Forest Economics and Policy Analysis
An Overview

William F. Hyde
and David H. Newman,
with a contribution by
Roger A. Sedjo
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Forest Economics and Policy Analysis
An Overview

William F. Hyde
and David H. Newman,
with a contribution by
Roger A. Sedjo

The World Bank
Washington, D.C.
ABSTRACT

This paper identifies the essential features of the forestry economics literature emphasizing what is different about forestry and what are forestry’s important features for project and program analysis. The important conclusion, is that economic tools are both available and appropriate for the analysis of a wide range of forest policy problems.

The presentation begins by reviewing the conceptual issues underlying production of wood and fiber and other forest resource services, including off-site services. Two characteristics that receive special attention are 1) the embodiment of both productive capital and final output in any standing forest inventory; and 2) the long time periods that often distinguish forest production. A third distinguishing characteristic is the joint production nature of many forest resource services. Finally, few other productive activities share forestry’s pervasive confrontation with underpriced joint outputs. These differences of degree largely explain the development of a distinct literature on the economics of forestry.

The second part of the paper visits seven special topics that are important to forestry and economic development: 1) timber production, including both plantation and planned natural management; 2) smallholder forest management, including social, community and agroforestry; 3) forestry research, education, and extension; 4) tenure, which can include Forest Ministry management, private commercial plantations, and some smallholder issues, as well as contracts between forest land managers and concessionaires; and 5) policy spillovers form other sectors of the economy that can substantially alter forests and forestland management; 6) non-timber multiple use values and 7) deforestation, timber famine or its counter, sustainable forest management.

The reviews of the forest economics literature and of seven specialized topics within it lead the authors to several judgements about a) the technical economic characteristics of forestry and b) the important forest policy issues of the day. These reviews are also suggestive of appropriate analytical approaches to these contemporary policy issues. The final section of the paper features their judgements on these two points.
FOREWORD

The application of generally accepted principles of economic analysis to policy formulation for the forestry sector has not been vigorously promoted due in part to a long tradition of viewing the forestry sector as special and apart from the rest of the economy. Forest policy has thus been guided by generally unstated rules of resource allocation. As the World Bank has more actively invested in forestry resources and has focused on improving the policy framework for sustainable forestry in its borrowing countries, a need has emerged to better ground this work on conventional, sector-based economic analysis. The comprehensive review of the forest economics literature which follows provides guidance in dealing with generalized economic distortions that may adversely affect the forestry sector.

This review is part of a broader forestry research effort being conducted by both the Asia Region Technical Department and the Bank's Agriculture and Rural Development Department. The ongoing Forestry Initiative of the Asia Region is intended to expand the Region's capacity to provide improved technical assistance and financial services in the forestry sector. The current work program focuses on a multi-disciplinary analysis of technologies, information services and approaches to social forestry. The research effort of the Agriculture and Rural Development Department has lead to the preparation of the World Bank Forest Policy Paper; numerous background papers prepared in support of the Policy Paper will be issued separately.

The authors of this report have synthesized a large body of theoretical and applied literature to present a strongly argued case that conventional economic analysis can play a leading role in improved forest resource allocation. While recognizing the conceptual and empirical limitations to such an approach to work in forestry, they have provided useful guidelines to staff for applied policy analysis.

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I. INTRODUCTION

Forest management is a critical policy interest for the 1990s. World consumption of fuelwood, industrial roundwood, and pulpwood each increased in the neighborhood of 25 percent in the decade from 1975 to 1985. Consumption increased even more rapidly in Africa and Latin America. (FAO/UN 1986, 1988. Also see our Table 3.) In some countries, the rate of deforestation exceeds three percent. Globally, deforestation occurs at an annual rate approaching 0.7 percent and it annually disturbs land cover on an area the size of Great Britain. This exploitation of global, and especially tropical, forests threatens the earth’s long-term climate patterns, its reserve of genetic resources, and the more immediate life support of dependent local human communities.

The direct causes of deforestation can be traced largely to land conversion for agricultural production and, to a lesser extent, to timber harvest practices. Some deforestation is economically efficient in the broadest sense of social optimality. Some is not, and the indirect causes of deforestation include a variety of market and policy failures, many having to do with secure tenure (for indigenous populations, for agricultural developers, and for commercial timber operations), some having to do with the forest and the wood processing industries, many having to do with agricultural expansion, some having to do with national macroeconomic planning.

These problems raise our interest in what economics has to say about forestry and what the forest economics literature has to say about efficient forest management. The purpose of this paper is to review that literature. Our intention is to identify the essential features of the forestry literature with particular emphasis on identifying what is different about forestry and what are forestry’s important features for project and program analysis. The essential differences in the forestry literature include some that are real, some that are perceived, and some that were created by misguided policies. The important conclusion, however, is that economic tools are both available and appropriate for the analysis of a wide range of forest policy problems.

Our presentation begins by reviewing the conceptual issues underlying 1) forest production of wood and fiber and 2) other forest resource services, including off-site services. The latter invites introduction of the literature on forest landowner objectives, including multiple objectives for both priced and underpriced values. These two reviews are brief because their intention is to emphasize the fundamental issues contained in the literature rather than to develop them in detail. These reviews should also be helpful in directing the reader away from some of the basic fallacies in forest policy and management. We conclude both initial reviews with comments on the economic differences that arise in their parts of forestry.

The second part of the paper visits seven special topics that are important to forestry and economic development: 1) timber production, including both plantation and planned natural management; 2) smallholder forest management, including social, community and agroforestry; 3) forestry research, education, and extension; 4) tenure, which can include Forest Ministry management, private commercial plantations, and some smallholder issues, as well
as contracts between forest land managers and concessionaires; and 5) policy spillovers from other sectors of the economy that can substantially alter forests and forestland management. The products of the forest are its commercial outputs, basically the wood and fiber products that are discussed at the close of the first special topic, 6) non-timber multiple use values (an important component of several of the previous topics), and 7) deforestation, timber famine or its counter, sustainable forest management. These seven topics are designed to introduce briefly a broad range of applied policy and management problems in forest economics. Each draws on underlying observations from the earlier two, more conceptual, reviews at the beginning of this paper.

The first two parts of the paper review the forest economics literature and the forest-related economics/policy literature, respectively. The final section of the paper is not so directly reliant on prior literature. It is our own summary statement of the critical issues in world forest management—and the relevant foci for economic evaluation of these issues.

II. THE BASIC CONCEPTUAL LITERATURE

The forest economics literature has its distinctive characteristics, but the differences between the economics of forestry and the economics of other productive sectors are fewer than the similarities. Furthermore, many of the differences are differences of degree rather than kind. For example, two characteristics that receive special attention are 1) the embodiment of both productive capital and final output in any standing forest inventory; indeed, in any tree; and 2) the long time periods that often distinguish forest production (Zivnuska 1949). Livestock and fish both grow and are harvested. Therefore, they share the first characteristic with forestry. Many productive activities; including various natural resource, agricultural, and industrial activities; use a certain amount of long-lasting capital inputs. Therefore, many share the second characteristic with forestry. Forestry’s difference is its relative emphasis on these characteristics. A third distinguishing characteristic is the joint production nature of many forest resource services. Once more, the distinction is one of degree rather than kind, as many other productive activities yield multiple outputs. Few, however, share forestry’s pervasive confrontation with underpriced joint outputs. These differences of degree largely explain the development of a distinct literature on the economics of forestry.

Historically, most analyses of the basic issues of forestry have been responses to the administrative needs of forest land managers. For example, questions of adequate long-run timber supply have frustrated planners and policy analysts at least since the Chinese Guanzi in the Fourth Century B.C. The Viceroy of Mexico City, who wrote the King of Spain in 1546 that North America was running out of timber; the American Association for the Advancement of Science in 1876, which appealed for federal intervention to prevent an impending timber famine in the United States; and those of us concerned with many aspects of global deforestation today share some aspect of this concern for scarce forest resources. The question of fair tax assessment of forestland led Faustmann in 1849 to derive the optimal forest rotation. The question of land allocation among many competing uses led von Thunen in 1875 to explain optimal
forest location. Doubts about the effectiveness of private forest resource management and, therefore, reliance on the public sector to manage the forest resource were one response to all of these earlier questions. These are the classic issues of forest economics—and the basic issues of our first conceptual section reviewing the literature on forest production of wood and fiber.

Our second conceptual section reviews the forest economics literature on multiple forest products and non-timber forest resource services. One more recent focus of the forest economics literature has been on developing tools to improve more localized management of both public and private forestland, particularly through a better understanding of the underpriced values of many forest resource services. The environmental interests of developed countries have strongly influenced this literature. The tools and concepts found in the literature on underpriced environmental valuation apply directly to the (often different) underpriced forest resource services that are important in developing countries.

The general natural resource economics literature has also grown rapidly in the last thirty years. This literature includes topics like measuring scarcity, multi-purpose economic development, intertemporal distribution of benefits, open access and the contractual arrangements necessary to secure tenure and justify long-term conservation-oriented investments, and valuing genetic diversity, all topics that are directly relevant for forestry today, in both developed and developing countries. Both the environmental valuation literature and this newer general resources economics literature contribute to our insights for underpriced and environmental forest resource services, the basic topic of the second conceptual section.

IIA FOREST PRODUCTION OF WOOD AND FIBER

Wood and fiber products (timber and pulpwood stumpage) were the first outputs associated with the forest. Forest economists initially focused their efforts on determining optimal harvest strategies for these products. Subsequently, as regeneration and timber management became more important, forest economists incorporated a full range on production options in their analyses of forest management.

Since Duerr (1960), wood and fiber production has been categorized by its short-run and long-run problems, by single stand production or aggregate supply problems, and by the behavioral characteristics and timber harvest and management responses of different landowner classes. This section of the paper reviews first the short-run, then the long-run problem, moving from single stand production to aggregate supply in each case. It also considers the conversion period problem for the dynamic adjustment of an existing forest to a new forest with some specified long-run growing stock. The discussion of landowner characteristics is delayed until the following section introducing other forest values.
2.A.1 Short-Run Objectives

In the short run, either the volume of timber (the forest inventory) or the land area covered with forest is known. The basic question is what part of it to harvest. Foresters recognize the derived demand nature of this problem (Weintraub 1959, Gregory 1987, Gray 1983). They start from the known price per unit of the processed good, say lumber $p_L$, and subtract processing costs to arrive at a residual price $p_s$ for a unit of unprocessed mature timber on the stump ("stumpage"). Processing costs include milling costs, transportation costs to the mill, and harvesting costs. The residual is the short-run return to the fixed factor of production: land, or land and managerial inputs. Figures 1A and 1B show this relationship. The marginal stumpage price is zero. Stumpage that is inframarginal with respect to access or quality (species, form, defect) attracts a higher price. Clearly, the demand price elasticity for the finished product, lumber, is greater than the elasticity for the same unit of stumpage.1

Practicing forest managers follow this residual estimation procedure to derive the stumpage demand price and then offer the predetermined volume, say $V_s$, at price $p_s$. Alternately, they may compare biological and economic characteristics from previous but comparable timber sale transactions with characteristics of the potential sale in question in order to determine their stumpage offer price. Jackson and McQuillan (1979) explain a regression-based form of this transactions evidence approach—although most applications of transactions evidence are not nearly so formal. [Weiner (1981) and Hyde (1984) review stumpage appraisal.]

Stumpage price appraisal is unnecessary for sellers in competitive markets. The relevant market is the timbershed, which can be defined as the timber producing region supporting a single mill or group of mills. Its boundaries are set where the derived stumpage value equals zero, or log transportation costs equal their delivered value at the mill.

Market power is a debatable issue, however, even where there are many loggers and many mills, because only a few may bid on any one timber sale [Mead (1966) discusses the evidence for static oligopsony in the logging industry.] Nevertheless, the high degree of substitution between timberstands within a timbershed and low entry costs restrict oligopsony power and create potential competition from additional buyers in most markets for fuelwood and developing countries, or logs and poles in lumber in both developed and developing countries. Pulp and paper are different. The high fixed cost nature of these latter two activities makes competitive entry less likely and increases the potential market power of existing firms.

1The demand price elasticity for stumpage in the aggregate is less than the demand price elasticity for lumber. The elasticity for stumpage within any particular timberstand is greater than the aggregate elasticity for stumpage because stumpage from all other timberstands can substitute easily for stumpage within the particular timberstand.
Figure 1: Derived demand for stumpage

Figure 2: Optimal rotation age

A: MSY rotations with and without a regeneration lag ($\tau$)

B: The common general rotation age solution for $i > i' > i^*$
A large number of varying factors make stumpage appraisal difficult in temperate forests (e.g., differences in access, species variation within any timberstand; as well as individual trees with varying volumes, form classes, and wood qualities). Appraisal is even more difficult in most developing countries where the tropical forests are richer in species variety and the foresters often are fewer in number or not as well-trained. Moreover, restricted local access to capital markets may help sustain oligopsony power in some developing country situations. Altogether, these problems may explain developed country preferences for differentiated prices originating from either stumpage auctions or independent appraisals for periodic sales in each new timberstand, yet developing country preferences for simpler systems with one, or only a few, undifferentiated national prices for long-term stumpage concession rights for large areas of nationalized forests.

2.A.2 Long-Run Optimization

The minimum appraised stumpage price must cover the short-run variable costs of offering standing timber for sale (the costs of advertising and administering the timber sale and protecting the residual timberstand, as well as the costs of the sale appraisal itself). Socially optimal short-run harvest decisions must add the off-site timber harvest costs, like soil erosion and visual disamenities from logging.

For long-run sustainable timber management, the appraised stumpage price for any timberstand must also cover the full costs of growing the crop ("rotation") of timber. This implicit long-run instruction from the stumpage price appraisal is often overlooked on public forestland. Repetto and Gillis (1988) and Boyd and Hyde (1989) provide aggregate examples from Indonesia, the Philippines, and the US. Hyde (1980, 1981) also provides examples of specific timber management cases in the US West. These examples all show timber sale receipts that may exceed short-run costs, but do not exceed long-run costs. Nevertheless, the respective Forest Ministries harvest, replant, and manage the next timber rotation at long-run opportunity losses to their public treasuries. Some examples even show short-run net financial losses.

Faustmann developed the correct long-run theory of the firm production model for forestry in 1849. His model features the optimal harvest time—or rotation age. Economists have been unable "to resist the sirens of the optimal rotation problem" (Binkley 1987a) since then and this topic is source of the most fully developed forest economics literature. [Ohlin formulated the "Faustmann" model independently in 1921. See Samuelson (1976) and Lofgren (1983).] In its simplest form, the landowner maximizes net return $\pi$ to the fixed factor, land, over time $t$.

$$\max \pi(t) \text{ where } \pi(t) = p_s V(t) e^{-lt} - \int_0^t re^{-is} \, ds \tag{1}$$

$p_s$ is the expected stumpage price, $V(t)$ is the biological production (or yield) function for standing timber, $l$ is the landowner's discount rate, $r$ is the annual rental return on the land, and $s$ is a variable of integration. This is the same as maximizing the difference between gross
revenues and total costs where revenues are harvest receipts and costs are the annual opportunity costs of forestland use. Restating the problem to allow either land purchase at the beginning of the timber rotation and land sale at harvest time, or continuous replacement of timber harvests with new seedlings, leaves the problem unchanged. The usual convexity and differentiability conditions apply.

The optimal rotation age \( t^* \) occurs when

\[
\frac{V_t}{V} = \frac{1}{(1 - e^{-lt})}
\]  

where \( V_t \) is the derivative of \( V \) with respect to time. Price is irrelevant to the optimal mathematical solution, but the discount rate is critical. Reintroducing price, landowners harvest their timber when the opportunity return on harvest revenues \( p_s/V \) just equals the expected return on an additional year's growth \( p_s V_t \) minus the rental payment for the additional year's land use \( p_s V_t e^{-lt} \). It can be shown that this economic optimum converges with the biological maximum \([\text{maximum sustainable yield, MSY, } (V_t/V = 1/t^* \text{ when } l=0]^2\) Otherwise, as \( l \) increases, \( t^* \) decreases, therefore \( V(t^*) \) decreases and \( V(t^*)/t^* \), the sustainable harvest from the fixed land base, decreases. [Bentley and Teeguarden (1965) contrast this correct economic solution with the most common incorrect economic and biological variants.]

Gaffney (1957) introduced most of the complexities to this problem. Various others have formalized them mathematically. [Newman (1988) reviews this literature.] We will examine a couple of the more important complexities.

Lags occur between harvests and regeneration of the subsequent stand \( (t_r) \) under most natural conditions. For example, the lags can be as long as 25 years in the highly productive Douglas-fir region of western Oregon. They are greater in drier regions and higher elevations. Regeneration lags shift the entire yield function right, as in Figure 2A. They increase the optimal rotation age (including this lag) and decrease sustainable yield per land unit.3

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2This result is the source of the misleading view that biological maximization (MSY) creates greater average annual harvest volumes than economic maximization. In fact, physical yields from biological maximization exceed those from economic maximization only in this selective, single land unit, case. Economic maximization is more profitable. Therefore, it justifies forestry on additional land and with increased levels of non-land inputs. Even in restrictive cases, economic supply from all profitable forest lands exceeds "biological supply" from that smaller share of all forests that return a positive return when constrained to maximize biological yields.

3Optimality now refers to the expression for \( \pi(t+t_r) \).
Prices appear in the optimality condition with the introduction of silvicultural investments. The basic silvicultural investment is a regeneration cost that reduces any natural regeneration lag and increases production beyond that anticipated for natural stocking with unimproved indigenous seedlings. It insures earlier regeneration and creates more even spacing of new seedlings, therefore more complete use of the land, as well as an improved likelihood of seedling survival, and it may introduce quality improvements in the new growing stock. This investment implies some level of silvicultural effort $E$ at unit cost $w$. Biological production is now a function of both $t$ and $E$ and the cost $wE$ must be subtracted from eq. (1).

The new optimality condition for rotation age is

$$\frac{V(t)}{(V-wE/p)} = \frac{1}{1-e^{-lt}}$$

(3)

Jackson (1980), Hyde (1980), Chang (1983) and Nautiyal and Williams (1990) discuss the full set of long-run comparative static conditions for rotation age and silvicultural effort. Figure 2B shows this relationship, highlighting the impact of changing landowner discount rates on the optimal rotation age.

Table 1 summarizes the commonly examined comparative static impacts on rotation age, silvicultural effort, and harvest volume per hectare. The harvest volume impacts are indeterminate wherever the increasing volume effects of longer rotations contrast with the decreasing volume effects of lower levels of silvicultural investments.4

Increasing relative regeneration costs increase the optimal rotation age and the sustainable yield per land unit. Temporally changing price Their impact on the optimality condition, eq. (3), depends on both the level expectations also add important realism to long–term problems like forestry, and the rate of price change (Newman et al. 1985, Brazee and Mendelsohn 1990).

Variations in access explain the extensive margin of land use (Ledyard and Moses 1974). Here, the stumpage price equals the delivered log price $p'$ minus access cost $x$ per unit of volume. The external margin occurs where the net revenue function $R(x)=0$, or all stumpage returns are absorbed by access costs. Less accessible timberstands have lower optimal levels of regeneration inputs, therefore smaller eventual harvest volumes, but longer optimal rotations.

4These harvest volume per hectare impacts should not be confused with aggregate timber supply impacts. For example, with silvicultural effort held constant, decreasing costs and increasing prices both shorten the optimal rotation age and the optimal harvest volume per hectare. Decreasing costs and increasing prices, however, increase overall profitability and, therefore, induce production on additional land. The net effect is usually decreasing harvest volume per hectare, but increasing aggregate supply. The difference between per hectare and aggregate supply effects are frequently confused in discussions of environmental implications and forest policy.
therefore greater final harvest volumes. Thus, decreasing accessibility has an indeterminate impact on sustainable yield per land unit.

Finally, the impacts of the various alternative timber taxes on optimal rotation depend on the timing of their imposition. Increasing yield and severance taxes charged at harvest time extend the optimal rotation. Increasing property and timber taxes, typically charged to the landowner annually, decrease the optimal rotation. [Chang (1982) and Boyd (1986) survey taxation impacts. Table 1 also reports their summary results.]

This entire literature relies on some specification of an endogenous production technology and then holds it constant. Constant technology, or an unchanging biological production function, is a reasonable assumption for that large share of forestry's world where the only technical inputs occur with regeneration. It is becoming a less realistic assumption for high production regions like the US South and regions like Chile, New Zealand, and perhaps Brazil, with emerging high-valued exotic plantations (Sedjo 1983, Sedjo and Lyon 1990). [Hyde et al. (1991) found 0.6 percent annual technical change in southern pine from 1950–1980.] In these cases, technical change may be embodied in each new rotation, or it may occur with intermediate inputs like fertilizers and thinning throughout the rotation. Technical change can be empirically important over periods as long as a 30–80 year timber rotation.

