

AN ANALYSIS OF THE IMPACTS OF PUBLIC TIMBER HARVEST POLICIES ON PRIVATE FOREST MANAGEMENT IN THE U.S.

INTRODUCTION

The market and welfare impacts of changes in public timber harvest have received much attention in the forestry literature over the past two decades. Most recently, proposals for large scale harvest reductions to preserve habitat for the northern spotted owl have undergone particularly comprehensive analysis.¹ For reductions of public harvest concentrated in the West, these studies have generally found that: prices of sawtimber stumpage rise in all regions; harvest shifts toward private lands with an increasing share of private cut coming from the US South; and private timber inventories in all regions decline in both the near and long-term. Considering only the markets for stumpage, consumer welfare losses as prices rise are of nearly the same magnitude as the increased benefits realized by private producers, with the biggest producer increments occurring in the West (see, for example, Montgomery, et al 1994).

In all past studies, however, the extent and intensity of private forest management has been treated as exogenous. While private harvest has been allowed to fluctuate with price, forest management investment was either ignored or presumed to move according to some preset pattern. But clearly silvicultural investment need not remain fixed in the face of shifting prices and price expectations. To the extent that investment does change, past studies have potentially misestimated: private harvest response in both the near and long-term, consumer and private stumpage supplier welfare impacts, and the extent of harvest changes and welfare impacts across US regions.

This paper examines the effects of public timber harvest policies on prospective future trends in the use and management of private land for timber production in the United States. We develop an intertemporal model of U.S. log markets in which both private harvest and forest management decisions are endogenous. The sensitivity of projected private harvest, management and land allocation decisions to key exogenous inputs is illustrated by shifting the discount rate, management costs, and intertemporal demand trends. We then simulate a set of alternative public harvest scenarios and examine the impacts on private harvest and management and welfare shifts among groups and regions.

DEVELOPMENT OF THE MANAGEMENT MODEL

The basic form of the model of private harvest and management decision is a "model II" even-aged harvest scheduling structure in the nomenclature of Johnson and Scheurman (1977, page 20, model II form IX) or a "transition" timber supply model as described by Binkley (1987)². A mathematical description is given in an appendix. The model operates on a decadal time step. Policy analysis is limited to results for the 50 year period from 1990 to 2040, but projections are made for 10 decades to accommodate treatment of terminal inventories. All exogenous model elements are held constant after the fifth decade.

We model the markets for logs which are differentiated by six product classes (hardwood and softwood sawtimber, pulpwood and fuelwood) and are assumed to be

competitive. The objective function [appendix equation (A-1)] involves the maximization of the discounted sum of future log consumer surpluses from the six products less costs of timber management, log production and transportation plus an adjustment for net returns beyond the end of the finite projection period (value of the terminal inventory). The costs of investments to expand domestic log processing capacity are also reflected in the objective. Export demand and import supply functions for "off-shore" log trade are included for each domestic log producing region and their respective surpluses are incorporated in the objective to emulate competitive trade.

There are four broad classes of constraints.

(1) The timberland area constraints [(A-2) and (A-3)] are those characteristic of a model II formulation:

a) over the projection period areas harvested and reserved from those stands existing at the start of the problem must equal the area of these original stands, and
b) areas reestablished in new stands in any period of the projection must equal the areas cut of original and reestablished stands in that period plus any net change in the land base due to shifts to other uses (assumed to occur after harvest).

(2) Interproduct substitution is permitted from sawlogs to pulpwood to fuelwood. Thus the log demand-supply balance constraints (A-4) require that log consumption for a particular product in any period equal total harvest less exports and substitution "out" of the product class plus imports and substitution "into" the product class. Regional timber harvest is computed as the sum of removals from original and reestablished stands (A-5) plus (exogenous) public harvests.

(3) Log processing industries are assumed to operate with finite bounds on the volume of logs processed. Capacity constraints (A-6) limit consumption in any period to be less than the sum of (depreciated) capacity at the start of the period and any (endogenous) additions in the current period.

(4) Inventories remaining at the end of the projection period are valued as if they comprised a fully regulated forest providing a fixed perpetual periodic yield. The terminal harvest volume equations (A-7) compute perpetual harvest levels.

Nine U.S. log producing regions are recognized but we consider only a single national demand "region". The six classes of products may occur on, and be harvested from, any given acre of timberland. Industrial and nonindustrial private ownerships are treated as separate classes. The timber inventory is further differentiated by four time-linked species order classes, five land classes based on suitability for or previous use in agriculture, three site productivity (quality) classes, and four broad classes of management or silvicultural intensity (that vary in turn by species, owner, site quality and land class).

Past studies of intertemporal timber supply using the model II format include a number of valuable theoretical treatments, but empirical applications have been limited.³ Berck (1979), using methods of optimal control, examined an individual region for a single product and a single endogenous owner. Several subdivisions of the resource base were recognized and management investment decisions were exogenous. Sedjo and Lyon (1990), also using methods of optimal control, examined timber supply in a global context with many regions and many subdivisions of the inventory. Investment decisions were

endogenous and there was a single product and a single endogenous owner in each region. The present analysis extends past work in several ways. We employ a relatively straight-forward nonlinear programming solution procedure in a large problem with many regions and many subdivisions of the inventory. Investment decisions are endogenous for two types of private owners in each region and there are several product classes which admit of opportunities for substitution.

Regions, Owners, and Products

The model employs nine timber supply regions as shown in Table 1. Regional definitions were based on availability of summarized private inventory data from the U.S. Forest Service RPA Timber Assessment data base (Powell et al. 1993). Each region is largely self-sufficient in log supply and there are only limited flows of logs across regional boundaries. Definitions of the private owner groups are the traditional ones, where industrial owners are integrated in some way to processing facilities and nonindustrial owners are not. Public timber harvests are treated as exogenous and are split between Forest Service and other public ownerships. Native American lands are included in the latter group.

The sawlog product class comprises the aggregate of logs used for lumber, plywood, miscellaneous products and ties. Pulpwood is restricted to roundwood (or roundwood equivalents of chipped material) excluding mill residues. All product volumes are measured in roundwood growing stock equivalents, thus they include any logging residues associated with harvest but exclude any non-growing stock volumes processed as sawlogs, pulpwood or fuelwood.⁴

Forest Inventory and Land Base Changes

Forest inventory data for private timberlands are derived from periodic surveys of the forest resources in each State and region by the USDA Forest Service (Powell et al. 1993). The data were aggregated into strata defined by the nine supply regions (Table 1), the two private ownership classes, softwood and hardwood species groups, three site classes, up to four timber management intensity classes, and 10 ten-year age classes.

The strata and mechanism for projecting timber inventories are similar to those employed in the 1993 RPA Timber Assessment Update (Haynes et al. 1994). Each aggregate in the initial inventory represents a certain number of timberland acres and associated average level of growing stock volume per acre. Each aggregate has an independent yield function and projected inventory aggregates reflect net cubic feet of inventory growing stock per acre. Decadal projection periods for the aggregates are consistent with the 10-year age classes. Yields are allocated by the product classes described above. Harvest of an acre of timberland can involve the simultaneous production of a mix of softwood and hardwood timber volume, translated into hardwood and softwood products in proportions that are assumed to be fixed. The product proportions change over time, as the aggregate ages, and between rotations if the timber management intensity changes.

Two species groups--softwoods and hardwoods--are used to reflect variations in timber yields, financial returns, and other attributes. Changes between species groups from one rotation to the next are possible, with yields varying as a function of the current

and immediately preceding species group. To describe the possible combinations of softwood and hardwood groups we used four time-linked species order classes. The first half of the order class name refers to the species in the previous rotation and the second half of the name to species in the current rotation (SOF-SOF, SOF-HAR, HAR-HAR, and HAR-SOF). For example, HAR-SOF describes acres currently in softwoods that were in hardwoods in the previous rotation. To reflect that some sites are naturally better suited for a particular species and to preclude unrealistic elimination or diminution of a species group in a region, limitations on interspecies shifts are imposed via constraints on the proportion of an ownership's timberland base that can be converted to softwoods or hardwoods.

The site productivity classification scheme is based on potential annual cubic-foot volume growth per acre at culmination of mean annual increment in fully stocked natural stands (Haynes et al. 1994). Inventory data allowed differentiation of lands into three site classes (low, medium, and high) in the two southern regions and the Pacific Northwest Westside. Elsewhere it was possible to identify only a single "average" site class.

Estimates of the conversion of timberland to urban and developed uses are based on projections by Alig et al. (1990). Related projections of timberland additions through government subsidized afforestation, such as through the Agricultural Conservation Program, are likewise incorporated.

