$

This says that net accumulation is the product of marginal rent times the negative of *net depletion* of the resource, where the latter is defined as the difference between current harvest and current growth. This is the method presented in Mäler (1991) and applied, with some modification, by Vincent (1997). Others, notably Repetto et al. (1989), have applied a method that differs only in terms of multiplying the negative of net depletion times average, not marginal, rent:

$$D(t) = [p - C(q(t))/q(t)]\ [q(t) - g(S(t))]\ . \quad (18)$$

In both cases, current harvest and current growth are multiplied by the same net price, either marginal rent (17) or average rent (18). If the cost function is linear in the quantity extracted, that is if $C(q(t)) = cq(t)$, then the two methods are identical.

The El Serafy variation for timber

The net depletion approach implicitly assumes that resource growth is immediately available for harvest. This is not the case with forest resources. Timber rotations typically span several decades. For an individual hectare of forest, the discrete-time asset value corresponding to (1) is

$$V_H(t) = (1+i)^{t-T}\ [pq(T) - C(q(T))]\ /\ [1 - (1+i)^{-T}]\ , \quad (19)$$

where t is the current age of the forest (not calendar year) and T is the harvest age that maximizes $V(0)$ (asset value for t = 0). That is, T is the optimal rotation age: the forest is harvested every T years, with no intervening production. $q(s)$ now represents both timber harvest and standing timber stock: all trees on the hectare are the same age, and all standing timber is harvested at maturity. This expression assumes that land remains permanently in forest use. Hartwick (1993) examined forest values and optimal rotation decisions under different land-use assumptions.

We can derive a correct method for estimating net accumulation in the model given by (19) by applying (3). To begin, consider the case when $t = T$: the forest is economically mature. An instant before harvesting, asset value equals

$$V_H(T) = [pq(T) - C(q(T))] / [1 - (1+i)^{-T}] \; .$$
(20)

One period later ($t = 1$), it equals:

$$V_H(1) = (1+i)^{1-T}[pq(T) - C(q(T))] / [1 - (1+i)^{-T}] \; .$$
(21)

Net accumulation for one hectare of mature forest is thus

$$D_H(T) = V(1) - V(T) \, ,$$

or, after some manipulation,

$$D_H(T) = iV(0) - [pq(T) - C(q(T))] \; .$$
(22)

This is the analogue to (4). Net accumulation reflects both the exploitation of rents from the current harvest, which decreases asset value, and the shifting of rents from future harvests toward the present, which increases asset value. Once again, current rent overstates the absolute value of net accumulation. Written out in full, (22) is

$$D_H(T) = i\,(1+i)^{-T}[pq(T) - C(q(T))] / [1 - (1+i)^{-T}] - [pq(T) - C(q(T))] \, ,$$

which simplifies to

$$D_H(T) = -[pq(T) - C(q(T))] \; [1 - (1+i)^{1-T}] / [1 - (1+i)^{-T}] \; .$$
(23a)

This is the forestry analogue to El Serafy's method for nonrenewable resources (14). Hence, we refer to it as the *El Serafy variation*. It indicates that net accumulation can be calculated from current rent if one also knows the discount rate and the optimal rotation age, which are needed to calculate the last two terms in brackets.

Now, consider the case when $t < T$. Through steps similar to those in the preceding paragraph, one obtains

$$D_H(t) = iV(t) \, ,$$

or

$$D_H(t) = [pq(T) - C(q(T))] \; i\,(1+i)^{t-T} / [1 - (1+i)^{-T}] \; .$$
(23b)

Like (23a), this includes per-hectare rent from harvesting the mature forest, but the discounting terms differ, and one of them includes current age (*t*) as well. Note that (23b) does *not* include current growth, even though it concerns net accumulation of an immature forest.

These results suggest a way to estimate the net accumulation of timber resources based not on changes in timber volumes, as in (17)-(18), but rather on changes in the *age class structure* of forests. For example, if A_T hectares of mature forests are harvested in a given period and A_t hectares of immature forests of age t are left to grow, then aggregate net accumulation of the forest estate is given by the sum

$$A_T D_H(T) + \sum A_t D_H(t) \, , \quad (24)$$

where the sum in the second term is evaluated over the interval $t = 1, \ldots, T\text{-}1$. This can be readily calculated using (23a) and (23b) if one knows, in addition to areas by age class, the per-hectare rents from harvests of mature forests, the optimal rotation, and the discount rate.

Continuous-time versions of (23a) and (23b) can be obtained by substituting e^{rx} for $(1+i)^x$. We do not show them here, as they are unlikely to be useful in practical applications.

The net price variation

The method presented in the preceding section would seem to have little in common with the net depletion method. Substitution of the Faustmann condition for optimal forest management into (23a) and (23b) converts the expressions into versions that can be more readily compared to (17) and (18).

The discrete-time Faustmann condition states that the forest should be harvested when

$$[p - C'(q(T))]\, q'(T) \,/\, [pq(T) - C(q(T))] = i \,/\, [1 - (1+i)^{-T}] \, . \quad (25)$$

That is, the forest should be harvested when the rate of growth in forest value equals the opportunity cost of funds, where the latter is adjusted for the effect of the current harvest decision on the timing of future harvests. Rearranging, we obtain

$$[pq(T) - C(q(T))] \,/\, [1 - (1+i)^{-T}] = [p - C'(q(T))]\, q'(T) \,/\, i \, ,$$

which can be substituted into (23a) and (23b) to yield

$$D_H(T) = -[p - C'(q(T))]\, q'(T)\, [1 - (1+i)^{1-T}] \,/\, i \quad (26a)$$

$$D_H(t) = [p - C'(q(T))]\, q'(T)\, (1+i)^{t-T} \, . \quad (26b)$$

These are the analogues to the direct method for nonrenewable resources given by (8), i.e. to the net price method. We therefore refer to them as the *net price variation*.

Note that both (26a) and (26b) include marginal, not average, rent. Hence, the net depletion method as formulated in (17) would seem to be more likely than the version given by (18) to yield equivalent expressions when the cost function in nonlinear. Upon disaggregation into harvest (mature forest) and growth (immature forest) components, the formulation in (17) yields

$$D_H(T) = -[p - C'(q(T))]\, q(T)$$
(27a)

$$D_H(t) = [p - C'(q(T))]\, q'(t)\ .$$
(27b)

Two differences are immediately obvious: first, (27a) includes the harvest volume at the optimal rotation age, while (26a) includes growth at the optimal rotation age; and second, (27b) includes current growth, while (27b) includes growth at the optimal rotation age. The comparison is complicated, however, by the fact that both (26a) and (26b) also include discounting terms. Let us consider the two pairs, (26a) and (27a) for mature forests and (26b) and (27b) for immature forests, more carefully in turn.

From (22), we already know that total rent overstates loss in value of mature forests due to harvesting. A comparison of (26a) and (27a) suggests that Hotelling rent (i.e., (27a)) does as well. The ratio of (27a) to (26a) is

$$\{q(T) / q'(T)\}\ \{i / [1 - (1+i)^{1-T}]\}\ .$$

Solving (25) for $q(T)$ and substituting the result into this expression, we obtain

$$\{[p - C'(q(T))] / [p - C(q(T))/q(T)]\}\ \{[1 - (1+i)^{-T}] / [1 - (1+i)^{1-T}]\}\ .$$
(28)

For the linear cost function $C(q(t)) = cq(t)$, this simplifies to just the second term in curly brackets,

$$[1 - (1+i)^{-T}] / [1 - (1+i)^{1-T}]\ ,$$

which is greater than one. Hence, the Hotelling rent associated with timber harvests overstates the absolute value of net accumulation in mature forests when the cost function is linear. Given that the discrepancy is due to the exclusion of just one $(1+i)$ term in (27a), however, the magnitude of the discrepancy will not be very large unless the discount rate is large.

When the cost function is nonlinear, the bias can in principle be in either direction, as the first term in curly brackets in (28) is less than one (marginal rent is less than average rent). All we can say is that the bias will tend to be upward — (27a) will tend to be greater than (26a) — when the discrepancy between marginal and average costs (the first curly bracket) is small relative to the discount rate (the second curly bracket), and downward when the opposite relationship holds. Forest economists usually assume that marginal and average logging costs do not vary within individual logging units, especially small ones. That is, they assume that the cost function is linear at the micro-level. To the extent that this assumption is valid, (28) will be greater than one in practice, and (27a) will unambiguously overstate the absolute value of net accumulation in mature forests.

The value of (27b) is also likely to be larger than the value of (26b). Economists usually assume that the function relating timber volume to age ($q(s)$) has either a concave or logistic shape (Hartwick 1993). In the latter case, they usually assume that the inflection point occurs at a relatively young age. Data from actual forests generally supports these assumptions. Hence, for all ages in the case of concave volume functions, and most ages in the case of logistic functions, $q'(t) > q'(T)$: the timber growth rate (the current annual increment to foresters) declines as the forest grows to maturity. For this reason alone, (27b) would tend to be larger than (26b), but the latter expression is reduced further by the inclusion of the $(1+i)^{t-T}$ term. Hence, we expect the net depletion method to overstate the increase in value of immature forests due to timber growth, except in very young forests with a logistic volume-age relationship. This result does not depend on the linearity or nonlinearity of the cost function. However, calculating (27b) by using average rent instead of marginal rent, in accordance with (18), would worsen the bias in the net depletion method when the cost function is in fact nonlinear.

APPENDIX 3 - CLOSED ECONOMY WITH TIMBER HARVESTING BUT WITHOUT DEFORESTATION

The focus of this appendix is valuation of the timber stock. Timber is harvested and used as an input by other sectors of the economy. Valuation is simplified by: (a) the absence of foreign trade, (b) the absence of changes in land use, and (c) the absence of nontimber values associated with forests. There is no explicit government sector, and the timber stock $S(t)$ is homogeneous (no variation in species, age classes, etc.). In subsequent appendices we discuss how to make the analysis more realistic (and we have already considered, in Appendix 2, how to deal with age-class issues). Valuation is done by connecting a model of a dynamic competitive economy to an accounts system. It turns out that a version of the classic social accounting matrix (a case we prefer to label as a *national* accounting matrix) captures all the accounting matters we analyze.

The analysis focuses on the economic appreciation or depreciation of the timber stock. From a broader perspective, changes in the timber stock are inextricably linked to changes in land use (whether areas are in forest or have been deforested during the accounting period). In that case, forestry accounting turns on both the economic depreciation of the timber stock and on the valuation of the land currently deforested. It involves simultaneous timber stock change valuation and land-use change valuation. In this appendix, there is no land-use change. We are starting with a simplified case.

Overview of the model and associated national accounts matrix

Before presenting the details of the model, we will present the principal results, relating them to the national accounts matrix in Table 1. Table 5 presents the matrix in more analytical detail than Table 1.

Aggregate production derives from the use of machine capital K, labour N, and timber H. Aggregate output $F(K,N,H)$ is used to produce new machine capital $\dot{K}$, consumption goods, C, and harvesting services $g(H)$. That is,

$$\dot{K} = F(K,N,H) - C - g(H).$$

The production function is constant returns to scale. Thus one can think of $F(\cdot)$ as comprising three types of firms, aggregated to three industries,

$$F(K^M, N^M, H^M) = \dot{K}$$
$$F(K^C, N^C, H^C) = C$$
$$F(K^H, N^H, H^H) = g(H),$$

where

$$K^M + K^C + K^H = K$$
$$N^M + N^C + N^H = N$$
$$H^M + H^C + H^H = H.$$

Each unit of $\dot{K}$, C, and $g(H)$ has a price of unity. Given constant returns to scale, we have

$$rK^M + wN^M + pH^M = \dot{K}$$
$$rK^C + wN^C + pH^C = C$$
$$rK^H + wN^H + pH^H = g(H)$$

where $r=F_K$, $w=F_N$, and $p=F_H$. The accounting is quite straightforward so far. In Table 5, row sums (receipts or revenues) for machines and consumer goods equal column sums (expenditures or costs). Total incomes from K and N (column sums for K-capital and labour) also equal total expenditures for using K and N (row sums for K-capital and labour) by firms.

We move on to the harvesting sector. The timber has net natural growth over the accounting period of $G(S)$ and net total growth of

$$\dot{S} = G(S)-H,$$

where H is the current harvest. Note that, for simplicity, we are using the net-depletion model, which ignores age classes. Each unit of stock commands a marginal rent (marginal stumpage value), $p-mc$. That is, if the owner of the timber harvests one more unit, she will get p for it and her cost of harvesting (and selling) is mc. The remaining revenue is marginal profit or rent or stumpage value. If a harvesting firm does the cutting and selling, it must pay $p-mc$ to the forest owner for the right to remove one more unit of timber. In a competitive economy, harvesting firms will be in a zero-profit position,

$$pH = [p-mc]H + g(H) + \pi(H)$$

where $\pi(H) = mcH - g(H)$, is net profit for harvesters. This net profit remains because we are assuming that harvest costs $g(H)$ are not linear (constant returns to scale) in "output", H. That is, harvest costs have rising marginal costs, a standard formulation.

The harvesting row in Table 5 is total revenue to the harvesting firms marketing their harvest, H. The column is total expenditure by the harvesting firms. Recall that total costs of harvesting are $rK^H + wN^H + pH^H$, equal to $g(H)$. The size of the rent term is determined by expectations about future timber values. The discount rate matters.

There remain two steps for completing the accounts. First, total rent paid to forest owners by harvesting firms, $[p-mc]H$ (in the column sum for harvesting), must be received as income by forest owners. But forest owners' wealth rises or falls by implicit net income $[p-mc]\dot{S}$. This entry appears as net income to forest owners in the "Forest" column of Table 5. The corresponding entry in the row "Forest" is economic depreciation of the timber stock. Here one should think of the households doing implicit saving or dissaving in amount $[p-mc]\dot{S}$. For $\dot{S}$ positive, households (forest owners) are implicitly saving. For $\dot{S}$ negative, there is implicit dissaving in the forest sector. Dissaving is associated with economic *depreciation* as distinct from appreciation. The column sum for households is "green" NDP.[15]

[15] The "net" in conventional NDP indicates that GDP has been adjusted so that net investment in

The corresponding row sum for households in Table 5 is also adjusted NDP. It comprises the value of total flows of services from primary factors into the economy. This sum is also referred to as total value-added for the economy. Of importance for green national accounting is that the two entries $[p\text{-}mc]\dot{S}$ and $[p\text{-}mc]H$ combine to leave

$$[p\text{-}mc]G(S)$$

as the contribution of the forest stock to current national economic activity. This is the value of the services the timber stock (nature) provides, before human harvesting activity "intervenes". This is, in fact, the intuitively correct entry for the service flow from the timber stock in the economy's value-added.

