

Assessing Effects of Mitigation Strategies for Global Climate Change with an Intertemporal Model of the U.S. Forest and Agriculture Sectors

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Abstract. A model of product and land markets in U.S. forest and agricultural sectors is used to examine the private forest management, land use, and market implications of carbon sequestration policies implemented in a "least social cost" fashion. Results suggest: policy-induced land use changes may generate compensating land use shifts through markets; land use shifts to meet policy targets need not be permanent; implementation of land use and management changes in a smooth or regular fashion over time may not be optimal; and primary forms of adjustment to meet carbon policy targets involve shifting of land from agriculture to forest and more intensive forest management in combinations varying with the policy target.

Key words: afforestation, climate change, intersectoral, land-use change

1. Introduction

Increasing forest area and enhancing productivity of existing forests are two options being considered by U.S. policy makers to mitigate global climate change through the sequestration of carbon (C) in forests and forest products. Forests are an attractive vehicle for policy action, in part because the stocks themselves have values beyond that of the C sequestered and because programs for expanding stocks have been used for a variety of other objectives over many decades in the U.S. Thus, increments of C sequestration may be achievable in conjunction with other objectives of forest policy. Since forests sequester C from the atmosphere as part of the growth process, any increase in forest biomass constitutes a sink that will reduce the build-up of atmospheric carbon dioxide. However, anthropogenic activities involving forests, such as land use change and timber harvest, can alter the amount and temporal distribution of C storage. In past analyses of C sequestration in forests, land market interactions, timber harvest, and forest investment have received far less attention than the biophysical relationships between forest biomass and C

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sequestered. The potential impacts on C storage and fluxes of adjustments in agricultural and timber markets have only been addressed in limited ways (Adams et al. 1993; Haynes et al. 1994). Opportunities to sequester more C in U.S. forests include both increasing net growth on existing timberland (Alig et al. 1992) and the conversion of suitable agricultural land to forest (Moulton and Richards 1990). In the latter case, programs designed to secure the afforestation of these agricultural lands could stimulate adjustments in both product and land markets that would partially offset land use shifts to forestry. Shifting agricultural lands to forestry should cause agricultural land rents to rise and forest land rents to fall, favoring a reverse flow from forestry to agriculture of lands not the direct object of the programs. The effects would be higher program costs and lower net increments in C sequestered relative to those suggested in static or single sector studies.

We apply a linked model of the U.S. forest and agriculture sectors, with endogenous land use and forest management investment decisions, to examine the consequences of intersectoral market forces on forest C storage, C fluxes, and costs. We investigate: 1) whether the effects of forest C sequestration programs differ significantly from those suggested in previous studies using static or single-sector approaches; and 2) the costs and the mixture of land base adjustments obtained when meeting a specific C sequestration target so as to minimize net social welfare costs in the intersectoral model. We briefly review previous studies that have estimated costs of terrestrial C sequestration. We then describe base case projections from our intersectoral model, results from simulation of an afforestation C program (Parks and Hardie 1995), and projected impacts of meeting specific C sequestration "output" targets in a least social cost fashion.

2. Methods of Past Studies

Previous studies of C sequestration through afforestation of marginal agricultural land can in part be differentiated by their treatment of management investment decisions and land prices in both the forest and agricultural sectors. A group of single sector studies, such as Haynes et al. (1994), focus on the impacts of various exogenous levels of land transfers on the forest sector and on forest C storage, based on econometric models centered on historical land use relationships (Alig 1986; USDA Forest Service 1990). Modeling of land transfers in these studies do not involve intertemporal feedbacks that recognize developments in agriculture or implications for forest land prices and the intensity of forest management on private ownerships. Moulton and Richards (1990) and Parks and Hardie (1995) explicitly consider the opportunity cost of the current use of land in deriving supply schedules for C sequestered in trees planted on marginal agricultural land. In Parks and Hardie (1995), for example, supply curves for transferable land are positively sloped (unit costs rise as more land is shifted) but are fixed over time with no feedback from changes in forest and agricultural markets. Moulton and Richards (1990) also provide supply curves for sequestering C by intensifying timber management on extant

nous for private owners. FASOM simulates the growth of existing and regenerated stands by means of timber yield tables that give the net wood volume per hectare in unharvested stands by age class for each stratum. Public timber harvests are taken as exogenous.

The agriculture sector component in FASOM is adapted from the equilibrium price-endogenous ASM, aggregated to regions matching those used in forest assessments (Chang et al. 1992; McCarl et al. 1993). To convert ASM to a (disequilibrium) decade time step, the basic relations in ASM were treated as if they represented an annual period and repeated ten times each decade. Demand and supply components were updated between decades by means of projected growth rates in yield, domestic demand, exports, and imports. 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 costs of such inputs are included in budgets for regional production variables. More than 200 production possibilities (budgets) represent agricultural production in each decade, including field crop, livestock, and tree production. Farm policy programs are included only for the first decade in the model (Adams et al. 1996b; Alig et al. 1996).

