ASSESSING EFFECTS OF GLOBAL CHANGE MITIGATION STRATEGIES WITH AN INTERTEMPORAL MODEL OF THE U.S. FOREST AND AGRICULTURE SECTORS

FASOM TEAM

********INTERNAL DRAFT--NOT FOR RELEASE OR DISTRIBUTION*******

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FASOM team notes: This is the first rough draft. We are still extracting some estimates to fill in tables, such as for Table 4. Figures will be faxed to you on Monday or Tuesday for comment. I will need your sections or comments/suggestions by noon Wednesday (5/10).

Some questions for your consideration:

1. Would inserting a FASOM tableau(s) in the Appendix be useful?

2. Would a figure showing relative marginal costs of attaining carbon output targets be an useful addition, per the cost numbers Mac is working up?

3. Should carbon targets and actual projections be displayed or presented in tabular form out beyond the usual 50-yr period?

During the conference call, we can discuss what sections you would like to tackle.

ABSTRACT

Policy makers are presently considering an array of actions to mitigate global change through the sequestration of carbon in forests and forest products. Forests appear to be a particularly attractive vehicle for policy action, in part because the stocks themselves have values beyond that of the carbon sequestered and because programs for expanding stocks have been in use for other objectives over many decades in the U.S. Thus, carbon sequestration policy may be achievable in conjuction with other aspects of forest policy. This study examines the economic implications of various forms of carbon sequestration policy using a model that solves simultaneously for market clearing prices and the spatial and temporal distribution of production, trade, and consumption in the forest and agricultural sectors. The Forest and Agricultural Sectors Model (FASOM) projects: (i) timber harvests and log prices for nine U.S. regions, two species groups, and three classes of products (sawtimber, pulpwood, and fuelwood); (ii) private timber management investment for two owner groups (forest industry and other private), (iii) agricultural prices in eleven regions for 36 primary and 39 secondary commodities, and (iv) the amounts of land transferred between the two sectors. The FASOM model maximizes the intertemporal sum of discounted consumers' and producers' surpluses in the agricultural and forestry markets, net of transport and management costs. We employ the FASOM model to simulate afforestation programs suggested in previous studies using static models or single-sector models. The results demonstrate the importance of using a dynamic two-sector model to capture landowner responses to program-induced price changes and the impacts on net carbon sequestration. We then apply FASOM to estimate the least net welfare costs of attaining specific terrestrial carbon sequestration targets or carbon growth paths over time, including projected changes in forest management, rotation length, and land transfers. In view of the model's intertemporal optimization of land use, timber harvest, and forest management investment decisions, we propose how the present model provides a useful platform for future research to examine implications of possible imperfections in both intertemporal product and capital markets.

INTRODUCTION

Increasing the area of forests and enhancing the productivity of existing forests are two options in the array of actions that policy makers are considering to mitigate global change through the sequestration of carbon in forests and forest products. Forests appear to be a particularly attractive vehicle for policy action, in part because the stocks themselves have values beyond that of carbon sequestered and programs for expanding stocks have been used for a variety of other objectives over many decades in the U.S. Because actively growing forests sequester carbon from the atmosphere as part of the growing process, an increase in forest biomass constitutes a sink that will reduce the build-up of atmospheric carbon dioxide (Sedjo 1989, Dudek and LeBlanc 1990, Moulton and Richards 1990). However, anthropogenic activities involving forests, such as land use change and timber harvests, can alter the level and temporal distribution of carbon storage. The economic ramifications of land market interactions, timber harvest, and forest investment have received far less modeling attention than that for biophysical analyses of the relationshops between forest area and/or biomass and the carbon sequestrated in forests (Sedjo and Wisnieskwi 1995). The potential impacts on carbon storage and fluxes from agricultural and timber markets from only been addressed in limited ways (Haynes et al. 1993, Adams et al. 1993). Although a large pool of land is suitable for conversion to forest to sequester additional carbon (e.g., Sedjo 198?), the economic effects of market dynamics (e.g., compensating land use changes) that could alter opportunity costs may act to increase program costs and reduce carbon sequestration relative to that suggested in static or single sector studies.

This paper describes the application of a linked model of the U.S. forest and agriculture sectors in which both land use and forest management investment decisions are endogenous, so that we can examine consequences of intersectoral market forces on carbon storage and fluxes. Through application of the model, we will investigate: 1) if effects of forest carbon sequestration programs differ significantly from those suggested in previous studies using static or single-sector approaches; and 2) how costs and the mixture of land base adjustments differ when attaining a range of carbon sequestration targets under a constraint of least net welfare costs in the intersectoral model. The paper is organized to first review previous studies that estimated costs of terrestrial carbon sequestration, with background information on key land use and forest resource conditions that affect the dynamics of terrestrial systems. Then, we describe base case projections from our intersectoral model, and compare those to results of simulating afforestation carbon programs as input targets drawn from other studies. Next, we discuss economic welfare and terrestrial changes projected by our model to attain output targets for carbon sequestration levels, in a least cost fashion.

LITERATURE REVIEW

Studies at the macro scale that examine the economics of afforestation, forest management, or other terrestrial ecosystem manipulation strategies for sequestering carbon are fairly recent. However, terrestrial carbon analyses have progressed by building upon data sources and models designed originally to address other natural resource policy questions, since several extant models contain some key elements (e.g., methods for projecting changes in timber inventory) needed in forest carbon analyses. Table 1 lists selected large-scale modeling studies, which drew upon extant models for the forestry or agricultural sectors. Terrestrial carbon analyses have exposed the need for multi-sector land use modeling, including endogenous determination of land rents. Although the agriculture side has a longer history of land use analyses, such studies (e.g., Potential cropland study cite) have tended to view forest land as a potential reservoir of cropland. On the forestry side, large-scale models in the last decade have used exogenous land use projections (e.g., Alig 1986). For example, the Haynes et al. (1993) study used exogenous projections of future afforestation in base case projections, and simulated additional increments of afforestation in order to project changes in forest carbon. They estimated the economic consequences in the forest sector of harvesting trees planted to sequester carbon, and conversely the impact on carbon levels from market-driven timber harvesting.

TABLE 1. Selected attributes of macro economic studies of forest carbon sequestration

Study	Land Base	Forest Inventory	Timber Harvest	Forest Investment
Adams et al. (1990)	agricultural	-	-	-
Adams et al. (1993)	agricultural, with endogenous afforestation	static	endogenous, myopic	- afforestation only
Haynes et al. (1993)	forest, with exogenous afforestation	dynamic	endogenous, myopic	exogenous
Adams et al. (1994)	endogenous, intersectoral	dynamic	endogenous, intertemporal	endogenous

The counterpart on the agricultural side to the Haynes et. al study was Adams et al.'s (1993) examination of the impacts of afforestation of pastureland and cropland on agricultural markets. They modified a price-endogenous, agricultural sector model developed by McCarl et al. (1993), and estimated impacts on stumpage prices by linking a representation of a U.S. timber supply model (Adams and Haynes 1980) with the agricultural model and simulating the harvesting of timber on afforested lands. They drew upon earlier studies that estimated the costs of afforesting marginal agricultural land for carbon sequestration goals, based on static supply curves models, with exogenous prices and fixed land rents at different levels of afforestation (e.g., Moulton and Richards 1990). Adams et al.'s findings that the harvest volume of the carbon tree plantings could be economically disruptive in timber markets was consistent with Haynes et al.'s projections. A gap in both studies was modeling how timberland owners would respond intertemporally to a carbon sequestration policy, such as increasing the rate of current harvesting to reduce future supplies. Given their separate or independent sector approaches, both studies lacked a linked land market. Adams et al. forced agricultural land over to forest use in order to meet carbon sequestration constraints, while Haynes et al. modeled afforestation as exogenous additions to the timberland base.