From a national accounting point of view, timber and timber harvesting raise some somewhat novel issues. A correct value of rent on a unit of the timber stock must be obtained. Economic depreciation of the timber stock must be entered as part of national dissaving or saving. And value-added for the timber stock must be correctly arrived at (the combination of rental income accruing to timber stock owners and the net change in the value of the stock to the owners).

Details of the model

The objective is

$$\max \int_0^\infty U(Q)\, e^{-\rho t}\, dt$$

subject to

$$\dot{K} = F(K,N,H) - g(H) - C$$
$$\dot{S} = G(S) - H$$
$$K(0) = K_0$$
$$S(0) = S_0.$$

The variables are defined as follows:

C = composite consumption
K = stock of human-made capital
N = labour force (constant; i.e., no population growth)

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human-made capital (gross investment minus the capital consumption allowance) appears in "consumption plus investment." The capital consumption allowance is frequently referred to as "depreciation" of human-made capital, K (machines, structures, infrastructure, etc.). We have ignored "wear and tear" in K, in order to focus attention on depreciation of the timber stock.

H = timber harvest (net of defect)
S = stock of standing timber (net of defect)
$G(S)$ = growth increment of timber (net of defect)
$g(H)$ = cost of harvesting H, in terms of the composite good.

The current-value Hamiltonian is

$$H(t) = U(C) + \lambda(t)[F(K,L,H) - g(H)-C] + \psi(t)[G(S)-H].$$

The first-order conditions are:

$$\frac{\partial H}{\partial C} = 0 \Rightarrow U_C = \lambda$$

$$\frac{\partial H}{\partial H} = 0 \Rightarrow \lambda[F_H - g_H] = \psi$$

In the last expression, F_H-g_H is *p-mc* in Table 5. The adjoint equations are:

$$-\frac{\partial H}{\partial K} = \dot{\lambda} - \rho\lambda \Rightarrow \dot{\lambda}/\lambda = \rho - F_K \qquad \text{(Ramsey savings rule; defines time path of } \lambda\text{)}$$

$$-\frac{\partial H}{\partial S} = \dot{\psi} - \rho\psi \Rightarrow \dot{\psi}/\psi = \rho - G_S \qquad \text{(defines time path of } \psi\text{).}$$

The translation of the current-value Hamiltonian into NDP involves dividing by "price" U_C and substituting for ψ and λ.[16] One gets

$$NDP(t) = \frac{H(t)}{U_C} = \frac{U(C)}{U_C} + \dot{K} + [F_H - g_H]\dot{S}$$

This is written in the "Household" column of Table 5 as

$$C + \dot{K} + [p\text{-}mc]\dot{S}.$$

[16] Weitzman [1997] has provided a formalization for translating price in utils into price in dollars. This allows the analyst to move freely between the accounts, as in a SAM, and a formal growth model representation of the economy under analysis.

APPENDIX 4 - CLOSED ECONOMY WITH NONTIMBER VALUES

The model in this appendix differs from that in Appendix 3 in just one way: standing forests yield direct benefits to citizens, in the form of nonmarket forest amenities. The benefits are $B(L)$, and their value emerges from the utility function,

$$U(C,B(L)).$$

In monetary terms, the value of the benefits is $[U_B/U_C]B(L)$. Hence, the value of forestland as a provider of the amenities is

$$[U_B/U_C]B_L L,$$

where B_L is the benefit from a marginal hectare of forestland.

As discussed in Chapter 2, the introduction of these direct benefits from the standing forest leads to a new "Forestland" row and column in the national accounting matrix in Table 2. Table 6 is the same as Table 2, except with more analytical detail. Both tables omit internal detail to highlight entries in the new row and column. The "Forestland" row is blank except for the entry in the household column, which represents direct benefits to households of standing forests having a value of $[U_B/U_C]B_L L$. This becomes a new entry in both GDP and NDP. $[U_B/U_C]B_L L$ is forest rent (there are no costs of forest maintenance) paid by beneficiaries (consumers) for the flow of services accruing to them from the forestland.

The corresponding "Forestland" column also has only one entry, again in the household row, namely $[U_B/U_C]B_L L$. This is rent payments accruing to owners of forested land, namely households. $[U_B/U_C]B_L$ is rent per hectare.

Thus green NDP (the household row sum) is augmented by the net value of services from forestland, and green net national income (the household column sum) is augmented by the land rent being generated by the forested land. The accounts have a new primary input, namely land in forests, and a net value of services from this capital good. Value-added in the economy includes new capital services, $[U_B/U_C]B_L L$.

APPENDIX 5 - OPEN ECONOMY WITH TIMBER HARVESTING AND DEFORESTATION

In this appendix, we revert to the case where timber is the only good provided by the forest. However, we allow for conversion of forestland to agriculture.

Overview of the model and key results

There is a fixed land area $\bar{L}$, mostly in forest initially. L is the area in forest. The forest yields net income $p^f f(L)$ from harvesting and exporting a timber volume of $f(L)$ at a net world price of p^f. Land area $\bar{L}$ -L is in agriculture, yielding net income $p^a g(\bar{L} - L)$ from agricultural exports.

World prices, initial areas, and concave production functions $f(\cdot)$ and $g(\cdot)$ make the initial price of land in forestry, $p^f f_L/r$, low and the initial price of land in agriculture, $p^a g_{\bar{L}-L}/r$, high (r is the social discount rate). This initial land price gap drives deforestation (clearing land for agriculture). Clearing area R costs $C(aR)$, but it yields timber worth paR (p is unit value of salvaged timber, a is timber salvaged per hectare, and total salvaged volume is $H=aR$). This timber production from conversion fellings is in addition to "sustainable" timber production represented by $f(L)$.

With the initial land price gap large, the amount cleared per period, R, will also be large. In fact, R can be large enough that marginal value $a[p-C_H]$ will be negative. This negative marginal value implies positive "investment" by forest clearing: an asset with a negative value at the margin, namely the forest, is eliminated. The national accounting entry for wealth change in the economy is therefore

$$\Delta V = -a[p-C_H]R.$$

The amount cleared diminishes as the marginal value of salvaged timber, $p-C_H$, becomes positive and prices of land in the two uses converge. At a certain point, land prices flip, with forestland becoming higher valued. Deforestation nevertheless continues for a while, due to the positive net timber value from conversion fellings. It ceases when land prices differ by the marginal profit from clearing (marginal value of timber harvest):

$$\left[\frac{p^f f_L(L(T))}{r}\right] - \left[\frac{p^a g_{L-\bar{L}}(\bar{L} - L(T))}{r}\right] \cong a[p- C_H(T)] = \lambda(T)$$

Forest area is now stable at $L(T)$. In the earlier phase, the transformation of forested land to agriculture land resulted investment in the economy. The net increase in land value was offset by a negative marginal payoff to clearing a hectare. In the later phase, there is a net decrease in land value offset by a positive marginal payoff to clearing a hectare of trees. The economic depreciation term, $a[p-C_H(t)]R(t)$, correctly reflects the net change in land value. Early on, low value land is transformed to high value land, whereas later, higher value land is being transformed to lower value land but with a positive harvest payoff.

NDP is therefore given by

$$NDP(t) = p^f f(L(t)) + p^a g(\overline{L} - L(t)) + paR(t) - C(aR(t)) - a[p - C_H(aR(t))]R(t).$$

The last term is the change in asset (land) value. Note that change in wealth or capital value pertains to the amount of forested land cleared of forest. That is, wealth change is

$$a[p - C_H(aR(t))]\,\dot{L}(t).$$

where $\dot{L}(t)$ is forestland cleared and $a[p-C_H(aR(t))]$ is land price (a capital value). This value is identical to the negative of rent on salvaged timber, namely

$$-[p - C_H(aR(t))]aR(t).$$

Hence wealth change manifests itself precisely in rent on salvaged timber volume. We are in the unusual position of being able to integrate wealth change into the product or output part of net national product, as in

$$NDP(t) = p^f f(L) + p^a g(\overline{L} - L) + \{paR(t) - C(aR(t)) - a[p - C_H(aR(t))]R(t)\},$$

where $\{\cdot\}$ contains the terms we combine. $\{\cdot\}$ reduces to

$$aC_H(aR(t))R(t) - C(aR(t)),$$

which is positive and declines to zero at the date defining the end of the clearing. This is a producer surplus, which can be linked to rent on land. At the moment the prices of land in agriculture and forestry become equal, the price of timber p equals the marginal cost of "harvesting" timber, and at that moment $aC_H R - C(aR)$ indeed defines the rent on the R hectares of land about to be cleared of timber.

In summary, rational forest clearing yields a timber payoff (worth negative dollars early on and positive dollars later) plus a land value capital gain (worth positive dollars early on and negative dollars later). The net value of these two effects is always positive, up to the point where clearing ceases. But the two effects are distinct from a national accounting perspective. One is essentially a value of product (timber cleared), while the other is a value of investment, possibly negative, in natural capital, namely land. From the perspective of national accounting, the terms should be kept separate, even though they each can be expressed in dollars of timber per se.[17]

The early phase bears strong resemblance to the formal structure of an extractive sector in an economy for the case of durable exhaustible resources. For example, gold, once mined, is used indefinitely above ground. A "useless" asset in the ground becomes useful above ground. Asset value increases by the act of extraction, and extraction is costly. The later phase bears strong resemblance to the formal structure of an extractive sector in an economy for the case of non-

[17] Hartwick [1992] integrated the two terms (compressed them to one term) in one section.

durable exhaustible resources. For example, oil extraction imposes an asset value decline on the economy, "in return for" current use of the oil extracted. In the forestry case, timber is cleared, opening up more low value land; the asset value decline is accepted "in return for" current profits from timber sales.

Reforestation

Reforestation of agricultural land is possible in the model. This process works as follows. At the equilibrium point *L(T)*, the landowner observes that her land is more valuable in forest than in agriculture (the land price gap noted above). If the land could be reforested without delay, then she would let it be reforested and then she would mine off the new trees again. There is then the incentive for the landowner, when the state is at *L(T),* to let land reforest itself, for free. The retarding tendency is of course agricultural output forgone while the land reforests itself. This cost will be relatively small if natural reforestation is rapid, and the incentive to allow reforestation to occur will be stronger as the land price gap, $p^f f_L - p^a g_{\bar{L} - L}$, is larger.

Routine calculation shows that for any plot with

$$(1+r)^{N+1}\, p^a g_{\bar{L} - L} < (>)\, p^f f_L,$$

it pays for the owner to wait (not wait) $N+1$ periods while re-forestation occurs. With more rapid natural reforestation, the factor N becomes smaller, resulting in more plot owners being induced to allow reforestation to occur, given state *L(T)*.

For cases of agricultural land price being pushed down sufficiently far as tree "mining" occurs, owners will find it profitable not to farm the cleared land. They will leave the land to reforest itself; subsequently, new clearing will follow. A perpetual cycle of the Faustmann sort occurs: harvest trees, leave for reforestation, harvest again, leave for reforestation, etc. The driving force is the relatively low value of cleared land for agriculture. Given this low value, the owner can afford to keep the land unfarmed, while timber regrows on it.

Another interpretation of the regrowth phenomenon is overshooting a quasi-equilibrium. It appears that forest owners are clearing land for agricultural use, when in fact the primary motive is to obtain the valuable timber. In a sense, agricultural land is a by-product of timber "mining". Once mined of timber, the land may be used for agriculture for a while, but ultimately it will be allowed to reforest itself. This scenario appears to have played itself out in Eastern Canada and New England in the United States. Timber was mined, low productivity farming followed, and then reforestation was allowed to occur.

Investment and consumption levels

In our small open economy we can associate all production with exports to the world. Then net revenue can be thought of as payment for imports of consumption goods plus possibly investment in banks abroad at, say, r percent. If $B(t)$ is bonds accumulated and held abroad paying $r\%$, then current consumption is

$$Y(t) = p^f f(L(t)) + p^a g(\overline{L} - L(t)) + [paR(t) - C(aR(t))] + rB(t) - \dot{B}(t),$$

where $\dot{B}(t)$ is current investment in bonds abroad. Consumption level $Y(t)$ will remain constant when investment $\dot{B}(t)$ is set at the level of the decline in natural capital value, namely, $-a[p-C_H]R(t)$. This implies that in the early phase $\dot{B}(t)$ will be selected at a negative value. Foreign bond holdings are being run down and the proceeds consumed. This corresponds to a developing country borrowing from abroad early in the development process. In the later phase, $\dot{B}(t)$ will be selected at a positive value as investment in capital abroad balances off the decline in natural capital at home. These arguments for sustaining constant consumption originate with Solow (1974) and Hartwick (1977), and a version paralleling ours here, but for a small open oil-exporting nation, is explored in Vincent, Panayotou, and Hartwick (1997).

Wealth accounting

A seeming alternative approach to national accounting, with due attention to natural capital, is to construct wealth accounts and to incorporate changes in wealth into expressions for net investment in the national accounts. Intuitively, it seems apparent that one should end up with the same values for the wealth change associated with changes in natural stocks when one does the wealth accounting correctly and when one does the change in wealth calculations, focused on in the previous sections. Formally, this link can be made but one needs to draw on dynamic efficiency conditions (optimization conditions) to make it. Total wealth in our small open economy, with no investment, is

$$W(t) = \int_t^\infty [\, p^f f(L(s)) + p^a g(\overline{L} - L(s)) + paR(s) - C(aR(s))]\, e^{-(s-t)r}\, ds.$$

Change in wealth $\dot{W}(t)$ is

$$\dot{W}(t) = rW(t) - \{p^f f(L(t)) + p^a g(\overline{L} - L(t)) + [paR(t) - C(aR(t))]\}.$$

This is a basic asset valuation condition: current change in asset value equals current "income" forgone, plus interest on the current value. The latter "wedge" occurs because as time moves forward, there is less discounting on the remaining wealth.

The above differentiation is a key ingredient in the understanding of wealth accounting. The other key ingredient is the observation that $rW(t) - \{\cdot\}$ equals $-a[p-C_H(t)]R(t)$. This result is from dynamic programming.