Timber Management Intensity Classes

Timber yields also vary by management intensity class (MIC). Four timber MIC's were identified for both private owner groups--high (HI), medium (ME), low (LO), and passive (LL)--based on qualitative groupings of the management categories used in the 1993 RPA Timber Assessment Update (Haynes et al. 1994) and from expert opinion. The specific mix of timber management practices in a MIC varies by region, ownership, species, and site group, but can be generally viewed as a hierarchy reflecting level of timber management intensity:

- passive--no management intervention of any kind between harvests;

- low--custodial management of naturally regenerated stands;

- medium--minimal management in planted stands; and

- high--relatively intensive management of planted stands.

Any portion, from 0 to 100 percent, of a management aggregate can be harvested in a given period. The harvested acres then flow back into a pool, from which they are allocated to one of the four timber MIC's, or converted to another land use. Shifts among MIC's can only occur at time of regeneration. Lands can be allocated to the passive (LL) MIC in any rotation after the first.⁵ This class is intended to represent developments under natural successional processes on lands effectively abandoned after initial harvest. Timberland acres in the passive MIC are given highest priority for conversion to other land uses to meet exogenous land use change projections.

Timber yields by age class for the low, medium, and high MIC's are based derived from yields used in the 1993 RPA Timber Assessment Update. For initial inventory aggregates representing other than fully stocked stands, timber yields are projected using the relative density change approach (Mills and Kincaid 1992). Timber growth is the result

of interaction between the current volume stocking, the yield (fully stocked) standard, and the density change function. Timber yields for passively managed stands are a proportion of those for the low MIC group and include a one-period regeneration lag. Minimum harvest ages are specified by region, owner, species, site, and MIC, effectively truncating yield curves in the lower age classes.

Costs of timber management include establishment and any intermediate treatments and vary by region, species, and MIC. Estimates of timber management costs were drawn from a variety of regional (e.g., Straka et al. 1993) and national sources (e.g., Moulton and Richards 1990). Each product has specific harvesting and hauling costs (hauling in this instance relates to the movement of logs from the woods to a regional concentration or delivery point). These costs were derived from the TAMM Timber Assessment data base and cost projections used in the 1993 RPA Timber Assessment Update.

Demand, Capacity and Trade

The demand for logs at the regional level is established by the technology and cost characteristics of the mix of regional log processing industries together with product prices. Transportation costs restrict log movements across regional boundaries in the US, but products are shipped and traded extensively in competitive national markets. Thus competition in national product markets, acting through the cost structures of regional processors, regulate regional log prices rather than direct interregional log trade. To emulate this interaction, "national" demand relations were developed for sawlogs and pulpwood. In both cases the "national" price is taken as the highest of the regional average prices observed during the 1980s. Transportation costs in the market model are then derived from the national price by deducting the historical average difference between the national and regional prices. These differences are assumed to be constant over the projection. Since all transactions are measured "at the mill" or in "mill delivered" terms, intraregional log haul costs are included in prices.

Recognition of multiple products with different demand elasticities and (potentially) different prices is a departure from the approaches of previous intertemporal harvest studies. Since the yield functions used in this study assume fixed proportions of products at various ages, the multiple product context might be viewed as analogous to the age or quality price premiums employed in static, single stand studies of optimal rotation. The source of demand equation projections was the 1993 RPA Timber Assessment Update analysis (Haynes, et al, 1994) and the associated TAMM (Adams and Haynes, 1993) and NAPAP (Ince, 1994) models for the solidwood and fiber products sectors, respectively. Demand equations for sawlogs for the five initial decades of the projection were derived from TAMM by summing regional derived demand relations for sawlogs (with prices adjusted to the national level). Demand elasticities varied between $-.34$ and $-.44$ for softwood sawlogs and $-.19$ and $-.23$ for hardwood sawlogs. Pulpwood demand relations were derived from the basic NAPAP roundwood consumption and price projections using a linear demand approximation with a demand elasticity of $-.4$ for both softwoods and hardwoods. Fuelwood demand was treated as insensitive to price. Fixed national demand

volumes by decade were derived from the Assessment Update report. The price of fuelwood was assumed to be fixed at a preset level.⁶

Sawlog and pulpwood processing facilities are assumed to possess some maximum capacity to produce output in any given period and hence that log demand has some upper bound. Additional capacity may be purchased at a fixed cost per unit in each period to augment current and future log consumption. Over time the initial capacity present at the start of the projection and any additions depreciate at a fixed rate. This treatment of capacity does not entail any changes in the slopes or positions of the log demand functions as a result of capacity investment.

"Downward" substitution was permitted in the model from sawlogs to pulpwood to fuelwood. A small charge was attached to these transfers, recognizing that some additional costs may be entailed, if for no other reason than to reduce the length of the log to customary standards for the lower grade. In addition, hardwood and softwood fuelwood were allowed to substitute for one another in meeting their respective fixed demands. In the present analysis, the substitution takes place on a unit for unit basis. This might be modified in future analysis to reflect the higher BTU yields of hardwoods.

Log trade with regions outside the US was treated by including price-sensitive product-specific demand (export) or supply (import) functions for each region as appropriate based on historical trading patterns. These relations were held constant over the projections. Their function was only to complete the accounting for regional log flows. Given their form, inclusion of these relations does not have the same effects on projections as would incorporation of a fully elaborated set of endogenous off-shore log trading regions.

Terminal Valuation Conventions

Timber inventory remaining at the end of a finite projection period should be incorporated in the objective function at the value that would obtain if managed in an optimal fashion in perpetuity (from the terminal time point onward). If all possible terminal inventory states were valued in a such a fashion, the infinite horizon harvest problem would involve (in the spirit of Bellman's principle of optimality) choosing the optimal path from a fixed starting point (the current inventory) to one of the several terminal inventory states, so as to maximize the sum of transition and terminal values. Valuing, or approximating the value of, the terminal states would be aided if they could be characterized in some general way. If all external conditions are held constant after some point, available theoretical studies generally concur that convergence to some form of equilibrium (fixed cycles or even flow) is to be expected, but it is difficult to be more specific except in special cases.⁷

If, as in the present case, policy concern is limited to the first few periods of the projection, a practical solution is to adopt some approximation for terminal inventory valuation and extend the projection period to the point where the discounted contribution of the terminal state is so small that it does not influence the results in the period of interest. This is the approach taken here. For any given terminal inventory volume, an associated perpetual periodic harvest volume is computed assuming the inventory is fully regulated. We used von Mantel's formula for this purpose (see, e.g., Davis and Johnson, 1987). Rotation ages for this calculation were drawn from harvest ages observed in the solution in

the decades prior to termination. The value of this regulated flow was computed as the consumers' surpluses from the last period's (2080) demand curves less all associated costs of harvest, management and transport with appropriate discounting adjustments. Terminal processing capacity is valued at replacement cost.

External conditions (demand equations, costs, public harvests, etc.) were held constant in all of the projections after 2040. With a 10 decade projection period, this allows one or at most two rotations of continued management before termination. In the base case projection, harvest and investment behavior in regions with relatively short optimal rotations were stabilizing in this interval, while regions with longer rotations were still in some phase of transition. Considering only the behavior in the first 5 decades of the projection, however, extending or reducing the projection period by one decade has only a limited impact. At a 4 percent real discount rate, the base case terminal conditions contribute only some 1.5 percent to the total objective function value in a 10 decade projection ($\$23.7 \times 10^9 / \1595×10^9), as opposed to 2.2 percent in a 9 decade projection and 1.0 percent in an 11 decade projection.

Variation in some representative elements of the projections are summarized in Table 2 for 9, 10, and 11 decade runs. Large aggregates such as total softwood and hardwood consumption, inventories and sawlog prices show only limited change relative to the base (100 year) run. The time paths of these elements (through 2040) are also essentially identical in terms of the timing of turning points. Highly detailed elements, such as acreage allocations to species and MIC classes by owner, show somewhat larger differences that increase, as would be expected, as the projection progresses. As in the case of larger aggregates, however, there is no difference in the time trends of these detailed elements between the base and the shorter or longer projections.

Solution methods

The model was constructed using the General Algebraic Modeling System (GAMS) to specify activities, objective function and constraints (Brooke, Kendrick, and Meeraus, 1992). Since all of the demand relations and constraints are linear, the problem is a quadratic program and is solved using a variant of the MINOS optimizer called GAMS/MINOS (Gill, et al, 1992--appendix D of the GAMS Brooke et al guide). The base case generates approximately 20,000 activities and some 4,000 constraints. Solution on a 486/66mhz micro-computer from a "cold" start generally required 24 hours. Using various methods to obtain an advanced starting point reduced solution times on the 486 to roughly 6 hours.