The Adams et al. (1994) study in Table 1 represents the development of the intersectoral and intertemporal model described later for application in this study. The Adams et al. (1993) and Haynes et al. (1993) studies served as foundations for the Adams et al. (1994) model, supplemented by data from other forest carbon studies pertaining to land conversion costs and afforestation timber yield data (Moulton and Richards 1990, Birdsey 1992). The new model endogenously determines land rents in both sectors, which is particularly important in the terrestrial carbon context in relation to variable opportunity costs of programs. Land market interactions can result in differing opportunity costs at different scales of afforestation or other policy vehicles. For example, the predecessor study by Adams et al. (1993) with endogenous prices indicated that higher levels of afforestation to sequester substantial amounts of carbon would be more expensive than earlier studies based on fixed land rents (e.g., Moulton and Richards 1990).

The new model by Adams et al. (1994) also coupled the endogenous modeling of land use changes and timber management investment. This requires a dynamic model of forest inventory changes that recognizes differences in growth potential, age classes, forest types, variable rotation lengths, and other forestry conditions by region. Capturing the dynamics of changes in the inventory of existing trees, including the forest management intensity, is likely to alter the period over which the trees that had been planted to sequester carbon[1] will be harvested. A key aspect of current private timberland in the forest carbon context is the relatively small amount of merchantable timber available for harvest on industry lands (see age class distributions in figure 1), which can influence timber supply and carbon storage projections well into the next century (Adams et al. 1995).

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[1]Carbon accounting is internal in the model and covers several pools of forest ecosystem carbon, and accounts for release of carbon during life cycle of wood products from harvested trees and for non-tree carbon for agricultural land.

****figure 1--age class distributions for private owners

Approximately 75 percent of the timberland in the U.S. is in private ownership,[2] totalling about 145 million hectares. As in Sweden, the possible response to policies (e.g., carbon sequestration program) by many private forest owners, including a nonindustrial majority who do not own wood processing facilities, are important considerations (Alig et al. 1990, Lonnstedt 1989). Efficacy of policy instruments may be adversely affected if owners react differently than originally envisioned by policy formulators, leading to outcomes markedly at odds with intended aims. To date, intensity of forest management is relatively low on the nonindustrial private ownership, with only 4 percent of the inventory area in plantations in 1990, compared to over 20 percent for forest industry. The nonindustrial private ownership has a portion of the respective land bases in both sectors that is suitable, to varying degrees, for use in either sector. Since 1952, private timberland area on the nonindustrial private ownership in the U.S. has been reduced by 7 percent (Alig et al. 1990), which contributed some carbon emissions and shrunk the extant forest base on which carbon could be sequestered.

When looking at the potential for additional land use shifts between the two largest users of land in the U.S., forestry and agriculture, classification of land uses by the National Resource Inventory (USDA SCS 1989, 1994) points to substantial potential for land use competition. The land capability class with the most likely convertible land is IV--land designated as not suitable for continuous cropping, but which contains over 45 million acres of cropland, about 60 million acres of forestland, and 25 million acres of pasture. In addition, at the ends of the land capability spectrum are large amounts of land that could be profitably shifted to another use. Approximately 45 million acres of forestland currently grow on land in LCC's I and II, which are prime farmland. Conversely, more than 20 million acres of cropland and more than 30 million acres of pastureland are in LCC's V-VIII, land with marginal crop productivity in many cases. Much of that marginal cropland and pastureland is in the South and many acres are suitable for planting to trees.

The Adams et al. (1994) model uses similar land suitability data to support dynamic land market-clearing in both sectors. The model assumes the climate and other environmental conditions will be similar to that in the recent past, so that growth and yield responses parallel those used in the 1993 RPA Assessment Update (Haynes et al. 1995). To investigate the relative

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[2] Timberland is forest land that is not reserved for other uses and is capable of producing 20 cubic feet per acre per year of industrial wood. See Powell et al. (1994) for U.S. timberland statistics.

importance of possible changes in the climate, we applied the model to examine economic impacts of global climate change scenarios on the southern forest sector (Burton et al. 1995). Scenarios for the biological response of forest productivity to climate change spanned a broad range, from X growth reduction to Y%. Results varied widely depending on scenario, both generally were not large. During the past decade there has been growing attention to the use of forest plantations as a means of sequestering atmospheric carbon in strategies to mitigate global climate change (Hoen and Solberg 1994; Adams et al. 1992a). Next, we specifically describe the FASOM model in the context of forest carbon analyses, including the growth and yield inputs, demand side parameters, and other model components.

MODEL OF FORESTRY AND AGRICULTURE

To allow land exchange and land price equilibration between the forest and agriculture sectors, we developed a linked intertemporal model of the two sectors. The **F**orest and **A**gricultural **S**ector **O**ptimization **M**odel (**FASOM**) is constructed as a multi-period, price-endogenous, spatial market, equilibrium model (Takayama and Judge 1971). Solutions are found by means of a nonlinear programming algorithm.[3] The objective function maximizes the discounted economic welfare of producers and consumers in the U.S. agriculture and forest sectors over a finite time horizon. FASOM's modeling of land use competition results in an equalization of land rents at the margin across competing uses, with competitive land rents leading to a normative social efficiency (Samuelson 1983). Quantity integrals of demand functions provide total willingness to pay and the difference between total willingness to pay and production and processing costs is the sum of producer and consumer surplus. The model operates on a decadal time step, with projections made for 10 decades to accommodate treatment of terminal inventories; however, policy analysis is limited to results for the 50 year period from 1990 to 2040. All exogenous model elements are held constant after the fifth decade. The model values terminal inventories (at the end of the finite projection period) in both sectors assuming perpetual, steady state management following the terminal year of the time horizon (Adams et al. 1994b).

Forest Sector

FASOM treats only the log market portion of the forest sector. Log demand is derived from the markets for processed products

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[3] FASOM is coded in GAMS (General Algebraic Modeling System) and solutions obtained by means of the MINOS optimizer (see Brooke et al. 1992).

such as lumber, plywood, paper, and so forth. Logs are differentiated by six product classes: hardwood and softwood sawlogs, pulpwood, and fuelwood. Empirical demand functions for softwood and hardwood sawtimber and pulpwood were derived from solutions of the TAMM solidwood and NAPAP pulpwood models by summing regional derived demands for logs from manufacturing at higher market levels (Adams and Haynes 1995, Ince 1994). Sawlog and pulpwood processing facilities possess some maximum capacity to produce output in any given period and hence log demand has some upper bound. Decisions to purchase additional capacity in each period to augment current and future log consumption are endogenous. Substitution is permitted between sawlogs and pulpwood, pulpwood and fuelwood, and between residues generated in sawlog processing and pulpwood. Log trade with regions outside the U.S. was treated by including price-sensitive product-specific demand (export) or supply (import) functions for each region as appropriate, based on historical or anticipated off-shore trading patterns.

The basic form of the model of private harvest and management behavior is a "Model II" even-aged harvest scheduling structure (Johnson and Schuermann 1977, page 20, model II form IX) or a "transition" timber supply model (Binkley 1987). A mathematical description is given by Adams et al. (1994). FASOM describes private timberland in terms of several strata that are differentiated by: nine geographic regions, two classes of private ownership (industrial and nonindustrial, four forest types (describing species composition, either softwoods or hardwoods, in the current and immediately preceding rotation), three site productivities (potential for wood volume growth), four management intensities (timber management regimes applied to the area)[4], suitability for transfer to or from agricultural use (four land suitability classes for crop or pasture plus a "forest only" class that can not shift use), and ten 10-year age classes[5]. Harvest age, management intensity, and forest type

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[4] The four management intensity classes are: "passive"--no management intervention of any kind between harvests of naturally regenerated aggregates; "low"--custodial management of naturally regenerated aggregates; "medium"--minimal management in planted aggregates; and "high"--genetically improved stock, fertilization and/or other intermediate stand treatments in planted aggregates. Specific practices vary by region, owner, site quality, forest type, and agricultural suitability.

[5] FASOM and the **T**imber **S**upply **M**odel (TSM) (Sedjo and Lyon 1990) both model the forest inventory in an even-age format, using a set of discrete age classes with endogenous decisions on management intensity made at time of planting. The TSM does not model land transfers with agriculture and is solved using methods

decisions are endogenous for private owners. Inventories on public lands are not explicitly modeled and public timber harvests are taken as exogenous.