Estimates of many types of natural wealth are difficult to obtain because the basic accounting inputs, the physical quantities of the resources, are hard to obtain. This is clearly the case for fish stocks and mineral stocks. The accountant cannot obtain only very approximate estimates of stock sizes, which are prone to large errors. Forests are easier to measure, through either field inventories (unlike fish, trees do not move) or remote sensing. Needless to say, considerable expertise is needed to translate satellite data into accurate timber stock estimates, as forests comprise trees of different ages, sizes, and species. Nevertheless, wealth estimation for timber stocks appears to be more feasible than for other natural resources.

Details of the model

At each date, the country exports some agricultural produce $g(\bar{L}-L(t))$ at net price p^a, some sustainable forest produce $f(L(t))$ at net price p^f, and timber $aR(t)$ salvaged from deforested land at price p. The cost of salvage timber operations is $C(aR(t))$.

$\bar{L}$ is the total land in the economy; $L(t)$ is in forest and $\bar{L}-L(t)$ is in agriculture. Forest output $f(L(t))$ is concave in forestland $L(t)$. Current net income from forestland is $p^f f_L(t)$. Output $g(\bar{L}-L(t))$ in agriculture is also concave, in $L-L(t)$, and current net income from farmed land is $p^a g_{\bar{L}-L}(t)$. Current net income from $R(t)$ hectares currently cleared of forests is $paR - C(aR)$, where $C(\cdot)$ is convex in harvest aR.

The marginal net payoff $a[p-C_H(t)]$ measures the first-order change in land value (forest to agriculture) from clearing the marginal hectare. The second-order effect is the capital gain, $\dot{\lambda}(t)/r$, where $\lambda(t) \equiv a[p-C_H(t))]$. Current clearing of one hectare yields timber worth $\lambda(t)$ plus a hectare of agricultural land worth $p^a g_{\bar{L}-L}(t)/r$ minus a hectare of forestland worth $p^f f_L(t)/r$, and some capital gains $\dot{\lambda}(t)/r$. That is, the basic asset equilibrium condition is

$$p^f f_L(t) - p^a g_{\bar{L}-L}(t) - \dot{\lambda}(t) = \lambda(t)r.$$

Roughly speaking, the net land price gap equals the net cost of clearing a hectare. The refined statement has capital gains factored in properly. $\lambda(t)$ is formally the net price (capital value) of a hectare of forestland because

$$R(t) = -\dot{L}(t).$$

The market "selects" the clearing level, $R(t)$, to maximize the present value of net wealth in the economy,

$$W(t) = \int_0^\infty [\, p^f\ f(L(t)) + p^a\ g(\bar{L} - L(t)) + [paR(t) - C(aR(t))]]\ e^{-rt}\, dt$$

subject to

$$\dot{L}(t) = -R(t)$$
$$L(0) = L_0,$$

with $L_0 > 0$ and $\overline{L} - L_0 > 0$. The current-value Hamiltonian is

$$H(t) = p^f f(L) + p^a g(\overline{L} - L) + paR - C(aR) - \lambda(t)R. \qquad \text{(A1)}$$

The necessary conditions are

$$\frac{\partial H}{\partial R} = 0 \Rightarrow a[p - C_H(t)] = \lambda(t) \qquad \text{(A2)}$$

$$-\frac{\partial H}{\partial L} = \dot{\lambda}(t) - r\lambda(t) \Rightarrow p^f f_L(t) - p^a g_{\overline{L}-L}(t) - r\lambda(t) = -\dot{\lambda}(t). \qquad \text{(A3)}$$

These two equations describe the pace of clearing forestland and the corresponding net price of land inclusive of capital gains. At some finite date T, clearing ceases, and the economy carries on with fixed amounts of land in agriculture and in forests. The steady state is reached when the Hamiltonian $H(T)$ equals the level of future steady income. That is, T is defined by

$$H(T) = p^f f(L(T)) + p^a g(\overline{L} - L(T)).$$

This implies that at T, $\lambda(T)R(T) = paR(T) - C(aR(T))$. Given our choice of $C(aR)$ convex in aR with $C(0) = 0$, this endpoint condition implies that clearing level $R(t)$ declines to zero at date T. Then $\lambda(T) = ap$. As this transition date is approached, capital gains $\dot{\lambda}(t)$ approach zero.

Reforestation

This steady state will be backwards-unstable in the sense that some owners of agricultural land will wish to let their holdings reforest themselves in order to reap an increase in land value. Consider a landowner with a vacant plot with rent (marginal profit) $p^a g_{\overline{L}-L}$ when worked in agriculture. If the plot could be instantaneously forested, it would be worth $p^f f_L$ when used in sustainable harvesting. Once forested, the land could be cleared and the timber sold off. Then the forestland would revert to vacant land, suitable for agriculture. Should the owner of the vacant plot farm it or let it reforest itself? There is an immediate capital gain if reforestation occurs instantaneously. The gain is delayed in the case of gradual reforestation. The cost of waiting for reforestation to occur is agricultural output forgone. This cost is $p^a g_{\overline{L}-L}$ per period. Hence the owner should wait (not wait) for re-forestation (N periods hence) as

$$p^a g_{\overline{L}-L}\{1+(1+r) + (1+r)^2 + \dots + (1+r)^N\} < (>) \{p^f f_L - p^a g_{\overline{L}-L}\}/r.$$

This inequality reduces to

$$[(1+r)^{N+1} - 1]\, p^a g_{\overline{L}-L} < (>)\, p^f f_L - p^a g_{\overline{L}-L}.$$

For large N (slow growing trees), the owner should simply farm her cleared land. Alternatively, if the gap between alternative land rents is large, the owner can afford to wait while the land reforests itself.

Investment and consumption levels

The definition of wealth for the economy is discounted future income (Irving Fisher):

$$W(t) = \int_t^\infty [\, p^f\ f(L(s)) + p^a\ g(\bar{L} - L(s)) + paR(s) - C(aR(s))]\ e^{-r(s-t)}\, ds\,.$$

Differentiation with respect to t yields

$$\dot{W}(t) = rW(t) - [p^f f(L(t)) + p^a g(\bar{L} - L(t)) + paR(t) - C(aR(t))].$$

When $R(t)$ is chosen optimally, the Bellman equation is satisfied, namely

$$rW(t) = p^f f(L(t)) + p^a g(\bar{L} - L(t)) + paR(t) - C(aR(t)) - R(t)[pa - aC_H(t)].$$

Using this in $\dot{W}(t)$ above yields

$$\dot{W}(t) = -R(t)\ [pa - aC_H(t)].$$

This basic relation indicates the change in wealth as forestland is cleared. In the early phase (low land prices for forested land), wealth change is positive because, roughly speaking, new agricultural land is very valuable. In the later phase, the economy is giving up high-priced forested land to be able to harvest the valuable timber.

How can the economy sustain consumption levels as these changes in the composition of wealth occur? Suppose the country can use some of its export earnings to invest in bonds abroad, earning $r\%$. Let $B(t)$ be bonds held abroad and $\dot{B}(t)$ be current investment in bonds. Current income from bonds is $rB(t)$. This leaves current consumption as

$$Y(t) = p^f f(L) + p^a g(\bar{L} - L) + paR - C(aR) + rB - \dot{B}\,.$$

Assume investment abroad is selected to cover the decline in asset value in the economy. Wealth change at any date (economic depreciation of assets, i.e. land) is $-a(p - C_H(t))R(t)$. This is

$-\lambda(t)R(t)$, in light of (A2). This, under our savings assumption, is $-\dot{B}(t)$. Hence

$$-\dot{B}(t) = \dot{\lambda} R + \lambda(t)\dot{R}(t).$$

Consider now the time path of consumption $Y(t)$. Differentiating $Y(t)$ with respect to time, we obtain

$$\begin{aligned}\dot{Y}(t) &= p^f f_L(t)\dot{L}(t) - p^a g_{\bar{L}-L}(t)\ \dot{L}(t) + [pa - C_H(t)a]\ \dot{R}(t) + r\dot{B}(t) - \ddot{B}(t)\\ &= [p^f f_L(t) - p^a g_{\bar{L}-L}(t)]\ (-R(t)) + \lambda(t)\dot{R} - r\lambda(t)R - \dot{\lambda}\cdot R - \lambda(t)\dot{R}\\ &= 0,\end{aligned}$$

given (A3). This establishes that consumption in the economy remains constant under investment arranged to offset asset value decline (or increase in the early phase).

Further issues

Two possible extensions of the model are to introduce (i) an exogenous upward drift in world timber prices, and (ii) clearing costs that rise with cumulative clearing. Methods for dealing with (i) are set out in Vincent, Panayotou, and Hartwick (1997). Dealing with (ii) is known in the literature as the introduction of stock size effects in costs. We simply note here that neither extension is trivial.

APPENDIX 6 - CLOSED ECONOMY WITH TIMBER HARVESTING AND DEFORESTATION

In this appendix we return to a model of a large closed economy, as in Appendix 3, but we introduce land clearing in addition to a pure harvesting activity. This model differs from the one in Appendix 5 in that all prices are now endogenous. Harvesting and timber growth are defined on homogeneous sub-areas. Economywide relationships are in part defined on the aggregated sub-units.[18] A new production activity is the clearing of forestland. This activity yields new land for agriculture plus marketable timber. The costs of clearing include the costs of felling and transporting salvaged timber. Harvesting and clearing are distinct activities and each is competitive, leaving only producer surpluses as profits. The two activities are linked because each yields marketable timber. Harvesting is assumed to be sustainable on land dedicated to forestry.

There are three elements of particular interest from an accounting perspective. First, we observe that "investment" in new agricultural land shows up in the accounts as a price gap multiplied by a stock change. The price gap is that between a unit of land in agriculture and a unit in sustainable forestry. This is a new measure of "rent."

Secondly, rent on forestland does not appear in the accounts. It is completely capitalized in timber stock rent. This in part reflects the fact that there are no explicit nontimber values in our model. It also reflects the general principle that land price is discounted rentals associated with the most profitable activity on the land.

Thirdly, we observe that land price can rise or decline during clearing, depending on the net cost of clearing a unit of land. This result is similar to the one for our small open economy. Here, however, land prices are endogenous. To see what is transpiring, one should think of a unit of forestland at date *t* as having two alternative uses. It can be harvested but retained as forest, which yields marginal profit $[F_R - g_H]\delta(S)$, or it can be cleared, with fraction $D(t)$ being cleared, which yields marginal profit $[\delta(S)F_R - f_D] + [\psi(t) - \gamma(t)]/\lambda(t)$. The land price change, $[\psi(t) - \gamma(t)]/\lambda(t)$, must adjust to equilibrate the current marginal profit from these two alternative uses:

$$\frac{\psi(t) - \gamma(t)}{\lambda(t)} = [F_R - g_H]\delta(S) - [F_R\delta(S) - f_D]$$

$$= f_D - \delta(S)g_H.$$

Whether land price rises or falls during clearing depends on whether current net marginal clearing cost $f_D - \delta(S)g_H$ is positive or negative. In a sense, the price gap adjusts to "accommodate" the current net marginal cost of clearing.

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[18] This approach differs from that in Hamilton [1997], our inspiration for this model.

Overview of the model and associated national accounts matrix

At any date, timber production derives from harvesting H cubic meters per hectare of forestland retained under forest cover and salvaging $\delta(S)D$ per hectare cleared. $\delta(S)$ is the density of timber stocking, which varies with the stock-land ratio. Hence, timber production is

$$R = HL + \delta(S)DL,$$

where L is land in forests and D is the tract cleared. Clearing yields DL of new agricultural land and diminishes L:

$$\dot{L} = - DL.$$

The timber stock, per hectare, changes as

$$\dot{S} = G(S) - H - \delta(S)D,$$

where S is the current stock and $G(S)$ is the growth increment per hectare. The sum of harvested and salvaged timber, R, enters as an input into aggregate production, along with agricultural land A. Total output $F(K,N,R,A)$ is allocated among current aggregate consumption, C, harvesting costs, $Lg(H)$, clearing costs $Lf(D)$, and new investment, $\dot{K}$, in human-made capital, K. N is the constant labour force. Hence, we have

$$\dot{K} = F(K,N,R,A) - C - Lg(L) - Lf(D).$$

The total land area is $\bar{L}$, with $\bar{L} = A+L$. This means that

$$\dot{A} = DL.$$

NDP for this economy turns out to be

$$NDP(t) = C + \dot{K} + \dot{A}\,[\psi-\gamma]/\lambda + [p^R-mc^H]\,\dot{S}\,L,$$

where

ψ/λ = price of a hectare of land in agriculture
γ/λ = price of a hectare of land in forestry
p^R = price of a cubic meter of harvested timber
mc^H = the marginal cost of harvesting a unit of timber.

When we work through the national accounting matrix for this problem, we will see that net national income (equal to NDP) is

$$NNI(t) = rK+wN + AF_A + [p^R-mc^H]G(S)L + L\pi^H(H) + L\pi^D(D),$$

where r is the rental rate on capital K, and F_A is the rental rate on a unit of agricultural land. $\pi^H(H)$ and $\pi^D(D)$ are net profits per hectare from timber-harvesting and land clearing that remain for households. They exist because $g(H)$ and $f(D)$ are not constant returns to scale processes. Two points are significant: (i) land in forests has no rental flow in NNI because this income is accruing to the timber stock owners directly and not indirectly to the forest landowners, and (ii) the timber stock rents derive from gross flow $G(S)L$ from stock SL, not from net flow $[G(S) - H - \delta(S)D]L$. It will, however, take some steps to reach NNI via the social accounting matrix.

NDP includes an entry for "investment" in agricultural land. This corresponds to land cleared of forests at a price and turned into land in agriculture. In Ricardian parlance, it is as if we drained swampy terrain, at a cost, to create usable agricultural land. This has been referred to as investment in land. Our switching of use from forestry to agriculture is analogous to the switch of land from swamp to agriculture, at a cost. However, the price of our (marginal) piece of land may rise or fall during the switch depending on the net cost of clearing it. Equilibrium in our model involves marginal profit being zero for timber harvesting and land clearing. Formally, we have

$$[F_R - g_H]L - \eta = 0$$

and

$$[F_R - f_D/\delta(S)]L + [\psi - \gamma]L/(\delta(S)\lambda) - \eta = 0$$

for timber harvesting and land clearing respectively. This implies that net profit is the same in each activity, or

$$[F_R - g_H] = [F_R - f_D/\delta(S)] + [\psi - \gamma]/\delta(S)\lambda,$$

which reduces to the fundamental condition defining the direction of change in land prices, namely

$$[\psi - \gamma]/\lambda\delta(S) = f_D/\delta(S) - g_H,$$

where the right hand side is the net marginal cost of "creating" a hectare of agricultural land. The net marginal cost comprises marginal clearing cost and marginal salvage harvesting cost. To clear a hectare, one salvage harvests $\delta(S)$ amount of timber at marginal cost $g_H(H)$ per unit. One clears a hectare at marginal cost f_D. Clearing includes the cost of removing timber. Hence the net cost of clearing is $f_D - \delta(S)g_H$. This represents the increase in the value of a hectare from clearing. The net clearing figure can be positive or negative. Relatively high marginal clearing costs are associated with an increase in the value of a hectare in the switch from forestry to agriculture. Relatively low marginal clearing costs are associated with mining forested land for the standing timber. In these cases, clearing is pushed into ranges in which new agricultural land is not very productive and has a value less than in forestry.