SIMULATION RESULTS

Base Case

As a datum for comparison in sensitivity analyses and policy simulations, we develop a BASE scenario. Exogenous inputs were derived from the Timber Assessment Update "base case" (Haynes, et al, 1994). In this projection, demand relations for all products rise at a decreasing rate as do the real costs of timber growing and stumpage-to-log processing. The forest land base declines steadily as a result of continued losses to urbanization, infrastructural development and agriculture. Projected harvests on public lands are well below average levels of the 1980s in all regions, reflecting the assumed

adoption of proposals in the FEMAT study (1993) for the far West and judgements regarding the impacts of growing concern for non-timber outputs on public harvests in eastern regions. Illustrative results for this projection are shown in Figures 1-4.

Aggregate US harvest and consumption of all product categories rise, in some case irregularly, over the next fifty years (Figure 1). At the same time, prices of hardwood logs are stable and equal for both sawtimber and pulpwood, reflecting substantial downgrading of volume from sawtimber to pulpwood (Figure 2). Softwood sawtimber and pulpwood prices are lower at the end of the projection than in the 1990 decade, diverging in the 2010-2020 period with the resumption of growth in sawtimber consumption.

Growth in harvest of softwoods is accommodated by a major projected expansion in the area of forest industry land enrolled in the higher management intensity classes on softwood types in the eastern regions, almost entirely in the SE and SC (Figure 4). These lands come primarily from the conversion of hardwood to softwood types and to a lesser extent from upgrading management on existing softwood types. Eastern nonindustrial ownerships (primarily in the South) also shift some hardwood acres into softwoods (to the higher management intensity classes) but at the same time shift large areas of lower quality softwood lands into the lowest or default management class. The impact of these management changes is reflected in a marked rise in softwood inventory on eastern industrial lands (Figure 3), with less pronounced shifts in other regions and ownerships.

In contrast, hardwood management intensity declines consistently across owners and regions with large areas lost to species conversion and shifted into the lowest management intensity class. Despite these reductions in growth potential, the largest element of the hardwood inventory in southern other private ownership continues to grow until 2010 (Figure 3). Inventories in other regions and ownerships decline steadily.

Figures 1 and 2 also illustrate the relation between the Timber Assessment Update base case projection and the BASE from the present model. In general harvest projections from the present model rise at least as fast as those from the Update and reach higher levels by 2000 or 2010. In contrast, prices in the present model trend generally downward while those in the Update are rising. Although the management intensity classifications used in the Update are not directly comparable to those used in the present study, a rough comparison of management assumptions and inventory trends indicates some of the primary reasons for these differences. In softwoods the Update's projected growth on southern nonindustrial ownerships is lower than the present study, despite some assumed intensification of management, and the Update inventory falls steadily over the projection. The Update does assume some shift in southern industrial lands from hardwoods to softwoods and of softwoods into higher management intensity classes, leading to a gradually rising inventory projection. These changes happen sooner and to a greater extent in the present model, however, with exaggerated inventory effects. For hardwoods, the present model projects substantially higher growth and inventories on the critical southern nonindustrial ownership.

Sensitivity Tests

To illustrate the sensitivity of projections to variations in exogenous economic assumptions, we examine three key cases: interest rate, costs, and demand trends.

Results are summarized in Table 3. The directions of deviations from the BASE conform to expectations in most cases. Changes in interest rate affect the opportunity costs of inventory holding. A rate one percent higher than the BASE leads to reduced inventories, lower harvest, higher prices and lowered private investment in management. A one percent lower rate produces the opposite results. Impacts are not symmetric between the two runs and differ markedly between regions and owner groups. Lower costs (including costs of species conversion) encourage additional management investment, raise inventories and harvests, and lower prices. Changes on Southern other private lands dominate the results, with large areas of hardwood conversion to softwoods leading to a small increase in hardwood sawtimber price inflation. Constant demand (all product demand functions were held constant at their 1990 decade levels) sharply reduces harvest in the longer term, and reduces inventory and management investment. It does not reduce near-term (first 30 year) price inflation, however, suggesting that price movements in this period are governed primarily by limitations in the starting inventory.

Policy Scenarios

We examine two alternative scenarios of public timber harvest. The LOCUT scenario is an arbitrary reduction in harvests from the BASE by 50 percent for national forests and 25 percent for other public lands in all regions, anticipating further restrictions on public timber production of the sort manifested during the past decade. The HICUT scenario assumes national forest harvests return to the levels proposed in the final land management plans adopted by the Forest Service in 1990 (see Adams and Haynes, 1989, for an earlier analysis of these plans). Harvests on other public lands are set at levels projected by the various state and federal agencies during the late 1980s. In the aggregate the LOCUT scenario represents a reduction of 6.0 billion cubic feet per decade in public harvest relative to the BASE, while average public harvests in the HICUT scenario are some 8.5 billion cubic feet per decade above the BASE. Given the concentration of public lands in the West, the largest changes in public cut occur in that region and involve primarily softwood sawtimber volumes.

Prices. As illustrated in Figure 6 (upper part), changes in product prices are nearly symmetric about the BASE even though the public harvest increment in the HICUT scenario is some 40 percent larger in absolute terms than the reduction in the LOCUT scenario. Prices depart most widely from BASE levels in the first three decades then gradually move back toward the BASE by the final decade. Prices move in the anticipated directions in all but the third and fourth decades. In these latter periods, pulpwood prices rise in the HICUT scenario and fall in the LOCUT. These unexpected shifts reflect both the assumption of fixed product proportions in the stand yield tables and changes in private management investment between the two runs. In the LOCUT case, higher levels of management investment in the South during the first two decades produce higher harvestable volumes of all products by decade three. This yields increased volumes of sawtimber output (in response to higher prices) but carries with it sufficient additional volumes of pulpwood to depress the pulpwood price below BASE levels. This process operates in reverse for the HICUT case.

Harvests. Averaged over the projection period (1990-2049) total US softwood harvest rises 2.6 billion cubic feet per decade under the HICUT scenario and falls 1.3 billion cubic feet per decade under LOCUT. On average private harvest rises in the LOCUT scenario and falls in the HICUT. The largest absolute changes in private harvest occur in the East under both scenarios, ranging from five to nine times the private change in the West.

As illustrated in Figure 6 (lower part), however, averages mask significant trends in private harvest response. In both scenarios, private cut shifts over time so as to gradually offset the change in public cut and move the net change in harvest (summed across all owners) toward zero. By the third decade, net harvest change is less than a third of the initial change in both scenarios due to compensating movements in private cut. During the first two decades of the projection changes in private harvest are accomplished by drawing down or building up inventory. In later decades reductions or increments in harvest are maintained largely without further inventory adjustment through changes in management investment and resulting growth.

The offsetting private harvest trends depicted in Figure 6 differ markedly from results of earlier studies. With preset intertemporal management investment plans, past estimates of private harvest response have been strictly a reflection of inventory shifts (see, for example, Adams and Haynes, 1989). Typically, in a reduced public cut scenario, private harvest at first expands in response to higher stumpage prices then declines or remains stable as inventory is drawn down. While growth may rise, it does so only because of movements along, rather than shifts in, yields functions. The response to increased public harvest presents the reverse pattern as inventory builds steadily over the projection.

Management Investment. Figure 5 show changes from the BASE case in **softwood** land area by MIC grouping for those regions and owners most heavily impacted. The pattern of changes on Western industrial ownerships is symmetric, indicating that lands already in softwood types in the initial inventory are simply being reshuffled between the higher and lower MIC groups. Response to the HICUT scenario is larger than the LOCUT, reflecting the irregular, step-like nature of the investment opportunities on this ownership.

Investment patterns on Southern industrial ownerships are also more sensitive to the HICUT scenario but involve larger area shifts than in their Western counterparts and do not have a symmetric form. The latter results from variations in the rate of conversion of hardwood to softwood types. For example, under the HICUT scenario there is a reduction of nearly 8 million acres allocated to the HI and ME softwood MIC groups while the increased allocation to softwood LO and LL is less than 2 million acres. The difference is a reduction of some 6 million acres in the conversion of hardwood to softwood types managed under HI or ME regimes. The largest absolute investment responses occur on Southern other private lands where, unlike industrial ownerships, investments are more responsive to the LOCUT policy. The pattern of change from the BASE is markedly asymmetric with more than 15 million acres of hardwoods shifted into softwood production over the course of the LOCUT projection.

Welfare Impacts. Table 4 summarizes welfare changes from the BASE case by group and region. Discounted surplus changes are plotted in Figure 7 for the sums of consumers plus private producers and consumers plus public and private producers. Total surplus changes for consumers exceed those for private producers (Table 4) but the differences are not great. As illustrated in Figure 7, the largest difference occurs in the first decade. Thereafter, the gains and losses of the two groups are quite close and the net change oscillates around zero in a narrow range. As a result the total change over all groups is strongly influenced by changes in public timber harvest revenues. At the regional level, Southern private producers realize the largest absolute and relative surplus changes.