FASOM simulates the growth of existing and regenerated stands by means of timber yield tables that give the net wood volume per acre in unharvested stands by age class for each stratum. Harvest of an acre of timberland involves the simultaneous production of some mix of softwood and hardwood timber volume distinguished by three classes of products (sawlogs, pulpwood, and fuelwood). Forestry budgets for private timberland include establishment costs, growing costs (e.g., fertilization), and timber harvest and delivery to a mill. Costs differ by region, species, and timber management practice (Adams et al. 1994, Moulton and Richards 1990).

Agriculture Sector

The agriculture sector component in FASOM is adapted from the Agricultural Sector Model (ASM) developed by McCarl et al. (1993), aggregated to regions matching the forestry ones. Temporally, to link effectively with the longer projection horizons used modeling of the forest sector where market interventions may take at least several decades to play out, the agricultural model was repeated each decade for the projection period of 100 years. Updating was done between decades using observed growth rates in yield, domestic demand, exports, imports, and cropland availability.

Operationally, ASM is a spatial price-endogenous agricultural sector model, with constant elasticity curves used to represent domestic consumption and export demands as well as input and import supplies. The production solution is required to be within a convex combinations of historical crop mixes, following McCarl, in the first two decades and is free thereafter. The ASM simulates the production of 36 primary crop and livestock commodities and 39 secondary, or processed, commodities. Crops compete for land, labor, and irrigation water at the regional level. The cost of these and other inputs are included in the budgets for regional production variables. There are more than 200 production possibilities (budgets) representing agricultural production in each decade. These include field crop, livestock, and tree production. The field crop variables are also divided into irrigated and nonirrigated production according to the irrigation facilities available in each region. Primary and secondary commodities are sold to national demands. Farm programs are included only for the first decade in the model

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of optimal control with an annual time increment. FASOM, using a decade time step, can be solved using a nonlinear programming algorithm.

(Adams et al. 1994a). ASM also includes assumptions regarding technical improvement in agriculture production and processing.

Land Balance and Intersector Exchange

FASOM links the land inventories in the agricultural and forest sectors (figure 2). Suitable land on nonindustrial private land in each of nine geographic regions can endogenously move, at any time, between agricultural and forest uses, based on considerations of inter-temporal profitability and subject to the availability of resources and the specific provisions of particular policies[6]. Estimates of the area of convertible forestland are from the NRI (SCS) estimates of forestland with medium or high potential for conversion to crop or pasture use; area estimates for convertible agricultural land are drawn from Moulton and Richards's (1990) study of land suitable for tree planting.

Land balances within sectors and exchanges between sectors are controlled in three types of constraints. In the forest sector, land areas are differentiated by "existing" and "new" activities, depending on whether their associated timber stands were present in the initial inventory at the start of the projection or were created during the course of the projection. Three sets of constraints control the interaction of these classes and the total conversion of forest land to agriculture, and two sets of constraints in teh agricultural sector regulate land use and limit land transfer to forestry (Appendix A). Land type is either cropland or pastureland in agriculture.

******figure 2--schematic of linked forestry and ag. model

Linking the sectors required putting the ASM-type component on a multi-period basis as in forest sector modeling, and part of this includes terminal valuation of inventory. Four types of terminal inventory are valued in FASOM and incorporated into the objective function: a) initial forest stands that are not harvested during the projection; b) reforested stands remaining at the end of the projection; c) underdepreciated forest processing inventory is valued at replacement cost, using a perpetual annuity; and d) agricultural land. On the forest

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[6]Rising relative prices for urban and developed uses, at the top of the economic hierarchy of land use, prompt exogenous shifts of forest and agricultural land to urban/developed uses, by region each period (figure 2), along with some timberland reclassified to reserved uses (Adams et al. 1994, Alig et al. 1990).

production side, the forest is assumed to continue perpetually, with a perpetual harvest volume computed by assuming the inventory is fully regulated (Adams et al 1994b). On the consumption side, the perpetual forest yield along with the 2090 level of imports, is assumed to continue perpetually, are applied to a demand curve that is the aggregate of the domestic demand and the export demand curves. After the last decade, remaining agricultural land is assumed to perpetually stay in agriculture, discounting it at a rate as if it were a perpetual annuity.

Carbon Accounting

FASOM accounts for changes in quantities of carbon in the major carbon pool in the private timberland and cropland, and over the life-cycle of wood products (Adams et al. 1994). FASOM accounts for: a) accumulation of carbon in forest ecosystems on existing and newly regenerated forest stands in the existing private timberland inventory during the simulation period; b) carbon losses in nonmerchantable carbon pools from stands that are harvested from the time of harvest until the stand is regenerated or converted into agricultural land; c) the fate of this carbon over the life-cycle of the products that are made from the wood (Appendix B).

In forest ecoystems, the four carbon pools are: trees, soil, forest floor, and understory. FASOM accounts for the accumulation of carbon in forest ecosystems on existing forest stands, and in reforested and afforested stands. The total carbon stored in the forest ecosystem of an unharvested stand is composed of the following carbon "pools": 1) Tree carbon; 2)Non-Tree Carbon; 3) soil carbon; 4) forest floor carbon; and 5) understory carbon. FASOM accounts for carbon losses in nonmerchantable carbon pools from stands that are harvested and carbon decay in products derived from harvested timber. The carbon accounting conventions associated with carbon in growing stock biomass and in the soil, forest floor, and understory closely follow the methodology of Birdsey (1992). Recently, Turner et al. (1993) have developed a somewhat different approach to carbon accounting, accounting for the build-up and decay of woody debris on forest stands. FASOM includes all of these carbon pools. FASOM does not include carbon from public timberlands due to a lack of inventory data.

*******Adapt Figure 2-2 out of final report? >>>>Mac

INTERSECTORAL PROJECTIONS

Linked sector projections were made for a base case, a simulated afforestation program using a standard input of 12 million acres in the 1990 decade (Parks and Hardie), and three simulated carbon target scenarios. We first discuss the base case, and then compare them to projections under the area input and carbon target scenarios. In addition to providing a datum for comparison, the Base Case projections reveal opportunities for land use reallocations and land management shifts, leading to improvements in societal welfare. For example, most nonindustrial timberland, in particular, is currently managed at a low level of timber management intensity, with substantial economic opportunities for more intensive use. Base case assumptions for the forest sector derive from the USDA Forest Service's 1994 RPA Update (Haynes et al. 1994b). Agriculture sector assumptions are discussed by Chang et al. (1992) and McCarl et al. (1993).

Base Case: Large Potential for Intensifying Timber Management On Extant Timberland

Economic Welfare--The model's objective function maximizes the discounted economic welfare of producers and consumers in the forest and agricultural sectors, and Table 2 indicates that the present value of economic welfare in the agricultural sector is much larger than for the forest sector. In terms of the distribution of welfare, the agriculture consumer surplus accounts for 99 percent of total net surplus in both sectors.

Table 2: Distribution of welare in the base cae and changes in the Present Value[1] of Selected Welfare Components for An Afforestation Input and Three Carbon Target Scenarios

Surplus Measure	Base Case (\$ 10_9)	Afforest. Input	Carbon Target # 1	Carbon Target #2	Carbon Target #3
Forest Sector		Percent Change from the Base Case			
Domestic Consumers	2294.8	-0.0	-16.0	-12.6	-26.8
Domestic Producers	108.7	0.7	11.4	11.4	19.3
Total	2541.5	-0.1	-7.0	-1.6	-12.0
Agriculture					
Domestic Consumers	638125.9	-0.0	-45.9	-60.4	-88.4
Domestic Producers	1008.8	1.6	38.5	48.1	78.6
Gov. Farm Prg. Costs	45.8	-	+	-2.4	+

Total	64248.1	-0.0	-10.2	-18.7	-19.5
Total (Both)	645022.5	-0.0	-17.2	-20.3	-31.5

[1]Net Present Values calculated using a discount rate of 4% over 90 years.
+/- signs indicate direction of changes less than $50 million.