The object of technical change in forestry is to obtain a more valuable product from the scarce land resource. It has two physical impacts, an upward shift in the entire yield function, \( V(t) \) in Figure 2A, and a localized upward shift capturing lost potential land productivity in the early years of slow forest volume growth, before \( t_1 \), for yield function \( V(t) \) in Figure 2A. [Hyde (1980), Lofgren (1985) and Johansson and Lofgren (1985) discuss technical change and its impact on optimal forest production in a rudimentary way.]

The long-run supply function per land unit becomes backward bending (volume per hectare decreases) as stumpage prices and silvicultural costs increase. [Clark (1976) identified this problem, Hyde (1980) explained it, Binkley (1987b) added formal precision to the explanation.] Aggregate supply, however, never bends backward because increased prices justify more expensive silvicultural technologies and induce land conversion to forestry at both the intensive and the extensive margins. Computing the optimal harvest quantity \( V(p)/t \) from the complete version of eq. (1), and summing across the most profitable yield and management relationships for all ownership and land quality and access classes produces one point on the aggregate supply function. Repeating this computation for a range of anticipated prices traces a long-run sustainable supply function.

Hoch [in Hyde (1980)] pointed out the important underlying assumption of constant returns to scale for this aggregation. Row (1978) and Cubbage (1983) examined the opportunities for scale economies in southern pine timber production.
2.A.3 Conversion

The transition from harvesting existing stands of mature timber subject to short-run optimization to harvesting from long-run steady state timber growth is known to foresters as the "conversion" period. Existing timberstands of various age (therefore, volume) classes, including ages and volumes greater than the steady state optimal ages and volumes ("old growth") complicate this transition. Foresters use various simple physical rules for rationing old growth harvests and for replacing absent age classes over time until they can anticipate a steady state or "normal" forest with equal area stands in each age class (Davis 1966). Of course, the existence of some old growth implies that initial harvest levels per land area cannot be duplicated without technical change.

The potential impact of technical change is small in most cases (relative to the difference between old growth and optimal rotation harvest levels) and technical change is nearly always ignored. This means that there must be some annual harvest "fall-down" (from any fixed area) as large volume old growth stands are converted to steady state management and smaller volume harvests begin to occur at younger optimal rotation ages. Foresters typically search for a means to avoid the fall-down by controlling harvest volumes at some constant level throughout this conversion period. One common formula is to restrict harvest levels to that level that can be maintained in perpetuity under the newly managed normal forest. This means foregoing all economic contribution from the excess volume in newly opened old growth stands.

Gould and O'Regan (1965) and Brazee and Mandelsohn (1988) showed that landowners are better off ignoring even-volume-flow (or "even flow") rationing and responding to randomly fluctuating price signals—with lower prices attracting smaller harvests and higher prices attracting larger harvests from greater areas. Daniels et al. (1991) measured the economic and social costs of insuring even flow in the presence of significant lumber price fluctuations. They found that even flow imposes large costs on the Forest Ministry treasury, yet does not guarantee either even flows of sawmill production, forest sector employment or forest sector wage bill.

Berck (1976) showed the economic solution path for the conversion problem. It depends on functions explaining timberstand aging to an eventual asymptotic volume, periodic harvest removals and regeneration, plus the restriction that total forest area in any age class equals or exceeds the harvested area. Imposing demand (or exogenous prices) identifies supply for each period. Most analyses specify a residual standing forest at some final period $T$. Brazee and Mandelsohn (1990) added dynamic price shocks to the problem. Lyon and Sedjo (1983) revised Berck with an optimal control specification of the problem.

A number of important results emerge from this research: First, timber markets satisfy all neoclassical economic conditions. Indeed, the rate of drawdown of the capital stock corresponds to the broader economy's return on capital. Berck (1979) and Johnson and Libecap (1980) found empirical evidence from 1880 to the present supporting this theoretical finding. Their results are an important rebuttal to claims uniqueness for forestry—and suggestions to modify the interest rate or capital markets applicable to forestry. Second, demand shifts in one
period cause comparable supply shifts in the same period and zero or opposite supply shifts in all other periods (Binkley 1980). And finally, long-run price changes are bounded under reasonable demand expectations over time (Lyon 1981). This is an important rebuttal to expectations of ever-continuing relative stumpage price increases.

2.A.4 The Different Economics of Wood and Fiber Production

The most important point to take from this brief discussion of timber production and supply is the critical role of time in all analyses of forestry issues. Although the production process may be as short as three years for some fast-growing fuelwood species, even three years is three times as long as most agricultural production processes and many times the length of most industrial production processes. Furthermore, 25 years is a more common pulpwood rotation age, 30–50 years are more common economic sawtimber rotations, and biological sawtimber rotations may exceed 80 years in Canada, the US West, and in some mixed stands of tropical hardwoods. Time and, therefore, capital theory are critical in any analysis of forestry activities.

The critical role of time as an input in forestry suggests the unusual importance of long-term price trends, of policy expectations, and of reliable contracts. Barnett and Morse (1963), and various others since them, have found a long-term upward relative price trend for some forest products. This long-term trend is unique to forestry among all primary economic resources. We will revisit this issue in our subsequent discussions of timber production, and forestry research.

Unpredictable policy environments and unreliable long-term contracts are perverse management incentives. They create greater uncertainty, therefore greater variation from optimal deterministic results, the longer the relevant time horizon. They can be a serious problem for long-term management activities like forestry (Nostrom 1975, Kao 1982, 1984; Reed 1984, Brazee and Mendelsohn 1988). They induce timber managers and timber harvest

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6 This is a small point. It is the only economic basis, however, for the important counter-economic concept of "ACE" which this paper visits below.

7 Ruttan and Callaham (1962), Barnett and Morse (1963), and Manthy (1978) found that relative US lumber prices have increased at approximately 1.8 percent per annum since the mid-Nineteenth Century. Nautiyal and Rezende (1983) anticipate a similar experience for Canada. It helps the ex ante case for forest investments to assume that this experience will continue indefinitely. Of course, indefinitely increasing prices imply the nonsense result that all investment eventually will be in forestry. Sedjo and Lyon (1990) and Hyde, Newman, and Seldon (1990) explain this historic experience as consistent with frontier economies and with the drawdown of an excess resource stock. Sedjo and Lyon (SL) explain that the growth in relative prices already has tapered off in some regions of the world and SL's modeling projects that this growth rate will severely decay as we move into the Twenty-first Century.
concessionaires to obtain available short-run gains before unpredictable changes in policies and contract terms can occur and, thereby, change the profitability of forest-based activities. Policy expectations and reliable contracts for public stumpage are critical issues for those countries subject to more frequent and more varied changes in political direction. Policy expectations and contract reliability are important issues for our subsequent discussions of tenure, policy spillovers, and sustainable management.

Large natural endowments of timber, together with the importance of time in forest production, suggest the economic importance of conversion period adjustment relative to the more common concern of both foresters and environmentalists for sustained biological yield. Adjustment is a critical issue for our subsequent discussions of tenure and for sustainability and deforestation. Finally, the importance of time implies the relative unimportance of labor in forest production. We will revisit this point in our subsequent discussion of forestry research.

Time also explains important problems in forest policy analysis. Data are a real problem. Even in the US, there is only a forty-year history of approximately decennial forest surveys. In most regions of the world forest inventory data exist for less than one full rotation. Furthermore, what inventory data that do exist often aggregate important species and age classes. They probably also include biological but uneconomic inventories. This means that many production runs, including irrelevant ones, are confused in one lump of data. Four confused observations, at best, over forty years of changing natural, economic, and policy environment are insufficient for most reliable statistical analyses.

Forest credit is a perceived policy problem. In fact, many production processes outside of forestry require borrowing for some long-term capital investments. Credit should not be a problem for forestry unless financial institutions explicitly exclude forestry's eligibility for credit, or unless they also fail to provide credit for producers with comparable risk characteristics in these other productive activities. Nevertheless, many foresters believe in an implicit credit failure. Some even argue for forestry interest rates that are lower than for other sectors of the economy. In the US, a prestigious panel, including outstanding foresters, bankers, and economists; rejected this credit failure hypothesis in 1958 (Forest Credit 1958).

Finally, there is a policy difference (common to forestry around the world) that attempts to create a separate capital theory for forests and Forest Ministries. This policy difference, known as the "allowable cut effect" or ACE, refers to the manner of calculating timber harvests. [Hyde (1980) reviews ACE and cites the best-known literature.] Some industrial forestry operations and most Forest Ministries determine their harvest levels and their stumpage offer prices in a three-step process. They first determine the forest management area, then determine annual harvest volume from this area according to some biological rule. Some land and some harvest volume may be uneconomic—although this process will not discover it. Finally, they derive their short-run stumpage offer price independently of the first two steps.

The results of this economically unsatisfying process do not show up in the industrial firm's or Forest Ministry's balance sheets because the institutions that use ACE calculate financial returns on forest investments by tying independent harvest and reinvestment
decisions. In the simplest case, reforestation investments (say $150) on one hectare are necessary to justify old growth harvests and forest revenues (say $165) on another. The net gain is calculated as a rate of return (i.e., 10%, from (165/150) - 1.0 = 0.10).8

There are many more complex variations on both the harvest calculation and the calculation of financial returns with ACE. The complexities are due to uneven-aged forest management, multiple species and forest types within a forest planning unit, and intermediate-timed forest management activities like fertilization and thinning. In all cases, these calculations violate all economic principles. Nevertheless, foresters use ACE widely and too successfully as a means of avoiding the "bogey of compound interest" (Shepard 1925).9

II.B MULTIPLE FOREST PRODUCTS AND NON-TIMBER FOREST RESOURCE SERVICES

Timber harvest and management decisions may be the core of forest economics, but the real life complexities of forest management often include, or even emphasize, timber production in association with various other forest produced goods and services. These goods and services can be market valued; like developed recreation and some fruits, nuts, and latex; or underpriced; like wilderness recreation and, perhaps, some local household consumed fuelwood, forage, and fodder. In some cases, timber is produced jointly with off-site environmental disservices like soil erosion. In other cases, timber production may even be unimportant and the real forest management problem may feature joint production of various other forest products. Joint production of fuelwood, forage, and fodder in many developing country forests—and without coincident timber production—is one example.

The joint product problem in forestry might be divided into two parts in the forest economics literature: multiple wood products from the same forest resource, and multiple use, including various timber and often underpriced non-timber forest resource services. There are four approaches to the latter: modifying the Faustmann equation to incorporate non-timber values arising with timber growth, regional modeling and its alternatives for allocating various forest resource services, applied and site specific evaluations, and household production models.

8 Hirshleifer (1974), recalling that Druids worshipped trees, called ACE the Druid effect. He likened the ACE investment to hiring a Druid. He also made the sacrilegious suggestion to fire the Druid and get on with business, thereby a) collecting the full $165 from harvesting one hectare in our example and b) forcing reconsideration of the reforestation investment on another hectare on the merits of its own expected discounted future returns.

9 This discussion also hints at another problem—the term "allowable cut" itself. The term can mean a) the ACE formula itself, b) the unadjusted harvest calculation from the three-step process discussed above, c) the management-adjusted, planned ex ante harvest level, d) the actual ex post harvest level for one year, and e) the actual harvest level over the duration of the specific contracted harvest from the specific land area. It is often unclear to which any particular discussion refers and the result can be most misleading. Our recommendation is to avoid use of the term "allowable cut" and to be explicit about the harvest term in question.
of joint production. This section reviews these approaches in turn and concludes with a summary statement on the differences for these multiple use issues in forestry in comparison with other joint production activities.

2. B. 1. Multiple Wood Products

Several recent econometric analyses examine joint pulpwood and sawtimber supply and demand from the same forest resource [Brannlund et al (1985) in Sweden, Kuuluvainen (1986) in Finland, and Newman (1987) in the US South]. The general finding is that pulpwood substitutes for solidwood supply in production. On the other hand, solidwood production is a weak complement to pulpwood supply. Apparently, the asymmetry occurs because pulpwood supply removes inventory otherwise available for (generally subsequent) solidwood production, yet the residuals from solidwood harvests of generally older trees can still add to pulpwood supply. We might anticipate the same relationships for fuelwood and poles, or fuelwood and sawtimber, or even fruit and any form of construction timber, in developing countries. That is, fuelwood supply removes inventory and substitutes for poles, yet the residuals of pole production from older trees produce a complementary fuelwood output. This can be an important restriction on the uniform general gains sometimes claimed for multipurpose trees in developing countries.

2. B. 2. Timber and Non-Timber Resource Services

Multiple use valuation of underpriced forest resource services is more complicated. The most direct form for introducing multiple use values to forestry assumes that they are related in some simple form to the biological production function for timber. Hartman (1976) introduced this approach with a non-timber benefit function that increases with timberstand age. In this case, non-timber benefits increase the optimal rotation age. The joint presence of non-timber benefits may also increase the land area suitable for timber production by adding to the net returns for growing timber on otherwise sub-marginal land (Bowes et al. 1984). The mathematical possibilities of Hartman’s approach are rich, and numerous others have followed with mathematical variations on Hartman’s original non-timber benefit function (Strang 1983, Snyder and Bhattacharyya 1990, Swallow et al. 1990).

Bowes (1983) points out Hartman’s error of realism. Often, non-timber benefits are inversely related to timber management inputs and unrelated to timberstand age. For example, timber management inputs can make forests look like crops. This is an undesirable characteristic from the perspective of many non-timber forest values. Furthermore, most wildlife prefer the edge around forests, recreational users like tall trees but they also like clearings for scenic vistas, and short-term water flow increases with timber harvesting. None of these is fully consistent with increasing timberstand age. Therefore, benefit measurement is too complex for confident use of the Hartman model. It requires a multiple stand Faustmann model; including clearings, edge, growing timber, and old growth timber; with each stand distributed according to the array of local timber and non-timber values and their relative magnitudes.

Bowes created a multiple stand Faustmann model and simulated optimal rotations and optimal harvest levels for various different timber and associated non-timber benefit functions.
He showed that the joint production forestry problem has many potential solutions, each highly dependent on the specialized accumulation of local values.

One response to Bowes’ findings might be the large regional linear-programming models of the US Forest Service [Timber RAM (Navon 1971) and FORPLAN (Johnson et al. 1986)]. These models optimize forest land use among competing forest resource outputs and optimize timber harvest allocations over time given the particular regional forest resource endowments and regional timber and non-timber values. The US Forest Service uses these models for long-term planning on each of its 156 national forests. [McKenney (1991) applied FORPLAN in Australia.] Others have suggested a goal programming orientation for these models with the goal being a set of regional output objectives over time (Baum 1990). Not infrequently, constraints like ACE or general environmental restrictions define the timber harvest solutions in the economic or the goal programming versions of these models (e.g., Fight et al. 1978). Timber RAM and FORPLAN are expensive consumers of human capital and computational time. Their applications have also created intuitively unsatisfying land allocations for specialized economic units within their overall regions of responsibility.

Empirically More Important Cases. Bowes and Krutilla (1989), however, show that there is often a simple response. They followed Bowes’ conceptual multiple timberstand simulations with five locally specific empirical cases involving joint production of timber with water, grazing, mining, hunting, and non-resource consumptive forest recreation. Their cases show that many theoretical complexities are irrelevant for any specific local case. There may be multiple biological and physical outputs, but seldom do more than two products compete economically for the same forested land area and seldom do they compete equally on all land within the given area. More often, the applied problems rapidly reduce to only two locally important economic uses in serious economic competition or, alternately, with important economic complementarities. Furthermore, these local complexities often appear on only a small share of the total land area in question.

Thus, the problems of joint product forestry may lie less in the technological difficulties of complex economics and more in applying simple economic concepts correctly. Bowes and Krutilla chose their cases to illustrate difficult analytical problems, yet the point about applying simple concepts correctly is an inescapable conclusion of their analyses. Numerous other joint production forestry cases chosen more for their local economic or policy importance, rather than their analytical complexity, only reinforce this view. The next few pages reflect further on it.

Various other extensive forestry and forest sector simulation models exist. Wardle et al. (1975) prepared one for Peninsular Malaysia. Holling (1975) prepared one for Nova Scotia. Kalilo et al. (1987) prepared a global model. These models all concentrate on the wood products sector. Allocation over multiple forest outputs is not among their basic objectives.
The basic applied economic principle of joint production originated with the applications of welfare economics to water resources: Single use benefits $B_i$ must cover their separable costs $C_i$, and the sum of net benefits from justifiable single uses must cover the costs common to all justifiable uses $C_C$ (Krutilla and Eckstein 1958).

$$B_i - C_i > 0 \quad \text{for all } i \text{ outputs} \quad (4)$$

and

$$\Sigma_i (B_i - C_i) > C_C \quad \text{for all } i \in (B_i > C_i) \quad (5)$$

Separable costs are identifiable each with their own independent output. Where independent benefits do not exceed their associated separable costs, that output fails economic justification. The sum of benefits in excess of separable costs for all remaining outputs justified by eq. (4) must exceed the costs common to their collective production, otherwise the remaining outputs also fail economic justification.

Eqs. (4) and (5) determine the economic combination of outputs. The efficient level of each justifiable output is that level which:

$$\max_i - C_C + \Sigma_i (B_i - C_i) \quad \text{for all } (B_i - C_i) > 0 \quad (6)$$

Finding the maximum for eq. (6) tends to be a straightforward exercise in application because there are usually only a few discrete and realistic alternative production levels.

Numerous case studies following these simple principles find that competitive, rather than complementary joint output is the norm, at least over relevant forestland areas. These competitive cases may be simpler analytically because a) one competitive output often has a negative value and fails the test of eq. (4), or b) policies may constrain production until the net economic return on one output is negative, or c) both competitive outputs yield positive net returns, but one output obviously dominates.

For example, Walker (1974), representing timber industrial interests, and Kutay (1977), representing environmental interests, examined similar national forests in Oregon. They independently found timber values dominant on some lands and negative on others. They found gains for both timber and environmental values, as well as for the federal treasury, from concentrating timber production on lands with unconstrained positive timber values. This would remove uneconomic environmental constraints on timber production and, as a result, increase total timber production. It would also remove some forest with negative timber value from timber production and, as a result, it would increase the amount of high quality environmental land set aside.

Peters et al. (1989) found that the net social returns from fruit and nut collection from the indigenous forest dominates either the timber resource value or the land value for agricultural conversion in select cases in Peru. Hyde examined three controversial timber versus non-market value cases and found negative timber values, therefore a social preference for the undeveloped wilderness alternative in the San Juan National Forest in Colorado (1981); negative
timber values when constrained by ACE and biological maximization, but unconstrained timber values great enough to offset all undeveloped forest recreation values less than the unlikely amount of $2000 per recreation visitor day in the French Pete drainage in Oregon (1983); and small or negative timber values, therefore minimal timber opportunities foregone when preserving endangered woodpeckers in South Carolina (1989). All of these examples support the contention that the problems of joint product forestry lie less in the technical difficulties of complex economics and more in applying basic economic concepts correctly.

These examples all finessed the problem of non-market valuation. Joint product problems of the next order of difficulty follow the rules of eqs. (4)-(6) but find no easy way of finessing the non-market valued problem. The classic forestry cases would involve off-site values in both developed and developing countries and recreation and other amenity values, largely in developed countries. Lately, environmental tourism, global concerns for biodiversity and climate change, and the prospects of debt-for-nature swaps, all raise the importance of recreation and amenity valuation in today's developing economies. Perhaps the most important off-site values for forestry are soil erosion and downstream sedimentation losses associated with timber harvests and erosion control gains associated with reforestation. The value of these off-site losses (or gains) is equal to the net change in the time streams of downstream market returns due to the different levels of sediment deposit (or soil stabilization) due to the timber management activity. Their calculation is straightforward. Anderson (1987) provides a tidy example for reforestation producing both timber benefits and adjacent agricultural gains from erosion control in west Africa.

Recreation and other amenity values are more difficult to assess because they are often unrelated to any market. In such cases amenity valuation requires careful application of survey techniques to obtain the underlying data necessary to assess consumer willingness-to-pay. The water sanitation literature (e.g., Whittington et al. 1989) is ahead of the forestry literature in applying these techniques in developing countries. There are potential opportunities to apply them for assessing fuelwood demand and international tourism, both important Issues in specialized developing country forestry situations. For example, Amacher et al. (1991b) used a travel cost approach to assess willingness-to-pay for collected fuelwood in Nepal.