DISCUSSION AND CONCLUSIONS

Some findings of our BASE case contrast markedly with other long-term studies of the U.S. forest sector and merit further emphasis. The simulation suggests that private forest lands in the U.S. have sufficient timber production potential to sustain consumption levels far higher than those foreseen in other projections with stable to declining prices in the long-term (once limitations in existing inventories are overcome). Expanding long-term harvest derives from changing patterns of private management investment. Under the competitive product market and perfect capital market assumptions of the model, large areas of industrial hardwood forest in the South would be converted to softwoods. At the same time, large areas of existing other private softwoods would be shifted into the least intensive (passive) management class.

Results of the low and high public harvest scenarios clearly reflect the effects of endogenous management investment decisions and differ in important ways from the findings of earlier studies as summarized in our introductory remarks. Prices do increase in the LOCUT scenario but in a more or less complex pattern depending on the product. In all cases, however, they then return almost to BASE levels by the 2040 decade. Price impacts are nearly symmetric for the HICUT and LOCUT cases despite large differences in the public harvest shifts, reflecting the "lumpy" nature of private management investment opportunities.

Harvest does shift to private lands and the South's share in total private harvest does increase in the LOCUT scenario as found in past studies. In the present model, however, reduced public harvest stimulates a pattern of increased private management investment which enables growing compensatory changes in private cut. This results in private softwood inventories that are not only rising but consistently higher than the BASE in the LOCUT scenario.

Our results confirm past findings that total discounted private log consumer and producer welfare impacts over the projection period are of roughly equal magnitude, total welfare changes being slightly larger for consumers. With endogenous management intensity, however, major net welfare transfers between consumers and producers are largely limited to the first decade. Gains or losses to public suppliers are persistent, reflecting the fixity of their supply, and dominate the net social welfare results in the second and later decades. Though public harvest changes are concentrated in the West, the largest absolute and relative welfare impacts are realized in the South.

While past studies of changes in public harvest have always found significant interregional impacts and transfers, the results presented here suggest that some of the largest effects may be realized outside of the regions in which public forest lands are concentrated. Southern harvest changes are far larger than those in the West as are the associated welfare impacts on Southern private timberland owners. Major shifts in management and the disposition of the forest land base also occur in the South. These have important economic implications, but they also signal major transfers of biological/ecological impacts as well. Conversion of (or failure to convert) several million acres of Southern hardwood types to softwood plantations may have important implications for biodiversity trends in the South and for habitat conditions for a wide range of wildlife species. Similar concerns attend the shifting of large areas of nonindustrial lands into the passive management category and the near-term rotation compressing effects on private lands of the LOCUT scenario.

c:\wp51\epa\forscims.doc

LITERATURE CITED

- Adams, D. M. and R. W. Haynes. 1989. Changing timber policies may bring other changes: the impact of potential changes in National Forest timber supply. *Journal of Forestry* 87(4): 24-27, 30-31.
- Alig, Ralph J., William Hohenstein, Brian Murray, and Robert Haight. 1990b. Changes in area of timberland in the United States, 1952-2040, by ownership, forest type, region, and State. USDA

Forest
Service
General
Tech.
Report
SE-
64.
South
eastern
Forest
Experiment
Station,
Asheville,
NC.
34pp.

Alig, Ralph J., J. Michael Vasievich, and Karen J. Lee. 1992. Economic opportunities to increase timber growth on timberland. pp. 115-125, In proceedings of the conference: "Forests in a changing climate; Climate Institute, Washington, DC. A. Qureshi, ed.

Haynes, Richard, Darius Adams, and John Mills. 1994. The 1993 RPA Timber Assessment Update. USDA Forest Service, Pacific Northwest Experiment Station, Draft

Johnson, R.N. and H.L. Scheurman. 1977. "Techniques for Prescribing Optimal
 Report. Timber
 Harvests
 and
 Investment
 Under
 Different
 Objectives."
Forest Science
Mono
graph
 No.
 18.

Lyon, K. S. and R. A. Sedjo. 1983. "An Optimal Control Theory Model to Estimate the
 Regional Long-Term Supply of Timber." Forest Science 29(4):798-812.

Mills, John and Jonna Kincaid. 1992. The aggregate timberland assessment system--
 ATLAS: A
 comprehensive
 timber
 projection
 model.
 USDA
 Forest
 Service
 General
 Technical
 Report
 PNW-

GTR-281. PNW Station, Portland, Oregon. 160pp

Moulton, Richard and Kenneth Richards. 1990. Costs of Sequestering Carbon Through Tree Planting and Forest Management in the United States. USDA Forest Service, GTR WO-58. Washington, DC.

Powell, Douglas; J. Faulkner; D. Darr; and others. 1993. Forest resources of the United States, 1992. USDA Forest Service General Technical Report RM-GTR-234. Rocky Mountain, Ft. Collins, Colo. 132pp

Straka, T.; W. Watson, and M. DuBois. 1993. Costs and cost trends. Forest Farmer ().

APPENDIX A

HARVEST AND MANAGEMENT DECISION MODEL

Subscripts (owner, land suitability class, and site class are omitted to reduce the complexity of notation):

- r region
- t projection period (1, 2, ... , T-1, T) measured in decades
- c age (cohort) of a stand in existence at start of problem (1, 2, ... , N-1 where N-1 is the oldest recognized age class measured in decades)
- h age of stand at harvest (1, 2, ... , N-1, N where N indicates "never harvested" or not harvested during projection period)
- d date of stand harvest (decade midpoints 1, 2, ... , T and N as defined above)
- m management intensity class (MIC = high, medium, low, and no or "passive" management)
- s species (order) class (softwood followed by softwood, softwood followed by hardwood, hardwood followed by hardwood, hardwood followed by softwood)
- g product (softwood and hardwood sawtimber, pulpwood, and fuelwood)

Variables (activities):

- $X_{r,c,d,m,s}$ acres harvested of an existing stand in region r, from cohort c, d periods after start of problem, in MIC m, and species s
- $N_{r,t,h,m,s}$ acres regenerated in region r, period t and harvested at age h, from MIC m and species s
- $H_{g,r,t}$ total volume harvested of product g in region r, period t
- $DD_{g,t}$ volume of product g consumed domestically in period t
- $DE_{g,r,t}$ volume of product g exported from region r in period t
- $DM_{g,r,t}$ volume of product g imported to region r, period t

$U_{g1,r,t}$	volume of product g1 "downgraded" to the next product class in region r, period t (sawtimber can substitute for pulpwood and pulpwood can substitute for fuelwood within a species and softwood fuelwood can substitute for hardwood fuelwood)
$K_{g,r,t}$	volume of log processing (consumption) capacity added for product g, region r, period t
$TH_{g,r}$	terminal (perpetual) harvest volume of product g in region r (beginning at the end of period T)

Exogenous variables and functions:

$DT_{g,r,t}$	per unit volume domestic transport costs for product g from region r, period t
$PC_{r,m,s,t}$	planting cost per acre in region r for MIC m and species class s, period t
$TT_{g,r,t}$	trade transport costs for product g in region r, period t
$XY_{g,r,c+t-1,m,s}$	per acre yields of existing stands of product g, in region r, at age c + t - 1, MIC class m and species class s
$NY_{g,r,h,m,s}$	per acre yields of stands originating during the projection period of product g, in region r, at age h, MIC m and species class s
$GC_{r,m,s,t}$	per acre stand growing (or tending) costs between origination and harvest in region r, MIC m, species s, in period t
$KC_{g,r,t}$	unit capacity costs for product g, region r, period t
$PD_{g,t}, PE_{g,r,t}, PM_{g,r,t}$	domestic demand (PD), export demand (PE) and import supply (PM) functions solved to give own price as a function of quantity for product g, region r, and period t
$UC_{g,r}$	unit cost of substituting (downgrading) product g to the next "lower" product class in region r
$R_{r,m,s}$	approximate optimal rotation for stands in region r, MIC m, and species s (derived from harvest ages observed in model projections)
$NLC_{r,m,s,t}$	net timberland area change due to shift to or from other uses in region r, MIC m, species s, in period t

$HC_{g,r,t}$	harvesting cost per unit volume removed of product g, in region r, period t
$A_{r,c,m,s}$	starting inventory of area in existing stands in region r, cohort c, MIC m and species s
δ_g	rate of capacity depreciation for product g
i	discount rate
$K_{g,r,1}$	volume of log processing capacity for product g, region r, at start of projection period
$HG_{g,r,t}$	harvest from public lands of product g, region r, period t