Land transfers--Table 2 shows the FASOM projections for intersectoral land transfers for all scenarios. In the base case, approximately 23 million acres in total are projected to transfer between sectors between 1990 and 2039, an area about equal in size to the State of Indiana. Agriculture has a net gain of 14.1 million acres (fig. 3): forestry has a net loss of 4.4 million acres to pasture use and 9.7 million acres to crop use. The capability to reallocate land uses between sectors is estimated to have an economic welfare benefit in net present value terms of approximately $140 billion for domestic consumers of agricultural products, while domestic agricultural producer welfare would be reduced by $140 billion[7] (Alig et al. 1995). Corresponding shifts between consumers and producers are approximately $1 billion for the much smaller forest sector. The relative sizes of the two sectors is reflected by the respective welfare economic estimates in Table 3. The economic worth of the agriculture sector is several hundred times that of the forest sector, and macro changes (e.g., lower cost of capital) may potentially give a proportionally large boost to the agricultural sector's ability to compete for land.

TABLE 2. FASOM Projections for Net Transfer of Land To Nonindustrial Private Forest from Agricultural Uses for the Base Case and Four Scenarios, 1990-2039 (positive number indicates net afforestation) (Thousand acres)

Year	Base	AFF0	CT#1	CT#2	CT#3
1990	-2707	2148	1348	45983	1713
2000	-4548	-6481	-798	-16352	-1544

[7]The surplus calculations include distortions induced by farm programs. Consumers surplus is computed at the prices that consumers pay, while producers surplus is calculated at the higher, supported/target prices. The sum of these surpluses minus farm commodity support payments is equal to the sum of consumers and producers surpluses computed at the market equilibrium prices minus the deadweight loss caused by the farm program.

1990-2039	-14117	-10180	14148	-6910	27951

******fig. 3: graph of intersectoral land transfers for base and carbon target scenarios
Agricultural sector

Projected decadal land transfers in the base case are in the range of historical land use shifts. Land transfers are several percent of the existing agricultural land base, consistent with overall land use largely in accordance with the land capability classes discussed earlier. Approximately half of the land transfers between sectors in the first decade, including the only transfers to forest use. The model concentrates reallocation of land upfront to increase the present value of the objective function. Factors contributing to the more immediate transfer of forest land to agriculture use are reduced subsequent availability of forest land for conversion and movement toward stabilization of land rents between the two sectors, effects of discounting in present value determination favoring agriculture uses in some cases, and existence of farm programs during the 1990-99 decade. Regional differences in land transfers include a concentration of land reallocation in the East. Less than a million acres of land transfers in regions west of the Great Plains.

Forest Management Investment--Intensified timber management represent some of the largest projected changes involving private timberland. One indicator of increased forest investment is expanded area in plantations, including conversion of hardwood types to softwoods. Private owners are projected to add 31 million acres of forest plantations in the first decade, leading to less naturally regenerated area (i.e., fewer low intensity and passively managed acres) (Table 4). The projected change in plantation area in the first decade is larger than the 24 million private acres planted to forests over the past decade in the U.S., with the difference largely on the nonindustrial private ownership. Nonindustrial private plantation area is projected to expand by more than 28 million acres or approximately a three-fold increase compared to the past decade. Overall increases in intensity of forest management is broadly consistent with investment opportunities identified in the 1993 RPA Assessment Update and earlier studies (Adams et al. 1982, Alig et al. 1992, Alig and Wear 1992).

In the second decade, private owners plant an additional 20 million acres, and then maintain the size of the total planted area for a decade before reducing it by 22 percent by 2039. Forest industry implements a larger share of the plantations early in the projection period, and in later decades NIPF owners invest in the bulk of new plantations. Industry owners are projected to apply a higher proportion of relatively intensive

plantation management (e.g., precommercial thinning, fertilization, and commercial thinning), but most plantations are projected to receive less intensive treatments. The 2039 level of total planted area is similar to that in the first decade (figure 4).
******fig. 4: MIC distribution across scenarios

If those investment opportunities in private forest management are implemented, forest product prices in 2039 would approximate those at the start of the projection period. While projected land use changes for timberland involve millions of acres, shifts in intensity of use and other market-based adjustments lead to no more than a 1 percent change in log production levels across scenarios through 2009. This is due in part to the price inelastic nature of the product demands within FASOM; in addition, the age class distribution contains relatively few timber stands at or over merchantable ages, which limits short-run supply response. Total production from all sources of stumpage varies relatively little across scenarios (figure ?). Timber demands are relatively inelastic and increased log prices from the reduced public harvest stimulates private investment and allows a fairly steady harvest level over time. The stimulated private investment leads to larger softwood inventory levels than under the base case, about 10 percent larger by 2039 (figure 5).

Most of the timber management intensification is in the South and the Pacific Northwest Westside. A key part of this forest investment is conversion of hardwood types, essentially all naturally regenerated, to softwoods. The conversion of hardwood types in the first several decades is fueled by a relative shortage in softwoods that contributes later, starting around 2020, to declining harvest volume levels and rising hardwood prices. However, less than one-fifth of the future private forest landscape in the U.S. would be planted. Most of the timberland area in nonindustrial private ownership is still concentrated in the lowest two management intensity classes that involve naturally regenerated stands.

TABLE 4. FASOM Projections of Plantation Area on Private Timberland for the Independent Case, and the Linked Base Case and Three Policy Scenarios, 1990-2039.

Decade	Base	AFFO	CT#1	CT#2	CT#3
	Million acres				
1990	57.9	62.6		100.1	
2000	78.4	81.8		98.6	
2010	77.7	81.7		73.1	

2020	68.8	71.7		57.8	
2030	60.7	62.2		53.3	

Carbon Projections--Carbon stocks under the base case are projected to grow (table 5). In the 1990's decade, the carbon stock grows by 7 percent, equal to a flux of 1.7 gigatons. Carbon fluxes remain positive over the projection period, but drop to 0.5 gigatons by the 2030s decade. Because large amounts of carbon are sequestered in parts of the forest system other than tree boles and because products generally decay slowly and release carbon gradually after harvest, the results also show that carbon levels can continue to rise even after the total merchantable bole volume has stabilized or begun to fall.

Table 5: Projected carbon stocks for the base case and three carbon targets, 1990-2039, in Gigatons (10^9 mt)

Decade	Base	Base Decadal flux	Fixed Increment (#1)		Fixed Increment Relative to Base (#2)		Growing Increment Relative to Base (#3)	
Initial	22.93	-	22.93		22.93		22.93	
1990	24.637	1.707	24.53	24.78	26.24	26.24	24.03	24.74
2000	25.766	1.129	26.13	26.36	27.37	28.13	25.33	26.24
2010	26.628	0.862	27.73	27.84	28.23	28.44	26.83	27.79
2020	27.282	0.654	29.33	29.33	28.88	28.88	28.53	29.51
2030	27.812	0.53	30.93	30.98	29.41	29.41	30.43	31.59

Base level carbon projections by FASOM are below levels projected by Turner et al. (1993) and Winnett et al. (1993) using forest sector projections from the Haynes et al. (1993) study. Differences relate largely to the intertemporal optimization approach of FASOM in contrast to the myopic model employed by Haynes et al. (1993).... >>>>Mac

Base Case Summary--The base case simulations indicate several potential future developments impacting options for sequestering carbon that merit further attention.
(1) Continuing trends of the past several decades, net land shifts to the agriculture sector may be substantial, reducing the forest land base. By 2040, about 6 million additional hectares are shifted to agricultural use in all simulations.
(2) In all regions, but particularly the South, there is some economic incentive to convert hardwood forest types to softwood

plantations. In the Base Case more than 12 million hectares of hardwood lands are converted to softwoods by the 2020 decade. In addition to carbon sequestration implications, these shifts may have important implications for biodiversity trends in many regions and for habitat conditions for a wide range of wildlife species.
(3) The projected harvesting decisions lead to a "shortening" of age class distributions in all regions and on both private ownerships, compressing a larger inventory volume into fewer, younger age classes. This has, of course, significant implications for carbon storage.
(4) Management intensity trends for industry ownerships are leading to increased forest productivity. Land managed in the two most intensive classes rises from one-fifth to three-fifths of the land base by 2040. The effect of intensive management is to move lands more rapidly into a closed canopy (full site occupancy) condition. In contrast, the shifting of large areas of nonindustrial private lands into the passive management category present remaining opportunities for enhancing forest productivity. As projected, these areas are essentially harvested and abandoned with tree densities and species compositions that may vary widely.
(5) Simulations show continued growth in the total cubic volume of private inventory and carbon stock in the U.S., with more rapid growth the first several decades of the projection. Although total merchantable wood volume may stabilize or begin to decline at some point, sequestered carbon in all parts of the forest system may continue to rise.