Amenity valuation and survey techniques are complex topics. They are the subjects of detailed literature surveys of their own. Brookshire et al. (1982), Freeman (1979), Johansson (1987) and Mitchell and Carson (1989) are the standard technical reviews. Gregersen and Contraras (1979) is the standard guide for multiple use forestry in developing countries. Dixon and Hufschmidt (1986) provide a series of environmental case studies for Asian developing countries.

Unavoidable Joint Production Problems. Finally, the household general equilibrium model provides the only fully satisfying approach where there is no avoiding assessment of efficient levels from continuous possibilities for joint production of underpriced resource services. Gregory (1955) showed the simplest conceptual form of this model for multiple use forestry. Binkley (1981) and Boyd (1984) made the first empirical applications in forestry—for small forest landowners in New Hampshire and North Carolina with multiple reasons for holding
forests and multiple income sources. Amacher et al. (AHJ, 1991a) show the usefulness of the household approach for assessing (mostly unpriced) fuelwood production and consumption in subsistence economies. [Singh et al. (1984) provide a useful survey of household models.]

The household production technique argues that household utility is a function of two or more forest resource uses and non-forest income. Income is the sum of income from exogenous sources, wages, and net forest receipts. The second forest resource use (e.g., recreation, fuelwood, fruit, forage) is consumed by the household directly. Labor is divided among non-forest labor, leisure, and labor spent on producing each forest resource value. Binkley and Boyd both found that, with higher household income, landowners attribute greater value to non-priced forest uses like recreation. Therefore, while stumpage price increases induce increased timber harvests and greater household incomes, they also increase the relative household valuation of competitive forest-based recreation. The net effect on recreation supply is positive but the final impact of timber price on stumpage supply is ambiguous.

AHJ examined household fuelwood production and consumption in Nepal. Households jointly produce agricultural products, agricultural residues for use as fuel, and fuelwood and consume all three products directly. They sell agricultural products and fuelwood in local markets. Otherwise, the basic model is comparable with Binkley’s and Boyd’s. AHJ found substitution between fuelwood and agricultural residuals among lower income farmers. Both women and men were involved in fuelwood collection, but men were more involved when fuelwood was collected from the household’s own fields. In these cases fuelwood and agricultural crops were joint products. Women were more involved when fuelwood was collected from more distant, open lands. Amacher et al (1991b) also found that new stove technologies substituted for fuelwood consumption in households with higher incomes, greater education levels, and other indicators of discretionary risk capital and when fuelwood prices are higher.

2.B.3 The Different Economics of Joint Production in Forestry

Joint production is different in forestry from other activities in its emphasis on underpriced values. On the other hand, underpriced values differ in forestry from their occurrence elsewhere in the degree to which they are components of joint production, often with a weakly competitive priced value. The result is that non-timber production and valuation remain among the more difficult conceptual and technical issues in forestry. Furthermore, efficient levels of underpriced production are generally unknown with any precision because the relevant marginal cost functions are virtually unexamined. [Daniels (1987) is the lone exception known to us.] Therefore, efficient levels of joint production often remain unclear.

Nevertheless, we would argue that the common perceptions of numerous market failures—and of important joint products on most every forest land area—are overdone. Indeed, these perceptions probably result in more failures of policy intervention than in corrected market failures in developed countries. [Boyd and Hyde (1989) examined twelve cases in US forestry and found but two cases where policy intervention created an arguable economic improvement. The other ten examples of public intervention; whether for market failure, distributive, or stabilization purposes; all failed on both efficiency and distributive grounds.] Growing doubts about the success of public interventions in developing countries (World Bank 1983, Srinivasan 1985, Krueger 1990) encourage a healthy skepticism regarding developing
country policy interventions to improve joint production of market and non-market forest resources.

We would also argue that policies like ACE compete with rational budgeting and land management in both developed and developing country forestry ministries. The competition may favor commercial timber products and it may be particularly damaging to underpriced local forest resource products like fuelwood, fodder, forage, fruit, nuts, poles for domestic construction, etc. in developing country subsistence economies. The local consumption of these latter products may continue to be important even as the local rural and subsistence economies grow. The income elasticities of demand for these products would provide insight regarding this contention about economic growth—yet these elasticities have been measured in few rigorous empirical analysis of our knowledge.

We will revisit these issues in subsequent discussions of smallholder management, policy spillovers, deforestation, and non-market values.

III. SPECIAL TOPICS

This second major section of the paper visits a collection of policy and management topics important in world forestry today. An economist’s organization of these topics might be: inputs, structure or institutions, and outputs. A list of specialized labels is more descriptive. The specialized labels are:

inputs: A. timber production: plantations and natural management
        B. smallholder management
        C. research

structure-direct D. tenure, contracts
structure-indirect E. policy spillovers from other sectors

outputs: commercial production and trade
        F. multiple use, joint products, non-market forest
        G. deforestation and sustainable forest management

The first input topic refers to all the standard issues of commercial wood and fiber growth and production. The second and third input topics are specialized inputs of current world interest. Smallholder management includes most of the issues in agroforestry, community forestry, and social forestry. It has particular distributive importance. Research is a specialized, and usually public, input to both industrial and smallholder wood production and to the production of some other forest resource services.

The most important institutions directly affecting forestry are tenurial arrangements and harvest contracts. There is also a growing conviction that spillovers from macroeconomic policies and from policies designed for their impacts on advanced wood and fiber processing
sectors, and even from policies on altogether different sectors like agriculture may have serious implications for forest-based activities of all kinds.

We might consider two output categories and one additional result of forestry activity which has great policy interest. The two outputs are industrial wood and wood products, and all other forest resource services. Wood and wood products are reviewed at the end of our discussion of timber production. Inputs. Many other forest resource services (poles, fuelwood, fodder, forage, fruit, nuts) are locally consumed. We include them in our "input" discussion of smallholder management because smallholders tend to be both producers and consumers. The important remaining forest resource services; local off-site values like erosion control, and global values like gene pool preservation, carbon sequestration, and global tourism; are the focus of our second output category. Policy concerns for timber famine and deforestation, and their policy opposite, sustainable forestry, are a result of forestry activities. They form our final topic in this section.

Each of these special topics relies, at least somewhat, on the conceptual background material in the first part of this paper. We continue to identify features of these seven topics that are unusual for forestry in comparison with other economic activities. These unusual features will be suggestive of the critical issues for today's world forest management—and the relevant foci for economic evaluation of these issues.

III.A TIMBER PRODUCTION: PLANTATIONS AND NATURAL MANAGEMENT

Table 2 shows the inventory of world forest resources by region. Since World War II, there has been a tremendous worldwide increase in plantation management as the preferred means for commercial forest reproduction. The Food and Agriculture Organization (FAO 1978) estimated the total area of plantation forests at 90 million hectares in the mid-1970s (about three percent of the total world closed forest). Plantations have increased substantially in the mid-1980s (Ewing and Chalk 1988).

Sedjo (1983) cites five reasons for the expansion: a) the increasing role of pulp and paper products in national economies, b) the need for relatively scarce long-fiber pulp from softwood trees (for paper production, and particularly in tropical countries), c) the high biological growth rates of non-indigenous trees, d) improved transportation systems that also improve the comparative advantage of forest production in the tropics, and e) rising real stumpage prices. In addition, the desire to reforest degraded agricultural areas, the wide availability of non-indigenous seeds and plantation technologies, the desire to incorporate technological improvements into the forest growing stock, and the potential for scale economies in timber production provide broad impetus for of plantation management techniques in all countries.

The worldwide expansion of the pulp and paper industry has had a significant impact on forest management. The large scale of cost efficient pulp mills and the high cost per unit weight of transporting logs, together require the close proximity of mills and large quantities of wood. Furthermore,
efficient pulp production requires homogeneous wood fiber inputs. Therefore, industrial managers generally favor single species plantations. Tropical forests lack softwood species and contain a broad diversity of hardwood species. This means that, for many industrial forestry processing activities, there is little choice but to adopt plantation management techniques for pine species (for softwood fiber) and eucalyptus or gmelina species (for hardwood fiber).11

A major advantage of plantation systems is that they allow the inputs of additional technologies to increase forest production. The resulting increases can be substantial. Plantation production ranges from 10–20 m³/ha/yr (Zobel et al. 1987), and is potentially as great as 60–100 m³/ha/yr for eucalyptus grandis plantations in southern Brazil (Brandao 1984). This compares with 1–2 m³/ha/yr for most natural forests.

Plantations often raise social and environmental objections. The social objections are usually associated with industrial plantations and government fuelwood plantations displacing local (usually agricultural) human populations. Forest plantations, however, rarely compete with agriculture as revenue producers. Therefore, the explanation for displacement must lie in either 1) unusual plantation returns exceeding local agricultural values or 2) a public agency or international donor mismeasure of the values associated with domestic agriculture.

The most common environmental objections have to do with nutrient deficiencies, soil degradation, and increased susceptibility to pests and disease.12 The psyllid attacks on Asian plantations of exotic (i.e., non-native) leucaena in the late 1980s was an example. Plantation management can make it profitable to spend resources combatting such environmental problems. Comparable environmental expenditures are usually uneconomic in natural forest production. Furthermore, such environmental problems are more common in agriculture than in forestry. Forest plantations are not as biologically pure as maize, soybean, or rice fields and foresters intervene only occasionally, and with light doses if at all, with pesticides, herbicides, fertilizers, and other inputs more generally associated with high intensity management. The financial returns do not justify frequent interventions, even in plantation forestry.

Finally, plantations often produce environmental benefits. Degraded forests and open areas are often preferred over naturally forested areas for plantation management because of the degraded areas easier access and lower site preparation costs (Zobel et al. 1987). In these cases, plantations improve the environment.

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11 There are unusual cases, such as in Colombia, where mixed tropical hardwoods have been used in pulp production (Gomez 1978).

12 For example, arguably negative environmental impacts from eucalyptus plantations have been reported in areas as diverse as the Amazon, California, and India. [Zobel et al. (1987) devote a full chapter of their book on exotic plantation management to rebutting political and biological arguments against the use of introduced species in forestry.]
3.A.1 Natural Forest Management for Wood Production

Natural management of Indigenous species is the alternative to plantation management. Natural management generally produces less wood per hectare. Therefore, the number of hectares necessary to produce a given output level is greater—and the environmental impact per unit of output may be greater. The production cost per hectare is smaller—unless there is a substantial decrease in the commercially useful share of all natural fiber. Regardless of these differences with plantation management, and regardless of the continuing advantages of exotic plantations in several important emerging forest producing regions (e.g., Brazil, New Zealand, and Chile), Sedjo and Lyon (1990) point out that approximately one-half of all timber production world-wide originates from natural stands. Furthermore, they project that the relative importance of natural stand production will not change in foreseeable future—at least through the mid-21st Century.

Natural timber management also permits the uninterrupted production of associated non-timber forest resource services. A growing body of literature provides evidence that these services are important. In special cases, the local economic value of these (often non-market) services can be greater than the timber values (Peters et al. 1989, Prance 1989). Nevertheless, the primary uses of natural forests probably will continue to be for their production of solid wood, especially for construction and fuel, and for the conversion opportunity from forestland to agricultural uses.

Sedjo (1991) uses financial examples from Indonesia to show that natural management can be the most profitable strategy, even for some cases in the tropics. There is, however, substantial concern regarding the sustainability of timber production from tropical moist forests. Poore (1988), Anderson (1989), and Roselle and Katelman (1990) claim that there has been only a "negligible" amount of sustainable tropical hardwood management to this time. The reasons are understandable: a) Some tropical harvests reflect optimal timber-mining (i.e., optimal draw-downs of an original natural stock). b) Some harvests occur only at large financial cost. They may combine with little long-term incentive for timber management. Therefore, the harvest activity may degrade the land or the residual forest so much that continued forest production is unlikely. c) Some harvests precede land conversion to a higher valued agricultural use. And d), some financial opportunities for natural management are only just gaining currency.

Anderson and Roselle and Katelman argue that developed countries should ban tropical timber imports in order to halt non-sustainable timber harvesting. Vincent (1990) argues that import restrictions could actually hasten the conversion of forest land as they would reduce the return to timber production and remove the economic incentive to keep land in forestry.

Tropical forest production, to date, largely can be explained by the frontier theory of resource use (Barnett and Morse 1963). Where there is an abundance of a resource, the price of the resource may be too low to justify management costs. Only as the resource is depleted and its price rises, will management efficiencies develop and incentives be created to reduce waste in production. This explains, in part, why there has been little effort until recently
to develop more efficient schemes for exploiting tropical forests. The frequent absence of full and secure property rights which would give stronger incentives to manage timber for the long term, only reinforces this explanation and its impact. [Sedjo (1990b) points out that local private interests may be obtaining more secure long-term position in forestland in some Asian countries that produce industrial hardwoods. He observes some changing management practice coincident with these more secure positions.]

3.A.2 Forestry in Development

The understanding of forestry's relationship to development has undergone substantial revision over the past forty years, partly in recognition that many early development policies were untenable. The early view emphasized forestry as a vital tool for the production of raw materials for industrialization and de-emphasized the other, non-commodity and household, uses of the forest (Westoby 1962). Forestry's strong forward and backward linkages to the economy were thought to offer an excellent vehicle for countries developing their own capital bases (Hirschman 1958). The World Bank's (1978) lending program emphasizing industrial plantations and pulp and paper mill construction was consistent with this view.

Both foresters and donor agencies began questioning these capital intensive programs in the 1970s. Many plantations and many pulp and paper mills did not live up to their initial expectations. Furthermore, expanding rural populations and increasing fuelwood consumption (urban and rural) attracted growing attention. The rural poor do not necessarily benefit from capital intensive projects, and the rural population and aggregate fuelwood consumption, together with local tenure problems, often limit the potential of plantations to meet development objectives (Douglas 1983, Westoby 1987)

The contribution of forestry to economic development remains an unsettled question. Meeting the needs of the rural poor—whether through multipurpose trees, fuelwood, jobs, income, or land—is a daunting endeavor. Many developing countries are committed to developing their internal wood processing capacities. This often has led to economic failure and wasted resources. The World Bank and other donor agencies have made numerous policy statements regarding the desirability of environmentally sound forestry activities. Their recent emphasis is on sustainable land uses and social efficiency as the most economically, and financially, satisfying means of addressing these objectives.

3.A.3 Commercial Products and Trade

The focus of this paper is on forests and forest management. Nevertheless, it may be useful to briefly examine the magnitudes of commercial forest production, international trade, and their determinants. Although a wide variety of goods are produced in the forest, wood and

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13 See Repetto and Gillis (1988) and Boyd et al (1990) for discussions of the losses from forest capacity expansion in wood processing industries in Indonesia and the Philippines, respectively.
wood products remain the primary commercial goods. The major wood products range from fuelwood and charcoal for domestic consumption, to roundwood products such as lumber and panel products, to pulp and paper products for domestic consumption and for export. Table 3 presents regional average annual production values of these goods between 1984 and 1986, along with the percentage output change from the previous decade, 1974–1976. Regional production depends on a number of factors including potentially forested area, the marginal area devoted exclusively to forestry, and the demand for alternative land uses. The distribution of land uses depends on the personal needs, potential substitutes, and industrial capabilities found within the region. For example, 82 percent of the North America’s total roundwood production (fuelwood and charcoal plus industrial roundwood) is an intermediate output in industrial production, while only twelve percent of Africa’s roundwood is an intermediate industrial product. The remainder is fuel.

Recent changes in industrial production reflect changes in prices, tastes, and industrial capacity. Relatively large increases in industrial roundwood production for Asia and Central and South America reflect large increases in panel and paper production. A number of countries in these regions, particularly Brazil, Chile, Indonesia, and the Philippines, expanded their processing capacities over the decade. The regional production capacity of Asia grew substantially in the past decade and Asian production now approaches or exceeds the level of European production for most forest-based commodities. Nevertheless, the major wood products producing region, for virtually all forest-based commodities, remains North America.

Forestry’s impact on national economies varies greatly. It is generally small relative to the total economy. In some cases, however, forestry is a significant portion of domestic production and trade flow. For instance, the forest sector in Papua New Guinea represented 4.6 percent of GDP and 8.5 percent of exports in 1988 (World Bank 1990); the forestry sector’s share of Philippine GNP was 1.6 percent in 1986 (World Bank 1989); and in Indonesia forestry was 1.2 percent of GDP, but 14.4 percent of exports between 1983 and 1987 (Repetto et al 1989). Table 4 shows the regional flows (exports and imports) for various forest products. The largest importers of forest products in absolute numbers tend also to be the largest exporters. South American exports of all products increased sharply in the last decade, while Asian imports increased. Both Asia and Africa display declining export capacity, due to either a declining resource base or increasing internal demand.

There are numerous econometric demand and supply estimates for primary forest products. Most are short-run estimates for sawtimber and pulpwood in developed countries. Table 5 summarizes several of the more reliable estimates. Both demand and supply elasticities generally show very little price response. Short-run timber supply decisions are generally limited by existing capital. Pulpwood demand decisions are also limited by existing capital. Solidwood demand tends to be a small part of total consumer demand for any finished product in which it is a component. In the only long-run econometric estimate known to us, Wear and Newman (forthcoming) find that timber producers are much more responsive to permanent real price changes.
Table 6 summarizes the econometric estimates of demand price and income elasticities for processed forest products. The demand price elasticities are small, but not generally as negative as the demand price elasticities for primary commercial forest products (from Table 5). Income elasticities are generally larger and, as shown in Table 7, they can become quite large when evaluated over discrete time periods. Income elasticities are relatively greater for developing countries than for the same processed products in industrial countries. Demand for all forest products (as measured by apparent consumption) has increased at a faster rate in developing countries than in industrial countries over the thirty year period from 1955 to 1985 (Ewing and Chalk 1988). Nevertheless, the overall consumption of all forest products (other than fuelwood) is substantially greater in industrial countries.

III.B SMALLHOLDER MANAGEMENT

Smallholder forest management usually refers to the ownership and management of forest land by individuals who do not also maintain further processing capabilities beyond their own personal uses. Smallholder management can range from small, several hectare or less, subsistence agroforestry schemes in which timber is only one of a number of outputs from the land and the trees, to extremely large forest holdings of private individuals in which timber is the primary output of the land. (In developed countries, land held by smallholders is often called nonindustrial private forestland, or NIPF.) Timber output levels from this ownership class vary from relatively small percentages of national production in those countries whose governments control the majority of timber output, to substantial percentages in both developed countries such as the US and the Scandinavian countries and widely settled developing countries like Bangladesh. Smallholders also produce important amenity services for their own consumption, and often for the consumption of others. The heterogeneity within the smallholder ownership type makes generalizations regarding smallholder objectives difficult—although substantial progress has been made in characterizing their behavior.

3.B.1 Developed Countries

Developed country forest policy analysis, for decades, has focused on the sociological characteristics of smallholders and the "problems" associated with their production. These problems are the perceived smallholder underproduction of timber—when compared with industrial ownerships, and the seemingly irrational smallholder production behavior. Recent formal analyses provide a clearer understanding of NIPF behavior (Binkley 1980, Boyd 1984, Johansson and Lofgren 1985, Kuuluvainen 1989). These analyses model NIPF landowners as utility

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14 These are the perceptions of public agency foresters. Economists (e.g., Clawson 1979) have long recognized the multiple objective rationality of smallholders. Boyd and Hyde (1989, chapter 3) cite the lengthy US literature of this topic.
maximizers, trading off between the amenity and income benefits which derive from their forestland. Income benefits arise from the sale of timber while amenity benefits may be hunting, non-consumptive outdoor recreation, second homes, or various other leisure activities. NIPF production behavior is rational and efficient within this understanding of household analysis. This result is analytically satisfying, but it is of little comfort to planners attempting to stimulate smallholder timber production through incentive or regulatory programs.

Econometric estimates show NIPF timber supply price responsiveness to be surprisingly similar to industrial ownerships. Adams and Haynes (1980) in the US, Loikkanen et al. (1986) in Finland, Hultkrantz and Aronsson (1989) in Sweden, and Newman and Wear (1990) in the southern US estimate short-run elasticities ranging from quite low values of 0.1–0.2 to values near 1.0, depending on the region, product, and estimation method. (See Table 5.) This low price responsiveness is related to the long-term nature of the forest investment, the difficulty that owners have in changing harvest plans in response to short-term price changes, and the utility NIPF owners obtain from their standing forests. In the only econometric estimates of long-run price elasticities, Newman and Wear (1990) show that both NIPF and industrial owners in the southern US make very price elastic long-term supply responses, between 2.0 and 3.5. Thus, while short-term timber supply responses may be small, smallholders do respond to increasing scarcity (and resulting increasing price levels) by increasing both their input and output levels.