Equations

Objective function:

maximize (for the set of activities shown above)

$$\begin{aligned}
 & \sum_{g=1}^T \int_0^{DD_{g,t}} PD_{g,t}(x) dx + \sum_r DT_{g,r,t} (H_{g,r,t} + DE_{g,r,t} + DM_{g,r,t}) \\
 & + \sum_m \sum_s \sum_h N_{r,t,h,m,s} PC_{r,m,s,t} + \sum_g \sum_r (DE_{g,r,t} + DM_{g,r,t}) TT_{g,r} \\
 & + \sum_g \sum_r (H_{g,r,t} + HG_{g,r,t}) HC_{g,r,t} \\
 & + \sum_s \left(\sum_c \sum_{d>t} X_{r,c,d,m,s} + \sum_{p<t} \sum_h N_{r,p,h,m,s} \right) GC_{r,m,s,t} + \sum_r \sum_g K_g \\
 & + \sum_r \sum_g \int_0^{DE_{g,r,t}} PE_{g,r,t}(x) dx + \sum_r \sum_g \int_0^{DM_{g,r,t}} PM_{g,r,t}(x) dx \tag{A-1} \\
 & + \sum_r \sum_{g1} U_{g1,r,t} UC_{g,r,t} > (1 + i)^t \left\{ \sum_g \int_0^{TH_{g,r}} PD_{g,T}(x) dx \right. \\
 & \left. + \frac{\left(\sum_c X_{r,c,n,m,s} + \sum_{p<T} N_{r,p,T\&p,m,s} \right) (PC_{r,m,s,t} + (R_{r,m,s} + 1) C)}{R_{r,m,s}} \right. \\
 & \left. + \sum_g TH_{g,r} (HC_{g,r,t} + DT_{g,r,t}) \right\} / \{ [(1 + i)^{10} + 1] (1 + i)^{-(T+1)} \}
 \end{aligned}$$

Existing acres constraints:

$$\sum_d X_{r,c,d,m,s} \leq A_{r,c,m,s} \tag{A-2}$$

for all r, c, m, and s.

New acres constraints:

$$\sum_c \sum_m \sum_s X_{r,c,t,m,s} \% \sum_{p < t} \sum_m \sum_s N_{r,p,t\&p,m,s} \quad (\text{A-3})$$

$$\& \sum_m \sum_s NLC_{r,m,s,t} ' \sum_m \sum_s \sum_h N_{r,t,h,m,s}$$

for all t and r.

Demand-supply balance constraints:

$$D_{g,t} ' \sum_r (H_{g,r,t} \& DE_{g,r,t} \% DM_{g,r,t}) \% \sum_r U_{g1(g),r,t} \& \sum_r U_{g2(g)} \quad (\text{A-4})$$

for all g and where g1(g) is the index for the product that can be substituted for g and g2(g) is the index of the product for which g can be substituted.

Regional timber harvest:

$$\sum_s (\sum_c X_{r,c,t,m,s} XY_{g,r,c\&t\&1,m,s} \% \sum_{p < t} N_{r,p,t\&p,m,s} NY_{g,r,t\&p,m,s}) \quad (\text{A-5})$$

for all g, r, and t.

Capacity constraints:

$$DD_{g,r,t} \# K_{g,r,1} (1 \& * _g)^t \% \sum_{k=1}^t (1 \& * _g)^{t\&k} K_{g,r,k} \quad (\text{A-6})$$

for all g, r, and t.

Terminal (perpetual) harvest volume:

$$\sum_m \sum_s \frac{(\sum_c X_{r,c,N,m,s} XY_{g,r,c\&T\&1,m,s} \% \sum_{p \# T} N_{r,p,T\&p,m,s} NY_{g,r,T\&p,m,s})}{R_{r,m,s}} \quad (\text{A-7})$$

for all g and r .

FIGURES AND TABLES

Table 1 Timber supply region definitions.

REGION	STATES
PACIFIC NORTHWEST WEST	Western Washington and Oregon
PACIFIC NORTHWEST EAST	Eastern Washington and Oregon
PACIFIC SOUTHWEST	California
ROCKY MOUNTAINS	Idaho, Montana, Wyoming, Colorado, Utah, New Mexico Arizona
LAKE STATES	Minnesota, Wisconsin, Michigan
CORN BELT	Missouri, Iowa, Illinois, Indiana, Ohio
NORTHEAST	Maine, Vermont, New Hampshire, Massachusetts, New York, Connecticut, Rhode Island, Pennsylvania, Maryland Delaware, West Virginia, New Jersey
SOUTHEAST	Virginia, North Carolina, South Carolina, Georgia, Florida
SOUTHCENTRAL	Kentucky, Tennessee, Mississippi, Alabama, Louisiana Arkansas, Oklahoma, Texas

Table 2. Average absolute percentage differences between the base (100 year) projection and 90 and 95 year projections.

CONCEPT / INTERVAL	Average Absolute Percentage Difference from Base
TOTAL SOFTWOOD CONSUMPTION 1990-2040	.20
TOTAL HARDWOOD CONSUMPTION 1990-2040	.44
TOTAL SOFTWOOD INVENTORY 1990-2040	.47
TOTAL HARDWOOD INVENTORY 1990-2040	.13
PRICE OF SOFTWOOD SAWLOGS 1990-2040	1.07
PRICE OF HARDWOOD SAWLOGS 1990-2040	1.94
TOTAL US LAND ALLOCATIONS TO SPECIES AND MIC CLASSES:	
FOREST INDUSTRY 2020	2.95
OTHER PRIVATE 2020	1.96
FOREST INDUSTRY 2040	7.21
OTHER PRIVATE 2040	6.72

Table 3 BASE and sensitivity test results for selected projection elements.

	BASE	INTEREST RATE		50% COST REDUCTIO N	CONSTAN T DEMAND
		3%	5%		
TOTAL US SOFTWOOD HARVEST (CUMULATIVE: BILLION CUBIC FEET)					
1990-2000	218.9	219.1	218.3	227.8	216.1
2010-2040	555.9	563.6	549.6	595.6	449.8
SOFTWOOD SAWTIMBER PRICE GROWTH (PERCENT/YEAR)					
1990-2010	.8	.6	1.1	.9	.8
2010-2040	-.7	-.7	-.7	-1.3	-.4
HARDWOOD SAWTIMBER PRICE GROWTH (PERCENT/YEAR)					
1990-2040	.1	.1	.0	.3	-.1
SOFTWOOD GROWING STOCK IN 2040 (BILLION CUBIC FEET)					
ALL WEST INDUSTRY	33.9	35.8	31.8	32.6	33.5
ALL SOUTH INDUSTRY	52.4	54.4	52.1	52.8	54.9
ALL WEST OTHER PRIVATE	25.4	28.3	22.9	25.6	25.6
ALL SOUTH OTHER PRIVATE	82.8	78.7	82.7	97.1	72.2
U.S. AREA BY MIC GROUP IN 2020 (MILLION ACRES)					
INDUSTRY (HI + ME)	43.0	43.1	41.5	41.5	35.4
OTHER PRIVATE (LL)	96.2	93.3	99.3	87.1	100.5

Table 4 Discounted changes in surpluses (cumulative 1990 - 2049) and percentage change relative scenario total.

SCENARIO	LOG CONSUMERS	LOG PRODUCERS				PUBLIC
		WEST	NORTH	SOUTH	TOTAL	
	Billion Constant Dollars (Discounted to 1990)					
LOCUT	-24.748	7.667	1.808	11.458	20.933	-8.885
Percent of BASE	-2.0	20.7	10.4	36.0	24.2	-20.0
HICUT	23.990	-7.408	-1.309	-10.713	-19.430	15.250
Percent of BASE	2.0	-16.6	-6.8	-24.8	-18.1	33.6