Recall that π^H and π^D are net profits accruing because harvesting costs *g(H)* and clearing costs *f(D)* are not linear in amounts harvested and cleared, respectively:

$$\pi^H(H) = Hmc^H - g(H)$$

$$\pi^D(D) = Df_D - f(D).$$

These two entries enter directly into the national accounting matrix under production activities. The zero marginal profit conditions for land clearing and harvesting become the following key entries for total profit per unit of land:

$$\pi^D(D) = p^R\delta(S) - (\psi-\gamma)/(\lambda\delta(S)) - [p^R-mc^H]\delta(S) - f(D) \qquad (1)$$

$$\pi^H(H) = p^R H - [p^R-mc^H]H - g(H). \qquad (2)$$

These conditions yield the respective row and column entries in the social accounting matrix for "Land clearing" and "Timber harvesting". One must keep in mind that column sums for "Land clearing" and "Timber harvesting," excluding the "Household" entry, are total costs of the respective activities.

Observe that neither harvesting nor clearing disburses rent to landowners. The rent a firm might be expected to pay to owners of forestland is paid instead to owners of the timber stock on the forestland. These two entries are $[p^R-mc^H]H$ and $[p^R-mc^H]\delta(S)D$ respectively. Land-clearing firms buy the forestland which they intend to clear at price γ/λ per hectare and, once cleared, sell the land at price ψ/λ per hectare. They sell salvaged timber for $\delta(S)Dp^R$ dollars. Clearing costs include salvage harvesting costs. Hence clearing an area of *D* hectares yields $\delta(S)D$ of marketable timber, and generates a profit, at the margin, of $[p^R-mc^H]\delta(S)D$. The standing timber is acquired by land-clearing agents when they purchase the land for clearing.

A central result of our analysis is that land rent accruing to owners of forestland is simply discounted net income (timber stock rent and surpluses, or π's) from using the forestland. Use involves both clearing and timber harvesting. Price γ/λ equals the present value of current net income,

$$[p^R-mc^H]\{H+\delta(S)D\} + \pi^H(H) + \pi^D(D),$$

from a hectare of land. Part of net income derives from clearing, namely $[p^R-mc^H]\delta(S)D + \pi^D(D)$, and part from timber harvesting, $[p^R-mc^H]H + \pi^H(H)$. Recall that if clearing and harvesting were constant returns to scale (i.e., $f(D) = \alpha D$ and $g(H) = \beta H$), then both $\pi^H(H)$ and $\pi^D(D)$ would be zero. The price of a hectare of forestland would then simply be discounted timber rent associated with the removal of stock $H+\delta(S)D$ in the current period. However, the general result for land price γ/λ is

$$\gamma(S) = \gamma_0 + \int_S^\infty \{[p^R(t) - mc^H(t)][H(t) + \delta(S)D(t)] + \pi^H H(t) + \pi^D(D)(t))\}\, e^{-(t-s)\rho}\, dt.$$

That is, current land price is discounted net income from forested land.

The implication of this for accounting is that land rent for forestland does not appear in national income. That land rent is incorporated in timber stock rent and the surpluses or π's. If one were to record both land rents and timber stock rents into the accounts, one would be double-counting.

We are now in a position to represent the model in the form of a national accounting matrix. Compared to Table 5, the national accounting matrix in Table 7 has two new columns (and matching rows): one for land clearing, and one for agricultural land as a primary input. Forestland, we repeat, is taken account of in the rows and columns for its products, namely timber and new agricultural land. The new conceptual aspect is that agricultural land is an output of the clearing activity, and forested land is an input. The net change in land value for a cleared hectare can be interpreted as investment in land.

The column and row sums have been discussed above, following equations (1) and (2). The new agricultural land column and row are straightforward. Agricultural land is an input in the general production function, $F(\cdot)$, and the rents on agricultural land are income to households. The new entry is "investment" $[v^A-v^F]\dot{A}$ in agricultural land as an output of the clearing activity. Clearing has joint outputs, salvaged timber and cleared land. Agricultural land is produced, in contrast to the timber stock, which nature bestows on the households via natural growth. Recall that the value of forestland is the discounted surplus, including timber stock rent, obtainable from the forestland. $v^F\dot{A}$ in the household column is the payment by the land clearing agents for the forestland that is transformed by clearing into agricultural land.

The central result for valuing primary inputs, or net national income, appears in the household row. The sum of incomes $[p^R-mc^H]HL$, $[p^R-mc^H]\delta DL$, and $[p^R-mc^H]\dot{S}L$ reduces to $[p^R-mc^H]G(S)L$. That leaves the household row sum as the value of gross flows from stocks plus the value of labour services and profits, $\pi^H(H)L + \pi^D(D)L$. Hence, national income is the sum of the value of primary flows, gross of harvests or withdrawals from those flows, plus producer surpluses ("profits"). This sum is the standard measure of aggregate value-added in the economy.

Details of the model

The timber stock, $S(t)$, has a net natural increment $G(S)$ per unit of forestland. Timber is obtained from harvesting on forestland and from clearing DL hectares. The density of timber per unit of land is $\delta(S)$. L hectares are in forest currently. Thus, per hectare, we have

$$\dot{S} = G(S) - H - D\delta(S), \qquad \text{(VI.1)}$$

and

$$\dot{L} = -DL. \qquad \text{(VI.2)}$$

Land in agriculture is $A = \overline{L} - L$. Thus

$$\dot{A} = DL. \tag{VI.3}$$

There are per-hectare harvesting costs *g(H)* in sustained forests, distinct from per-hectare clearing costs of *f(D)*. Human-made capital *K* is invested according to

$$\dot{K} = F(K,N,A,R) - C - Lf(D) - Lg(H) \tag{VI.4}$$

where $F(\cdot)$ is a constant returns to scale, neoclassical production function. *N* is labour services, a constant; *R* is the sum of harvested timber, *LH*, and salvaged timber, $\delta(S)DL$; and *C* is aggregate final consumption.

Market equilibrium derives from (corresponds to) the solution of the optimal planning problem, to maximize

$$\int_0^\infty U(C)\, e^{-\rho t}\, dt \tag{VI.5}$$

subject to VI.1, VI.2, VI.3, VI.4 and initial conditions

$$K(0) = K_0 \qquad L(0) = L_0 \qquad S(0) = S_0. \tag{VI.6}$$

The current-value Hamiltonian for this problem is

$$H = U(C) + \lambda[F(K,N,A,R) - C - Lf(D) - Lg(H)] + [\psi - \gamma]DL + \eta\,[G(S) - H - D\delta(S)], \tag{VI.7}$$

where

λ = until price of a unit of human-made capital
ψ = until price of a unit of land in agriculture
γ = until price of a unit of land in forestry
η = until price of a unit of the timber stock.

Until prices become monetary prices when divided by the until price of a unit of consumption, namely $U_C(C)$.

The necessary conditions for an optimum are

$$\frac{\partial H}{\partial C} = 0 \Rightarrow U_C(C) = \lambda \qquad \text{(VI.8)}$$

$$\frac{\partial H}{\partial H} = 0 \Rightarrow \lambda[F_R - g_H]L = \eta \qquad \text{(VI.9)}$$

$$\frac{\partial H}{\partial D} = 0 \Rightarrow \lambda[F_R \delta(S) - f_D]L + [\psi - \gamma]L = \eta\delta \qquad \text{(VI.10)}$$

$$-\frac{\partial H}{\partial K} = \dot{\lambda} - \rho\lambda \Rightarrow -\lambda F_K = \dot{\lambda} - \rho\lambda \qquad \text{(VI.11)}$$

$$-\frac{\partial H}{\partial A} = \dot{\psi} - \rho\psi \Rightarrow -\lambda F_A = \dot{\psi} - \rho\psi \qquad \text{(VI.12)}$$

$$-\frac{\partial H}{\partial L} = \dot{\gamma} - \rho\gamma \Rightarrow \lambda\{F_R[H+\delta D]-g(H)-f(D)\}+[\psi-\delta]D = \rho\gamma - \dot{\gamma} \qquad \text{(VI.13)}$$

$$-\frac{\partial H}{\partial S} = \dot{\eta} - \rho\eta \Rightarrow -\eta G_S + \delta_S D = \dot{\eta} - \rho\eta \qquad \text{(VI.14)}$$

There are two zero-profit arbitrage conditions to note. First, the net marginal cost of obtaining timber from harvesting and land clearing must be the same. This is captured in (VI.9) and (VI.10). Each activity pays timber owners their rent on timber harvested. The marginal profit net of rent must be equal for the two activities. That is,

$$\lambda\delta(S)[F_R - g_H] = \lambda\delta(S)[F_R - f_D/\delta(S)] + [\psi - \gamma].$$

This reduces to the fundamental condition

$$f_D - \delta(S)g_H = [\psi - \gamma]/\lambda.$$

At any date, the wedge in the price of a unit of land in agriculture versus forestry is the net marginal cost f_D-$\delta(S)g_H$. Note that f_D is the marginal clearing cost per hectare, including tree felling costs, whereas g_H is the marginal cost of harvesting *H* volume of timber. *D* of a hectare corresponds to δD volume of timber felled or cleared. This is different from volume *H* being harvested from a hectare of forestland. Thus f_D -$\delta(S)g_H$ derives from two different cost functions and from marginal costs for two different margins, one at *D* and one at *H*.

In brief, the equilibrium land price spread must equal the marginal cost of transforming one type of land to the other type. Here the process is only allowed to go "one way," from forest to agricultural use. But even with the process only moving one way, two possibilities remain: a higher price in agriculture or a lower price in agriculture, depending on the relative magnitudes of current marginal clearing costs and marginal harvesting costs, per hectare. We argued earlier that in the early stages of development, as with Canada in the eighteenth century, land in forestry should command a relatively low price whereas much later, even as clearing continues, land in agriculture would command a lower price. Our model can display this switch from clearing "leading to" higher priced land in agriculture to clearing "leading to" lower priced land in agriculture.

Second, the price of land in forestry must be linked to the value of its current and alternative uses. The current use is timber harvesting, and the alternate use is agriculture. The price of land γ/λ is reflected in VI.13. $\dot{\gamma}$ is the price change. If one substitutes VI.9 and VI.10 into VI.13, one gets

$$\rho\gamma - \dot{\gamma} = \eta[H+\delta D] + \lambda[\pi^H(H) + \pi^D(D)]$$

or

$$\gamma(t) = \gamma_0 + \int_t^\infty \{[H(v)+\delta(S)D(v)]\,\eta(v) + [\pi^H(H)+\pi^D(D)]\,\lambda(v)\}e^{-\rho(v-t)}dv.$$

Land price $\gamma(t)$ is discounted surplus (rent and net profit) per hectare, where surplus derives from current land clearing and timber harvesting. The definitions of net profits (producer surpluses) are

$$\pi^H(H) = Hg_H - g(H)$$

and

$$\pi^D(D) = Df_D - f(D)$$

for harvesting and clearing, respectively. Note that $\pi^D(D)$ derives from clearing per se, not from timber cut and sold from the cleared land. Clearing will in general involve more than simply felling or harvesting the $D\delta(S)$ timber removed.

Our land price "formula" for forested land is a variant of the classic result that price is discounted net timber rents (Samuelson 1976). In a sense the value of the land is the profit remaining when the land is employed in its most profitable activity. This has significant implications for accounting and valuation in general. Careful and comprehensive accounting of rent for timber stocks will make the accounting of land rent in forestry redundant. If we do the accounts correctly, including timber stock rents, we will have dealt with land rent for forested land, *en passant*. To be specific, when forest harvesting firms pay $H\eta/\lambda$ to timber stock owners for the timber currently harvested, and land clearing agents pay $\delta(S)D\eta/\lambda$ to timber stock owners for the timber currently harvested, they are implicitly covering off much of the land rent that the land in forests commands. The bottom line is then: the land value of forestland derives from the timber stock rental corresponding to the timber currently removed from the land in question.

APPENDIX 7 - DETAILS OF EMPIRICAL STUDIES REVIEWED IN THIS REPORT

This appendix provides summary descriptions of the forestry accounting studies reviewed in Chapter 4. It presents the studies in chronological order. It focuses on studies that attempt to link forestry accounts explicitly to national income accounts.

Although we attempted to identify and review all existing studies, in the end we were unable to obtain copies of several that we identified, including da Motta (1993) for Brazil, Kong and Naihui (1993) for China, Solberg and Svendsrud (1992) for Norway, and Adger (1993) for Zimbabwe. Undoubtedly, we did not identify all studies, given the tendency of the studies to be published in the gray literature.

Unless otherwise indicated, net accumulation estimates mentioned in the descriptions were negative, indicating a decline in asset value.

Global

Reference: World Bank (1997).

Period: 1970-93 (net accumulation), 1994 (valuation of stocks).

Scope: Subsoil assets, cropland, and pasture land, in addition to forest resources.

Forest resources: Roundwood, nontimber benefits, protected areas.

Links to national accounts: (i) Current accounts—Added net accumulation of roundwood resources to net domestic savings (gross domestic investment minus net foreign borrowing minus depreciation of human-made capital). (ii) Asset accounts—Calculated asset value of forests for timber and nontimber benefits, and also asset value of protected areas, and compared them to values for other natural capital, human-made capital, and human capital.

Physical accounts: For net accumulation, compiled data on roundwood harvest and natural growth, and set net depletion equal to the difference between harvest and growth. For asset valuation, used preceding data as well as data on forest area and protected area.