The impacts of public policies on smallholder timber production have been a major issue for policy analysis. The focus of this analysis has been landowner responses to taxes and subsidies. At the turn of the century, a number of US states placed high ad valorem taxes on timber in an attempt to maintain local revenues (Fairchild 1935). This particular tax is difficult for NIPF owners to accommodate and it may have led to increased deforestation at that time. The tax calls for increasing annual payments based on the growing value of the standing timber. Annual payments are difficult for small landowners who do not receive a regular inflow of timber income. The tax may have caused smallholders either to convert their land out of timber in order to avoid the tax or to give up their land through tax default. Unfortunately, a number of states still use ad valorem of taxes, rather than more neutral severance or yield taxes payable when the timber is harvested (Boyd 1986).

Timber input subsidies and regulations have been the primary policy instruments for governments desiring to promote forest management by private owners. The impacts of these instruments, however, have been less than encouraging. For example, Boyd and Hyde (1989) found no statistically significant impacts from seed tree laws in Virginia; de Steiguer (1983) could not reject the hypothesis that regeneration subsidies in the southern US cause

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15 The market failure that these subsidies and regulations intend to overcome is not well-identified. The public agency concern is with long-run timber supply. Yet all casual empirical evidence suggests that the markets for wood do respond to price expectations and NIPF landowners do behave rationally. The available analytical evidence also supports the contention of market rationality (Berck 1979, Johnson and Libecap 1980).
capital substitution rather than stimulate planting; \(^{16}\) and Carlen and Lofgren (1986) found no statistically significant supply impacts from thinning subsidies in Sweden. The limited impacts of these instruments, while discouraging for those promoting active policies to increase NIPF timber production, is not surprising when considered in conjunction with smallholder supply responses. Increasing prices are a much better inducement for long-term production. Stop-gap policies designed to encourage some specific form of intermediate-period timber management may induce some timber growth but they have only indirect and uncertain impacts on eventual harvests.

A final issue involving NIPF management in developed countries has been the production of multiple outputs. Binkley's (1980) and Boyd's (1984) analyses clearly delineate the multiple use trade-offs that smallholders face when determining their harvest and management decisions. For some, timber is a standing bank account that grows until a withdrawal is needed. \(^{17}\) Other landowners may actively include the value of amenity benefits in their management decisions and make their harvest decisions accordingly. Binkley and Boyd show that amenity valuation rises with NIPF owner income levels. Newman and Wear (1990a and 1990b) found that NIPF owners place a much higher shadow value on standing timber and timberland than industrial owners. They ascribe the presence of non-market benefits for this difference in valuation. Berck (1979) also found that NIPF owners manage their land for substantially longer rotations, although their time preferences (discount rates) are comparable with industrial owners.

3.B.2 Developing Countries

Smallholder forest production in developing countries probably has comparable characteristics, although supporting econometric analyses are less common. Smallholders obtain a multiple of products from the forest—or from their privately owned trees: poles for domestic construction, fuelwood, fodder, forage, fruits and nuts, latex, native medicines. (We will discuss off-site values like erosion control and ecotourism in a later section.) The critical inputs seem to be private land used competitively for agricultural crops, the community's common lands, and household labor, particularly women's labor.

The literature on subsistence agriculture, as well as various sociological and anthropological characterizations of smallholder forest activities, argue for the importance of land tenure, capital access, smallholder time preference, risk aversion, and market access (Arnold 1983, Gregersen et al. 1989, Hosier 1989). Competition for arable land places a premium

\(^{16}\)Romm and Washburn (1987) obtained similar results in California, although they also found positive investment effects.

\(^{17}\)This is the "Volvo" argument for harvesting discussed by Johansson and Lofgren (1985). Swedish forest landowners cut timber when they need a new car. Their behavior creates backward bending individual supply curves because their Volvo purchases require only a fixed revenue from any timber sale. Therefore, individual landowners harvest less timber when stumpage prices are higher.
on forest activities which can be satisfied as part of an overall agricultural scheme (agroforestry), yet which are not provided by marginally productive common lands (community forestry). Therefore, sacrificing family labor to collect forest products may be a lower cost alternative than giving up arable land for tree planting. Of course, it is not an alternative that encourages sustainable forestry because there is little incentive for continuing forest management on many commonly held lands.

Insecure tenure places a premium on short-term activities. It removes access to credit (using land as collateral) and reduces incentives for long-term conservation activities like tree planting. It also encourages over-exploitation of the standing forest resource (Feder et al. 1988, Fortmann and Bruce 1988). On the other hand, it causes the poorest households to view the less secure common lands as a source of some protection against risk to their own alternative sources of fuelwood, fodder, and forage (Jodha 1985, 1986; Griffin 1991).

Market access limits the acceptance of social forestry activities. Rafiq (1988) compared various upland villages in Pakistan and found that access to roads and markets improves the likelihood of adoption of social forestry activities. He also found that local markets are more important than external markets. Markets expand the demand-side opportunities for both quantity and variety of forest products. Therefore, market existence can increase the incentives for social forestry activities (Rafiq 1988, Dewees 1989).

Mixed forestry systems, such as intercropping in agroforestry, offer lower risk than more uniform systems, like plantations. They may also yield lower returns. Therefore, while mixed forestry systems are a means of spreading risk, they may be a less preferable means for accomplishing this for households with other alternatives (Blanden 1985, Gregersen et al. 1989).

Fuelwood probably receives the greatest attention of any smallholder forest product. The implicit hypotheses in the fuelwood literature are that fuelwood a) consumes a large share of household budgets (of both labor and income); b) is relatively demand price elastic; and c) has relatively few substitutes, therefore a lower price elasticity, but higher income elasticity for the poorest households.\(^{18}\) Table 8 reviews the findings of the sparse empirical evidence. Fuelwood collection is often a woman's responsibility. Once more, the available literature is general and intuitive. Kumer and Hotchkiss (K&H 1988) is an exception. K&H examine fuelwood collection in Nepal's hills and find that releasing women's labor from fuelwood collection yields greater gains in both household nutrition and household agricultural production.

These hypotheses regarding fuelwood elasticities and the K&H findings for women's responsibilities are probably valid for many forest products consumed by subsistence

\(^{18}\)Dewees (1988) critically examines the fuelwood energy literature. Hyde (1991) catalogues the specific hypotheses underlying contemporary thought about the adoption of fuelwood projects by poor rural communities.
agricultural households. They are the basis for economic arguments about the importance of forestry in rural development. Unfortunately, there is little rigorous analytical evidence either to support or to reject these hypotheses.

There are various attempts to formalize arguments about the impacts of fuelwood collection and technical substitution between fuelwood and other fuel sources (i.e., charcoal, liquid petroleum gas) on deforestation. Many of these focus on urban fuelwood consumers with the implicit justifications that rural demands are approximately sustainable, but urban demands are not. Furthermore, urban demands are concentrated, therefore more susceptible to policies enforcing their modification.

The usual presumption is that the presence of substitutes decreases fuelwood consumption and increases forest stocks. Amacher et al. (1991a) found inelastic substitution between fuelwood and agricultural residues in Nepal's hills. Clarke and Shrestha (1989) found that, with sufficient demand elasticities, the introduction of improved stoves (fuelwood substitution, or utilization and conversion technologies) actually might reduce long-run forest stocks. This is because price increases, or rising profitability, can induce greater forest use than existed prior to the new technology. Dick (1980) and Pitt (1985), in studies of Indonesian energy use, found little substitution between kerosene and fuelwood. Kerosene subsidies had little impact on fuelwood consumption and the benefits from the subsidies primarily went to urban, and not rural, households. Thus, while alternate technologies may suggest some solutions to deforestation and land use problems, their recommendations must be tempered by local conditions and the actual potential for behavioral changes.

III.C RESEARCH

Forestry research may be one answer to some of the problems of rural development, as well as one response to global deforestation. The well-known gains from world agricultural research encourage the expectation that there may be counterpart gains in forestry. We will review the few empirical analyses of forest research productivity, attempt to reconcile their findings with other economic evidence, and consider their implications for future forest research investments, particularly in the developing world.

Initial speculations of gains from forestry research are based on an agricultural history of select but spectacular field research results (like IR-8 at the International Rice Research Institute) and of more general research investments returning 35–110 percent annually (Brumm and Hemphill 1976, Ruttan 1980). Mergen et al. (1988) reveal the generally implicit expectation that forestry research should be comparable. Field trials showing greater than 100 percent annual

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19 Residues are an inferior good. An unmeasured wealth effect dominates these Amacher et al. price changes. We can anticipate that this really reflects an important difference between preferences for residues and higher quality substitutes (like kerosene) for fuelwood. Amacher et al. do not have evidence on kerosene substitution for fuelwood as little kerosene reaches the more isolated communities in Nepal's hills.
increases in site productivity in certain temperate locations—even greater in tropical areas—reinforce them (e.g., Campbell and Hughes 1980). Finally, these speculations take on greater social merit when combined with the knowledge that forests provide many basic services (food, heat, construction wood for shelter, forage and fodder for draft animals) for the poorest rural populations and also help to protect their agricultural productivity (soil and watershed protection, nitrogen fixation).

Several recent international activities lend formal credibility to these speculations. The International Union of Forest Research Organizations, under the leadership of Robert Buckman, has encouraged international donor agencies to set up regional forest research centers in developing countries around the world. One response was Bellagio II, a November 1988 meeting of donor agencies, to discus research strategies for tropical forests. Lists of recommended research concentrations are one frequent result of Bellagio II and similar meetings (e.g., Kandy in 1984, East-West Center in 1986). These reflect the considered judgments of the most thoughtful senior forestry experts but they are seldom based on thorough analysis. The lists usually include a) tree improvement, b) soil and watershed protection, c) forest products, d) conservation and biodiversity, and sometimes e) policy research. [Indeed, this is John Spears summary list (1988).]

Our observation is that the economic evidence is encouraging for the role of forestry research in general. It is much more cautious about general production gains from biologically-oriented (timber growth and management) forestry research.

3.C.1 Research Evaluations in Forestry

There has been a 30-year history of economic agricultural research evaluations (since Grilliches 1958). The experience in forestry is more recent—and largely restricted to the US.

Forestry research evaluations can be divided into two broad industrial categories: forest products and utilization, and timber growth and management. All evaluations in both categories are for publicly-funded, not private industrial, research. Evaluations in both follow the pattern of the established agricultural research literature in measuring outward production shifts or downward cost or supply shifts. Forest products evaluations use the most recent econometric techniques (e.g., duality) and often achieve greater statistical reliability than the previous agricultural literature. On the other hand, timber management research evaluation suffers from the paucity of time series data discussed in section IA of this paper. The long time lags between timber management research, implementation, and final output, together with this data weakness, require that timber management evaluations rely on sensitivity tests for realistic ranges of some input data. The result is that some timber management results must be presented as upper bounds and optimistic policy interpretations.

Evaluations of structural particleboard (Bengston 1984), softwood plywood (Seldon 1987, Seldon and Newman 1987), sawmills (Seldon and Hyde 1990c), woodpulp and wood preservatives (Seldon and Hyde 1990a,b) report average rates of returns ranging from 33 percent to over 300
percent for forest products research. These rates exclude the additional environmental benefits of woodpulp and wood preservatives research. Including them would increase returns in these two industries above 33 percent. Further examination shows that public funding in each of the five industries is justified on basis of either the large consumer benefits (highly inelastic demand functions) or the competitive nature of the industry, therefore the necessarily wide sharing of research benefits or pooling of research costs.

Timber management research evaluations are not nearly so encouraging. General southern pine research through 1980 produced physical growth responses approximating 0.6 percent annually, but negative economic returns (Newman 1986, 1990). Therefore, we can conclude that timber management research has paid few dividends in the US South, arguably the most dynamic timber producing region of the world. Convincing evidence of low research productivity in this region suggests that timber management research in general has been even less productive in other regions of the world and for other species. Nevertheless, there may be a few select and specialized exceptions to this South–wide and timber management–wide finding. Apparently, containerized seedling (Westgate 1986) and herbaceous weed control (Huang and Teeter 1990) research, which return approximately ten percent annually, are two examples.

This timber management experience contrasts with the biological research gains shown in field trials. The explanation lies in low production costs; therefore, small opportunity for cost-saving productivity gains in timber management—even where knowledge of potential biological gain is irrefutable. This describes the US South where most forestry research is land- and capital (production time)-saving, but where forestland and production time are not scarce resources. The South has a history of abandoned old fields naturally converting to forests and providing a continuing source of inexpensive wood fiber.

Our general timber management research observation is consistent with recent casual observations of industrial firms downgrading their timber research activities. It is also consistent with observations of labor–saving technical change bias in the wood products industries (Kendrick 1961, Robinson 1975, Stier 1980, Greber and White 1982). Labor–saving bias implies a capital and resource–using bias which means that the basic resource, wood fiber, is insufficiently scarce, or stumpage prices are insufficiently high, to induce resource–saving technical change.

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20 Long-run values of marginal products (VMP) for woodpulp and wood preservatives are negative. The rates of return and these VMPs, taken together, imply that research investments in these industries were most productive on the average, but overextended at the margin. Average returns would have been greater if unproductive marginal investments had not occurred.

21 Less than forty percent of southern US industrial forests are managed plantations. Industrial forests are only 11.5 percent of all southern forests (USDA Forest Service 1988). Non–plantation forests and non–industrial lands are managed extensively, if managed at all.
This body of evidence is also consistent with the frontier hypothesis for development of the timber growth and management industry. Land and resources are relatively plentiful on the frontier while labor is relatively scarce. Relative factor scarcities will adjust over time as the frontier fills in, or as the industry matures. (Section IA of this paper spoke of forestry's experience with long-term relative price increases.) We might anticipate that southern pine timber growth and management research will not achieve its full productivity until the rate of stumpage price increase eventually tapers off. There is some argument that this has recently occurred—or will occur early in the 21st Century (Adams and Haynes 1980, Sedjo and Lyon 1990).

3.C.2 Implications for the Developing World

These narrow expectations are only partially transferable to the rest of the world. Their relevance outside the US depends on specialized local market situations and policy incentives. Davis et al. (1988) argue that local market size and market efficiency are critical factors in judging the potential impacts of Australian forestry research in developing countries. We might consider what are those market situations and policy incentives.

Processing industries are less developed and markets for processed wood products are less extensive in most developing countries than in the US. Therefore, the scope for forest products research in general is smaller in most developing countries than in the US. The result may be fewer research opportunities, but those research opportunities that do exist probably offer the same high social rewards that forest products research offers in the US.

The logging industry may be a particularly good candidate. It is the first step in all wood processing. Therefore, the market for new logging technologies is broad. Furthermore, most logging technologies were developed for economically advanced countries where labor is scarcer relative to capital equipment. The relative difference in these factor endowments suggests developing country opportunities for new, relatively more labor intensive, technologies.

The large developing country demand for wood as a domestic fuel suggests additional research opportunities that are not so important in developed countries. Charcoal and improved stove research are obvious examples. Furthermore, the poorest households spend the largest budget shares and probably have the highest income elasticities for fuelwood and its substitutes. This may suggest an important equity perspective for research on these technologies.

Finding timber management research opportunities is more problematic. Many developing countries possess existing stands of mature timber and many, with less extensive stands, are still in the process of drawing down their mature stocks. Countries in these frontier situations are comparable to the US South: the wood resource is not scarce relative to local labor or capital equipment. Indeed, Sedjo and Lyon (1990) find that the frontier hypothesis and a low cost forest resource describe fully one-half of the world's annual industrial production. Sedjo and Lyon project that this description of world wood production will not change—even into the middle of the 21st Century.
The promise of timber growth and management research is better where forestry is a financially successful venture and where the existing stands of timber are largely privately managed. These two characteristics suggest that the policy research issues of tenure and macro-policy impacts have been resolved. Successful agroforestry activities are one example. Bangladesh and Malawi provide examples within our own personal experience. These are cases where there are real local costs to forest production, yet private incentives for timber management. They recommend timber growth and management research concentrating on those few species with large and widespread markets, as well as minimum competition from species growing naturally on the extensive margin. [Hyde et al. (1991) reviews these prospects in greater detail.]

III.D SECURE RIGHTS: CONTRACTS AND TENURE

The prevailing institutional rights to the resource identify a set of boundaries within which all economic activity takes place. The important institutional structure for commercial timber operations are the contracts between the governments that tend to own the largest shares of all forestland, particularly in developing countries, and the industrial firms, the concessionaires, that log and process the timber resource. The important institutional structure for smallholder management and use of the forest resource is the smallholder’s resource tenure—or lack of it. Tenure may be established for land with trees or for the trees themselves (Fortmann and Bruce 1988). It may be held singly by individual persons, or communally in accordance with specialized set of local rules or customs (Runge 1981). The important characteristic is the security of the individual or group possession.

Commercial timber contracts and smallholder tenure arrangements determine the incentives for the exploitation of, and investment in, forest resources. The absence of secure arrangements encourages overexploitation and disinvestment. The presence of secure resource tenure permits the resource user to obtain the returns on long-term investments in the resource, including conservation and resource protecting investments. A substantial literature seeks to identify the characteristics of forest tenure (Fortmann and Riddell 1985, Fortmann 1985), but the opportunity for empirical analysis has been untapped—to our knowledge.

3.D.1 Timber Concessions

Timber management is a long-term investment. Timber concession agreements between the host governments, who usually hold the rights for the forest, and the forest industry must

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22 Ruttan (1989) has long stressed the need to increase the social science research component in international research programs. Schuh (1990) argues that significant breakthroughs for many staple crops are limited and that ecological considerations are now the most important factors in agricultural production. Forestry's "green revolution" may still be forthcoming. Nevertheless, the advice of Ruttan and Schuh should carry over from agriculture to forestry.
permit adequate incentives to make these investments. Too often the concession arrangement is too short to permit private receipt of gains from concessionaire silvicultural activities after the first harvest. In Sabah, for example, half of all concessions are for 21 years, most of the remainder are for ten years, and five percent are for one year. The full timber rotation, in contrast, exceeds seventy years. Concessionaires, in the Sabah case, may harvest gradually over a 21-year period, but with disregard for any residual growth or reforestation in that time.

The environmental results of short-term concessions are forest depletion, little or no sustained silvicultural management, and severe soil erosion—even where a second forest would be commercially viable. Where the Forest Ministry designs harvest restrictions to protect the residual of unharvested timber and the future site productivity, the Ministry may not have the means to enforce these harvest restrictions. Furthermore, the restrictions may conflict with short-term concessionaire maximization. Where incentives do permit sustained silvicultural activity, they focus too often on subsidized, short rotation, exotic plantations when either natural or managed stands of native species may be sustainable, more profitable, and more socially efficient (Sedjo 1990).

These results create additional demand for a) policies to regulate "short-sighted" timber concessionaires and b) larger Forest Ministries to administer the additional regulations. Nevertheless, greater administrative costs and regulations that are often unenforceable are generally poor substitutes for improved private incentives. Longer-term contracts or contracts with provisions for performance-based extensions would force concessionaires to bear the costs that their initial harvests impose on future resource returns. They would also permit concessionaires to reap the future rewards that are the necessary incentives for good harvest and regeneration practices. (Canada is the developed world model for long-term forest concessions.)

In some cases, longer-term contracts have been a problem because national governments could not guarantee consistent policies over periods long enough to secure silvicultural investments. An alternative seems to be developing in some countries (the Philippines, Indonesia, Malaysia) where timber concessions generally have become the property of wealthy local private interests. The economic positions of these local interests may be more durable than the government itself. Such local private interests can make reliable long-term commitments to invest in sustained silvicultural activities where the anticipated returns justify them.

These private arrangements, however, raise an important distributive question. A few affluent local citizens, perhaps in association with foreign corporate interests, may capture the rents from what may have been a public forest resource. These rents are the topic of a burgeoning, and sometimes confused, literature of their own. Our appendix A, by Hyde and Sedjo,

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23 Alternately, the land management agency must be able to enforce harvest restrictions that protect its own economic interests in the land and the residual forest stand. This is the US Forest Service case: The timber contract is brief in time (usually three-five years) and only permits current harvests at an agreed level in an agreed area. Subsequent management investments, and subsequent long-run economic returns, are the Forest Service's responsibility.
reviews the critical conceptual issues and errors. The resource rents are not dissipated, they are only spread around: to concessionaires, to the Forest Ministry or the public treasury, or to Forest Ministry employees. Therefore, the rent distribution question is probably more important than the question of optimal rent recovery by the Forest Ministry.