FASOM links the land inventories in the agricultural and forest sectors (Alig et al. 1996). Suitable nonindustrial private land can move, after timber harvest in the case of timberland conversion, between agricultural and forest uses based on considerations of inter-temporal profitability and subject to the availability of resources and the provisions of particular policies.³ Estimates of the area of convertible forestland are derived from USDA studies and inventories of forestland with medium or high potential for conversion to crop or pasture use (USDA SCS 1989; 1994). Area estimates for convertible agricultural land are drawn largely from Moulton and Richards' (1990) study of land suitable for tree planting. Land balances within sectors and exchanges between sectors are controlled by constraints.

3.2. CARBON ACCOUNTING

FASOM accounts for forest C and stock changes for lands moving between sectors. The total C stored in the forest ecosystem of an unharvested stand is composed of five C pools: 1) tree; 2) woody debris; 3) soil; 4) forest floor; and 5) understory. FASOM accounts for C losses in nonmerchantable C pools from stands that are harvested, displaced fossil fuel from the burning of wood for fuel, and C decay in products derived from harvested timber. FASOM also accounts for differences in soil and understory C as land shifts between forest and agricultural uses. Soil and vegetation C on agricultural land is assumed to be a constant that varies according to land type (cropland and pastureland) and region. When a hectare of land is afforested, the C account is credited by an amount equal to the difference between the agricultural level and the higher, steady-state level of soil plus understory C for

timberland, but do not consider interactions between the afforestation and timber management supply schedules. Adams et al. (1993) link a highly simplified model of forest sector markets (assuming exogenous management investment decisions) with a detailed model of agriculture that includes agricultural land – the Agricultural Sector Model (ASM) (Chang et al. 1992; McCarl et al. 1993). In a long-run equilibrium analysis, they establish the costs of land transfers for afforestation with (partial) adjustment in the agricultural sector, but with no feedback from, or management adjustment in, the forest sector.

3. 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 Forest and Agricultural Sector Optimization Model (FASOM) is constructed as a multi-period, price-endogenous, spatial equilibrium market model (Takayama and Judge 1971). 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. 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 surpluses. The model operates on a decadal time step, with projections made for 9 decades to accommodate treatment of terminal inventories. Policy analysis is limited to results for the 50-year period from 1990 to 2040. Exogenous model elements in the forest sector component, drawn from the Timber Assessment Market Model (Adams and Haynes 1996), are held constant after the fifth decade. Terminal inventories (at the end of the finite projection period) are valued in both sectors, assuming perpetual, steady state management following the last year of the time horizon (Adams et al. 1996a). Solutions are obtained using a separable programming approach.

3.1. FOREST AND AGRICULTURE SECTORS

FASOM treats only the log market portion of the forest sector. Log demand is derived from the markets for processed products such as lumber, plywood, and paper. Logs are differentiated by six product classes: hardwood and softwood sawlogs, pulpwood, and fuelwood (Adams et al. 1996a).¹ FASOM describes private timberland in terms of strata that are differentiated by: nine geographic regions, two classes of private ownership (industrial and nonindustrial), four forest types (describing species composition – 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)², suitability for transfer to or from agricultural use (four classes for crop or pasture plus a “forest only” class that can not shift use), and ten 10-year age classes. Harvest age, management intensity, and forest type decisions are endoge-

forests. As the forest stand matures, this soil C difference lessens as the soil and understory C move toward a steady state condition. When forested hectares revert back to the agricultural sector, the net loss of C associated with the soil, understory, and timber inventory is accounted for in reverse fashion.

4. Intersectoral Projections

With the linked model, we project a base case (BASE), a simulated fixed afforestation program assuming a 4.9 million hectare transfer from agriculture to forest plantations in the 1990s, and three C flux target scenarios. We examine the fixed afforestation scenario as an example of programs that have been proposed involving large one-time afforestation actions. In the C target scenarios, we look more broadly at the land base and management adjustments that would be necessary to achieve specific C flux trajectories over time.

4.1. BASE CASE

We first consider the BASE and then compare those projections to model results under the fixed afforestation and C target scenarios. The BASE projection entails an array of land use reallocations and land management shifts. Assumptions on exogenous inputs to the BASE case for the forest sector derive from the USDA Forest Service's 1993 RPA Update (Haynes et al. 1995) while agriculture sector assumptions were taken from Chang et al. (1992) and McCarl et al. (1993).⁴

4.1.1. *Economic Welfare*

Projected welfare measures for the BASE and changes associated with the alternative simulations are shown in Table I. Differences in the size of BASE welfare measures between sectors, while striking, are unimportant to our analysis. We are concerned only with changes in the welfare measures at the margin, which are not necessarily proportional in size to the components of the overall welfare estimates.