Valuation: (i) Calculated net accumulation of *roundwood* by net price method: multiplied net depletion times average stumpage value (weighted average price of logs and fuelwood minus average logging cost). Set net accumulation equal to zero if net depletion was negative (growth exceeded harvest). (ii) Calculated asset values by present value method. For *roundwood*, if growth exceeded harvest (which implies that harvest can be sustained indefinitely), multiplied harvest times average stumpage value and divided by the discount rate (4 percent). If harvest exceeded growth, treated forest as a mine and capitalized the product of roundwood harvest and average stumpage only up until the projected date of exhaustion. For *nontimber benefits*, divided forest area by ten (on the assumption that one-tenth of forest generated significant nontimber benefits), multiplied by $112 per hectare in developing countries and $145 per hectare in developed countries, and divided by 4-percent discount rate. For *protected areas*, multiplied area times asset value of one hectare of pasture land, the assumed minimal opportunity cost of protection.

Official status: Study conducted by the Indicators and Environmental Valuation Unit of the World Bank's Environment Department, for the Rio + 5 process.

Additional comments: Heavily revised update of World Bank (1995). Covered nearly 100 countries. Concluded that the asset value of forests (for timber, nontimber benefits, protected areas) was smaller than the asset values of both cropland and subsoil assets in most cases. Asset value of timber production was, on average, 3-10 percent of the total value of natural capital (depending on country income class); corresponding figures were 2-5 percent for nontimber benefits and 2-11 percent for protected areas. In general, forest values as a percentage of natural capital were higher in countries in higher income classes.

Asia

Reference: Vincent and Castaneda (1996).

Period: 1970-92.

Scope: Subsoil assets and agricultural soils, in addition to forest resources.

Forest resources: Roundwood in natural forests and plantations.

Links to national accounts: (i) Current accounts—Added net accumulation of roundwood resources to gross domestic savings. (ii) Asset accounts—Did not calculate asset value of forests.

Physical accounts: Pertained to growing stock, not forest area. Compiled data on roundwood growing stock (gross volume in all living trees with DBH ≥ 10 cm) and roundwood harvest. Defined "timber depletion coefficient" as ratio of change in stock between 1980 and 1990 (years of FAO forest inventories) to cumulative harvest during that interval. Used this coefficient to account implicitly for growth, defect, etc. in estimating net accumulation (see next section).

Valuation: Followed Vincent (1997) and Vincent, Rozali, and Associates (1997) in calculating net accumulation of roundwood by applying a generalized version of El Serafy's method, which relaxed the assumption of an infinitely large marginal cost elasticity. Assumed the elasticity equaled 1. Estimated the number of years until exhaustion by dividing roundwood stock by the product of harvest and the timber depletion coefficient. Used a 10-percent discount rate.

Official status: Study conducted for the Asian Development Bank.

Additional comments: Covered 14 countries in Asia. One of the few studies to apply the generalized El Serafy method. Concluded that net accumulation was greater for soils than for roundwood or subsoil assets in most countries, and that net accumulation summed across all resources was small relative to gross domestic savings. The ratio of net accumulation to total resource rent rose sharply during the period, however.

Australia (I)

Reference: Young (1993).

Period: 1980-89.

Scope: Subsoil assets, soil erosion, and salinization, in addition to forest resources.

Forest resources: Natural habitat.

Links to national accounts: (i) Current accounts—Added net accumulation of habitat, due to conversion of native forests, to GDP. (ii) Asset accounts—Did not calculate asset value of forests.

Physical accounts: Estimated annual rate of conversion of native forests at 230,000 hectares per year.

Valuation: Multiplied annual area of converted native forests times $1,000 per hectare, their assumed asset value as natural habitat.

Official status: Academic study.

Additional comments: Concluded that net accumulation of habitat was equivalent to about 0.1 percent of GDP, was much smaller than net accumulation of subsoil assets (by a factor of about 1,000), and was also smaller than agricultural land degradation, though not by nearly as much.

Australia (II)

Reference: Skinner (1995), Joisce (1996).

Period: 1989-92.

Scope: Subsoil assets, land, and livestock, in addition to forests.

Forest resources: Timber in native forests (including broadleaved plantations) and coniferous plantations.

Links to national accounts: (i) Current accounts—Made no adjustments. (ii) Asset accounts—Calculated asset value of forests for timber production and linked it to asset accounts. Treated native forests as non-cultivated, tangible, non-produced, non-financial assets, and plantations as inventories of produced, non-financial assets.

Physical accounts: Classified forest areas and associated growing stocks by state, ownership (public/private), legal availability for timber production, type (species), management system (even-aged/uneven-aged), and age class.

Valuation: For *mature native forests*, set asset value equal to total stumpage value: multiplied standing commercial volume times applicable official stumpage fees. For *immature native forests*, set asset value equal to projected harvest volume, times applicable stumpage fees (current levels), discounted by the number of years until maturity. Used a range of discount rates (5, 7.5, and 10 percent), though Skinner (1995) showed value estimates for just one (7.5 percent). Ignored value of thinnings. For *coniferous plantations*, used insured values, which were regarded as providing good estimates of market values.

Official status: Pilot project conducted by Australian Bureau of Statistics, to investigate implementation of SNA93 recommendations.

Additional comments: Provides probably the most sound estimates of asset values of timber stocks. Incorporated uneven-aged forests as well as even-aged forests, by using data on tree diameters to estimate years until harvest in the former case. Intend to estimate stumpage values, rather than using stumpage fees as a proxy, when data become available (expected “very shortly”). Found that native forests accounted for 1.3 percent of the value of non-produced, non-financial assets in 1992, while coniferous plantations accounted for 0.5 percent of produced, non-financial assets. In absolute terms, the value of native forests was about a third higher than the value of plantations.

Austria

Reference: Sekot, Gerhold, and Knieling (1996).

Period: Early 1990s (?).

Scope: Forest resources only.

Forest resources: Timber in high forests.

Links to national accounts: (i) Current accounts—Made no adjustments. (ii) Asset accounts—Calculated asset value of forests for timber production, with the eventual intention of linking it to asset accounts.

Physical accounts: Drew data from Austria's national forest inventory, which (with some additional work) provided information on growing stock by age class and species group.

Valuation: For *mature forests*, set asset value equal to total stumpage value: multiplied standing timber volume times stumpage value (average log price for species group minus country-wide average logging cost). For *immature forests*, multiplied area times per-hectare total stumpage value of mature forests times an "age constant," an implicit discount factor based on age class and rotation length.

Official status: Study sponsored by Austrian Central Statistical Office, to investigate implementation of ESA95.

Additional comments: Only study to use the "age constant" approach.

Canada (I)

Reference: Anielski (1992a, 1992b, 1994, 1996).

Period: 1979-91.

Scope: Forest resources only, for just the province of Alberta.

Forest resources: Timber and carbon sequestration in natural forests and plantations.

Links to national accounts: (i) Current accounts—Anielski (1992) added net accumulation of timber to provincial value added in forestry (1979-90). Anielski (1994) did this too and also added net accumulation to provincial GDP (1979-91). Made no adjustment for carbon sequestration, though calculated value. (ii) Asset accounts—Calculated asset value of forest for timber production, but did not link it to asset accounts.

Physical accounts: For growing stock, modeled after Repetto et al. (1989; see **Indonesia**), with additional detail on forest areas. Additions to growing stock included growth, with mature and immature stocks distinguished, and reforestation (treated as immature stock). Subtractions included harvest, fire, insect infestations, energy development, and agricultural land-use conversion. For carbon, Anielski (1992a) estimated gross annual carbon sequestration by multiplying forest area times annual wood increment (cubic meters per hectare) times a factor converting wood volume to tons of carbon.

Valuation: (i) Calculated net accumulation of *timber* by net price method: multiplied net depletion (defined as including only mature timber in commercial forests) times average stumpage value. For *carbon*, calculated value by multiplying quantity sequestered times estimated carbon values (taken from previous studies) ranging from $20/ton to $300/ton. (ii) Set asset value for timber equal to total stumpage value: multiplied volume of mature timber in commercial forests times average stumpage value.

Official status: Study conducted as part of a joint initiative by Statistics Canada and the provincial governments of Alberta and Ontario, to develop pilot renewable and nonrenewable resource accounts for Canada (see **Canada** (II), below). Author is an official in the Alberta Treasury.

Additional comments: Anielski (1992b) presented the first timber account in Canada, and Anielski (1992a) presented one of the first forest accounts to include carbon values. According to Anielski (1994), net accumulation of timber ranged from -27.2 percent to 34.3 percent of provincial forestry value added, but only -0.29 percent to 0.50 percent of provincial GDP.

Canada (II)

Reference: Statistics Canada (1997), Baumgarten (1996).

Period: 1961-91.

Scope: Forest resources only, for just the province of Ontario.

Forest resources: Timber in natural forests and plantations.

Links to national accounts: According to reports cited above, eventually intend to implement recommendations in SNA93, in particular to include timber in asset accounts. Had not done so at the time of those reports.

Physical accounts: Based on *Canada's Forest Inventory 1991*, with values for earlier years constructed using an internally consistent model that simulated the impacts of growth, harvest, natural losses, and other factors. Contained information on both forest areas and growing stocks, for three forest types and 180 single-year age-classes. Categories in the area accounts included: productive and unproductive forests for commercial timber production; reserved (protected), nonreserved but inaccessible, and nonreserved and accessible forests; stocked and nonstocked forests; age class; and hardwood, softwood, or mixed wood. Timber accounts showed opening and closing stocks, growth, and four causes of depletion: harvest, fire, mortality, and roads.

Valuation: Used both the present value method and the net price method to calculate asset value of timber. For the present value method, first calculated the total annual stumpage value of timber harvested and utilized in the province, by subtracting the costs of felling, transporting, and processing timber from the annual production value of forest products industries. In estimating costs, set the return on capital equal to the borrowing rate on corporate bonds. Second, subtracted total annual forest management expenditures (capital expenditures as well as current expenditures) incurred by the government from total stumpage value. Third, used a 5-year moving average to smooth the resulting estimates of net total stumpage values. Fourth, divided the smoothed estimates by 2 percent and 4 percent to calculate asset values. For the net price method, first divided the smoothed estimates from the present value method by annual timber harvest to calculate average net stumpage value per cubic meter. Then, multiplied average net stumpage value times standing timber volume.

Official status: Pilot project conducted by Statistics Canada.

Additional comments: Presented the longest time series of any study, and had access to some of the best data. One of the few studies to compare the asset value and net price methods and to use smoothed values. Found that the latter generated larger estimates, though only slightly larger toward the end of the period than those from the capitalized-value method for a 2-percent discount rate. According to all methods, the value of Ontario's timber stocks was larger in 1991 than in 1961.

Chile

Reference: Claude and Pizarro (n.d.).

Period: 1985-93 (plantations), 1985-94 (native forests).

Scope: Subsoil assets and fisheries, in addition to forest resources.

Forest resources: Timber in native forests and plantations (pine and eucalyptus).

Links to national accounts: According to report cited above, eventually intend to add estimates of net accumulation to NDP. Had not done so at the time of that report.

Physical accounts: Pertained to forest areas, not growing stocks. Classified native forests into protected and unprotected areas, site quality (for unprotected forests only), causes of deforestation (fire, agriculture, timber plantations), and managed logging vs. unmanaged logging ("creaming"). Prepared similar accounts for plantations, recording source of land for new plantations (native forests vs. other land).

Valuation: Not completed at the time the report was written. The report did not describe the methods to be employed.

Official status: Study initiated by National Accounts Department of the Central Bank of Chile, to investigate implementation of SNA93 and SEEA recommendations.

Additional comments: The physical accounts for native forests attracted world-wide attention when preliminary results were leaked to the press, as they indicated a sharp decrease in remaining area. The Central Bank has reportedly terminated the project.

Costa Rica (I)

Reference: Repetto et al. (1991).

Period: 1970-89.

Scope: Agricultural soils and fisheries, in addition to forest resources.

Forest resources: Timber in natural forests. Focused on two processes: deforestation of old-growth forests and reestablishment of second-growth forests. Second-growth forests referred to forests that had naturally reestablished themselves in abandoned pastures and farms, not to residual forests left by logging.

Links to national accounts: (i) Current accounts—Added net accumulation of timber to NDP, net domestic investment, and value added in agriculture. (ii) Asset accounts—Calculated asset value of second-growth forests for timber production, but did not link it to asset accounts.

Physical accounts: Used a geographic information system (GIS) to construct estimates of forest areas over time, and ecological relationships to construct estimates of growing stocks in those areas. Regarding areas, began by using spatial data on ecological life zones, soil groups, slope, and geology to define land units. Then overlay land-use maps for 1960 and 1984 on the land units to identify forested areas. Interpolated and extrapolated those areas to other years, using supplemental data from agricultural censuses conducted in 1963 and 1973. Regarding growing stocks, used ecological relationships (based on data from permanent plots) to estimate potential standing biomass and potential biomass growth rates in all trees with DBH $\geq$ 10 cm. Converted those estimates to expected values net of defect and biomass in tree parts other than the bole and main branches.

Valuation: Calculated net accumulation by the present value method. For *deforestation*, set net accumulation equal to the sum of two components: loss of standing timber value and loss of future harvest value. Set the former equal to total stumpage value (average stumpage value times net commercial standing timber volume), and the latter equal to the asset value of total stumpage values from an infinite series of future timber harvests. For *reestablishment of second-growth forests*, estimated the asset value of total stumpage value from future timber harvests, and then set net accumulation equal to the difference between these values from one year to the next. For both deforestation and reestablishment of second-growth forests, excluded forests in inaccessible areas or on slopes too steep for logging, and excluded timber volumes in trees below 50 cm dbh or in noncommercial species. Calculated site-specific stumpage values by adjusting for composition of standing volume by density class and by varying hauling costs according to distance from mill.

Official status: Study conducted by the World Resources Institute and the Tropical Science Center in Costa Rica at the invitation of the Costa Rican Minister of Natural Resources, Energy, and Mines.

Additional comments: After the World Resources Institute study in **Indonesia**, the second-most widely cited study on natural resource depletion and national income accounts. Pioneered the use of a GIS and asset values for estimating net accumulation of natural resources. Found that net accumulation of forests was substantially larger than net accumulation of soils and fisheries, due primarily to the loss of standing timber value due to deforestation. Net accumulation of second-growth forests was positive in most years, indicating an increase in asset value. Net accumulation of forests was equivalent to approximately 4 percent of GDP and 20 percent of gross domestic investment.

China

Reference: Li (1993).

Period: 1980-88.