It is solely an empirical question whether the national economy and the poorer local population gain more from private harvests and reinvestment than they would from the Forest Ministry's management of the resource. How much would private operators reinvest locally, how much would filter down to the local poor, and how much would the private operators transfer to secure accounts overseas? Alternately, how much resource rent would the Forest Ministry collect for the public treasury, how much of this would be reinvested in socially beneficial activities and how much would the Forest Ministry dissipate in excess employment, poor financial management, and insufficient ecological awareness?

3.3.2 Smallholder Rights

Trees are generally low-valued resources and they tend to grow on low-valued land. Therefore, historical claims on them, in general, were pursued and enforced less actively. As a result, these claims are less well-developed now. This is particularly true in countries with newly developing national institutions.

Most tropical forests are the de jure property of the national government. The de facto land managers, however, may be indigenous populations or squatters. Without legal rights, these populations have little incentive to protect the long-run productivity of the forest. Rather, their incentives are to extract what they can in the short run and to move on. Preventing short-run forest exploitation by these populations usually requires more forest guards and greater administrative expense that the Forest Ministry or even the army can assemble. The potential of forced removal may always be a threat to these populations, but this threat only reinforces their incentive to exploit what they can before the forest guards or the army actually do remove them.

Where the resource is scarce, then fully authorized transfers of title from the Forest Ministry to the population of generally poor local users may protect the values of minor forest products and also encourage more permanent agricultural settlement by the current population of

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24. The general assumption is that trees are the lowest valued commercial crop. Therefore, managed tree crops grow at the extensive economic margin. Beyond this margin, trees with no local economic value may grow naturally. This natural forest serves as a buffer to fluctuating local and regional markets for tree products.

The exceptions to this general assumption are a) horticultural crops and b) a few cases in central Africa (e.g., Kenya, Malawi) where wood fuel consumes a large share of household budgets. In these latter, unusual cases, trees are a relatively higher valued crop and they may be grown on higher valued land (even replacing small amounts of some agricultural crops) and land closer to both rural households and urban markets.
shifting cultivators (e.g., delos Angeles 1988, Stevens 1988). Permanent and transferable title would provide the new local landowners with access to credit and inducement for longer-term investments like conservation practices.

Feder et al. (1988) measured the benefits of transferable titles for agricultural communities in rural Thailand. They found that the benefits, in terms of additional long-term productivity, outweighed the initial administrative costs. Migot-Adholla et al (1990) examined tenure in sub-Saharan Africa. They found that Indigenous African (Kenya, Ghana, Rwanda) Institutions adapt as needed and that insecure tenure does not retard agricultural development in these three countries. The Feder et al. and Migot-Adholla et al. analyses, although they feature agricultural land uses, may be instructive to smallholder forestry. They suggest that the problems with de facto insecure tenure occur where the national constitutional order and institutional arrangements are well-established but where recent population growth and human development cause the old institutions to be unenforceable. There certainly are cases that fit this description in Thailand, Nepal, and the Philippines. The description may be generalizable to Asia. On the other hand, the relevant institutions may still be flexible and insecure tenure may not be a problem where settled agricultural development—as opposed to hunting and gathering or herding—is more recent, but old normative behavioral codes still legitimize changes in land use behavior. The latter may be a good description for much of Africa. (See Feder and Feeny 1990.)

In any event, property must be the right of the de facto manager, usually the squatter who lives on the land, in order to provide the incentives for conservation practices and long-term land and forest stewardship. Only the squatter’s family can police the property’s boundaries on a regular and long-term basis. Property rights must also be fully transferable. Without transferability, the property owner forgoes both access to credit, which may be used to support conservation investments, and the right to sell, therefore one access to the potential returns on the owner’s investment. Removing the opportunity to make land sales and transfers, removes the incentive to leave the property in good condition should the owner choose to move.

III.E POLICY SPILOVERS

The second general set of structural impacts on forestry arises from a range of policies designed for other objectives but which negatively affect the forest resource. These can be macroeconomic policies designed to affect all sectors alike but having special unintended impacts on the forest, or they can be policies designed to benefit another sector like forest products or agriculture but spilling over from that sector to negatively affect a nation’s forests.

The normal tendency of policy analysts is to look for direct effects. Therefore, there are few empirical examinations emphasizing indirect impacts like these. Two country-specific examinations, of Brazil and the Philippines, serve as examples. Even these two are impressionistic.

25 There is an increasing literature on the risk protection that lands with less secure tenure provide the poorest rural populations. See Jodha (1985, 1986) and Griffin (1991).
rather than thorough empirical examinations (at this date). Numerous additional examples await examination. Nevertheless, we submit the hypotheses that a) unintended forest policy spillovers are most important in countries with remaining undeveloped forestry frontiers and b) policy spillovers are among the major causes of global deforestation.

3.E.1 Brazil and the Philippines

Arguably one-half of the forest destruction in Brazil’s Amazonia has been the direct result of government subsidies for livestock production and agricultural settlement. Livestock production often is especially erosive of the open grazing range. Brazil’s inflationary monetary and fiscal policies encourage wealth accumulation in fixed assets like land but the only legal way to establish new land claims is to convert forests to agricultural use.26 Furthermore, agricultural land and agricultural income were exempt from most taxes until 1989, and subsidized rural agricultural credit still encourages yet additional agricultural encroachment on the forest. Natural forest production of any sort (commercial timber, latex gathering, fruit and nut gathering) is not entitled to counterpart government incentives. The result is both rapid deforestation and a livestock subsidy alone estimated at one billion dollars (US) for the ten years preceding 1986 (Mahar 1988, Binswanger 1989, Lewandrowski and McClain 1990).

In the Philippines, a labor–capital tax ratio five times that in developed western countries (Habito 1983), export subsidies on manufactured goods, and a minimum wage law that was at least marginally effective in major urban areas, all encourage capital displacement of labor. They drive large numbers of laborers and their families to the agricultural sector. The same capital displacement of labor occurs, if at a smaller rate, in the developed agricultural sector. Capital input subsidies and rice price supports may be complementary inducements for labor mobility to the rural areas. In the end, some displaced labors can only be driven from developed agriculture on to the uplands where they and their families become subsistence farmers and squatters on the nationalized forestland (Boyd et al. 1990). An upland population growth rate of 2.6 percent per annum is the result. The upland population is now thirty percent of the Philippine total (M. Cruz et al. 1988).

Squatters convert the forest and produce agricultural crops, but under regular threat of their forceful removal from the land. Therefore, tenure problems also arise in this Philippine case. Squatters farm the forest extensively and without the long-term security that is a necessary incentive for introducing simple and well-known conservation practices. The resulting soil erosion reinforces the non-sustainability of upland agriculture and induces the further conversion of forestland to agriculture. It also causes downstream sedimentation, a serious problem for the reservoirs supporting both hydropower and irrigated agricultural production, and for the off-shore coral reefs and associated fisheries (W. Cruz 1988).

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26 The US similarly required forest destruction as the “improvement” necessary to justify land claims during 19th Century homesteading of America’s western frontier.
3.E.2 Other Cases

Restrictions on timber harvests and international log trade and laws requiring domestic log processing spillover from the harvesting and trade sectors to result in doubtful impacts on the forests of many developing countries—including Brazil and the Philippines, and also Indonesia, Liberia, Gabon, and the Ivory Coast. Harvest and trade restrictions may decrease harvests, but they also may encourage more rapid harvests in anticipation of future stricter enforcement of the new restrictions. (The Bangkok Post argued that this explained southern Thailand’s great forest landslides in spring 1990.) Furthermore, harvest and trade restrictions reduce the incentives for long-term silvicultural management. Finally, required domestic processing compounds the issue by dissipating domestic returns on the resource.27

These policy spillovers are not in the long-run best interest of world social welfare. They serve special political interests and they may serve localized agricultural and industrial development objectives, but they are largely counter to the domestic government’s financial interests—in the short and the long run. As governments become aware of this final point—and if the special interests are not too strong—then an opportunity exists to alter these policies and to improve the condition of global forests.

III.F MULTIPLE USE, JOINT PRODUCTS, NON-MARKET FOREST OUTPUTS

Multiple use, or non-market forest production, is among the most discussed general issues in world forestry, especially for tropical and developing country forests. The discussion focuses on five forest resource services: potential climate change and the ability of forests to sequester carbon; biodiversity or the preservation of genetic diversity; attraction for global environmental tourism; production of specialized local forest products like fruits, nuts, latex, forage, and fodder; and watershed protection or downstream erosion and sedimentation.

These are also among the least carefully examined forest resource services. They are new as topics of great discussion and the discussions themselves are often general. Therefore, our review of these discussions can only be suggestive of reasonable hypotheses. There are no definitive results to survey.

The basic economic questions are the importance of, and the best means for correcting, market failure in the provision of these five forest resource services. The important characteristics for addressing these questions are the public good nature of some and their classifications as global or local human values and the site specificity of their sources.

27 Repetto and Gillis (1988) estimated that required domestic processing creates net welfare losses in Indonesia, the Philippines, Liberia, Ghana, and the Ivory Coast. Indonesia alone lost $500 million (US) of potential profits between 1979 and 1982 to required high-cost domestic processing. Boyd et al. (1990) found that domestic wood processing incentives in the Philippines encourage more harvesting than log export restrictions prevent.
These characteristics indicate whether the demand or the supply of the forest resource service is specific enough to anticipate that local economies might have an abiding interest in market rationalization, and whether exclusion from the production site and the establishment of secure rights and contracts is possible.

3.F.1 Global Climate Change

The discussion about global climate change divides into two subtopics: a) the effects of climate change on forests—which has to do with changes in the extent of forest cover in response to anticipated global climate change (Sedjo and Solomon 1990)—and b) the mitigating effects of forests on climate change. The latter is probably of greater interest. It can help preclude the former.

Increases in the atmospheric levels of CO₂ cause global warming. On this much, most are in agreement. The level and importance of global warming, to date or in the foreseeable future, are uncertain and debatable issues. Harvesting timber and processing wood products both release CO₂ into the atmosphere but not nearly at the rates that world fossil fuel combustion or land use change (mostly agricultural conversion of the forest) the release CO₂ (Houghton et al. 1987). Indeed, wood processing releases only a portion of the carbon originally in the tree because so much is stored in the soil (roots, soil carbon, forest floor detritus), in the product (lumber), or in landfills (paper) (Tans et al. 1990).

Reducing the rate of forest conversion to agriculture, particularly where conversion is associated with burning the forest cover, would decrease the rate of atmospheric CO₂ build up. Growing trees in new plantations, harvesting, and storing the final biomass would store some CO₂. Storage could be a long-term solution to increasing atmospheric CO₂. Growing trees in new plantations and storing them on the stump could be a short-term solution for the duration of the timber growing period. (There is little additional storage on the stump once trees mature and the rate of tree growth slows.) This short-term solution could be used to buy time until world markets substitute other energy sources for fossil fuels (Sedjo and Solomon 1989).

The problem confronting economic approaches to controlling global climate change is the mismatch between the non-exclusive, global impact and the more identifiable and general locations of production or control. Future impacts from the build-up of atmospheric CO₂ are most keenly anticipated in higher income developed countries, but agricultural land conversion from forests is most rapid in the developing tropical countries. (Northern temperate forests have actually expanded in the last thirty years.)
Various import restrictions, taxes, and subsidies have been suggested for addressing the problem. Import duties and restrictions on tropical wood products are not attractive because they would remove forest production incentives and, therefore, decrease timber growth and additional carbon storage. The economist's natural solution would be to tax the negative externalities, fossil fuel combustion and land conversion, and to subsidize the positive externality, forest plantation management. It would be difficult to tax agricultural land conversion, largely in developing countries where much of it is a response to population growth, insecure tenure, or domestic development policy. A more feasible alternative might be to combine developed country fossil fuel taxes with transfers of the tax revenues to subsidize developing country forest protection and new forest plantations.

The absence of defendable benefit estimates precludes any reasonable opportunity to assess optimal taxes. Nevertheless, Weimer (1990) shows that even a small tax proportionate to emissions from oil, natural gas, and coal consumed and comparable to 0.5 percent of the price of a barrel of petroleum would extract $9 billion annually from developed countries. This tax might be transferred to tropical developing countries. Shared on a per hectare basis across all forested hectares, this tax would be too small to alter most marginal forestland allocation decisions. Weimer suggests the alternative of tying the transfer to addition to some base level, say ninety percent, of the current forest in each developing country. This would concentrate all transfers on the marginal ten percent and the recipient government would have the freedom to choose the location of that margin or of the substitute hectares on which new plantations could replace harvests on the margin.

Weimer anticipates difficulties in obtaining a universal developed country taxation convention. He minimizes the monitoring difficulties associated with changing measures of forest inventory in developing countries and he fails to anticipate the difficulties of enforcing exclusion from the forest and protecting against forest conversion. While even a small tax would create a large budget partially available for enforcement, enforcement would be a problem for the full extent of forest and not just around the marginal, say ten percent, of forested land. Its protection costs could be immense.

While Weimer's approach bears further inquiry, the importance of these limitations also bears inquiry. It may be that establishing secure smallholder tenure, providing appropriate timber concession incentives, and removing policy spillovers are no more difficult and would have greater impact on the size of the final forestland base; therefore, on short-term carbon sequestration. It is unclear where the greater cost effectiveness lies. It should be clear that either the tax and transfer alternative or improving tenure and concession arrangements and policy biases are both only short-term solutions to the global build up of atmospheric carbon.

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28 Kokoski and Smith (1987) did attempt to measure the welfare effects of climate change for the US.
3.F.2 Biodiversity

On first impression, the economic problems associated with biodiversity seem comparable to those associated with global climate change. The wealthier developed countries more clearly anticipate the future public good importance of biological diversity. Resource protection and control, however, is concentrated in the tropical moist forests of developing tropical countries. Nevertheless, a more careful assessment may suggest potentially simpler economic solutions reliant on property rights and preservation of selective habitats rather than vast tracts of natural forest.

There are numerous examples of great social and economic gain from species with no prior scientific identification (e.g., Dally 1988). We also know that the seven percent of the Earth’s land that is tropical moist forest contains over one-half of the Earth’s species of flora and fauna, many of them unknown and uncatalogued as yet (Prance 1986). The lesser current development of the uses of these tropical species may anticipate only a) their lack of prior development and b) world focus on temperate region organisms at all levels of development. It is possible that tropical species have even greater economic potential than the residual potential for better known temperate species. Our concern for protecting this tropical potential can only be heightened by suggestions that 100 species, half of them as yet unknown, become extinct each day (attributed to P. Raven, in Jackson 1990).

The production side of biodiversity poses an easier problem than it does for global change. Species can be protected by preserving select “islands” of specialized habitat. These islands are smaller and the foregone development opportunities associated with them are smaller than those for the vast forest tracts necessary for carbon sequestration. These island habitats may be high value opportunities for debt–for–nature swaps. They suffer, however, from high maintenance costs, and maintenance costs are not something that debt–for–nature swaps are well–designed to provide. Maintenance costs arise from the high ratio of perimeter to land area, therefore the greater problems with exclusion characteristic of small habitats. Blocked forest hectarage of similar total size to the aggregate of many “islands” would have a smaller perimeter, therefore a lesser problem with exclusion and smaller maintenance costs, but it could not contain all the characteristics of specialized habitats chosen without regard for location within some large forest block. Some (e.g., McNeely 1988) suggest that developed countries could provide the fiscal support for on–going maintenance costs. This would imply long–term commitments to single projects unusual in donor agency experience.

The few empirical studies from temperate regions suggest that the foregone development opportunities associated with endangered species protection are small. The land areas lost to development are often small and the values foregone are marginal. Political constraints on competing opportunities for public assistance may make them seem larger than they really are (e.g., Hyde 1981, 1989). Bishop (1990 proposal to Man and Biosphere), Mendelssohn (proposal to Carnegie Foundation), and Conrad (1991) have only just begun the first empirical economic analyses known to us for endangered species protection in tropical forests.
Further reflection on the protection of biodiversity suggests an alternative strategy. What we have called global values for a public good are really an assembly of private values held by currently unidentified final consumers but established and identifiable biotechnology developers. These private values will become clearer as current opportunities for biotechnology develop further yet. Furthermore, species can be preserved both in situ and ex situ. That is, a second option for preservation of biodiversity is a) ex situ germplasm banks (Harrington and Fisher 1982) and b) the establishment of property rights for germplasm (Sedjo 1988, 1989, 1990a)

The property rights could belong to single firms or to institutions that pool the interests of various economic actors. Establishing property rights would, however, raise distributive questions. What share belongs to the original source, the developing country with tropical moist forests and critical species habitat? What share belongs to the breeder whose activities are critical for realizing all eventual benefits?

Ex situ banking of germplasm places a premium on identifying and cataloguing currently unknown species. Evenson (1990) examined the social values for rice germ preservation at the International Rice Research Institute and reflected on the possible gains from identifying and cataloguing germplasm for other agricultural crops and livestock. He found positive net gains from an intermediate effort and greater gains yet from a more extensive—near complete level of germplasm identification and banking.

Evenson's analysis also provides insight to the distributive issue. IRRI is a public institution funded by international donors. It is not a pharmaceutical firm. Consumers in India receive some of the greatest gains from rice germplasm preservation. IRRI and the food consumers of India would not be considered private concentrations of wealth or "bad" distributions of gains for most investments.

Clearly, all germplasm can not be catalogued and banked immediately, before further species become extinct. Clearly, public institutions cannot hold all germplasm in trust for the masses of small consumers. And clearly, gene banks are static institutions that fail to capture and preserve the dynamic genetic evolution. Just as clearly, all species and all tropical moist forests will not disappear overnight. Therefore, property rights for germplasm in ex situ preservation, can be potentially important contributors to the preservation of biodiversity.

3.6.3 Ecotourism

Ecotourism, an abbreviation for a global environmental tourism, is the summary term for holiday and vacation visits to unique natural environments. The ecotourism that interests us for this discussion includes visits, usually by wealthier citizens of developed countries, to unique forest and wooded natural areas of developing countries; i.e., camera safaris to Kenya, trekking in Nepal, jungle boat trips in the upper Amazon basin, etc. Ecotourism apparently produces large shares of the available hard currency in the economies of Kenya, Nepal, Costa Rica, and perhaps other countries (Healy 1988, Laarman and Perdue 1988, Dixon and Sherman 1990).
Ecotourism is largely a private good. Those who demand the ecotourism forest resource service generally come long distances, and require special guides, food, and lodging services. Exclusion is not an important problem because the ecotourists can be stopped at national borders and at other major access points to their eventual forest destinations. Fees can be charged at these same points.

The production side of ecotourism bears resemblance to the production side of biodiversity in that the relevant natural environments could be described as "islands". That is, production usually focuses on special features of the natural forest environment but not the forest in its entirety. These ecotourism islands, however, are larger in total area but fewer in number than those identified for the protection of biodiversity. They, like the biodiversity islands, can suffer from infringement and destruction by local populations with other dominant competing values. The large relative values of the ecotourism islands, however, are more likely to justify protection of their boundaries.

The appropriate analytical techniques for assessing the values at stake are regional or national sectoral models and travel cost, willingness-to-pay, and contingent valuation surveys. Sectoral models with exogenous injections of foreign tourist expenditures can measure the impacts of ecotourism on the local economy. Travel cost, willingness-to-pay, and contingent valuation techniques can be used to estimate the global social valuation of the ecotourism use of any select natural environment. All three techniques are in standard use in developed countries, but few analyses have been conducted for ecotourism in developing countries. (Dixon and Sherman (1990) is a notable exception.)

3.F.4 Fruit/Nuts/Latex/Forage/Fodder/Fuelwood/Gum Arabic

The issue, in this case, is local forest exploitation, often for domestic consumption. The forest products and forest resource services in question are numerous and varied. They may be consumed at home, or some (nuts, latex, gum arabic, fuelwood) also may be exchanged in local markets and redistributed further. The values of these forest products and forest resource services are generally limited by the demand of the local population and by the network of access for undeveloped means of transportation (e.g., footpaths). Nevertheless, combined fruit, nut, and latex values may exceed commercial timber values in select local cases in Latin America. Gum arabic in the Sudan and fuelwood, fodder, and forage in South Asia may be the dominant values for large areas of forest. The forest is often treated as an open access reserve for these values and they are most often used by the poorest local people and in the hardest times.