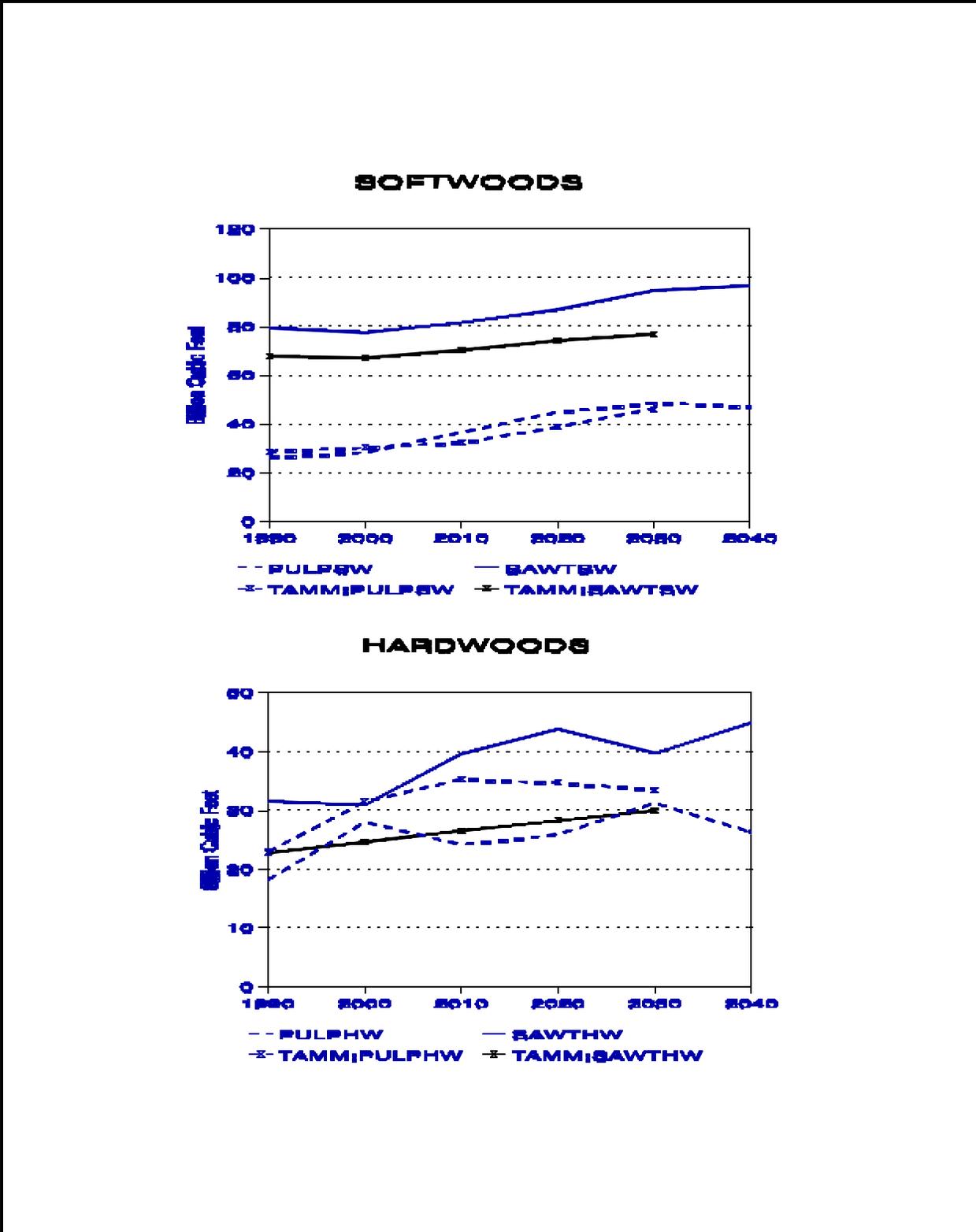


Figure 1: U.S. pulpwood and sawlog harvest volumes projected in present study and by TAMM (Ha 1994).

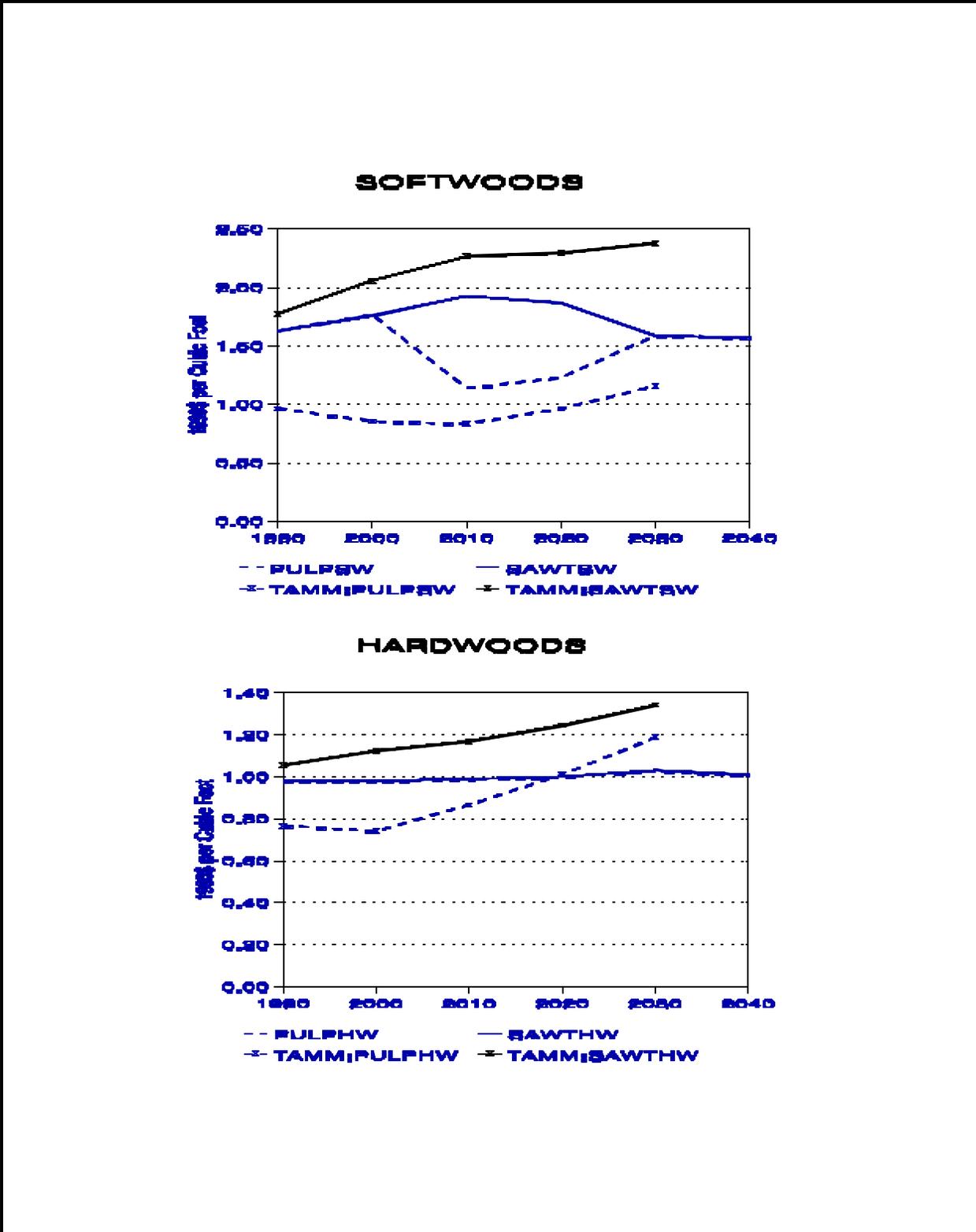


Figure 2: Real pulpwood and sawlog delivered log prices projected in present study and by TAMM (Ha 1994).