Scope: Forest resources only.

Forest resources: Timber.

Links to national accounts: (i) Current accounts—Added value of growth of timber to GDP, and added net accumulation of timber to NDP. (ii) Asset accounts—Calculated asset value of forests for timber production, but did not link it to asset accounts.

Physical accounts: Based on physical accounts in Repetto et al. (1989; see **Indonesia**). Included six categories of subtractions from timber stocks: harvest, "construction in forest area," "consumption in culture operation," "consumption of energy" (fuelwood?), "calamities and other losses," and "other consumption."

Valuation: (i) Valued timber growth by multiplying annual volume of growth times accumulated forest management costs expressed on a unit basis. Accumulated costs with interest, from the year of forest regeneration up to the current age. Calculated net accumulation by a variant on the net price method: multiplied net depletion times the unit accumulated cost. (ii) Calculated asset value of timber by multiplying timber stock at beginning or end of year times unit accumulated cost. Did not separate out a capital gains ("revaluation") entry.

Official status: Study sponsored by the World Resources Institute and the Ford Foundation, and conducted by Chinese experts from numerous government agencies.

Additional comments: Kong et al. (1994) describe subsequent work, which included case studies on how to value particular forest functions. They did not calculate the values at the national level.

Costa Rica (II)

Reference: Aguirre (1996).

Period: 1993.

Scope: Forest resources only.

Forest resources: Timber in natural forests and plantations, carbon sequestration, watershed protection, ecotourism.

Links to national accounts: (i) Current accounts—Added net accumulation of timber, carbon stocks (a function of timber volume), and watershed and ecotourism services (a function of forest area) to net value added in forestry. (ii) Asset accounts—Did not calculate asset value of forests.

Physical accounts: For growing stock, similar to those in Repetto et al. (1989; see **Indonesia**). Defined stock as standing volume in commercial timber trees with DBH ≥ 10 cm. Included two additions to stocks (growth, reforestation) and five subtractions (harvest, logging damage, deforestation, fire damage, and stand mortality). Assumed net amount of carbon sequestered was proportional to net depletion of timber stock. For *watershed* and *ecotourism services*, constructed accounts showing forest areas.

Valuation: Calculated net accumulation by the net price method and variants thereof. For *timber*, multiplied net depletion times average stumpage value. For *carbon*, converted net depletion of timber from cubic meters to tons of carbon, and then multiplied by US$10 per ton of CO_2. For *watershed services*, multiplied change in forest area times 9000 cubic meters per hectare per year times average water rate paid by Costa Rican water consumers. For *ecotourism*, multiplied change in forest area times US$74.04 per hectare, the estimated net expenditure by international ecotourists.

Official status: Academic study, to investigate how SEEA can be adapted to Costa Rican forest resources.

Additional comments: Concluded that actual net value added in forestry was only 4.3 percent of the official value. Net accumulation of timber accounted for most of the discrepancy (more than half), followed by net accumulation of *watershed services*.

Ecuador

Reference: Kellenberg (1995).

Period: 1971-90.

Scope: Subsoil assets (petroleum), in addition to forest resources.

Forest resources: Timber in natural forests and plantations.

Links to national accounts: (i) Current accounts—Added net accumulation of timber to NDP and net domestic investment. (ii) Asset accounts—Did not calculate asset value of forests.

Physical accounts: Reportedly similar to accounts constructed for Indonesia by Repetto et al. (1989; see **Indonesia**), although this is not entirely evident from the report cited above.

Valuation: Calculated net accumulation by variations on the two methods in Sadoff (1993; see **Thailand**), i.e. the net price method (called the "depreciation method") and the replacement cost method (called the "user cost method"). For the former, multiplied an adjusted measure of net depletion of timber stocks times average stumpage value. Adjusted net depletion downward to include only the potential "volume actually commercialized." Differentiated stumpage values according to 9 timber-producing regions and 3 potential export sites. For the second method, estimated the replacement cost of timber plantations required to offset the value of the net depletion of natural timber stocks. Did this in three steps. First, divided the net accumulation estimate from the net price method by the net present value of one hectare of a representative timber plantation, to estimate the number of hectares of new plantations required to offset the reduction in timber value of the natural forest. Then, reduced this number by the actual area of new plantations. Finally, multiplied the resulting amount times the capitalized cost of establishing and maintaining one hectare of a representative plantation.

Official status: Academic study (Ph.D. dissertation).

Additional comments: One of two studies to compare net accumulation estimates from the net price and replacement cost methods. Found that the two methods yielded estimates differing by about a third, with estimates of the net price method being larger. Net accumulation of timber was much smaller than net accumulation of petroleum and was equivalent to about 0.6 percent of GDP and about 5 percent of depreciation of human-made capital.

Finland (I)

Reference: Koltolla and Mukkonen (1996).

Period: 1990-94.

Scope: Forest resources only.

Forest resources: Timber in natural forests and plantations.

Links to national accounts: (i) Current accounts—Added value of net growth of timber to GDP and value added in forestry and logging. (ii) Asset accounts—Did not calculate asset value of forests.

Physical accounts: Similar to Repetto et al. (1989; see **Indonesia**), with more detail on species composition. Included estimates of opening and closing stocks, annual growth, and "total drain," comprised of net removals (sawlogs, pulpwood, fuelwood), silvicultural waste, and natural losses. Presented this information for three forest types: pine, spruce, broadleaved.

Valuation: Multiplied net growth (growth minus total drain) in each forest type times corresponding average stumpage value.

Official status: Study conducted by Statistics Finland, to investigate implementation of recommendations for forest resources in SNA93 and ESA95 (European System of Accounts). Did not consider recommendations in SEEA.

Additional comments: Critiqued the SNA93/ESA95 recommendation that net growth in cultivated forests be treated as "work-in-progress," arguing that it is "in contradiction with the aim of avoiding imputed concepts of income in national accounts" (p. 185) and that it creates an inconsistency with the treatment of net growth in "controlled but uncultivated" forests and non-controlled forests, which may differ little from cultivated forests. Concluded that the adjustment (for all forests, not just cultivated ones) would be equivalent to only 0.3-0.6 percent of GDP as currently calculated, but up to 30 percent of value added in forestry and logging.

Finland (II)

Reference: Hoffrén (1996).

Period: 1990-95.

Scope: Forest resources only.

Forest resources: Timber; Christmas trees and game; berries, mushrooms, reindeer farming, and lichen; peat; carbon sequestration, biodiversity protection, and recreation; acid deposition and defoliation.

Links to national accounts: Similar to Hulkrantz (1992; see **Sweden** (I)), but did not distinguish between values of stocks and flows. (i) Current accounts—Made several adjustments to value added in forestry: subtracted depreciation of silvicultural investments and added net accumulation of timber; reallocated the value of production of berries, mushrooms, reindeer farming, and lichen from agriculture; reallocated the production of peat from mining and quarrying; added the nonmarket value of carbon sequestration, biodiversity protection, and recreation; and subtracted damage to timber production caused by acid deposition and defoliation. Made no adjustment for game and Christmas trees, which were already included in forestry value added. (ii) Asset accounts—Did not calculate asset value of forests.

Physical accounts: Apparently drew information on growing stocks from existing physical balance sheets for timber resources maintained by Statistics Finland. Structure of accounts for other forest resources varied considerably.

Valuation: Used various methods. Did not need to estimate values for *game, Christmas trees*, *berries*, *mushrooms*, *reindeer farming*, *lichen*, *peat*, and depreciation of investments in timber cultivation, as used existing values in the national accounts. Calculated net accumulation of *timber* by the net price method: multiplied net depletion (harvest minus growth) times average stumpage value. For *carbon*, converted net depletion of timber volume to net change in tons of sequestered carbon, and multiplied the latter times the Finnish carbon tax. For *biodiversity*, calculated cost of complying with forestry regulations intended to protect biodiversity (e.g., forgone stumpage value associated with more selective harvesting). For *recreation*, multiplied number of visitors times value estimates for a visitor-day from willingness-to-pay studies. For *acid deposition*, multiplied tons of nitrogen oxides and sulfur dioxide deposited in forests times unit abatement costs to polluting industries. For *defoliation*, multiplied estimated forgone timber growth times average stumpage value.

Official status: Study initiated by Statistics Finland, to investigate implementation of SEEA recommendations. Objective is to integrate forest resource accounts and Finland's national accounts.

Additional comments: Most ambitious study in terms of addressing nontimber values. Found that gross and net values associated with timber production differed little, and that the net value of timber production accounted for two-thirds of total net value in forestry. Recreation and carbon sequestration provided next largest values.

Indonesia

Reference: Repetto et al. (1989).

Period: 1970-84.

Scope: Subsoil assets (petroleum) and agricultural soils, in addition to forest resources.

Forest resources: Timber in natural forests and plantations.

Links to national accounts: (i) Current accounts—Added net accumulation of timber to GDP and gross domestic investment. (ii) Asset accounts—Calculated asset value of forests for timber production, but did not link it to asset accounts.

Physical accounts: Pertained to growing stock, not area, although data on area underlay some of the volume estimates (e.g., for additions to timber stocks due to plantation establishment, and subtractions due to deforestation). Applied the annual accounting identity,

Closing stock = Opening stock + Additions - Subtractions.

Additions included growth and reforestation; subtractions included harvest, logging damage, fire damage, and losses due to deforestation. Defined growing stock as gross wood volume in the boles of all living trees with DBH ≥ 10 cm. For growth in natural forests, assumed constant area of logged-over forests, growing at 1.5 m^3/ha/yr (net commercial volume). Assumed harvests occurred only in old-growth forests. For deforestation and fire damage, multiplied area estimates times estimates of gross standing volumes for all trees with DBH ≥ 10 cm.

Valuation: (i) Calculated net investment (value of the change) for timber by a variation on the net price method. For *natural forests*, multiplied net depletion of timber stock (subtractions minus additions) times average stumpage value (average price minus average logging cost). But valued additions due to growth, and subtractions due to logging damage, fire damage, and deforestation, at half the average stumpage value, as a proxy for the average asset value of eventual harvests in logged-over forests. Set net accumulation of *plantations* equal to zero, because they generated only an ordinary rate of return on invested capital. (ii) Calculated asset value of timber by multiplying timber stock at beginning or end of year times corresponding average stumpage value. Separated out a capital gains ("revaluation") entry, defined as the difference between change in value of the stock and net investment.

Official status: Study conducted by the World Resources Institute, independent of the Indonesian government. The "Acknowledgments" section of the report notes interest by the Minister of Environment and Population.

Additional comments: The most widely cited study on natural resource depletion and national income accounts. Popularized the net price approach for estimating net investment and valuing the timber stock. Found that net investment in timber was substantially smaller than for petroleum and substantially larger than for agricultural soils, and was equivalent to approximately 5 percent of GDP and 25 percent of gross domestic investment.

Malaysia (I)

Reference: Vincent et al. (1993).

Period: 1971-89.

Scope: Subsoil assets and agricultural soils, in addition to forest resources.

Forest resources: Timber, carbon sequestration, biodiversity, and game in natural forests.

Links to national accounts: (i) Current accounts—Added net accumulation of timber to NDP and net domestic investment. Calculated net accumulation of carbon and biodiversity stocks, and value of nonmarket production of game, but did not link them to the national accounts. (ii) Asset accounts—Did not calculate asset value of forests.

Physical accounts: For timber, similar to the physical accounts in Repetto et al. (1989; see **Indonesia**), with more explicit attention paid to forest areas and the distinction between old-growth and second-growth forests. Constructed accounts to be internally consistent in terms of transfers of areas from old-growth to second-growth forests due to logging, and accounted for harvesting and deforestation in both old-growth and second-growth forests. Defined growing stock as including only trees of commercial size. Created separate regional accounts for Peninsular Malaysia, Sabah, and Sarawak. For carbon, converted timber volumes to tons of carbon equivalents. For biodiversity, used forest areas to calculate a habitat index (based on island biogeography theory), which predicted percentage of original species that had been driven to local extinction. For game, assumed game harvest was proportional to forest area.

Valuation: Calculated net accumulation of *timber* by net price method: multiplied net depletion of timber (subtractions from timber stock minus additions) times smoothed value of average stumpage value (smoothed by using fitted values from regression on time trend). Calculated net accumulation of *carbon* by converting net depletion of timber from cubic meters to tons of carbon, and then multiplying by range of estimates of carbon taxes for U.S. Calculated net accumulation of *biodiversity* by multiplying number of new extinctions times unit value of a species. Used various methods to estimate the latter: expenditure to relocate a locally endangered species (the Asian elephant) to protected areas, expenditure to reintroduce a locally extinct species (the milky stork), and net present value of genetic improvements due to wild genes from a local fruit tree (durian). Calculated value of nonmarket production of *game* by multiplying hectares of forest in Sarawak times $10.28 per hectare, the assumed value of annual game production (based on reported values in the literature).

Official status: Study sponsored by the Economic Planning Unit in the Prime Minister's Department, as part of the Malaysian *National Conservation Strategy*.

Additional comments: One of the first studies to include a range of nontimber benefits as well as timber, although it did not link the former to the national accounts. Concluded that net accumulation of timber exceeded net accumulation of subsoil assets.

Malaysia (II)

Reference: Vincent (1997), Vincent et al. (1997).

Period: 1970-90.

Scope: Subsoil assets, in addition to forest resources.

Forest resources: Timber in natural forests.

Links to national accounts: (i) Current accounts—Added net accumulation of timber from NDP and net domestic investment at both the national and subnational (Peninsular Malaysia, Sabah, Sarawak) levels. (ii) Asset accounts—Did not calculate asset value of forests.

Physical accounts: Same as in Vincent et al. (1993; see **Malaysia** (I)).

Valuation: Calculated net accumulation of timber by applying a generalized version of El Serafy's (1989) formula, which relaxed the assumption of an infinitely large marginal cost elasticity. Applied the formula to just timber depletion in old-growth forests, on the assumption that second-growth forests would be managed for sustained-yield timber production. Excluded defect and logging damage from calculation of net depletion. Used a marginal cost elasticity of 3 and a 10-percent discount rate.

Official status: Academic study, conducted in collaboration with Institute of Strategic and International Studies Malaysia. Updated and revised Vincent et al. (1993), which was sponsored by the Malaysian government.