The important analytical issues associated with these forest products and forest resource services are the issues of smallholder management and secure tenure, the topics of sections 1.II.B and I.II.D in this paper. Allocation decisions are be more efficient if where are no institutional barriers to the local exercise of smallholder and landless forest collector choice—and where the relevant national institutions adjust to permit enforcement of these choices.

We anticipate that the provision of these forest products and forest resource services is part of the greater issue of forest sustainability, as currently expressed in wealthier developed
Countries. The traditional concern was for a sustained timber supply. We anticipate that the more recent concern is for sustainable provision of basic needs for local populations and protection of biodiversity and protection against global climate change. Thus, together with biodiversity and global change, this collection of local forest values becomes part of a greater international policy discussion.

3.F.5 Erosion

Soil erosion, and its counterpart, downstream sedimentation, are largely agricultural issues. Agricultural land conversion and livestock use of the uplands create an important association between soil erosion and developing country forests.

The developed country experience is that the off-site costs of soil erosion exceed the on-site costs. On-site costs are small because they are internalized in the production decision of managers with long-term claims on the resource (Crosson and Stout 1983, Benbrook et al. 1984, Crosson 1985). Recent evidence from Indonesia and the Philippines challenges this orthodox conclusion.

Magrath and Arens (1989) used aggregate physical evidence of soil and weather conditions, together with evidence of farm response to declining productivity, to value erosion in five major regions of Java. They found that 90–95 percent of all losses were losses of on-site productivity. Their result held over all five regions.

Barbler (1988) looked more closely at farm level activity, including adoption of conservation practices, also in Java. He relies on a model relating profitability to erodability on private land. Adoption of conservation practice, in his model, is a function of the profit incentive. Unsurprisingly, Barbler found that crop choice makes a difference. For some crops, soil erosion had little impact on profitability, and there was little incentive for introducing conservation practices. More importantly, however, government policies (e.g., high agricultural price supports and fertilizer subsidies) provided incentives to convert upland forests and to produce agricultural crops on highly erodible lands.

W. Cruz et al. (1988) collected physical evidence from one major watershed in north central Luzon and compared their ex post assessment with ex ante expectations of siltation and reduced irrigated agriculture and hydropower potential for the Pantabangan Dam. They found that soil disturbance varies with land use and that soil disturbance is more important than slope in determining the volume of eroded nutrients. For example, steeper sloped but terraced rice land erodes less than land used for open livestock grazing. Cruz observes that siltation was more rapid than originally anticipated and that the economic value of on-site losses could exceed the downstream loss. He hypothesizes that insecure tenure and government policies encouraging large livestock operations are prime causes.

In sum, the evidence is skimpy, only three careful analyses, but that evidence is also consistent with findings discussed in various other parts of this paper. Agricultural land conversion from the forest can cause economic losses of important magnitude. In this case, the losses are
foregone productive opportunity, on-site as well as downstream. Some of the inducement for agricultural land conversion is supportive public agricultural policy. Some inducement may be inflexible institutional barriers to secure smallholder tenure. The corrective conservation policy could be removal, in both Indonesia and the Philippines, of agricultural policy disincentives and Forest Ministry restrictions on permanent settlement.

III.G DEFORESTATION AND SUSTAINABILITY

Deforestation and its opposite, sustainable forest production, are traditional subjects of both local and global attention for both their physical and their economic characteristics. The economic characteristics have both supply and demand features, although the supply features receive greater attention. Slowing the rate of deforestation where it is important will address most local and world concerns for sustainability.

The background for concern with deforestation is the general Malthusian expectation that growth in human demand will outstrip the fixed availability for any basic resource. The more specific history of this concern in forestry can be traced through the Chinese Guanzi in the Fourth Century B.C. and the Viceroy of Mexico City in 1546. Both expressed the belief that a whole continent was running out of timber. The US government has expressed the same expectation for the American forest resource repeatedly since 1817 (e.g., early acts to protect naval stores in 1820, 1822, 1827; the Timber and Stone Act 1878, the 1891 Presidential authority for preserving public timberlands). This expectation of timber shortage was a basic tenet of the conservation movement of Theodore Roosevelt's time and it underlies the statutory requirement for decennial US Forest Service projections of the US timber situation. Every US Forest Service projection since 1909 anticipates a future timber shortage.

Timber shortage is also a basic tenet of today's more global, more environmental, concerns with resource availability. Today's global concerns include resource and environmental forest values in temperate regions (e.g., sustainable logging in Oregon in the US, western Canada, and Sweden; acid deposition and deforestation in the forests of eastern Canada, Germany, Sweden, and Poland), but more often feature tropical forests and developing countries. Some global concerns may be shared locally as, for example, a) non-sustainable commercial and industrial harvests in the Philippines or Indonesia, or, perhaps, b) non-sustainable harvests for domestic consumption in poor and rural countries like Nepal and Malawi. Other global concerns, such as maintenance of biodiversity and protection against climate change, may arouse less local interest, particularly in tropical developing countries. These latter concerns are public goods that largely reflect the values of the better-off citizens of the developed world. These public goods may best be satisfied, however, by protecting tropical, developing country forests known for their species diversity and their vast extent, therefore their vast sequestration of carbon. These developed country values for preserving tropical forests often conflict with local desires for economic development.

The Malthusian arguments for natural resource scarcity in general, and those for timber in particular, have been rejected for good economic reasons. We will review those reasons briefly. Forestry does have its special features which cause some to understand its protection as different
from other resource sustainability issues. These issues will receive our sharper attention. The non-market nature of some values arising from the forest resource is one of those differences. The non-market natures of biodiversity and carbon sequestration add an important new dimension to the old Malthusian dilemma.

3.G.1 Rejections of the Timber Famine Argument

Expectations of timber scarcity are often expressed more emphatically as "timber famine." There are two reasons to reject expectations of timber famine, historical evidence that it has not occurred, despite centuries of warnings by distinguished public figures, and economic arguments that increasing scarcity induces higher relative prices and attracts economic and social adjustment rather than famine and hardship.

Policy makers should learn from the long history of expectations of timber famine. If so many doomsayers have been wrong in the past, then either the next doomsayer is also likely to be wrong or he/she must be able to show that new projections are characterized by conditions unfamiliar to the past—and to all those previous projections. Yet seldom do we learn this historical lesson.

Clawson (1979) reviewed the approximately decennial US Forest Service timber projections since 1909. He found that every one of them projects consumption outstripping production. Hindsight told Clawson that every one of these projections underestimated eventual production. Yet the latest Forest Service projection (USDA Forest Service 1982) draws the same conclusion for the mid-21st Century. Its only variation from previous projections is its ostensibly more sophisticated analytical technique.

In forestry, worldwide and throughout history, where there is evidence of declining physical stocks, there is only limited evidence of associated local hardship. Declining stocks may create hardship for indigenous populations. They also may reflect agricultural settlement and potential improvements in the quality of life for previously semi-nomadic populations (e.g., Stevens 1988, delos Angeles 1988). Apparently this agricultural settlement of a previously unsettled population explains Malawi's deforestation today (Hyde and Seve 1990).

Declining physical stocks in forestry usually reflect either the optimal policy of drawing down a mature stock (timber mining) or agricultural land conversion. Johnson and Libecap (1980) showed that optimal timber mining explains, first, the harvest rate, and then the departure of the timber industry from the US Lake States pinery in the late 19th Century. Apparently agricultural land conversion largely explains deforestation in Brazil today (Binswanger 1989, Mahar 1989). A few years ago Eckholm (1976) focused world attention on deforestation in Nepal. Yet we might hypothesize that deforestation in Nepal largely reflects new settlement and agricultural conversion in the taral region, the Gangetic plain of Nepal. The taral has become the richest agricultural production region of Nepal. The taral is now the major rice producing region of the country and Nepal's standard of living would be lower without conversion of the wooded taral to productive agricultural land.
The social impacts of declining stocks and increasing relative scarcity should be reflected in rising relative prices. Barnett and Morse (1963) examined US price changes over time for all primary resources. They found that timber was the lone possible exception to decreasing prices, therefore decreasing relative scarcity over time. Timber is only a "possible" exception because Barnett and Morse found no basic price or cost series for timber. Relative lumber prices did increase, but pulp prices did not increase over time.

Increasing scarcity and increasing relative prices should induce technical change in timber growth and management, investment in reforestation, and substitution to alternate products. All three would dissipate the long-term effects of decreasing physical timber availability. The limited available evidence suggests that forestry has been slower than most economic activities to adopt technical modifications (Hyde et al. 1991). This is probably due to the existence of a large extensive margin of forestland worldwide. The world is still drawing down a stock resource. We would hypothesize that prices must rise further yet before they induce greater adoption of known timber growth and management techniques and more reforestation.

Sedjo and Lyon (1990) observe that historical rates of worldwide timber price increase have begun to taper off. (Price increases have disappeared in some regions.) Nevertheless, Sedjo and Lyon anticipate some overall worldwide price increase into the mid-21st Century. They also project that half of the world's timber harvests will still come from extensively managed (or unmanaged) forests even in 2050 A.D. Their evidence argues that we may anticipate some continuing forest drawdown and slower rates of technical change at least until 2050, but there is no reason to anticipate long-term timber scarcity or global hardship from a shortage of marketed timber.

On the other hand, rising prices do not reflect the increasing scarcity of non-market forest values. Therefore, they do not induce technical change, investment or substitution with respect to these values in forestry (Hyde 1988). This is the common criticism of Barnett and Morse. It is an indication that the non-market forest values (i.e., biodiversity, carbon sequestration, environmental protection, and some recreation and tourism values), not timber, are the reasonable features of any anticipated future forest-related shortages (Krutilla 1967, Smith 1974, 1979).

### 3.2.2 Forestry's Special Features

Concerns for anticipated timber shortage persist—regardless of historical evidence, rigorous analysis, or economic intuition. We observe similar public concerns for other primary resources but, for some reason, these public concerns seem greater for the world's forests. We might anticipate three general reasons. They relate to the greater visibility of the forests themselves, to particular features of tree and forest growth, and to the institutions most directly affecting forestry.

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30 Also see Ruttan and Callaham (1962), Olson (1971), Bradley (1973), Manthy (1978), Smith (1978), and Slade (1982).
First, forests are simply more visible than hardrock minerals or pool resources buried underground, or even other biological resources like fisheries and wildlife. It is easier to see the forests. It is easier to visualize where they were and it is easier to visualize the resource and land use changes that occurred with their harvest. Furthermore, it is difficult to visualize early regrowth through the residual slash of former harvests that lies on the ground around the emerging young growth. And it is difficult to comprehend the impacts of technical change in wood processing that will permit young managed forests growing from today's seedlings to replace the processed products of mature native old growth from yesterday's harvests. That is, production of similar products from both 200-year-old native forests today or from young managed forests thirty years in the future is difficult to visualize—even for experts. The contrasting ability to see and identify the current forest but inability to visualize its replacement is one reason for public concern with timber supply and sustainability.

Forests grow naturally. This is a characteristic they share with neither hardrock minerals nor other producer goods, whether agricultural or industrial. It means that, as other goods grow in relative value, the opportunity always exists to convert the forest and to develop the forest land on the extensive margin of currently developed land. There always will be a residual natural stock of additional trees on the new extensive margin.

Second, there are three problems with timber harvesting and forest conversion to agriculture at the extensive margin of developed land. a) Land at this margin is often the most environmentally risky. This can be a real problem. The extensive margin includes the steeper slopes, rockier outcrops, and shallower soils. Managing this land for regular timber rotations, for agriculture, or for any other commercial use tends to be riskier than halting commercial development at the previous margin of extensive developed land management. b) Once natural timber stands are harvested, they tend to regenerate slowly. They can regenerate immediately and naturally. Nevertheless, poor seed years, drier weather, and animal destruction of young growth often delay new growth as long as decades. This delay becomes a real problem where timber managers and consumers of wood fiber fail to build reasonable expectations about natural regeneration into their future harvest expectations. Finally c), harvests on the extensive margin tend to be harvests of high volume stands of old, biologically mature, timber. Harvest volumes from these stands are greater than the maximum sustainable yield \[ V_{t} = \frac{1}{t} \] from eq. (2)) for the young stands that replace them. This biological exchange gives rise to the popular concern that current harvests exceed growth. Therefore, it is one source of the concern for future timber scarcity. Yet the high volume, slow growing, mature stands must be harvested before more timber can be grown on the land. It is a fact of biological growth that harvests can only be greater than growth during the period of conversion from natural old growth stands to managed forests. These three features of timber growth and harvest cause many misassessments of the forest inventory and the future timber supply.

The third general explanation for greater public concern with timber than with scarcity of other resources is institutional, specifically the institutions that manage, and the policies that affect, forest resources. There is a large public agency presence, even in commercial timber production, in forestry worldwide. Public agencies justify their budgets, not in the market but
before national legislatures that, arguably, are more risk averse and more responsive to extreme concerns for future timber shortfall. This means that there are budgetary advantages for public agency managers to provide their own evidence of future timber scarcity. Public agency foresters are also more likely than industrial foresters to manage all lands, including those beyond the extensive margin of justifiable economic management (Marquis 1948, Klemperer 1976). This means various silvicultural investments, as well as timber harvests, where the market fails to justify them. It can mean additional environmental damage and slower reforestation, or even deforestation and loss of non-timber forest resource services, on lands that are usually environmentally riskier.

Thus, the Forest Ministry has institutional reasons, not all based on fact or greater social welfare, to encourage public concern for future timber supply. The Forest Ministry may also pursue internal policies which conflict with long-term market values and economic efficiency. These institutional issues are reasons for public concern over future timber supply.

Public policies external to the Forest Ministry can also generate concern. These too can be real sources of deforestation. Agricultural incentives without forestry counterparts induce deforestation and land conversion. Inducements for domestic log processing can expand timber harvests more than they restrict log exports (Boyd et al. 1990). Sections III and IIE of this paper discussed the possibilities for short-term timber concessions, insecure tenure, and macroeconomic policy spillovers to encourage suboptimally rapid timber harvests.

III.G.3 Conclusion

Timber shortage has not been a problem historically, and concerns with deforestation have been overstated in general worldwide. Rising relative timber prices should induce reforestation where reforestation for future timber supply is a socially optimal activity. We observe exactly this. Commercial timber production is price responsive in the US South, Chile, and New Zealand. Similarly, farmer reforestation is responsive to high fuelwood values in Malawi and Bangladesh.

Nevertheless, we anticipate that deforestation can be important in specialized cases. Those cases occur where administered policies bias the relative price structure and where non-market values for forest resource services are ignored. The former can be important in a dynamic world that relies heavily on static policy solutions. The latter is ever more important as higher income populations worldwide place greater values on their utilities for non-consumptive goods and services. The magnitudes of deforestation associated with either case are unknown. These are rich opportunities for further research.

IV. SUMMARY OBSERVATIONS FOR FOREST POLICY ANALYSIS

Our previous reviews of the forest economics literature and of seven specialized topics within it leave us with several summary judgments about a) the technical economic characteristics of forestry and b) the important forest policy issues of the day. These reviews are also suggestive of appropriate analytical approaches to these contemporary policy issues. This final section of our paper features our judgments on these two points.
4.1 The Technical Economic Characteristics of Forestry

There are no fundamental differences between forestry and other economic resources. The basic principles of neoclassical economics equally apply to the problems of forestry. Forestry applications of economics do have their characteristic emphases, but there is no justification either for revising the principles of economics for forestry, or for creating a unique forest economics.

The characteristic emphases of forest economics are two features of timber production and the multiple product nature of many trees and forests. The two characteristic features of timber production are its long production period and its inclusion of both capital input and inventory of mature product in the same tree and at the same time.

Timber Production The production period ranges from three to eighty or more years in forestry. Therefore, discounting takes on unusual importance and capital carrying costs can dominate forestry decisions. Small adjustments in the opportunity cost of capital can have substantial impacts on timber management decisions.

Long production periods imply greater output uncertainties. The longer the production period, the greater the likelihood of unexpected input effects like fire, or unexpected technological breakthroughs like new fertilization applications. Longer production periods also imply greater potential for changes in final product demand by the time the product is ready for harvest. Each of these uncertainties makes prediction difficult and causes wise producers to prefer a final product with multiple alternative uses; for example, woodpulp, dimension lumber, and plywood, or fuelwood, fruit, and fodder.

Long production periods also suggest data weaknesses. Historical data often do not exist for even one full timber production period. Furthermore, those data that do exist usually reflect multiple forest stands from overlapping and incomplete production periods (i.e., many timberstands of various ages). Data from overlapping periods also may reflect non-identical input technologies. Finally, historical data from the last full production period probably do not reflect accurate technological expectations for forthcoming production periods. As a result, an entire sub-discipline, forester mensuration, is largely devoted to identifying accurate production (yield) estimates. Neither data from "fully stocked natural stands" nor experimental data are fully satisfactory.

Trees and Timberstands. Trees and timberstands are both capital input and a standing inventory of final product. This means that trees can be harvested when mature for one market, or held while they grow and markets for the same or other products become more favorable. This characteristic of trees and forests adds elasticity to the short-run price responsiveness of forest outputs. It also helps provide the flexibility necessary in planning for long production periods.

Another natural feature of tree and forest growth also compensates for the economic problems caused by long production periods. Trees grow naturally, without human management, at and beyond the frontier of economic land use. That is, almost everywhere in the world a frontier of standing mature timber is available for consumption as the demands for forest products and
forest resource services increase. This is a natural frontier of forests grown at zero opportunity cost on the extensive margin of economically productive land use. This frontier creates important opportunities for land and resource use tradeoffs; e.g., the tradeoff between a) larger inventories in intensive timber production on inframarginal forestland but more marginal land reserved for other uses and b) larger harvests from land at the frontier but less marginal land reserved for other, often underpriced environmental, uses.

The vast remaining world forest frontier will provide substantial shares of the world's supplies of industrial forest products into the indefinite future. This means that the world's long-run timber supply and the rate of conversion from mature natural forest to managed forest will not threaten the world's demand for wood and wood products in the near future. The frontier creates many opportunities for shifting land use and optimal forestland allocation is probably a more important problem than long-run timber supply.

Nevertheless, use of the frontier may be limited by three factors: bulkiness of the forest product, differences in forest quality on marginal and submarginal forestland, and insecure claims to the forest. Logs are bulky (high volume/value ratio) and cannot be shipped profitably overland for great distances regardless of the availability of extensive areas of natural forest. Forest recreation, on the other hand, is comparatively unaffected by a few extra miles travel into the woods. Biodiversity exists where it is found and carbon sequestration is totally unaffected by location. The frontier—and beyond—is a useful producer of the latter three forest resource services. It is a lower valued producer of wood and fiber.

Previously unharvested timberstands at the frontier usually contain larger volumes than inframarginal stands of mature managed timber. Lands at the frontier, however, tend to be poorer sites (shallower soils, steeper and drier slopes). Natural reforestation occurs more slowly on them and the new forest stands are less dense. These lands also tend to be environmentally more risky and more attractive to recreational users.

The market defines the frontier as land with low or zero financial value. Often this means that secure claims to this land have not been established. As social values adjust upward, the frontier becomes susceptible to open access exploitation. Market values and development policies will dominate in determining the new land use allocation from the frontier. Values held by local rural populations may be overlooked as a matter of policy. For example, in many countries, national policy incentives for timber processing and commercial agricultural production may induce socially suboptimal forestland shifts away from the subsistence activities of local populations and toward commercial timber and developed agricultural uses.

The Multiple Product Nature of Trees and Forests. The second characteristic emphasis of forests is its capacity to produce multiple outputs. Many trees and many forests produce multiple products and multiple resource services. Additional goods and services add complexity for analysis and for land use allocation, particularly since they are demanded by several spectra of consumers; fully collective to individual and private, distant to local, wealthy to poor. The products can be complements or substitutes in production. They can be pure market-valued, administered, or non-market valued.
The most traditional of the multiple forest products are the variety of commercial wood and fiber outputs. These are the source of forestry's classic focus on biological production and measures of the standing forest inventory. Nevertheless, the classic application of the term "multiple use" to forestry refers to a multiple of non-timber outputs (like recreation, range for livestock grazing, and watershed protection) that are largely valued outside any working efficient market and that are consumed locally. These multiple use outputs are usually rationed by the state Forest Ministries that control the extensive margins of most countries' forestlands. In developing countries, the multiple use outputs, often from de jure Forest Ministry lands, may extend to include household consumption goods like fuelwood, forage, and fodder. Finally, carbon sequestration and protection of biological diversity are two more recently recognized services provided by the world's forests. These two forest resource services are different in that their demands are widely dispersed and they seem to be in greatest demand by those who live furthest from the forest itself.