Alternative Scenarios: Afforestation Area Input and Carbon Targets

We simulated two sets of scenarios to compare against the base case results: 1) an input-based target of afforestation, and 2) three carbon output targets representing different amounts and temporal distributions.

1) Afforestation Program of 12 million acres, 1990-1999 (AFFO)--Tree planting has been proposed as one of the less expensive means for reducing carbon in the atmosphere, through sequestration in tree biomass. We simulate one of the larger levels of tree planting examined in related research (Haynes et al. 1993) to see if afforestation of that amount would significantly increase the opportunity costs of converting agricultural land. The strength of the such spillover effects between sectors will affect efficicacy of programs for inducing afforestation or other forest-based strategies for sequestering additiional carbon. We are also interested in the relative effects of the afforestation program on the agriculture and forest sectors.

Simulation of the afforestation program (AFFO) demonstrates intersectoral responses that can potentially cause outcomes to diverge from those intended in policy formulation (table 2). In response to the relatively large amount of pasture land transferred to forest plantations, the model projects the agricultural sector to substantially increase the conversion of other forest land to agricultural use. In the South, in the primary region of the afforestation, the conversion of forest to pasture use almost doubles compared to the base case. Thus, the net effect on amount of land in forest versus agriculture is significantly smaller than projected in static analyses (Moulton and Richards 1990, Parks and Hardie 1992). As a result, projected differences in timber harvest levels and timber inventory volume are relatively small between the base case and the afforestation scenario.

Comparing the AFFO results to those for the base case, especially over the next 10 to 20 years, indicates the strong influence on near-term outcomes of the extant age class distribution and limited merchantable timber volumes available for harvest. The initial rise in log prices in the first two decades, due largely to the limited harvestable volume, stimulates more forest investment, which subsequently leads to fairly stable log prices. Projected intensification of timber management under all scenarios is substantial. The area in the highest two management intensity classes--representing tree plantations--increases over the projection period (table 4), and then levels off and slowly declines similar to the base case. The largest changes in management intensity occur in the first decade, similar to the timing of land transfers. The Base Case and all scenarios indicate numerous opportunities for shifting more area to the commercially-preferred softwood types. Softwood areas are projected to increase under all scenarios, reflecting timber investment opportunities primarily in the South and Pacific Northwest Westside.

The AFFO policy scenario has relatively little impact on the agricultural sector. Overall, welfare changes are not large compared to other scenarios (Adams et al. 1995).

****figure 5--timber inventory and carbon projections across scenarios****

<u>2) **Carbon Targets**</u>--Three scenarios involved carbon goals expressed as a series of decadal carbon flux targets (table 5), which the FASOM model was required to meet or exceed. The three scenarios are: 1) fixed flux of 1.6 gigatons per decade; 2) fixed increment of 1.6 gigatons of carbon relative to the base case; and 3) a flux amount that expands each decade, with an initial flux of 1.1 gigatons per decade that then grows by 0.2

gigatons per decade. No restrictions were placed on the way in which these carbon targets were met. Consequently, the resulting solutions can be considered least social cost allocations, where least social cost is defined as the minimum loss in the net present value of the welfare of producers and consumers in the agriculture and forest sectors.

Since the carbon targets were expressed in terms of greater than or equal to constraints, the model might well exceed a specific target in order to achieve targets in later periods, especially if the targets were quite large at the end of the projection period. The optimal carbon stock levels selected by FASOM for each scenario are shown in the right half of each column for the scenario in Table 5. Most targets were exceeded, although a larger proportion of CT#2 targets were hit exactly. (Mac??)

Welfare costs of the three carbon target scenarios ranged from $17 billion (#1) to $31 billion (#3). The overall welfare cost of these carbon sequestration programs is not due strictly to the size of the carbon stock targets employed in the analysis, but also to the temporal specifications of these targets. The scenario with the highest cost, #3, has relatively high targets in the last three or four decades of the projection period, including the highest terminal carbon targets. The scenario with the next highest cost, (#2), has carbon stock targets that are consistently higher in relation to the base case in all years. Scenario #2 had a carbon target fixed in relation to the base case and this added to the cost of achieving the target, including the largest near-term land use adjustments and reforestation investment compared to the base case. Afforestation of 46 million acres under Scenario #2 in the first decade is ten times more than in the base case, and at least five times larger than for either of the other two carbon target scenarios not tied to the base case carbon trajectory. This contributes to a planted softwood area of more than 100 million acres in the first decade for Scenario #2, almost twice that of the base case. Afforestation and reforestation areas decline in subsequent decades, after an early build-up in intensively managed timberland area that results in exceeding later targets.

Scenario #3 has the highest long-term carbon target, based on a increasing rate of increase compared to the base case (i.e., second differnce). The model had to exceed the carbon targets in all of the intermediate years in order to achieve the terminal stock requirement, and attain much higher longer term levels of intensively managed softwood area than in the base case. Relative to the commodity-based welfare estimate in the base case, scenario #3 reduces net benefits by $31 billion, the highest social cost of the scenarios.

Scenario #1 with fixed carbon flux targets involved neither the near- or long-term extremes of carbon targets and was the least costly and required the least land base adjustments relative to the base case. The key time period for scenario #1 was several decades into the projection period, since sufficient near-term carbon fluxes could be attained by mimicing the time path of the optimal base case. Attaining increased carbon fluxes in excess of those in the base case was necessary starting in the 2000 decade.

The impacts of the carbon target scenarios on welfare in the agricultural sector was consistent with expectations. Consumers' surplus falls in all of the cases, relative to the base case. These losses in the present value of consumers' surplus were also largest in the case of scenario #3, $88 billion. The higher longer term carbon targets (table 2) required net afforestation over most of the projection period, and reducing the amount of agricultural land reduces agricultural production and drives up land rents and agricultural commodity prices. Higher agricultural commodity prices translate into losses in consumers' surplus. This is because any increases in consumer prices, holding demand curves constant across scenarios, must result in lower consumers' surplus. Producer surpluses increase, on the other hand, because of the inelastic nature of agricultural commodity demand curves, for reasons previously discussed. The highest producers' surplus increase was the $79 billion in scenario #3.

Government costs are not significantly affected except for scenario #2, the only scenario where much larger afforestation is projected in the 1990 decade while farm programs are in effect in the model. The 46 million acres of afforestation acts to reduce the net present value of the deficiency payments to farmers by reducing agricultural land availability. This increases agricultural commodity prices, raises the prices consumer pay, and narrows the gap between target prices and market prices (McCarl and Callway, in press), leading to reduced government payments of more than $2 billion.

The results in Table 2 contained a few interesting surprises, having to do with the direction of the change of domestic consumers' and producers' surpluses in the forest sector. In a previous study by Adams et al (1993), it was suggested that if afforestation programs are accompanied by higher harvest levels, timber prices will fall leading to increases in consumer surplus and losses in producers' surplus. In a subsequent study by Haynes et al (1994), simulated afforestation programs increased timber production and this, in turn, lead to small increases in consumers' surplus relative to the base case. Both of these studies assumed that higher wood supplies would equate with outward shifts in the supply curve for stumpage and lower product prices. However, neither of the models used in these two studies provided solutions that were consistent with intertemporal welfare optimization.