Additional comments: One of the few studies to modify subnational accounts, to exclude defect and logging damage from the calculation of net depletion, and to apply the generalized version of El Serafy's formula. Unlike Vincent et al. (1993), concluded that net accumulation of subsoil assets exceeded net accumulation of timber toward the end of the period. Concluded that net accumulation of timber was very large relative to NDP and net domestic investment in Sabah and Sarawak, but not at the national level.

México

Reference: van Tongeren et al. (1993).

Period: 1985

Scope: Subsoil assets (petroleum) and environmental degradation (air and water pollution, solid waste, soil erosion, and groundwater depletion), in addition to forest resources.

Forest resources: Timber, apparently in both natural forests and plantations, and soil erosion in forestland.

Links to national accounts: (i) Current accounts—Added net accumulation of timber, forestland, forest soils, and developed land (land used in agriculture, pasturing, and urban areas) to NDP and value added in pertinent industries (e.g., ones using converted forestland as an input). (ii) Asset accounts—Did not calculate asset value of forests, as viewed them as "nonproduced environmental assets."

Physical accounts: Details not clear. Drew data on forest resources (area and growing stock, without detail on species composition) from the national forest inventory, data on changes in land use from an inventory prepared by the Secretaria de Agricultura and Recursos Hidraulicos, and data on soil erosion in different land uses from a report prepared by the Comision Nacional de Ecologia.

Valuation: Calculated net accumulation of *timber* by both the net price method (multiplied net change in timber stock times the national average stumpage value) and El Serafy's method. Calculated net accumulation of *forestland* and *developed land* by the present value method. Estimated that asset values equaled 38.15 million pesos/ha for forestland (timber production only), 2.64 million pesos/ha for agriculture, 1.99 million pesos/ha for pastureland, 75.50 million pesos/ha for urban land, and zero for abandoned shifting cultivation. Calculated net accumulation of *forest soils* by the replacement cost method: estimated cost of fertilizer required to offset productivity decline caused by erosion.

Official status: Study conducted by the U.N. Statistical Division, the World Bank, and the Mexican Instituto Nacional de Estadistica, Geografia, e Informatica (INEGI), with partial funding from UNDP. Intended to test and illustrate key features of the SEEA. INEGI is the government agency responsible for compiling the Mexican system of national accounts.

Additional comments: The only study to compare net accumulation estimates from the net price and El Serafy methods, and one of the few to treat deforestation as a process that not only reduced the stock of forestland but increased the stock of developed land. Found that the net price method yielded much higher (factor of 15) estimates of net accumulation of timber, and that deforestation decreased the total value of land. Net accumulation of timber was equivalent to 2.3 percent of NDP, net accumulation of forestland 52 percent, and net accumulation of forest soils 0.2 percent. All these values were much lower than values associated with petroleum depletion.

Nepal

Reference: Katila (1995).

Period: 1991.

Scope: Forest resources only.

Forest resources: Timber, fuelwood, fodder.

Links to national accounts: (i) Current accounts—Added the value of nonmarket production of timber, fuelwood, and fodder to GDP, and the net accumulation of timber and fuelwood to GDP thus modified and to modified value added in forestry. Did not calculate net accumulation of fodder, citing rising stocks. (ii) Asset accounts—Did not calculate asset value of forests.

Physical accounts: Assumed nonmarket production of timber, fuelwood, and fodder equaled consumption, with a 5-percent adjustment to account for logs smuggled to India. Constructed consumption estimates using data from various sources. For timber and fuelwood, set net depletion equal to the difference between estimated production and "sustainable supplies" as reported in the *Master Plan for the Forestry Sector of Nepal*. Did not calculate net depletion of fodder.

Valuation: a. For adjustments to GDP for nonmarket production, used different methods for the three nonmarket goods. For *timber*, multiplied production times proxy for national average stumpage value (log price of one species, sissoo, minus manual harvesting costs and risk margin). For *fuelwood*, multiplied production times shadow price estimated by three methods: opportunity cost of time spent collecting fuelwood (weighted average of shadow wage rate during slack season and market wage during peak season), price of fuelwood sold in local markets, and price of a substitute fuel (cattle dung). Preferred the first method, which yielded median estimate. For *fodder*, multiplied production times shadow price estimated by two methods: opportunity cost of time spent collecting fodder, and the implicit value of fodder as an input in producing milk (roughly speaking, the input-output coefficient times milk price). Preferred the latter method, which yielded slightly lower estimate (conservative approach).
b. For net accumulation, intended to multiply net depletion times net price, and add the "revaluation" term as defined by Repetto et al. (1989; see **Indonesia**). Due to lack of data on price changes, did not calculate "revaluation" term. For *timber*, set net price equal to proxy for stumpage value described above. For *fuelwood*, used shadow price described above instead of net price.

Official status: Academic study.

Additional comments: Report cited above presents main findings of a study funded by the Finnish International Development Agency, *Modified GDP Accounts for Nepal: Case Study of Accounting for Market and Non-Market Production of Timber, Fuelwood, and Fodder* (1993). We were unable to obtain the full report of the study. One of the few studies to adjust GDP for production of nonmarket forest-related goods; in some ways, modeled after Peskin (1989; see **Tanzania**). Found that the addition of the three nonmarket goods increased forestry's GDP share from 4.9 percent to 14.6 percent, with timber being responsible for more than half of the increase. Net accumulation was equivalent to 18 percent of modified value added in forestry.

New Zealand

Reference: Bigsby (1995).

Period: 1978-present.

Scope: Forest resources only.

Forest resources: Timber in plantations. Clough (1992) proposed a framework for natural forests but did not implement it.

Links to national accounts: (i) Current accounts—The New Zealand System of National Accounts (NZSNA) treats growth of plantations as "work in progress" (change in inventories) and adds the associated value to GDP. (ii) Asset accounts—NZSNA records changes in value of plantations in asset accounts.

Physical accounts: NZSNA obtains growing stock estimates for plantations from annual updates of the *National Exotic Forest Description* (NEFD).

Valuation: NZSNA multiplies aggregate standing timber volume times national average stumpage value for plantation species.

Official status: NZSNA is implementing the procedures summarized above.

Additional comments: Changes in value of plantations accounted for about 1.5 percent of GDP during 1989-93. Bigsby (1995) argued that asset values would provide more accurate estimates of plantation values, and that the NEFD contains sufficient data to calculate them (e.g., regionalized data on areas planted by species, age, silvicultural treatment, and yield tables).

Papua New Guinea

References: Bartelmus et al. (1992, 1993), Bartelmus (1994).

Period: 1986-90.

Scope: Subsoil assets and energy, in addition to forest resources.

Forest resources: Nontimber values ("ecological, social, and spiritual values") in natural forests.

Links to national accounts: (i) Current accounts—Subtracted value of nontimber values lost due to deforestation and logging from NDP and from net value added in agriculture. (ii) Asset accounts—Did not calculate asset value of forests.

Physical accounts: Divided forests into two categories: potential economic use (forests where logging is financially viable) and environmental use (forests where logging is not viable, due to inaccessibility or low timber quality). Assumed that the area of each remained constant over time. Subdivided the first category into virgin and logged-over forests, and the second into shifting agriculture, shrubs, forest plantations, and natural forest. Estimated changes in areas in these subcategories over time.

Valuation: Calculated net loss of nontimber values due to logging and deforestation by multiplying areas logged and converted to shifting cultivation, respectively, by per-hectare values. After considering several possible valuation approaches (restoration costs, avoidance costs, defensive expenditures), decided to use compensation awards as an indicator of per-hectare values, as tribal groupings and clans, who own land and water resources in Papua New Guinea, are legally entitled to receive compensation when forests are degraded. For deforestation, used 7 kina/m^3, converted to a hectare basis, which is the amount of compensation paid by logging companies to landowners. For logging, added 2 kina/m^3 (the "forest management levy") to this compensation rate. The authors noted that conventional national accounts should already reflect these payments, but only if the payments are actually made, which is not always the case.

Official status: Study sponsored by the U.N. Statistical Office and the World Bank to test and illustrate key features of the SEEA. The study team consulted with, among others, the National Statistical Office, Department of Finance and Planning, and the Office of the Prime Minister in Papua New Guinea.

Additional comments: Found that value of forest degradation was smaller in most years than the value of environmental degradation associated with mining, and was equivalent to 0.7-6.7 percent of NDP and 7.6-57.3 percent of value added in agriculture. The authors originally intended to estimate net accumulation of timber, but they were unable to translate their estimates of changes in forest areas into estimates of changes in timber stocks. They commented that the large variety of forest types prevented them from simply multiplying areas times a simple conversion factor (cubic meters of timber per hectare of forest), that reported timber harvests were probably understated, and that reliable data were not available on forest regeneration. They suggested that if they had been able to estimate net depletion of the timber stock, they would have calculated net accumulation by an approach similar to the one in Repetto et al. (1989); (see **Indonesia)**.

Philippines (I)

References: IRG et al. (1991, 1992).

Period: 1970-89.

Scope: Forest resources only. Phase II of the project planned to cover additional resources.

Forest resources: Roundwood (timber, fuelwood, charcoal) in natural forests (dipterocarp forests, pine forests, mangroves) and plantations; rattan.

Links to national accounts: (i) Current accounts—Added net accumulation of roundwood and rattan to NNP. (ii) Asset accounts—Calculated asset value of dipterocarp forests for timber production, but did not link it to asset accounts.

Physical accounts: Essentially identical to the physical accounts in Repetto et al. (1989; see **Indonesia**), with more explicit attention paid to the distinction between old-growth and second-growth forests.

Valuation: (i) Calculated net accumulation by both the net price method and the present value method. For the former, set net accumulation equal to not just the product of net depletion of roundwood or rattan stocks and the corresponding average stumpage value (as in Repetto et al. 1989; see **Indonesia**), but to the sum of that product and the "revaluation" term as defined by Repetto et al. (1989). For the second method, calculated the asset value of dipterocarp forest by assuming a 15-percent discount rate, a 20-year time horizon for liquidating timber stocks in old-growth forests (i.e., 1990 = depletion date), and sustained-yield timber production from second-growth forests under a 40-year cutting cycle. Set net accumulation equal to the difference between successive annual values. (ii) Calculated asset value of dipterocarp forest by procedure described above.

Official status: Study conducted by International Resources Group, Ltd., in association with Mandala Agricultural Development Corporation and Edgevale Associates, for the Philippines Department of Environment and Natural Resources (DENR), with technical support from the DENR and the National Statistical Coordination Board.

Additional comments: Apparently the first study to compare alternative methods for estimating net accumulation of timber. Found that the net price and present value methods yielded very different estimates, with the net price method yielding estimates approximately 30 times larger than those from the present value method. Concluded that the latter method was the more sound. Estimates of net accumulation from that method were equivalent to only 0.2 percent of NNP. Net accumulation of plantations, pine forests, mangroves, and rattan resources was tiny compared to net accumulation of dipterocarp forests.

Philippines (II)

Reference: Cruz and Repetto (1992).

Period: 1970-87.

Scope: Agricultural soils and fisheries, in addition to forest resources.

Forest resources: Timber in natural forests.

Links to national accounts: (i) Current accounts—Added net accumulation of timber to GDP and to gross investment in agriculture, which includes forestry and fisheries. (ii) Asset accounts—Calculated asset value of forests for timber production, but did not link it to asset accounts.

Physical accounts: Essentially identical to the physical accounts in Repetto et al. (1989; see **Indonesia**).

Valuation: Essentially identical to valuation in Repetto et al. (1989; see **Indonesia**).

Official status: Study conducted by the World Resources Institute, independent of the Philippines government. The "Acknowledgments" section of the report notes "encouragement" provided by several government officials, for example for Director-General of the National Economic and Development Authority and the Secretary of the Department of Environment and Natural Resources.

Additional comments: The third in a series of studies by the World Resources Institute (see **Costa Rica** (I) and **Indonesia**). Unlike the other two, placed the net accumulation of natural resources in the context of structural adjustment programs. Found that net accumulation of timber was substantially larger than for agricultural soils and fisheries, was equivalent to approximately 3 percent of GDP, and was larger than gross investment in agriculture in most years.

Sweden (I)

Reference: Hulkrantz (1992).

Period: 1987.

Scope: Forest resources only.

Forest resources: Timber; fuelwood, berries, mushrooms, and game; reindeer forage; carbon sequestration; biological diversity; and forest soils.

Links to national accounts: (i) Current accounts—Added the value of nonmarket production of several nontimber benefits (fuelwood, berries, mushrooms, and game), and the net accumulation of timber stocks, reindeer forage, sequestered carbon, biological diversity, and forest soils, to net value added in forestry. (ii) Asset accounts—Did not calculate asset value of forests.

Physical accounts: None.

Valuation: a. Used a variety of methods to value nonmarket production. For *fuelwood* and *berries*, scaled official estimates upward using the ratio of estimated actual physical production to official production. For *mushrooms* and *game*, used survey estimates of physical production and market prices. b. Also used a variety of methods for net accumulation. For *timber*, used a variant on the net price method: multiplied net depletion times average stumpage value, and added silvicultural expenditures. For *reindeer forage*, used the present value method: valued a unit of forage by the price of its substitute, hay, and applied a 5 percent discount rate. For *carbon*, converted net depletion of timber volume to net change in tons of sequestered carbon, and multiplied the latter times the Swedish carbon tax. For *biological diversity*, used the opportunity costmethod: stumpage value of forests that needed to be taken out of timber production to increase protected area to 10 percent of total forest area. For *forest soils*, used the replacement cost method: calculated cost of limestone and magnesium needed to offset acid deposition and maintain stocks of base cations.

Official status: Academic study. Consulted officials in the Central Bureau of Statistics.

Additional comments: One of first studies to address nonmarket values, and still one of the most ambitious (surpassed only by Hoffrén 1996; see **Finland**). Concluded that net value added in forestry was 34 percent larger than gross value added reported in official income accounts. Discrepancy was due mainly to appreciation of timber stock and sequestration of carbon. Values associated with timber far exceeded nonmarket values: the former accounted for 81 percent of net value added.

Sweden (II)

Reference: Eliasson (1996).

Period: 1987, 1991. Estimates for 1987 are minor revisions of Hulkrantz's (1992) estimates. See **Sweden** (I).

Scope: Same as Hulkrantz (1992).

Forest resources: Same as Hulkrantz (1992).

Links to national accounts: Same as Hulkrantz (1992).

Physical accounts: Same as Hulkrantz (1992).

Valuation: Same as Hulkrantz (1992).

Official status: Same as Hulkrantz (1992).

Additional comments: Replication of Hulkrantz (1992) study. Obtained very similar results for both 1987 and 1991.