This wide array of forest produced goods and resource services creates many analytical complexities for the determination of optimal allocations of forests to their joint products. These complexities are important—but they also can be overdone. Most demands for wood products and forest resource services have minimal allocational impact on any particular timber stand or any single hectare of forest land. Furthermore, administered policies rather than either local or global social welfare, may dominate the final allocational decision.

The analytical complexities created by multiple products can be avoided in many cases by following the problem-solving sequence: a) Choose important policy and large resource allocation problems first. b) Among these, assess the simplest, market value, cases first. Policy makers find market values easiest to believe. b1) Insure that there is no confusion between inputs and outputs. b2) Accept as productive only those activities with benefits in excess of their independent separable costs. We maintain that careful accounting of all market benefits and costs will convincingly reduce the large number of debatable multiple product cases. It will show many market value forest allocations to be unintended subsidies. It will also provide convincing evidence on many out-dated or ill-advised policies. c) Finally, turn to more difficult travel cost, hedonic, and contingent valuation techniques for assessing value for those remaining important cases where optimal allocation is not clear and non-market forest values are potentially important.

Final Comment on Economic Analysis. In conclusion, the tools of economics are not lacking. They have been applied successfully to the traditional, often commercial, issues of forestry. Furthermore, the economic tools are available to examine other forestry problems.

If forest economics has been isolated, it is because the substitutions between tree crops and other land uses and between wood and other fuels have never before been as important as they are now. Historically, there was less reason to integrate forest economics with the mainstream of economics as applied to other, say agriculture and energy, resources. We anticipate that the new level of importance attached to these opportunities for substitution between tree crops and other land uses and between wood and other fuels will be a significant development in the future of forest economics.

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31 Public agency foresters, for example, often consider fire control and roadbuilding as outputs.
crops and other land uses and between wood and other fuels will lead to new inquiry and new applications of standard economics tools to these newer forestry problems. It will create a healthy extension of the forest economics literature.

4.2 Forest Policy

There is a wide perception that forest management, and particularly tropical forest management creates public policy problems that are felt both locally and globally. Deforestation is often seen as the tangible measure of these problems. There is also a widely-held perception that developed country citizens, their governments, and the international donor agencies should "do something" about these problems. Surely, these agents should have a public position on deforestation and tropical forest management. We might examine these perceptions within the context of our previous review of the literature and the economics of forestry.

A policy problem is an indication that resource allocation is unsatisfactory. Therefore, we are interested in identifying those situations in which the current system does not work, or where the current allocation overlooks important social values. We are interested in redesigning policies to correct these failures. For forests and forestry, this means finding the critical market and policy failures and their land use impacts. Where there is evidence of market failure, then we are most interested in those failures with large land use impacts. Alternately, where we can identify large forestland uses, then we might search for those which are substantially influenced by market or policy failures.

The important shifts in forest resource allocation are due to 1) agricultural land conversion, 2) commercial logging, and 3) rural development and local domestic uses of forestland. The important policies with regard to each of these are:

1) agricultural land conversion: Agricultural land conversion is the largest single cause of deforestation. Some of this is the natural result of rising populations and increasing agricultural values. Some of it is the result of government incentives that encourage extensive agricultural production beyond the socially optimal margin of agricultural land use.

2) logging: Timber concession arrangements, domestic processing requirements, and incentives for and restrictions on international log and wood products trade can all alter the socially optimal levels of harvest and forest management.

3) local rural development: The pattern of local use of the forest and local rural development might proceed differently if the Forest Ministry guaranteed the security of local claims for forest tenure. We can anticipate that local forest would reflect longer term, conservation-oriented values. Forest land use would also be more intensive, and less of the extensive reach of the forest would be exploited, if the Forest Ministry acknowledged local market incentives for household consumption of forest resource goods and services.
In all three cases, we need to understand the logic of any argument for a particular policy impact on the cause of deforestation, the size of the impact (both in land area and in relative value), and the characteristic locations where the impact is important. Knowledge of these characteristics will help identify other places with comparable policy problems.

The size of the impact is important. There are many market and policy failures. It makes sense to concentrate scarce analytical and administrative effort on correcting the big ones. This is an important point for a dispersed resource like forestry. It is all the more important because domestic forest management agencies are well-known for their inefficient management—even in developed countries. Presumably, bureaucratic inefficiency is even greater in most developing countries and asking developing country Forest Ministries to add staff to correct minor inefficiencies is a sure invitation to add costs exceeding their social gains.

The previous three categories permit us to trace direct policy impacts on the forestland base. There also may be two serious policy impacts which are less direct: 4) ex-sector policies and 5) biodiversity and global climate change.

4) ex-sector policies: These are macroeconomic policies and policies directed at other, non-forestry or agricultural sectors, whose impacts spillover to the agriculture sector and the forest. Their impacts can include unintended deforestation.

5) biodiversity and climate change: Protection of existing biodiversity and sequestering carbon (to restrict potential climate change) requires some amount of forest growth and protection.

Any forest policy statement must examine these five items for their potential interference with socially optimal forestland use. The applied research has only just begun on some of these topics, but the various tools appropriate for their examination are well-known in other, non-forestry, applications of economic analysis. Certainly, the potential importance of the infringements on optimal forestland use varies from country to country. Therefore, general statements would be risky. We might start by inviting research designed to identify and measure the greatest causes of socially suboptimal deforestation. We might anticipate that the greatest policy problems have to do with security of land tenure, an issue which cuts across our first three items, and ex-sector policies.

Identifying the relative importance of biodiversity and climate change may be particularly difficult. It might be initially reasonable to finesse these two problems by correcting ill-advised tenurial arrangements and ex-sector policy spillovers. These policy corrections will reduce the rate and level of deforestation—perhaps substantially. Fortunately, the direction of these changes in deforestation would coincide with the direction of change necessary to protect biodiversity and climate change. Revised tenure and ex-sector policies may cause larger reductions in the rate of
deforestation than social efficiency can justify for only the combined purposes of protecting
diversity and climate change. It would be useful to formalize and test this hypothesis before
deciding where to focus further research and policy on deforestation.
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Appendix A

Managing Tropical Forests:

Reflections on the Rent Distribution Discussion

Tropical forest destruction has been one focal issue of recent environmental discussions. Economists have only begun to participate in this discussion and their orientation to date is mostly qualitative. There is, however, a specialized economics literature on the rents and royalties associated with commercial extraction of tropical timber that is becoming more explicit (Gillis 1980, 1988; Gray 1983; Grut, Egli and Gray 1990, Vincent 1990). The major premise of this literature is that the royalties charged by Forest Ministries are too low and that the public would gain financially and environmentally from raising these royalties.

This literature is helpful in organizing the discussion but it confuses economic measures of efficiency and distribution while failing to account explicitly for external effects and, depending on local biologic, economic, and institutional conditions, its financial and environmental conclusions can be misleading—or even wrong. We will use a variant of the common construct of this literature to explain our arguments and to propose an alternative.

The basic construct is figure 1 where $p$ is the competitive price for delivered logs, $V$ is the harvest volume and $MC_1$ is the timber concessionaire's marginal cost curve for delivered logs. Concessionaires buy timber under contract from the Forest Ministry which manages the public forests. $MC_1$ reflects the private and short-run costs of harvest and removal. The critical issues for forest management are the level of privately efficient harvests; the level of socially efficient harvests when accounting for environmental externalities; the alternative royalty arrangements, and their implications for trespass, high-grading, and other environmental losses; and the associated rent distributions. "Trespass" is the forester's term for losses due to logging theft. (This definition loses no economic content if it is expanded to include graft.) "High-grading" is the forester's term for removing high-valued timber and leaving a degraded residual stand. Efficiency refers to the optimal Forest Ministry royalty and the associated concessionaire harvest level. The important distributive issue has to do with allocation of the area between price and the marginal cost curve in figure 1. The efficiency and distributive issues are best understood when examined independently.

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Efficiency

The optimal short-run and private harvest level is $V_1$, or the level at which $p=MC_1$. This is only a short-run and private optimum because $MC_1$ refers to the short-run marginal costs of timber harvests and removal. The long-run public costs also include: 1) the costs of protecting expected future returns from both the land and the residual timberstand left after all extraction permitted by the short-run harvest contract and 2) the off-site environmental costs of timber extraction (e.g., soil erosion and downstream sedimentation). Consider these two costs in turn.

Rational timber concessionaires harvest the best stands first. Concessionaires with short time horizons harvest the existing stand without regard for future possibilities for ingrowth from the residual stand; therefore, without regard for expectations of greater discounted future returns from 1) leaving some immature stems undamaged and growing or 2) harvesting low-valued stems in order to release high-valued stems for more rapid growth. This particular variety of high-grading creates social opportunity losses that can be internalized with improved contractual arrangements between Forest Ministries and concessionaires. Two possibilities are longer-term contracts, or short-term contracts with provisions for continuation dependent on satisfactory concessionaire performance, and outright sale of the land to the concessionaire. Correcting for this opportunity cost adds a term, $MC_2$, to figure 1. The optimal long-run private harvest level is $V_2$.

$MC_3$ reflects off-site environmental costs. Forest Ministries intend to protect, for the public, both the long-run and the off-site values associated with sustainable forest management. These public values justify a Forest Ministry charge, a severance tax equal to $MC_3 - MC_1$. This tax, together with extraction costs $MC_1$, implies long-run socially optimal harvests $V_3$ at a lower level than the long-run private optimum $V_2$.

In summary, harvesting only in response to short-run marginal cost, creates inefficiency in the form of overharvesting. Internalizing long-run private benefits would reduce the extent of the inefficiency but would not address the off-site damages. Marginal costs must incorporate both private and off-site effects to be socially efficient.

The shift from the short-run private optimum $V_1$ to the long-run social optimum $V_3$ implies withdrawal of timber harvest operations from some marginal (less accessible and lower quality) land, and from some marginal trees and species on inframarginal land. It does not change the incentive for concessionaires with short time horizons to contract, high-grade, and then avoid the severance tax and trespass and damage the environment. That is, concessionaires, since they have no long-run interests in the forest, perceive an incentive equal to the difference bc between long-run social and short-run private marginal costs, to deceive the Forest Ministry and harvest the marginal trees and species on the inframarginal land. (It is easy to enforce restrictions of all harvests on extramarginal lands by simply closing these lands to all harvests. It is not so easy to protect selectively only some trees and some species on
inframarginal lands.) Thus, there is a tradeoff between (unidentified) larger Forest Ministry costs for enforcing long-term public values and greater concessionaire incentives to extract immediate private gain, thereby damaging these same values. Precise calculations of the efficient Forest Ministry tax would take this tradeoff into consideration.

Rents—and Distribution

Unfortunately, the level of Forest Ministry severance taxes and the Forest Ministry management of concessions are unrelated in practice. Forest Ministries do not charge to recover their costs and their costs are not associated in any direct way with recovery of long-run and off-site values.

The standard calculation for most Forest Ministries begins with an estimate of available forestland. This estimate usually exceeds any economic or financial measure. Estimates of planned harvest levels from this land proceed from an independent biological calculation of timber volume and growth. Finally, estimates of logging fees or royalties proceed from yet another independent estimate summarized as: lumber price at the mill minus harvest, extraction, and (log to lumber) conversion costs equals the derived stumpage price or royalty. Negative derived stumpage prices are replaced with a minimum reservation price. The greater of the derived stumpage price or the reservation price is the advertised sale price. Of course, a) not all advertised sales are sold and b) where the advertised price is the basis for an auction, some final sale prices are greater than the advertised price. This only indicates the difficulties of accurate appraisal.

Most developing country Forest Ministries learned a variant of these calculations from early German, British, or American foresters. British and American foresters themselves trace their intellectual history to Germany. Countries as diverse as the Philippines, Indonesia, and Malawi use variants of it. As a result, many Forest Ministries do not recover their costs of operation. Others cover their costs but suffer large financial opportunity losses.

Forest Ministries do, however, recognize the opportunity for public financial gain, an opportunity equal to area \( p_{a1} \) in figure 1 in the short run or area \( p_{b1} \) if all social values are accounted for. Some (Gillis, Vincent) call \( p_{a1} \) economic rent. The true economic rent, after adjustment for long-run private costs and external environmental effects, is \( p_{b1} \).

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2Note that this royalty is not the severance tax of the previous page. That tax was the difference between long-run public and short-run private costs. This royalty, common to most of world forestry, is the short-run derived demand price for the primary timber resource. It reflects no long-run or social values.

3Hyde (1980 ch. 2) discusses the US calculation in detail.
The allocation of this rent does not alter either the efficient short-run private or the efficient long-run public harvest levels. These remain \( V_1 \) and \( V_3 \), respectively. The allocation of area \( a \); whether to the public treasury, to Forest Ministry management, to concessionaires, or to anyone else; reflects a distributive preference. This allocation is a primary topic of discussion in the tropical forest economics literature. We will examine the three basic public options for recovering some of this allocation before suggesting a fourth option, and then questioning the merit of the alternate distributions.

The three basic options are charges on the volume of timber harvested. They are a fully differentiated royalty, a flat rate or ad valorem royalty, and a uniform fixed rate royalty. Fully differentiated royalties discriminate among various tree qualities, tree species, and land quality and access classes along the marginal cost curve. They intend to extract, for the Forest Ministry and the public treasury, everything between the delivered resource price and the short-run private marginal cost curve. Full discrimination is impractical but Vincent reports that Sabah and Sarawak, for example, discriminate among nine and five species groups, respectively. The success of Sabah and Sarawak in implementing even this degree of discrimination is questionable.

Discrimination is difficult in temperate developed countries. The greater numbers of tropical than temperate species and the greater quality variation in natural timberstands than in plantations make discrimination more difficult in tropical developing countries. The generally poorer training of developing country foresters and their greater preference to live in cities away from the resource itself reinforce this observation.

Flat rate or ad valorem royalties are percentage charges on net revenues. They can be described by the line segment \( p_a \) in figure 2, where the percentage charge is \((p-r_a)/p\). Ad valorem royalties do not affect the marginal harvest volume decision. Concessionaires contract to harvest at their short-run private optimum \( V_1 \) but receive smaller net private gains, area \( a \); The Forest Ministry receives \( p_a \). Gillis (1988) seems to prefer this royalty. The literature is not as clear as it might be on its impacts. Concessionaires will continue to high-grade and cause off-site environmental damage because the ad valorem royalty does not alter either the short-run private harvest optimum or the incentive to take the high-value trees. Concessionaires also retain their incentive to contract and then avoid some royalty payments because \( p \) is greater than the function explaining ad valorem royalties on all hectares, including harvests on those hectares between \( V_1 \) and \( V_3 \). \( (V_3 \) is unidentified, but somewhere to the left of \( V_1 \) in figure 2.) This is an incentive to trespass, high-grade, and ignore off-site environmental values. This incentive to avoid payment is greater for better quality trees, higher-valued species, and on higher quality, more accessible lands because these are closer to the origin in figure 2, where the difference between \( p \) and the function explaining ad valorem royalties is even greater. The incentive may be mitigated by Forest Ministry enforcement of timber contracts—but enforcement also comes at a cost. In sum, there is no reason to anticipate either harvest volume or environmental improvements with ad valorem royalties.
Uniform fixed royalties are flat fees per unit of harvest. They can be described by the line segment $pr_u^u$ in figure 2. Unlike ad valorem royalties, uniform fixed royalties alter the marginal harvest decision. Concessionaires contract to harvest some smaller volume, $V'$ in this case. $V'_1$ may be either greater than or less than the long-run social harvest optimum $V_3$, depending on the level of $r_u^u$. The uniform fixed royalty may be an efficiency improvement on the ad valorem royalty because $r_u^u$ restricts some harvests from all land and all harvest from some land that is submarginal from both long-run timber and from environmental perspectives. On the other hand, the uniform fixed royalty leaves intact both the incentive to high-grade and the incentive to avoid payment (and create some amount of trespassing and off-site environmental damage) on the inframarginal land. The net environmental effect of this royalty is unclear.

Gillls and Vincent both call for increasing the uniform fixed royalty as a means of increasing Forest Ministry revenue recovery. Their argument is often invalid. Increasing a uniform fixed royalty $r_u^u$ (i.e., increasing the line segment $pr_u^u$, or shifting $r_u^u$ down the vertical axis of figure 2) increases Forest Ministry receipts only when the royalty elasticity ($e_{Pr}$) is less than one, or $e_{MC} < 1$. Yet, Vincent estimates an $e_{MC}$ for Malaysia between 1.57 and 2.10. Cardellichio et al (1988) find elasticities greater than one for other Southeast Asian countries. These elasticities imply an opportunity to increase Forest Ministry receipts—but only by decreasing the existing uniform fixed royalty and increasing harvests.

Most analysts concerned with Forest Ministry revenue recovery are also concerned with long-term timber and off-site public values. Yet the greater the royalty, the greater the concessionaire incentives to take only high-valued trees and to avoid payment (for example, increasing line segment $de$ to $fh$ in figure 2—where $e_{MC} < 1$ at $V'_1$ and $V'$). Increasing Forest Ministry recovery to its maximum with a royalty like $r_m^m$ in figure 2 may reduce harvests below the long-run social optimum at $V_3$ (that is, if $V'' < V_3$, as in the construction of figure 2). Maximizing the royalty also leaves the high-grading incentive intact and increases the retained incentive to deceive the Forest Ministry. Whether Forest Ministry enforcement costs exceed the additional recovery, areas $r_m^mghr_m^m$ minus $defg$, is another question. In sum, increasing an ad valorem royalty yields no certain revenue or environmental gains. Increasing a uniform fixed royalty often decreases public agency revenue recovery and still yields uncertain environmental effects on inframarginal lands. Preference between ad valorem and uniform fixed royalties depends on the Forest Ministry enforcement structure.

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4 The proof is in an appendix.

5 The problem is more complex if $r_u^u$ is the royalty but Forest Ministry recovery is less than the area $pder_u^u$. In Malawi, for example, the Forest Ministry collects less than fifty percent of the receipts due from timber harvests. Large avoidance of legal royalties may be the norm in most developing countries. It causes us to have little confidence in a) Forest Ministry enforcement and b) strictly theoretical constructs that assume no slippage.
A Fourth Option

These first three royalty systems all involved fees per unit of harvest volume, usually charged as the forest is logged. A fourth option would be to charge a competitively bid lump sum fee for the right to harvest a particular area. This fee would be an initial charge independent of the harvest volume. Concessionaires would be willing to pay a sum equal to $p b p_1$ to harvest volume $V_3$ in figure 1. Therefore, the Forest Ministry could collect the full rent. Enforcement to protect long-term residual timber values and to protect against off-site environmental costs (together equal to line segment $bc$ for the marginal log) would remain a problem on inframarginal land.

The competitively bid lump sum fee captures the full rents for the public treasury and it transfers to concessionaires the costly process of scaling the harvest. It does not, however, eliminate monitoring the subsequent harvest to insure that the harvest site conforms with logging and environmental harvest standards.

The lump sum fee shifts all the risks for accurately bidding the contract to the concessionaires. [Rucker and Leffler (1991) discuss risk allocation in timber harvests.] A variation of this option would be to combine a uniform fixed royalty for extracted logs with the prior, competitively contracted, lump sum fee for the right to harvest. The higher the royalty, a) the less concessionaires would bid for the contract and b) the greater share of risks absorbed by the Forest Ministry. The royalty would decrease harvest to a level like $V'$ in figure 2. The prior lump sum fee would extract the full remaining rents, $r e p_1$. Of course, determining the efficient fee (be in figure 1) and enforcing it remains a problem.

A Final Distributive Comment

It is in the general nature of our times to be suspicious of public market interventions and the efficiency of public agencies (World Bank 1983, Srinivasan 1985, Krueger 1990). This suspicion should carry over to question the efficiency of Forest Ministries. It also raises an important distributive question regarding preferences for rent allocation between private concessionaires and public Forest Ministries. In one case, a few affluent local citizens, perhaps together with foreign corporate interests, may capture rents from what is legally a public forest resource. It is an empirical question, however, whether the national economy and poorer local populations gain more from private harvests, private rent capture, and reinvestment, than they would from the Forest Ministry's resource management and rent capture. How much would private interests reinvest locally, how much would filter down to the local poor, and how much would private operators transfer to secure accounts overseas? Alternately, how much resource rent would the Forest Ministry dissipate in hidden personal transfers, excess employment, poor financial management and weak investments, and insufficient environmental awareness? How much would be lost in incentives for concessionaires to trespass, high-grade, and disregard off-site environmental values?
Consider the Philippines, where the Forest Management Bureau’s 25,000 employees manage 15 million forested hectares. This compares with the US Forest Service’s 18,000 employees who manage 75 million hectares. The US Forest Service also suffers annual timber losses of $1.3 billion (1977$) in financial opportunity (Boyd and Hyde ch. 8 1989, also see Repetto 1988). The Philippine Bureau of Forest Management employs 7,000 more to manage one-fifth as many hectares. It fails even to cover its infrastructure costs (Repetto 1988a). Yet the Philippines has one of the largest and oldest forestry colleges in the world. (UPLB College of Forestry was founded in 1909.) Philippine foresters are among the best trained in the developing world. In sum, the US does poorly. The Philippines does more poorly yet. It is a reasonable hypothesis that less-well-trained forestry cadres from other developing countries, also practicing in complex tropical forest ecosystems, produce even greater proportionate losses for their public treasuries.