Solutions from FASOM are consistent with intertemporal welfare optimization and the results from these scenario projects, using FASOM, paint a different pattern than could be depicted with ASM, a static agricultural sector model used by Adams et al. (1993), or TAMM/ATLAS a dynamic, but myopic, forest model used by Haynes et al. (1994). In the FASOM model projections, the presence of carbon targets that are increasing relative to the base, over time, leads, initially, to incentives to increase timberland acreage, intensify timber management, and reduce harvest levels (i.e., production) in order to achieve intermediate and final carbon stock targets. As was expected, the present value of the total surplus in the agricultural sector and for the combined sectors fell in all of the scenarios. For the agricultural sector, the largest loss of $19 billion was for scenario #3 with an increasing rate of carbon flux growth.

In the scenarios we examined, the present value of consumers' surplus fell. Consumer surplus losses ranged up to almost $27 billion in CT #3. These losses indicate a pattern of increasing stumpage demand prices, which is consistent with the incentives for long-term resource conservation required to sequester carbon. However, as will be seen later on in the paper, the pattern of price changes relative to the base case, over time, was very uneven across the various scenarios. Consistent with long-term resource conservation, prices generally tended to be higher, relative to the base case, in the earlier periods of the projection period. Thus, the consumers' surplus losses in these earlier periods tended to outweigh any consumer surplus gains later on in the projection period, when any gains were weighted less heavily due to discounting.

The increases in producers' surpluses are consistent with the observed pattern of prices (see figure ?--Mac??) and consumers' surplus changes in Table 2. Increases in producers' surplus ranged up to $19 billion in CT#3. The fact that losses in consumers' surplus are so closely correlated with gains in producers' surplus is explained both by the timing of the price changes and the inelastic nature of the demands for both sawtimber and pulpwood. When stumpage prices increase, producers are made better off because they are able to shift much of their higher costs onto consumers and receive higher revenues even as output drops. In periods when stumpage prices fall, the opposite is true. However, because stumpage price increases were always high initially, subsequent price decreases were not large enough to offset the early gains in producers' surplus. Thus, while the future value of producers' surplus tended to decline, by varying degrees, over time the net present value of producers' surplus was positive over the projection period.

On net, the present value of the total surplus in the forest sector fell in all of the scenarios. This was due to a combination of two factors: 1) the losses in consumer surplus which in most cases are not offset by producer surplus gains and 2) decreases in the present value of the surplus of foreign producers (not shown). Foreign producers were made worse off in all the scenarios because of the increased competition from the U.S. Overall, the losses in the present value of total surplus in this sector ranged up to a high of around $12 billion in CT#3. This is an important conclusion, since it contradicts most previous thinking on the subject, as well as applied research using models that are not truly dynamic in nature.

Marginal costs of attaining carbon targets....less than $10 per ton?? >>>>>>Mac

Discussion and Conclusions

Programs to promote terrestrial carbon sequestration can produce complex interactions among the forest and agricultural sectors, compounded by interrelationships with forest management investment on existing timberland that involves interowner and interregional aspects. Many past studies have examined policy impacts by either: (i) ignoring spillovers in the other sector, or (ii) simply "adding up" impacts across the two sectors, ignoring feedbacks or interactions through the markets for land. To examine forest-based policies proposed for sequestering additional carbon while considering intersectoral competition for land, we applied a linked model of the U.S. forest and agriculture sectors that has both land use and forest management investment as endogenous decisions. The base case, under the assumptions of perfect foresight and perfect capital markets, projects levels of investment in timber management intensification that are notably larger than recent historical trends for the largest private ownership containing nonindustrial lands. Although the trend in recent decades has been one of rising forest investment levels, the projections involve an order of magnitude increase for the nonindustrial private lands, reflecting in part the relatively small percentage of that large ownership currently in plantations. If projected forest investments were undertaken, carbon stocks are projected to increase, log prices are fairly stable after extant timber inventory limitations are modified, and timber harvest levels increase. Projected prices and production levels in the agricultural sector also indicate sustainable levels of production.

The base case projections of land use shifts are broadly consistent with the net transfer of timberland to agriculture in recent decades. The net transfer to agriculture contributes to projected intensification of timber management on private timberland, which has been increasing in recent decades. However, the substantially larger amount of projected investment in forest management compared to recent decades, especially in the first projection decade and on nonindustrial private lands, includes a sizable amount of hardwood area that would be converted to softwood timber types. The total areas projected to be financially profitable for regeneration to planted softwood stands are large relative to existing tree nursery capacity and other related constraints not included in the model. Nonindustrial private owners also have diverse land ownership and management goals (Alig et al. 1990), and even though timber production and forest carbon sequestration can be complementary joint products, incentives necessary to induce a relatively large increase in planting may be relatively expensive or operationally quite difficult to implement.

Simulation of an afforestation program during the next decade several times larger than the afforestation total of the last decade in the U.S. results ultimately in a smaller net gain in total forest area. The projected net gain in total forest area by the end of the decade is less than one-fifth of the 12 million acres of induced afforestation, principally because of compensating intersectoral land transfers to agriculture. Projected changes in carbon stocks and timber investment under the afforestation scenario are more similar to the base case than to outcomes projected under strategies required to meet carbon stock targets.

Carbon targets involving increments above the base case carbon trajectory lead to larger land base adjustments and higher welfare costs, compared to a constant carbon flux not pegged to the base case carbon projection. Relatively large first-decade intersectoral transfers of land and timber management intensification are required to attain a fixed carbon increment of 1.6 gigatons more than the base case. Within higher long-term targets, the most costly scenario is attaining an increasing rate of growth in carbon flux compared to the base case. The South would be the region most impacted by attainment of carbon output targets, falling largely on the nonindustrial private ownership. Attaining targets pegged to the base case are most costly because the base case represents an efficient set of land use and forest management investment trajectories; however, per unit costs of incremental cost appear relatively low in terms of available policy options because the large private timberland and agricultural land bases allow for considerable flexibility in altering future outcomes. Changes in prices and profitability stimulate changes in investment that can act to dampen swings in an intertemporal sense. This is reflected by substantial changes possible in intensity of forest management, rotation length, and land transfer responses across scenarios without commensurate disruptions in economic markets. As in any model with endogenous optimal investment [see, for example, Sedjo and Lyon (1990)], long-term price and volume responses to perturbations are damped. The forest sector has the potential in the face of rising timber demand to sustain net land losses of millions of acres to agriculture and urban and developed uses, but intensify timber management on remaining acres so that log prices are fairly constant over the projection period. Over the next 10 to 20 years, extant timber inventory characteristics (e.g., limited merchantable timber volumes available for harvest) markedly influence forestry outcomes for all scenarios.

The potential for future applications of FASOM seem numerous (e.g., Burton et al. 1994). Investigating the sensitivity of FASOM projections to a range of different assumptions, as under additional scenarios, can be useful for policy analysis. The U.S. Farm Bill is up for renewal in 1995, and linkages between forestry and agriculture are likely to receive increased attention, including both economic and environmental consequences of different policy alternatives. In FASOM any change in future conditions is optimally anticipated (from a net social welfare viewpoint) and investment is freely flexible to vary over time. A representation of "real world" behavior would doubtless be somewhat less adaptable, recognizing limitations of the decision maker. The structure of the present model provides a useful platform for future research to examine some of these questions of "stickiness" in product and capital markets, including limits on investment borrowing or capital budgets (as explored by Kuuluvainen and Salo 1991), increasing marginal costs of borrowing, and uncertainty regarding future market conditions. A second area of some interest would involve extending the markets considered in the model from the log to the product level (sawnwood, panels, paper and board, etc.). This would allow representation of some aspects of substitution endogenously, changes in processing technology, and new product development. Other future model development or extensions could include biomass analyses, and extending the carbon analyses to value carbon in the objective function instead of constrained to meet specific targets. The latter extension could permit modeling carbon subsidies directly in the model without having to estimate carbon equivalents associated with specific subsidy prices.