Tanzania

Reference: Peskin (1989).

Period: 1980.

Scope: Forest resources only.

Forest resources: Fuelwood.

Links to national accounts: (i) Current accounts—Added the value of nonmarket production of fuelwood to GDP and NDP, and the net accumulation of fuelwood to NDP. (ii) Asset accounts—Did not calculate asset value of forests.

Physical accounts: None.

Valuation: a. Adjusted GDP for value of nonmarket fuelwood production by the opportunity costmethod. First, multiplied estimated person-days per year spent by households collecting fuelwood times the opportunity cost of time (assumed to equal the Tanzanian minimum wage). Then, deducted from this amount the value of household fuelwood collection already included in the national accounts. Finally, added the remaining amount to GDP. b. Calculated net accumulation of fuelwood by a method equivalent to the net price method. First, estimated annual volume of regenerated fuelwood. Then, multiplied this volume times the imputed unit value from the calculations in “a.” Next, subtracted this product from the total fuelwood value in “a.” Finally, subtracted the remaining amount from NDP.

Official status: Example included in World Bank study covering broader issues of natural resources and national income accounts.

Additional comments: First study to correct GDP for exclusion of nontimber values, and one of the first to correct NDP for net accumulation of forest capital. Concluded that actual production value of fuelwood was more than 10 times greater than official value, and this increased estimated GDP by 6.3 percent. Net accumulation was equivalent to 69 percent of forestry value added and 5.5 percent of adjusted NDP.

Thailand

References: Sadoff (1993, 1995).

Period: 1970-90.

Scope: Forest resources only.

Forest resources: Timber in natural forests. Focused on reductions in timber stocks due to deforestation.

Links to national accounts: (i) Current accounts—Added net accumulation of timber to NDP, net domestic investment, and value added in forestry and agriculture. (ii) Asset accounts—Did not calculate asset value of forests.

Physical accounts: Estimated areas and associated densities of standing commercial timber volumes (cubic meters per hectare, for trees with a girth ≥ 100 cm at breast height) for four forest types (tropical evergreen, mixed deciduous, dry dipterocarp, pine) in four regions (northern, northeastern, central, southern). Related change in density between forest inventories to change in forest area, and used this relationship to predict densities for years other than inventory years. Multiplied area times density to estimate timber stock, and set net depletion equal to change in stock from one year to the next.

Valuation: Calculated net accumulation of timber by both the net price method (referred to as the "depreciation method") and the replacement cost method (referred to as the "user cost method"). For the former, multiplied an adjusted measure of net depletion times stumpage value. Adjusted net depletion downward to exclude noncommercial species and a "normal" amount of timber damaged during logging. For the second method, multiplied net area deforested times the per-hectare cost of reforestation. Set the latter equal to the discounted sum of establishment and maintenance costs over a single plantation rotation.

Official status: Academic study (Ph.D. dissertation).

Additional comments: First study to compare net accumulation estimates from the net price and replacement cost methods. Found that the two methods yielded similar estimates from the mid-1970s forward. According to both, net value added was negative in forestry in most years (net accumulation, which was negative, exceeded value added), but positive in agriculture in all years. Net accumulation of timber was equivalent to about 2 percent of GDP and about 20 percent of the depreciation of human-made capital.

United States

Reference: Howell (1996).

Period: 1987.

Scope: Subsoil assets, land, and air and water quality, in addition to forest resources.

Forest resources: Timber, forestland.

Links to national accounts: (i) Current accounts—Developed framework for linking changes in forest resources to current accounts, but did not implement it. (ii) Asset accounts—Calculated asset values of timber and forestland stocks and included them in asset accounts. Treated both as "Produced assets" ("Developed natural assets"), with timber being a "Cultivated fixed natural growth asset" (not "Work-in-progress") and forestland being in the "Developed land" category. Also included line items for "Timber and other plants of uncultivated forests" and "Undeveloped land" in the "Nonproduced/environmental assets" section of the asset accounts, but did not completely fill in those lines.

Physical accounts: For timber, compiled data on growing stock of live trees of commercial species with DBH ≥ 5 inches on commercial timberland. Apparently, also compiled data on timber harvest and natural growth. For forestland, compiled data on area of all forestland, excluding land in parks, wildlife areas, and other special land uses.

Valuation: Calculated asset value of *timber* by the net price method. Calculated value of "Opening stocks" by multiplying timber stocks at beginning of year by average stumpage value at the beginning of the year. Calculated value of "Closing stocks" analogously. Set "Depreciation, depletion, degradation" equal to the negative of the product of harvest times average of stumpage values at beginning and end of year. Similarly, set "Capital formation" equal to product of growth times average of stumpage values. Finally, set "Revaluation and other changes" equal to residual amount after subtracting "Opening stocks," "Depreciation, depletion, degradation," and "Capital formation" from "Closing stocks." Calculated asset value of *forestland* similarly. Calculated value of "Opening stocks" by multiplying forestland area at beginning of year by corresponding average agricultural land price, the assumed opportunity cost of forestry. Calculated value of "Closing stocks" analogously. Set "Depreciation, depletion, degradation" equal to product of net change in forestland area (which turned out to be negative) times average of average agricultural land prices at beginning and end of year. Did not include "Capital formation" entry. Finally, determined "Revaluation and other changes" as a residual.

Official status: Product of the first phase of a three-phase workplan by the U.S. Bureau of Economic Analysis to develop a framework of Integrated Economic and Environmental Satellite Accounts (IEESAs). Presented the proposed framework in April, 1994. According to Howell (1996, p. 181), "At the request of Congress, the work has been put on hold pending completion of a National Academy of Sciences study of the IEESA's."

Additional comments: One of the few studies to attempt to value timber stocks and forestland separately. Used "smoothed" stumpage values to remove extreme fluctuations reflecting short-run market rigidities. Concluded that asset values of timber and forestland were similar, with the former being slightly larger than the latter, and that both rose during 1987. In both cases, the increases were due overwhelmingly to the "Revaluation and other changes" entry. Both values were a small proportion (less than 3 percent) of "Produced assets."

Zimbabwe

Reference: Crowards (1996).

Period: 1980-89.

Scope: Subsoil assets (gold) and agricultural soils, in addition to forest resources.

Forest resources: Roundwood (fuelwood, construction timber) in natural forests.

Links to national accounts: (i) Current accounts—Added net accumulation of roundwood to GDP and to value added in agriculture, which includes forestry. (ii) Asset accounts—Did not calculate asset value of forests.

Physical accounts: Estimated roundwood consumption in various end uses (fuelwood for rural and urban households and tobacco curing, construction timber for rural households and mining) and additional roundwood lost during land conversion (burning to clear woodlands for agriculture). Set net depletion equal to the difference between the sum of these estimates and the estimated mean annual increment in accessible woodlands.

Valuation: Calculated net accumulation of roundwood by net price method: multiplied net depletion times average stumpage value. Set stumpage value equal to the difference between consumption-weighted roundwood price and opportunity cost of labor used in collecting roundwood (based on the wage rate for female casual agricultural labor).

Official status: Academic study.

Additional comments: One of the few studies conducted in Africa. Found that net accumulation of roundwood accounted for only 0.1-0.3 percent of GDP and was much smaller than net accumulation of subsoil assets and agricultural soils.

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TABLES

Table 1 National accounting matrix for timber-producing forest (no deforestation or depreciation of human-made capital).

	Labor	*Capital*	*Forest*	*Consumer goods*	*Investment goods*	*Logs*	*Households*
Labor				Wages paid to labor employed in production of consumer goods	Wages paid to labor employed in production of investment goods	Wages paid to labor employed in timber harvesting	
Capital				Earnings on capital employed in production of consumer goods	Earnings on capital employed in production of investment goods	Earnings on capital employed in timber harvesting	
Forest							-Depreciation of timber
Consumer goods							Expenditure on consumer goods
Investment goods							Expenditure on investment goods
Logs				Logs used in production of consumer goods	Logs used in production of investment goods	Logs used in timber harvesting	
Households	Total wages	Total earnings on capital	-Depreciation of timber			Total resource rent	

Table 2 Additional entries to national accounting matrix in Table 1, due to forest amenities.

	Labor	*Capital*	*Forest*	*Consumer goods*	*Investment goods*	*Logs*	*Households*
Labor							
Capital							
Forest							Value of forest amenities
Consumer goods							
Investment goods							
Logs							
Households			Value of forest amenities				

Table 3 National accounting matrix for timber-producing forest, with deforestation.

	Labor	*Capital*	*Forest*	*Agricultural land*	*Consumer goods*	*Investment goods*	*Logs*	*Land clearing*	*Households*
Labor					Wages paid to labor employed in production of consumer goods	Wages paid to labor employed in production of investment goods	Wages paid to labor employed in timber harvesting	Wages paid to labor employed in land clearing	
Capital					Earnings on capital employed in production of consumer goods	Earnings on capital employed in production of investment goods	Earnings on capital employed in timber harvesting	Earnings on capital employed in land clearing	
Forest									Depreciation of timber
Agricultural land					Payments to agricultural land employed in production of consumer goods	Payments to agricultural land employed in production of investment goods			
Consumer goods									Expenditure on consumer goods
Investment goods									Expenditure on investment goods
Logs					Logs used in production of consumer goods	Logs used in production of investment goods	Logs used in timber harvesting	Timber used in land clearing	
Land clearing									Price of agricultural land minus price of forestland, times area deforested
Households	Total wages	Total earnings on capital	Deprecia-tion of timber	Agricultural rents			Total resource rent from timber harvesting in remaining forest	Total resource rent from timber harvesting during land clearing	

Table 4 Net accumulation of timber: comparison of approaches

Characteristics of forest				Depreciation approaches			
t (yr)	*q(t)* (m^3/ha)	*q'(t)* (m^3/ha/yr)	*V(t)* (RM/ha)	Present value (RM/ha)	El Serafy variation (RM/ha)	Net price variation (RM/ha)	Net depletion (RM/ha)
1	0.0	0.00	1041	42	42	42	0
2	0.0	0.00	1082	43	43	43	0
3	0.0	0.00	1126	45	45	45	0
4	0.0	0.00	1171	47	47	47	0
5	0.0	0.00	1217	49	49	49	0
6	0.0	0.02	1266	51	51	51	1
7	0.0	0.05	1317	53	53	53	4
8	0.1	0.12	1369	55	55	55	8
9	0.3	0.22	1424	57	57	57	15
10	0.6	0.35	1481	59	59	59	24
11	1.0	0.49	1540	62	62	62	35
12	1.6	0.65	1602	64	64	64	46
13	2.3	0.82	1666	67	67	67	57
14	3.2	0.98	1733	69	69	69	69
15	4.3	1.14	1802	72	72	72	80
16	5.5	1.29	1874	75	75	75	90
17	6.8	1.42	1949	78	78	78	99
18	8.3	1.54	2027	81	81	81	108
19	9.9	1.65	2108	84	84	84	115
20	11.6	1.74	2193	88	88	88	122
21	13.4	1.82	2280	91	91	91	128
22	15.3	1.89	2371	95	95	95	132
23	17.2	1.95	2466	99	99	99	136
24	19.1	1.99	2565	103	103	103	140
25	21.2	2.03	2668	107	107	107	142
26	23.2	2.06	2774	111	111	111	144
27	25.3	2.08	2885	115	115	115	146
28	27.4	2.09	3001	120	120	120	147
29	29.5	2.10	3121	125	125	125	147
30	31.6	2.10	3245	130	130	130	147
31	33.7	2.10	3375	135	135	135	147
32	35.8	2.10	3510	140	140	140	147
33	37.9	2.09	3651	-2610	-2610	-2610	-2650

Notes:1. $q(t) = 0.65 * 132 * e^{1-60/t}$

2. $q'(t) = 60 * q(t)/t^2$

3. V(t): see (19) in Appendix 2. p = RM115/m^3, c = RM45/m^3, i = 4%, T = 33 yrs.

Table 5 - National accounting matrix: closed economy, no deforestation

	Expenditures						
	Primary factors			Production activities			
	Labour	Capital	Forest	Consumer goods	Investment goods	Timber harvest	Households
Labour				wN^C	wN^M	wN^H	
Capital				rqK^C	rqK^M	rqK^H	
Forest							$[p\text{-}ms]\ \dot{S}$
Consumer goods							C
Investment goods							$\dot{K}$ (savings)
Timber harvest				pH^C	pH^M	pH^H	
Households	wN	rK	$[p\text{-}mc]\ \dot{S}$			$[P\text{-}mc]H+\pi(H)$	

Table 6 Partial national accounting matrix: nonmarket forest amenities

	Expenditures							
	Production activities			Primary factors				
	Consumer goods	Investment goods	Timber harvest	Timber stock	Forested land	Capital	Labour	Households
Consumer goods								C
Investment goods								$\dot{K}$
Timber harvest								
Timber stock								$[p^R\text{-}mc^H]\,\dot{S}$
Forested land								$\frac{U_B}{U_C} B_L L$
Capital								
Labour								
Households			$\pi^H(H)L +$ $[p^R\text{-}mc^H]HL$	$[p^R\text{-}mc^H]\,\dot{S}\;L$	$\frac{U_B}{U_C} B_L L$	rK	wN	

Table 7 National accounting matrix: closed economy, with deforestation

	Expenditures								
	Production activities				Primary factors				
	Consumption goods	Investment goods	Timber harvest	Land clearing	Timber stock	Agric. Land	Capital	Labour	Households
Consumption goods									C
Investment goods									$\dot{K}$
Timber harvest	$Lp^R H^C$	$Lp^R H^M$	$Lp^R H^H$	$Lp^R H^D$					
Land clearing	$Lp^R(\delta D)^C$	$Lp^H(\delta D)^M$	$Lp^R(\delta D)^H$	$Lp^R(\delta D)^D$					$[v^A\text{-}v^F]\,\dot{A}$
Timber stock									$[p^R\text{-}mc^H]\,\dot{S}\,L$
Agric. land	$rv^A A^C$	$rv^A A^M$	$rv^A A^H$	$rv^A A^D$					
Capital	rK^C	rK^M	rK^H	rK^D					
Labour	wN^C	wN^M	wN^H	wN^D					
Households			$[p^R\text{-}mc^H]HL + \pi^H(H)L$	$[p^R\text{-}mc^H]\,\delta DL + \pi^D(D)L$	$[p^R\text{-}mc^H]\,\dot{S}\,L$	AF_A	rK	wN	