**Conclusion**

The economic literature on rent recovery from harvesting tropical forests has focused on rent distribution not economic efficiency, although some of the literature confuses the two. Our analysis suggests a simple conceptual framework for beginning a discussion of efficiency. This framework suggests that the imposition of higher logging fees does not necessarily reduce the harvest level or increase public revenues, as often asserted. For example, higher ad valorem payments for stumpage rights do not affect the level of logging effort. Rather, they simply change the distribution of the rents between public and private sectors. Higher uniform extraction fees often decrease Forest Ministry revenue recovery. Higher uniform extraction fees do reduce logging from marginal lands, but they increase the incentive to take high-valued trees and to leave marginal trees on harvested lands, i.e., to high-grade. Thus, rather than discouraging high-grading as often asserted, one effect of higher fees is to encourage the practice. The net environmental impacts are always unclear—contrary to some of the literature. Does reduced logging offset the incentive to high-grade? We do not know.

An initial lump sum fee equal to the true rent, reflecting all long-term and environmental timber management costs, could be a partial solution. It captures the full rents for the public treasury, but it also leaves the concessionaire with incentives to disregard long-term and environmental costs, subject to unidentified Forest Ministry enforcement of harvest standards.

Finally, it is strictly an empirical question whether rent capture by the Forest Ministry or by private concessionaires produces greater gains for the domestic economy. The answer to this empirical question may vary from country to country. This answer must go in hand with any compelling argument favoring a specialized royalty structure or a particular managerial orientation for any country’s domestic forestry institutions.
Elasticity and the Rent Gradient

The purpose of this appendix is to show how rent (or Forest Ministry revenue recovery) changes with changes in a) a uniform fixed royalty and b) marginal cost.

Let rent $R$ equal the uniform fixed royalty $(p-r_u)$ multiplied by volume harvested $V$, which itself is a function of $r_u$:

$$R = (p-r_u) \cdot V(p-r_u) \quad (A1)$$

To maximize rent, differentiate eq. (A1) with respect to the royalty and set the derivative equal to zero.

$$\frac{dR}{d(p-r_u)} = V(p-r_u) + (p-r_u) \cdot \frac{dV(p-r_u)}{d(p-r_u)} = 0 \quad (A2)$$

Rearranging terms:

$$\frac{(p-r_u)}{V(p-r_u)} \cdot \frac{dV(p-r_u)}{d(p-r_u)} = -1 \quad (A3)$$

The LHS of eq. (A3) is the elasticity of harvest volume with respect to the uniform fixed royalty $e_r$.

Since $p - r_u = MC$ \quad (A4)

substituting eq. (A4) into eq. (A3) shows that $e_r$ and $e_{MC}$ are identical in absolute value. Therefore, rent is maximized where the elasticity of the uniform royalty and the elasticity of the marginal cost curve equal one.

Reference to figure 2 shows that $e_{MC}>1$ where $V$ is small. Increasing the royalty $(p-r_u)$ in this range clearly decreases harvests, increases $e_{MC}$ further yet, and decreases rent. On the other hand, where $e_{MC}<1$ (V is large), increasing the royalty decreases harvest volume, changes the elasticity toward unity, and increases rent. The first case agrees with Gillis’ and Vincent’s arguments. The second case disagrees, but agrees with Vincent’s and Cardellichio et al.’s estimated elasticities.
Literature Cited in the Appendix


Table 1: Volume, rotation length, and silvicultural effort impacts from increases in prices, costs, and interest rates, and from the imposition of various forms of taxes.\(^1\)

<table>
<thead>
<tr>
<th>Impact on</th>
<th>Volume/ hectare ((V^*/ha))</th>
<th>Rotation Length ((t^*))</th>
<th>Silvicultural Effort ((E^*))</th>
<th>Total Volume ((V^*))</th>
</tr>
</thead>
<tbody>
<tr>
<td>From increase in the value of (p)</td>
<td>-</td>
<td>-</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Effort Cost ((w))</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Interest rate ((i))</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

**Tax Forms\(^2\)**

<table>
<thead>
<tr>
<th>Tax Form</th>
<th>Volume/ hectare ((V^*/ha))</th>
<th>Rotation Length ((t^*))</th>
<th>Silvicultural Effort ((E^*))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Property Tax</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Site Value Tax</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Timber Tax</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Yield Tax</td>
<td>+</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>Severance Tax</td>
<td>+</td>
<td>+</td>
<td>-</td>
</tr>
</tbody>
</table>

1. The results presented in the table are general case results. Chang (1983) shows that, under certain conditions, all the results shown in table 1 can become ambiguous. The cause of the uncertainty is whether \(V_{TE}^*\) is positive or negative. Generally, \(V_{TE}^*\) is assumed to be negative.

2. These results show the increase or decrease in optimal rotation length and volume per hectare depending on the form of tax. The taxes analyzed are:

- **Property tax** = each year taxes a fixed percentage of land and timber value.
- **Site value tax** = each year taxes a percentage of the value of the land only.
- **Timber tax** = each year taxes a fixed percentage of the standing timber only.
- **Yield tax** = taxes a percentage of the value of the harvested timber.
- **Severance tax** = taxes a fixed charge per unit of timber volume harvested.
Table 2: Forest resources by region in the 1980s.

<table>
<thead>
<tr>
<th>Region</th>
<th>Forest and Woodland (1000 ha.)</th>
<th>Reforested in 1980s (1000 ha/yr)</th>
<th>Managed Closed Forest (1000 ha.)</th>
<th>Protected Closed Forest (1000 ha.)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Open</td>
<td>Closed</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Africa</td>
<td>483,943</td>
<td>221,376</td>
<td>196</td>
<td>2,331</td>
</tr>
<tr>
<td>North/Central America</td>
<td>277,772</td>
<td>528,791</td>
<td>2,528</td>
<td>102,884</td>
</tr>
<tr>
<td>South America</td>
<td>204,590</td>
<td>662,505</td>
<td>416</td>
<td>NA</td>
</tr>
<tr>
<td>Asia</td>
<td>65,120</td>
<td>431,072</td>
<td>5,649</td>
<td>49,415</td>
</tr>
<tr>
<td>Europe</td>
<td>21,887</td>
<td>137,005</td>
<td>1,031</td>
<td>74,628</td>
</tr>
<tr>
<td>Oceania</td>
<td>71,557</td>
<td>87,186</td>
<td>114</td>
<td>NA</td>
</tr>
<tr>
<td>USSR</td>
<td>137,000</td>
<td>791,600</td>
<td>4,540</td>
<td>791,600</td>
</tr>
<tr>
<td>Total</td>
<td>1,121,869</td>
<td>2,859,535</td>
<td>14,474</td>
<td>1,020,858</td>
</tr>
</tbody>
</table>

Sources: Table 18.1 in World Resources Institute, World Resources 1988-1989: An Assessment of the Resource Base that Supports the Global Economy, New York: Basic Books, Inc. The WRI sources are the UN Food and Agriculture Organization, UN Economic Commission for Europe, and country data sources.

Closed Forest - Trees cover a high portion of the ground and there is no continuous layer of grass on the forest floor (FAO); Tree crowns cover more than 20% of the area and the land is used primarily for forestry (ECE).

Open Forest - Mixed forest/grasslands with at least 10% tree cover and a continuous grass layer (FAO); Tree crowns cover 5-20% of the area, have no more than half a hectare covered by groups of trees, are not used for agricultural purposes, or have shrubs or stunted trees covering more than 20% of the area (ECE).

Reforested - Establishment of plantations for industrial and nonindustrial uses.

<table>
<thead>
<tr>
<th>Region</th>
<th>Average Annual Production (1000 m³)</th>
<th>Fuelwood &amp; Charcoal</th>
<th>Industrial Roundwood</th>
<th>Sawnwood</th>
<th>Panels</th>
<th>Pulp (1000 M tons)</th>
<th>Paper (1000 M tons)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Africa</td>
<td>384,694 35</td>
<td>53,386 23</td>
<td>23,468 309</td>
<td>1,792 59</td>
<td>1,551 35</td>
<td>2,233 84</td>
<td></td>
</tr>
<tr>
<td>N. America</td>
<td>108,119 374</td>
<td>494,271 13</td>
<td>142,456 26</td>
<td>38,582 24</td>
<td>71,252 25</td>
<td>77,238 26</td>
<td></td>
</tr>
<tr>
<td>C. America</td>
<td>46,268 33</td>
<td>44,380 293</td>
<td>3,563 -12</td>
<td>997 180</td>
<td>548 44</td>
<td>2,596 81</td>
<td></td>
</tr>
<tr>
<td>S. America</td>
<td>216,961 25</td>
<td>91,694 90</td>
<td>24,836 67</td>
<td>3,831 54</td>
<td>5,293 141</td>
<td>6,623 81</td>
<td></td>
</tr>
<tr>
<td>Asia</td>
<td>739,144 18</td>
<td>245,669 95</td>
<td>98,057 21</td>
<td>22,313 56</td>
<td>12,680 14</td>
<td>37,582 69</td>
<td></td>
</tr>
<tr>
<td>Europe</td>
<td>56,508 9</td>
<td>292,143 9</td>
<td>86,409 5</td>
<td>31,772 7</td>
<td>33,593 19</td>
<td>56,088 32</td>
<td></td>
</tr>
<tr>
<td>Oceania</td>
<td>8,800 33</td>
<td>28,314 23</td>
<td>5,669 -4</td>
<td>1,308 28</td>
<td>1,994 28</td>
<td>2,266 -67</td>
<td></td>
</tr>
<tr>
<td>USSR</td>
<td>85,567 3</td>
<td>284,933 -7</td>
<td>98,167 -14</td>
<td>12,737 40</td>
<td>10,283 19</td>
<td>9,972 16</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>1,800,448 2,073,440</td>
<td>628,444 152,911</td>
<td>208,995 274,430</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>


Fuelwood & Charcoal = All rough wood used for cooking, heating, and power production.
Industrial Roundwood = All roundwood products other than fuelwood and charcoal: sawlogs, veneer logs, sleepers, pitprops, pulpwood, and other industrial products.
Sawnwood = Wood that has been sawn, planed, or shaped into products such as planks, beams, boards, rafters, or railroad ties.
Panels = All wood-based panel commodities such as veneer sheets, plywood, particle boards, and compressed or non-compressed fiberboard.
Pulp = Mechanical, semi–chemical, chemical and dissolving wood pulp.
Paper = Newsprint, printing and writing paper, and other paper and paperboard.
Table 4: Volume of imports (M) and exports (X) of forest products by various regions in 1984-1986 and change from 1974-1976.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M tons</td>
<td>M tons</td>
<td>M tons</td>
<td>M tons</td>
<td>M tons</td>
<td>M tons</td>
</tr>
<tr>
<td>Africa</td>
<td>897 65</td>
<td>3,541 118</td>
<td>568 6</td>
<td>508 45</td>
<td>244 31</td>
<td>1,411 74</td>
</tr>
<tr>
<td></td>
<td>4,667 .24</td>
<td>105 -11</td>
<td>756 8</td>
<td>321 3</td>
<td>547 -21</td>
<td>235 109</td>
</tr>
<tr>
<td>N. America</td>
<td>7,267 26</td>
<td>33,125 97</td>
<td>1,445 18</td>
<td>3,925 17</td>
<td>4,272 28</td>
<td>10,683 54</td>
</tr>
<tr>
<td></td>
<td>25,669 15</td>
<td>41,777 85</td>
<td>1,353 75</td>
<td>2,790 82</td>
<td>10,776 31</td>
<td>13,813 26</td>
</tr>
<tr>
<td>C. America</td>
<td>84 53</td>
<td>1,555 39</td>
<td>180 61</td>
<td>263 109</td>
<td>379 61</td>
<td>897 8</td>
</tr>
<tr>
<td></td>
<td>12 -92</td>
<td>251 -57</td>
<td>18 -64</td>
<td>39 49</td>
<td>0 --</td>
<td>35 56</td>
</tr>
<tr>
<td>S. America</td>
<td>175 21</td>
<td>376 92</td>
<td>557 10</td>
<td>151 251</td>
<td>422 -8</td>
<td>900 -12</td>
</tr>
<tr>
<td></td>
<td>1,167 690</td>
<td>873 66</td>
<td>833 31</td>
<td>1,115 338</td>
<td>1,513 345</td>
<td>845 390</td>
</tr>
<tr>
<td>Asia</td>
<td>61,672 -2</td>
<td>6,240 39</td>
<td>3,649 103</td>
<td>3,179 124</td>
<td>4,432 118</td>
<td>5,287 118</td>
</tr>
<tr>
<td></td>
<td>20,707 -41</td>
<td>310 -1</td>
<td>6,503 49</td>
<td>6,756 80</td>
<td>95 -53</td>
<td>1,615 137</td>
</tr>
<tr>
<td>Europe</td>
<td>38,492 7</td>
<td>26,449 8</td>
<td>5,545 23</td>
<td>10,832 35</td>
<td>11,830 19</td>
<td>20,275 56</td>
</tr>
<tr>
<td></td>
<td>24,480 28</td>
<td>22,046 22</td>
<td>2,798 -1</td>
<td>7,686 18</td>
<td>7,815 17</td>
<td>23,379 75</td>
</tr>
<tr>
<td>Oceania</td>
<td>5 -53</td>
<td>1,077 39</td>
<td>297 -19</td>
<td>138 -5</td>
<td>229 -23</td>
<td>816 32</td>
</tr>
<tr>
<td></td>
<td>9,445 86</td>
<td>435 88</td>
<td>50 -15</td>
<td>110 58</td>
<td>464 48</td>
<td>381 67</td>
</tr>
<tr>
<td>USSR</td>
<td>229 .13</td>
<td>138 101</td>
<td>156 -39</td>
<td>122 37</td>
<td>177 -17</td>
<td>746 39</td>
</tr>
<tr>
<td></td>
<td>16,522 .11</td>
<td>7,556 -6</td>
<td>0 --</td>
<td>973 19</td>
<td>980 79</td>
<td>1,064 16</td>
</tr>
<tr>
<td>Total</td>
<td>116,173</td>
<td>107,182</td>
<td>14,023</td>
<td>23,345</td>
<td>26,636</td>
<td>52,597</td>
</tr>
<tr>
<td></td>
<td>128,350</td>
<td>115,380</td>
<td>13,692</td>
<td>22,518</td>
<td>32,967</td>
<td>55,237</td>
</tr>
</tbody>
</table>


Industrial = All roundwood products other than fuelwood and charcoal: sawlogs, roundwood veneer logs, sleepers, pitprops, pulpwood, and other industrial products.
Sawnwood = Wood that has been sawn, planed, or shaped into products such as planks, beams, boards, rafters, or railroad ties.
Panels = All wood-based panel commodities such as veneer sheets, plywood, particleboards, and compressed or non-compressed fiberboard.
Pulp = Mechanical, semi-chemical, chemical and dissolving wood pulp.
Paper = Newsprint, printing and writing paper, and other paper and paperboard.
<table>
<thead>
<tr>
<th>Author(s)</th>
<th>Range</th>
<th>Region</th>
<th>Product</th>
<th>Time-Frame</th>
<th>Type</th>
<th>Price</th>
<th>Inventory</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abt (1987)</td>
<td>1963-1978</td>
<td>US South</td>
<td>Sawlogs</td>
<td>Short-run</td>
<td>Demand</td>
<td>-0.25</td>
<td></td>
</tr>
<tr>
<td>US West</td>
<td>Short-run</td>
<td>Demand</td>
<td>-0.20</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adams &amp; Haynes (1980)</td>
<td>1966-1976</td>
<td>PNW (west)</td>
<td>Industry stumpage</td>
<td>Short-run</td>
<td>Supply</td>
<td>0.26</td>
<td>1.00*</td>
</tr>
<tr>
<td>PNW (east)</td>
<td>Short-run</td>
<td>Supply</td>
<td>1.46*</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PSW</td>
<td>Short-run</td>
<td>Supply</td>
<td>0.28</td>
<td>1.00*</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rocky Mts.</td>
<td>Short-run</td>
<td>Supply</td>
<td>0.06</td>
<td>1.00*</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>South Central</td>
<td>Short-run</td>
<td>Supply</td>
<td>0.47</td>
<td>0.46*</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Southeast</td>
<td>Short-run</td>
<td>Supply</td>
<td>0.47</td>
<td>0.48*</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>North Central</td>
<td>Short-run</td>
<td>Supply</td>
<td>0.99</td>
<td>0.20*</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Northeast</td>
<td>Short-run</td>
<td>Supply</td>
<td>0.32</td>
<td>0.37*</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PNW (west)</td>
<td>Short-run</td>
<td>Supply</td>
<td>0.06</td>
<td>1.00*</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PNW (east)</td>
<td>Short-run</td>
<td>Supply</td>
<td>1.19*</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>PSW</td>
<td>Short-run</td>
<td>Supply</td>
<td>0.12</td>
<td>1.00*</td>
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<tr>
<td>Rocky Mts.</td>
<td>Short-run</td>
<td>Supply</td>
<td>0.06*</td>
<td>1.00*</td>
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<td></td>
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<tr>
<td>South Central</td>
<td>Short-run</td>
<td>Supply</td>
<td>0.30</td>
<td>0.66*</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Southeast</td>
<td>Short-run</td>
<td>Supply</td>
<td>0.30</td>
<td>0.72*</td>
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<tr>
<td>North Central</td>
<td>Short-run</td>
<td>Supply</td>
<td>0.31</td>
<td>0.35*</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Northeast</td>
<td>Short-run</td>
<td>Supply</td>
<td>0.96</td>
<td>0.28</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Brannlund et al. (1985)</td>
<td>1953-1981</td>
<td>Sweden</td>
<td>Pulpwood</td>
<td>Short-run</td>
<td>Supply</td>
<td>0.74</td>
<td></td>
</tr>
<tr>
<td>Kauranen (1986)</td>
<td>1962-1982</td>
<td>Finland</td>
<td>Sawlog</td>
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* denotes significance at the 95% level or better.

Inventory refers to the value of growing stock rather than the inventory quantity.
Table 8: Summary of selected estimated forest products demand and supply elasticities.

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<tr>
<th>Author(s)</th>
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<th>Type</th>
<th>Price</th>
<th>Income</th>
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<td>Short-run</td>
<td>Demand</td>
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<td>Long-run</td>
<td>Demand</td>
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<td>0.98</td>
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<td>Demand</td>
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<td>Demand</td>
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<td>Demand</td>
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<td>3.08*</td>
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<td>Demand</td>
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<td>Demand</td>
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<td>0.70*</td>
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<td>Demand</td>
<td>-0.63</td>
<td>0.96*</td>
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<td>Demand</td>
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<td>0.71*</td>
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<td>Demand</td>
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<td>US</td>
<td>Plywood</td>
<td>Short-run</td>
<td>Demand</td>
<td>-2.70*</td>
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<tr>
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<td>1950-1980</td>
<td>US</td>
<td>Softwood Lumber</td>
<td>Short-run</td>
<td>Demand</td>
<td>-0.60*</td>
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<td>Treated Lumber</td>
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<td>Demand</td>
<td>-1.62*</td>
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* denotes significance at the 95% level or better.
Table 7: Estimated period demand/income elasticity of selected forest products from 1955 to 1985 for developing and industrial countries.

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<th>Product</th>
<th>1955-65</th>
<th>1965-75</th>
<th>1975-85</th>
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<tr>
<td>Total</td>
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<td>0.85</td>
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<tr>
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<td>0.83</td>
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<td>0.23</td>
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<td>2.43</td>
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Table 8: Summary of selected estimated fuelwood demand and supply elasticities.

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* denotes significance at the 95% level or better.
Argentina
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