LITERATURE CITED

Adams, Darius M. and Haynes, Richard W. 1980. The 1980 Softwood Timber Assessment Market Model: Structure, Projections, and Policy Simulations. Forest Science Monograph 22. 62pp.

Adams, D.M., R. J. Alig, D. Anderson and others. 1992. Prospects for western Washington's timber supply. University of Washington, College of Forest Resources, Institute of Forest Resources Contribution Number 74. Seattle.

Adams, Richard; Darius M. Adams; J.M. Callaway; and others. 1993. Sequestering carbon on agricultural land: Social costs and impacts on timber markets. Contemporary Policy Issues XI: 76-87.

Adams, D., R. Alig, J.M. Callaway, and B.A. McCarl. 1994a. Forest and Agricultural Sector Optimization Model: Model

Description. Final report to the Environmental Protection Agency, Climate Change Division, Washington, DC. Variously numbered.

Adams, D., R. Alig, B.A. McCarl, J.M. Callaway, and Steven M. Winnett. 1994b. An analysis of the impacts of public timber harvest policies on private forest management in the U.S. Forest Science (in press).

Alig, Ralph J. and David N. Wear. 1992. U.S. private timberlands, 1952-2040. Journal of Forestry 90(5): 31-37.

Binkley, Clark. 1987. Economic models of timber supply. In Kallio, M. et al. (eds), The Global Forest Sector: An analytical perspective. John Wiley and Sons.

Brooke, A., D. Kendrick, and A. Meeraus. 1992. *GAMS: A User's Guide, Release 2.25*. The Scientific Press, So. San Francisco, CA.

Burton, Diana, and others. 1994. An exploratory study of the economic impacts of climate change on southern forests: Preliminary results. In proceedings of the 1994 Southern Forest Economics Workshop, Savannah, GA. March, 1994.

Chang, C., B. McCarl, J. Mjelde, and J. Richardson. 1992. Sectoral implications of farm program modifications. Amer. J. Agr. Econ. 74(1992): 38-49.

Haynes, Richard; Ralph Alig, and Eric Moore. 1994a. Alternative simulations of forestry scenarios involving carbon sequestration. USDA Forest Service Gen. Tech. Report PNW-GTR-335. Pacific Northwest Experiment Station. Portland, Oregon. 66p.

Haynes, R.W., D.M. Adams, and J. Mills. 1994b. The 1993 RPA Timber Assessment Update. USDA Forest Service Gen. Tech. Rep. RM-in process. Ft. Collins, CO., Rocky Mountain Forest and Range Experiment Station.

Hoen, H. F. and B. Solberg. 1994. Potential and Economic Efficiency of Carbon Sequestration in Forest Biomass Through Silvicultural Management. Forest Science 40(3): 429-451.

Ince, Peter. 1994. Recycling and long-range timber outlook. USDA Forest Service Gen. Tech. Rep. RM-242. Ft. Collins, CO., Rocky Mountain For. and Range Exp. Stn. 23p.

Johnson, Norman and Lynn Schuermann. 1977. Techniques for prescribing optimal timber harvests and investment under different objectives. Forest Science Monograph No. 18.

Kuulavainen, J. and J. Salo. 1981. Timber supply and life cycle harvest of nonindustrial private forest owners: An empirical analysis of the Finnish case. Forest Science 33(4): 932-945.

Lonnstedt, Lars. 1989. Goals and cutting decisions of private small forest owners. Scandavian Journal of Forest Research 4: 259-265.

McCarl, Bruce A.; C. Chang; J.D. Atwood; and W.I. Nayda. 1993. The U.S. Agricultural Sector Model. Texas A&M University, College Station, TX. Draft.

Moulton, Robert J. and Kenneth R. Richards. 1990. Costs of Sequestering Carbon Through Tree Planting and Forest Management in the United States. USDA Forest Service Gen. Tech. Rep. WO-58. Washington D.C.: U.S. Department of Agriculture, Forest Service, Washington Office. 44p.

Powell, Douglas; J. Faulkner; D. Darr; Z. Zhu; and D. MacCleery. 1993. Forest resources of the United States, 1992. USDA Forest Service RM General Tech. Report 234. Rocky Mountain Forest and Range Experiment Station, Ft. Collins. 132p.

Sedjo, R. A. and K. S. Lyon. 1990. The Long-Term Adequacy of World Timber Supply. Resources for the Future, Washington, DC.

Takayama, T. and G.G. Judge. 1971. Spatial and temporal price and allocation models. North-Holland Press, Amsterdam.

Turner, D. and others. 1993. The forestland carbon budget of the U.S. Current status and evaluation of the carbon sequestration potential of alternative forest management practices. Final report for the Environmental Protection Agency. ManTech, Corvallis, Oregon.

USDA Forest Service. 1990. An analysis of the timber situation in the United States: 1989-2040. USDA Forest Service RM General Tech. Report 199. Rocky Mountain Forest and Range Experiment Station, Ft. Collins. 268p.

USDA Soil Conservation Service. 1989. The second RCA appraisal: Soil, water, and related resources on nonfederal land in the United States; analysis of conditions and trends. Washington, DC. 280p.

APPENDIX A: SECTORAL LINKAGE EQUATIONS: **Land Balance and Inter-sector Exchange**

Land balances within sectors and exchanges between sectors are controlled in three types of constraints. In the forest sector, land areas are differentiated by "existing" and "new" activities, depending on whether their associated timber stands were present in the initial inventory at the start of the projection or were created during the course of the projection. Three sets of constraints control the interaction of these classes and the total conversion of forest land to agriculture.[8]

Existing acres constraints

$$\sum_{DECADES} \textit{AREA HARVESTED FROM EXISTING STANDS} \leq \textit{INITIAL AREA}$$

New acres constraints (DECADE)

$$\begin{aligned} &\sum \textit{AREA HARVESTED IN EXISTING STANDS} + \sum \textit{AREA HARVESTED IN NEW STANDS} \\ &- \sum \textit{AREAS REFORESTED OR AFFORESTED} \\ &+ \textit{LAND CONVERTED FROM AGRICULTURE}(\textit{LAND CLASS}, \textit{SPECIES}) \\ &- \textit{LAND CONVERTED TO AGRICULTURE}(\textit{LAND CLASS}, \textit{SPECIES}) \\ &= \textit{EXOGENOUS FOREST LAND LOSSES} \end{aligned}$$

The agricultural conversion activities in this constraint incorporate the full land class and species detail used in the forest sector.

Maximum forest land transfer (LAND CLASS, COST CLASS)

$$\begin{aligned} &\sum_{DECADES} \textit{LAND CONVERTED TO AGRICULTURE}(\textit{LAND CLASS}) \leq \\ &\textit{MAXIMUM FOREST ACREAGE SUITABLE FOR CONVERSION}(\textit{COST CLASS}) \end{aligned}$$

Limits on convertible forest lands are grouped into three classes (COST CLASS) corresponding to (rising) costs of converison.

Within the agriculture sector, two sets of constraints regulate land use and limit land transfer to forestry. Land type is either cropland or pastureland.

Agricultural land allocation (DECADE, LAND TYPE)

$$\begin{aligned} &\sum_{USES} \textit{CROP OR PASTURE LAND USES} \\ &+ \textit{LAND SHIFTED BETWEEN LAND TYPES} \leq \\ &\textit{INITIAL AGRICULTURAL AREA} + \textit{LAND CONVERTED TO AGRICULTURE} \\ &- \textit{LAND CONVERTED FROM AGRICULTURE}(\textit{LAND TYPE}) \end{aligned}$$

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[8] Names in parentheses following constraint descriptions indicate the major state descriptors over which the constraints are defined. For example, the "new acres" forestland constraints are defined for each decade in the projection. All of these constraints are also defined by region.