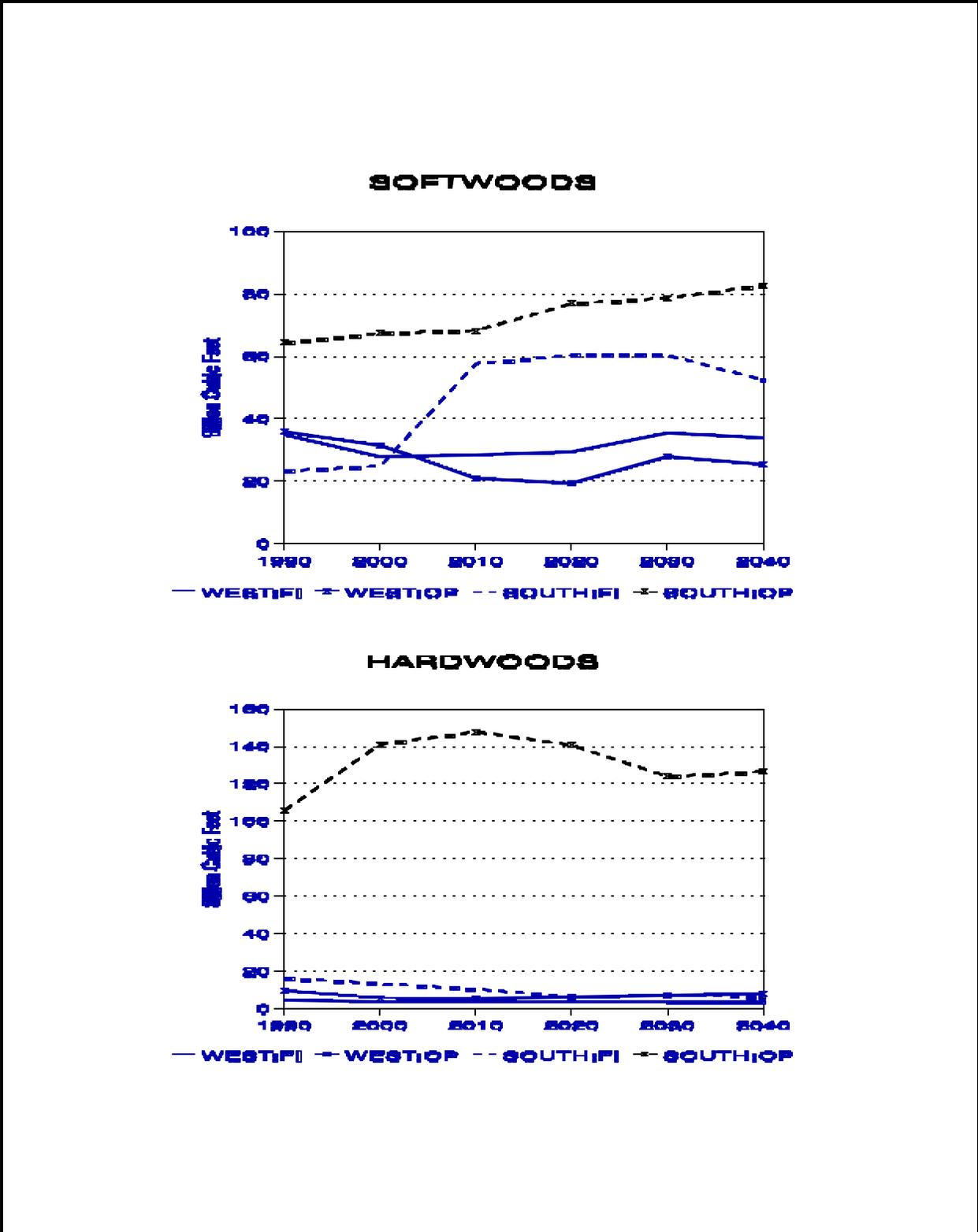


Figure 3: Growing stock inventory for forest industry and other private owners in the South and combine regions.

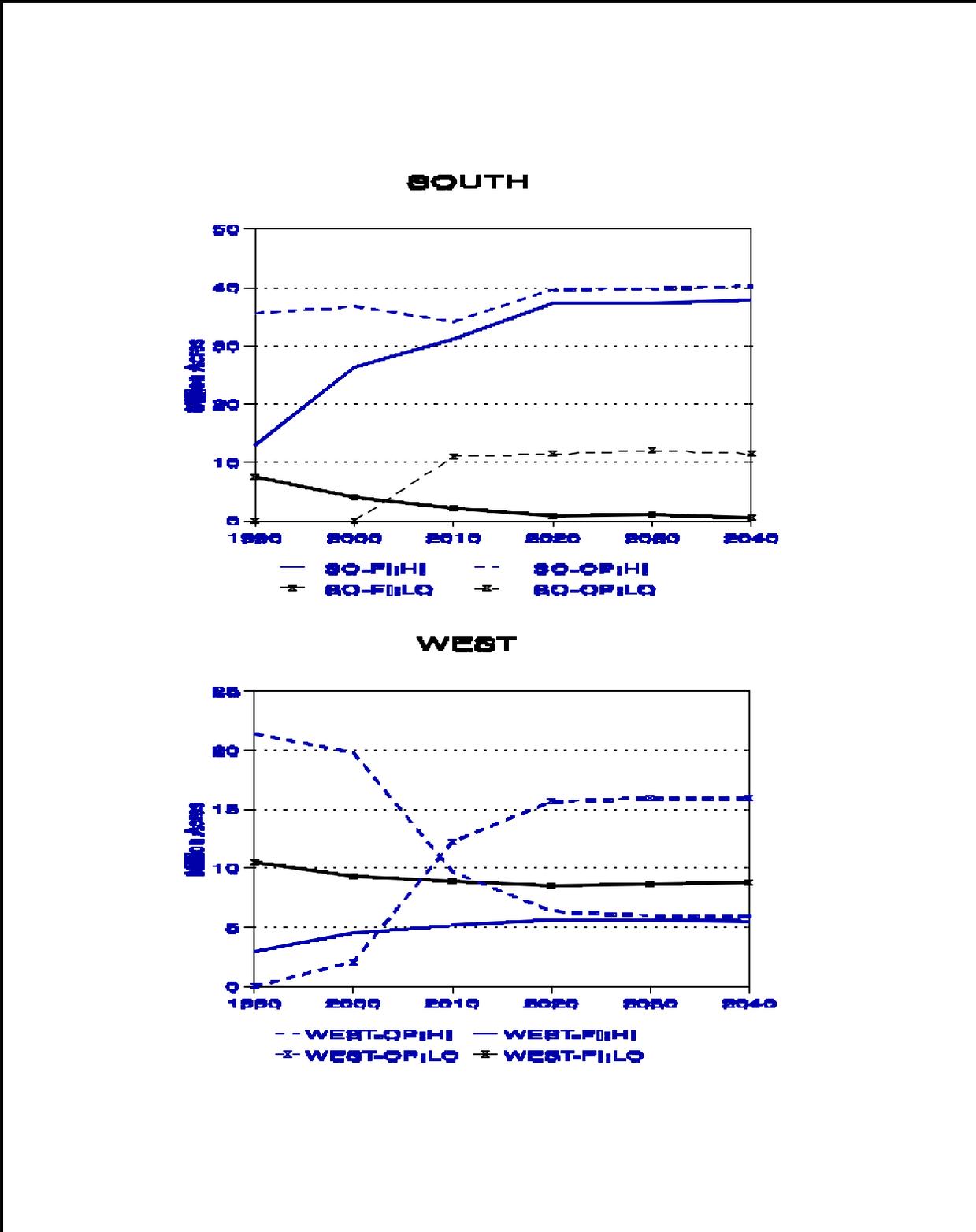


Figure 4: Softwood forest area by management intensity class for forest industry and other private own South and combined western regions: BASE case.