Maximum agricultural land transfer (LAND CLASS)

$$\sum_{DECADES} LAND\ CONVERTED\ FROM\ AGRICULTURE - \sum_{\substack{DECADES \\ COST\ CLASS}} LAND\ CONVERTED\ TO\ AGRICULTURE \leq MAXIMUM\ AGRICULTURAL\ ACREAGE\ SUITABLE\ FOR\ CONVERSION$$

Constraints forming the interface between forestry and agriculture simply link transferred areas with the minimum land description in one sector with corresponding areas in the other sector.

Other land-based constraints include a biophysical limit on the amount of hardwood area suitable for conversion to softwood timber types. The shadow price is the cost of maintaining an additional forested acre in the hardwood types. Another constraint "forces" land into a particular land use to represent policies, such as afforestation to sequester additional carbon in forests. In the context of this paper, this constraint forces some minimum amount of land to be transferred from agriculture to forestry. The shadow price represents the deduction from agricultural land values or the addition to forest land values to trigger this shift: the implicit subsidy that must be paid to cause the transfer to happen.

Shadow Prices. The shadow prices...

$$\sum_{SPECIES} LAND\ CONVERTED\ TO\ AGRICULTURE(LAND\ CLASS, SPECIES) \geq$$

$$\sum_{SPECIES} LAND\ CONVERTED\ FROM\ AGRICULTURE(LAND\ CLASS, SPECIES) \leq$$

$$\sum_{COSTCLASS} LAND\ CONVERTED\ TO\ AGRICULTURE(LAND\ CLASS, COST\ CLASS)$$

$$LAND\ CONVERTED\ FROM\ AGRICULTURE(LAND\ CLASS)$$

APPENDIX B: FASOM CARBON ACCOUNTING

The carbon sector in FASOM is designed with a number of different features in mind. First, FASOM is able to account for changes in the quantities of carbon in the major carbon pools in private timberland and cropland. Second, the carbon sector in FASOM is structured such that policy constraints can be imposed on either (or both) the size of the total carbon pool at any given time or the rate of accumulation of carbon from year to year. Third, these constraints can be imposed by region, owner group, land class, etc., consistent with proposed policy instruments. The carbon accounting conventions associated with carbon in growing stock biomass and in the soil, forest floor and understory closely follows the methodology of Birdsey (1992b). Recently, Turner et al. (1993) have developed a somewhat different approach to carbon accounting, taking into account the buildup and decay of woody debris on forest stands. The carbon accounting in FASOM includes all of these carbon pools.

Tree Carbon--On average, tree carbon ranges from as low as about 30 per cent of ecosystem carbon to about half of total ecosystem carbon, depending upon species, region and age. Tree carbon on a stand in FASOM, prior to harvest, is the product of four factors: 1) merchantable timber volume per acre; 2) the ratio of total volume to merchantable volume in the stand; and 3) a carbon factor that translates tree volume into carbon, and 4) acreage (which is endogenous). Merchantable volume, by age, on each representative stand is obtained from the growth and yield tables in the model. The volume factor and carbon factor parameters vary by species and region and are obtained from Birdsey (1992b).

At harvest, tree carbon is divided into two smaller pools: 1) merchantable carbon that is translated into products; and 2) nonmerchantable carbon, consisting of carbon in bark, branches and leaves, etc., that is not harvested and not useable or is not harvested and below ground carbon in roots. Each of these pools is a fixed fraction of tree carbon at the harvest age, as determined by the region- and species- specific volume factors.

When a cohort is harvested in FASOM, the fraction of total tree carbon that is merchantable is maintained. No losses occur at harvest to this fraction. The remaining fraction - carbon that is in nonmerchantable timber - is adjusted to reflect immediate harvest losses. The fraction of tree carbon left on site immediately after a timber harvest was determined by adjusting the nonmerchantable fraction derived from Birdsey's volume factors to agree with information about the magnitude of this fraction from Harmon (1993).

FASOM physically tracks the fate of carbon, after harvest, from both merchantable and nonmerchantable timber carbon pools. FASOM translates the merchantable carbon in harvested stumpage into carbon in three products: sawlogs, pulpwood; and fuelwood, which is burned. Output from the HARVCARB model (Row, 1992), is used to simulate the fate of carbon in trees after they are harvested, converted into wood and paper products, are used in a variety of ways and then burned or disposed in landfills. The fate of carbon for each product is determined by a set of coefficients, showing the "average" fraction of merchantable carbon remaining after harvesting a specific cohort in each subsequent time period in four different "uses": 1) wood products in use; 2) wood products in landfills; 3) burned wood products; and 4) emissions to the atmosphere (i.e., oxidization). These carbon fate coefficients vary by product, species, and length of time after harvest. The fate of carbon in wood that is burned is determined by fixed proportions that divide this carbon into two categories: displaced fossil fuels, an addition to the carbon pool, and emissions to the air. These fractions only apply for a single decade. All wood is assumed to be burned within a decade of harvesting.

The same general treatment is accorded fuelwood, except that it is assumed that fuelwood displaces conventional fossil fuels in fixed proportions, representing the average fossil fuel use mix for residential space heating. Thus, not of all the carbon that is released in fuelwood burning will be lost. However, as in the case of other products that are burned, the accounting caries forward for only a single period, to reflect the fact that fuelwood must be used relatively quickly after harvest to be an effective source of space heating fuel.

Nonmerchantable carbon, or woody debris, also decays after harvest. The decay rates vary by region, species, and decade. Data for modeling these decay rates were obtained from Harmon (1993). One problem in tracking the buildup and decay of woody debris is due to the fact that FASOM does not track stands, on an acreage basis, after harvest. Once a cohort is harvested in FASOM, the land on which that cohort resided is thrown into an undifferentiated pool of acres from which new acres can be drawn for regeneration purposes. Thus, if one assumes that all nonmerchantable carbon decays at the rates indicated in Harmon's data, there is a tendency for very large accumulations of carbon to develop in this pool. One way to deal with this problem is to truncate the number of periods over which the woody debris from any given cohort can accumulate. A truncation of 3 to 4 periods, tends to produce a terminal woody debris pool that converges on the size of the pool simulated by Turner et al. (1993).

Non-Tree Carbon--We grouped soil, forest floor and understory carbon into a single large pool, called non-tree carbon. In FASOM, the carbon in this entire pool is treated as being independent of tree volume. Non-tree carbon is the product of two factors: 1) a carbon factor that varies by region, species, and land type (forested land, afforested pastureland, afforested cropland, pastureland and cropland), and 2) acreage (which is endogenous). Estimates of non-tree carbon, by region, forest type, land type and age were obtained from USDA.[9] These tables were aggregated into hardwoods and softwoods using forest-type - species distribution information (Waddell et al. 1989).

In the initial period, non-tree carbon on an acre takes on different "steady state" level depending on whether a particular cohort is on: a) timberland, b) cropland, or c) pastureland. Non-tree carbon on timberland is fixed over the life-cycle of a cohort, and does not vary with the age of the tree. As long as land remains in timberland, non-tree carbon retains this value. Non-tree carbon on agricultural land must be accounted for in FASOM to prevent the model from finding free carbon, but this amount is deducted off total carbon after the run is completed.

Crop or pastureland that is afforested both have initially lower, but different, non-tree carbon volumes than does timberland. However, once these types of land move over into the forest sector, the non-tree carbon on these lands increases steadily until about age 55, at which point non-tree carbon per acre reaches a value that is the same as the constant timberland value for that land class (afforested crop or pastureland). That non-tree carbon volume then remains constant on a per acre basis until a cohort is harvested.

At harvest, non-tree carbon per acre depends on the "fate" of the land. If land remains in a timberland category, then the non-tree carbon remains constant on a per acre basis. If the land returns back to crop or pastureland, then FASOM adjusts for this transition, and acres that return to cropland or pastureland are given a lower non-tree carbon value consistent with agricultural land.

[9] The approach used differs from Birdsey's (1993) in two ways: 1) understory carbon in FASOM is treated as independent of tree voume, and 2) non-tree carbon does not increase with the age of a stand, unless the land was afforested.