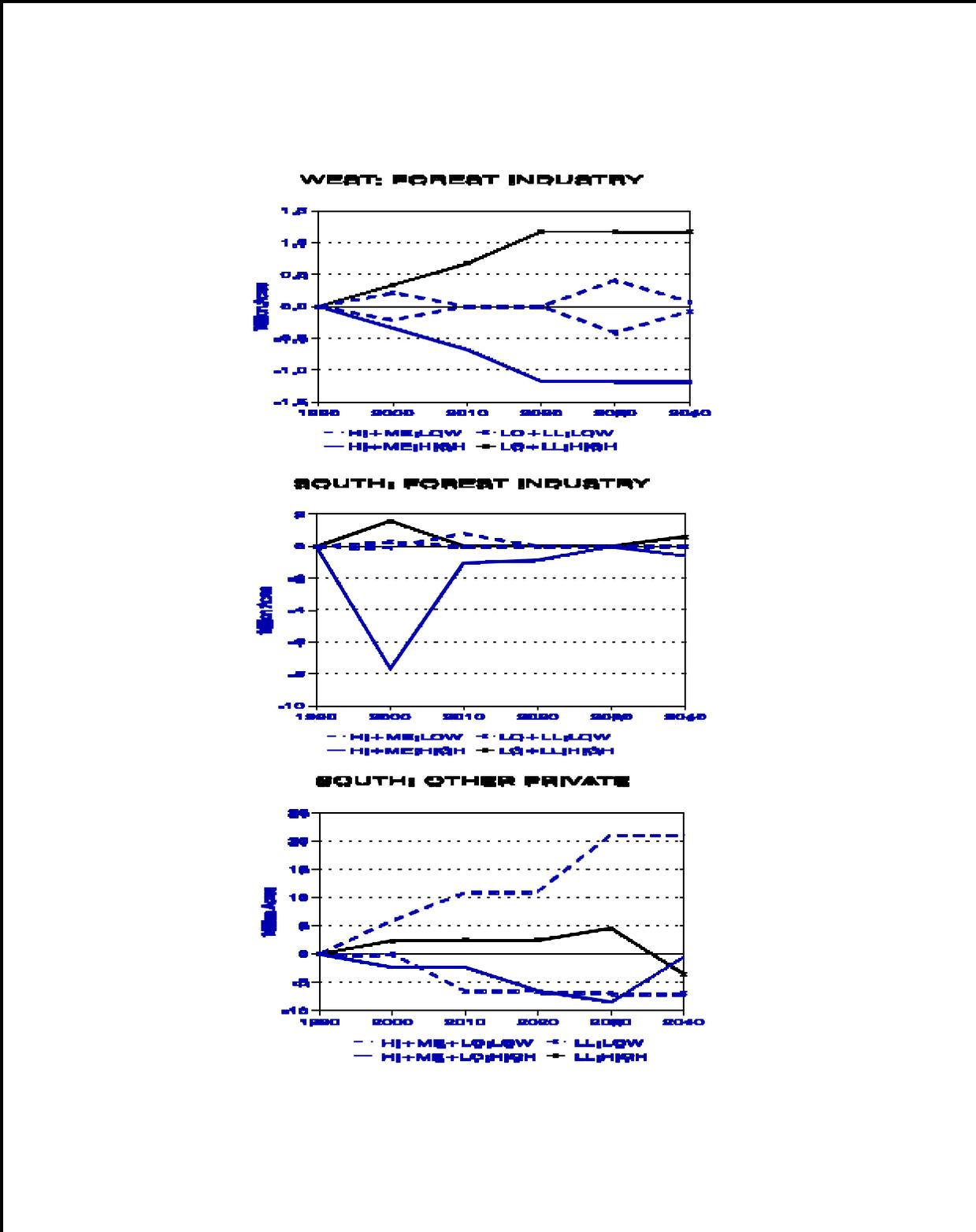


Figure 5: Changes from BASE case levels of land allocation by management intensity class under low public harvest scenarios.

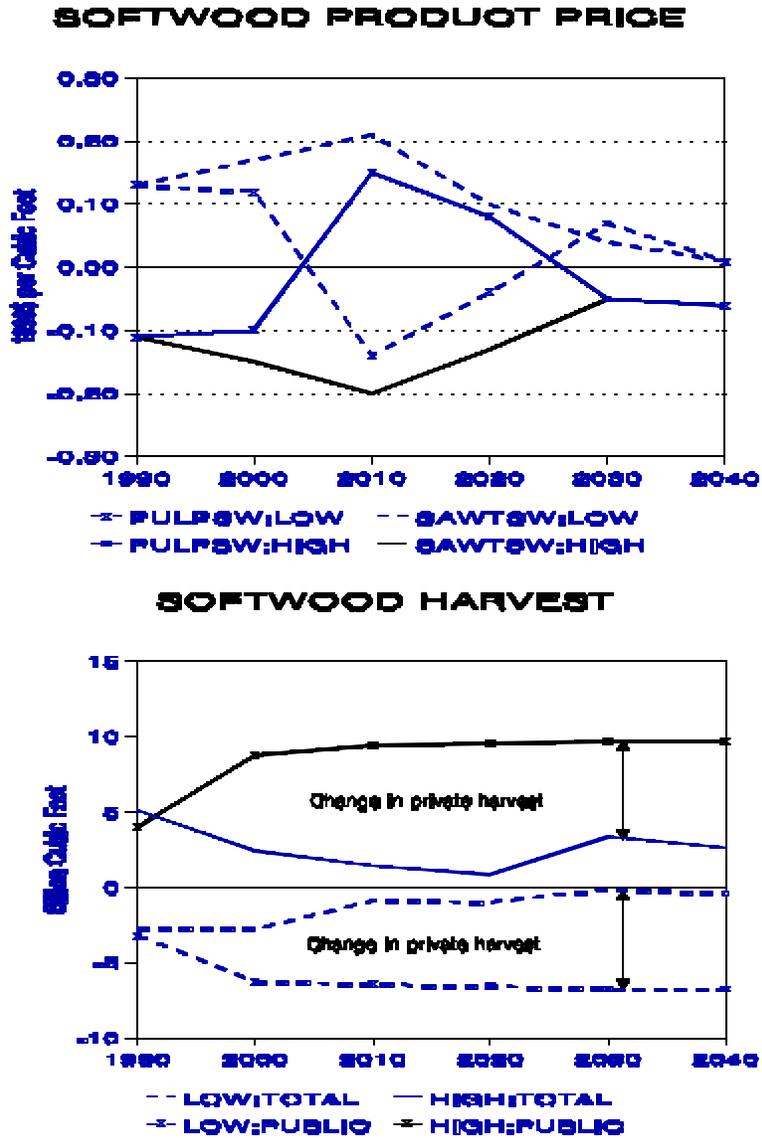
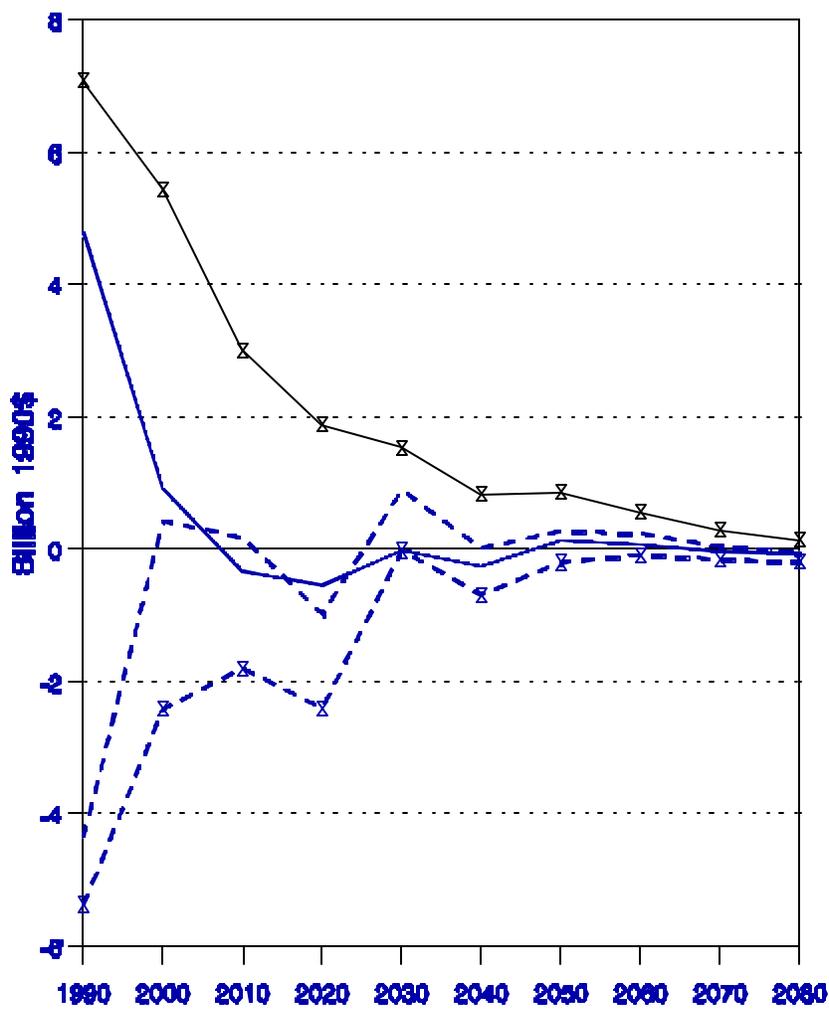


Figure 6: Softwood product price and harvest level changes from the BASE case (BASE - scenario) 1 high public harvest scenarios.



-- LOW: CONS+PROD — HIGH:CONS+PROD
 × LOW:CONS+PROD+PUBLIC × HIGH:CONS+PROD+PUBLIC

Figure 7: Welfare changes from the BASE case (BASE - scenario) for low and high public harvest sc

FOOTNOTES

1. See, for example, Vaux (1970), Adams (1974), Adams, Haynes, and Darr (1977), Adams and Haynes (1989), and Boyd and Hyde (1989). Examination of recent changes related to the spotted owl include: Perez-Garcia (1991), FEMAT (1993), and Montgomery, Brown and Adams (1994).
2. See also Johansson and Lofgren (1985) and Berck (1976--thesis) for useful summary treatments of this class of problems.
3. Wear and Parks (1988) provide a useful discussion of the theoretical structure and potential solution procedure for a problem similar to that addressed in the present study, though the scope is regional.
4. Define growing stock and non-growing stock.
5. There are no lands classed as LL in the initial inventory, since they could not be distinguished from the LO, ME and HI classes based on available data and expert judgement.
6. As has been true in all previous intertemporal harvest studies, our analysis does not include a feedback representation in its demand relations. The TAMM and NAPAP derived sawlog demand and pulpwood quantity projections are linked to specific (endogenous) price projections. Alternative intertemporal price trajectories would be associated with different demand projections. Thus our use of the demand equations and quantities from specific projections from these models may misrepresent actual demand development to the extent that our price projections differ from those of the Update. A later sections compares our base case results with those of the Update.
7. See Binkley (1987) and Montgomery and Adams (1993) for summary discussions of the several available studies.