4.1.2. *Land Transfers*

Projections of intersectoral land transfers for all scenarios are provided in Table II. In the BASE, approximately 21.4 million hectares are transferred between sectors from 1990 to 2039. Forestry realizes a net gain from agriculture of 5.0 million hectares (Figure 1); 2.3 million hectares from crop uses and 2.7 million hectares from pasture uses. BASE land transfers fall within the range of historical experience, representing less than 10% of the existing agricultural land base. Indicative of regional differences in land capabilities, transfers are concentrated in the East. Less than 0.3 million hectares change use in regions west of the Great Plains. Transfers of agriculture land to forestry use are concentrated in the first two projection decades. This is due in part to the relatively tight supply and demand situation for

Table I. Distribution of welfare in the BASE and changes in the Net Present Value^a of selected welfare components for afforestation and carbon target scenarios (\$1990 billion).

Surplus measure	Base case	Fixed afforestation	Carbon target 1	Carbon target 2	Carbon target 3
	Change from the base case				
Forest sector					
Domestic consumers	2,388.9	0.3	-7.5	5.4	-11.4
Domestic producers	228.8	-0.2	6.6	-4.6	8.9
Total ^b	2,753.5	0.2	-1.3	1.2	-3.0
Agriculture					
Domestic consumers	34,633.7	-1.4	-76.4	-31.4	-66.0
Domestic producers	956.7	-3.3	39.6	12.3	40.1
Govt. ag. prog. costs	44.0	0.3	-2.1	-1.3	-0.1
Total ^b	38,965.9	-4.1	-49.5	-21.9	-40.4
Total	41,719.4	-3.9	-50.8	-20.7	-43.4

^a Calculated using a discount rate of 4% over 90 years.

^b Includes surpluses from foreign trade not shown in detail.

Table II. FASOM projections for net transfer of land to nonindustrial private forest from agricultural uses for the BASE and four scenarios, 1990-2039 ('000 hectares)^a

Decade(s)	BASE	Fixed afforestation	Carbon target 1	Carbon target 2	Carbon target 3
1990	2431	3902	8855	6382	2464
2000	4061	3315	-1851	3109	3576
1990-2039	4983	3311	12649	8410	13664

^a Positive number indicates net afforestation.

forest products that is influenced by the existing age class structure of forests that contain limited merchantable volumes.

4.1.3. Forest Management Investment

In addition to land transfers, the BASE involves significant changes in the intensity of private timber management. One indicator of the intensity of management is area in plantations, including conversion of hardwood types to softwoods. Relative to the 1990 level, the BASE adds 15.5 million hectares of private forest plantations in the first decade (Figure 2), leading to reduced area of naturally regenerated stands, i.e., fewer low intensity and passively managed hectares. This exceeds the 9.7 million private hectares planted to forests over the past decade in the

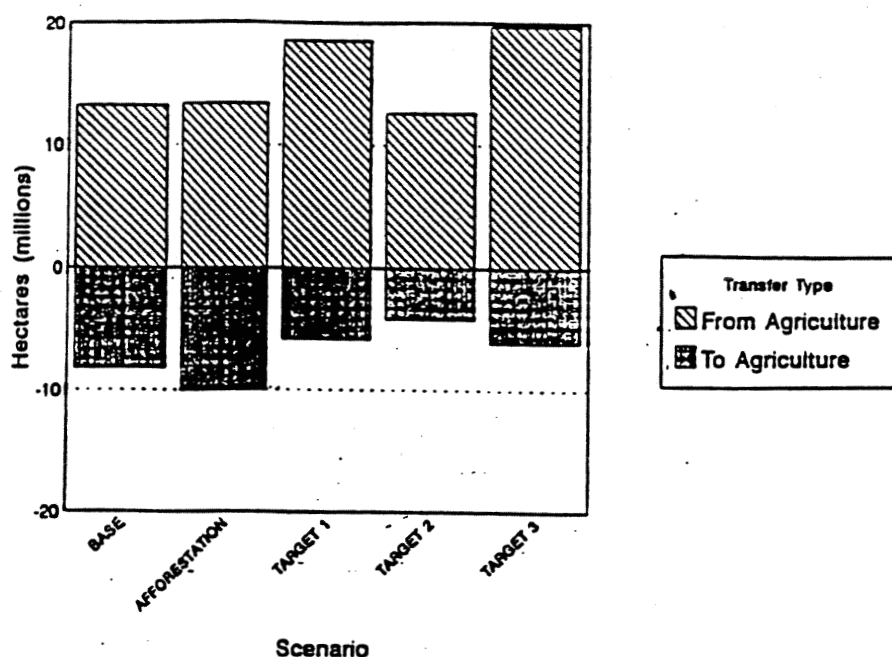


Figure 1. Projected cumulative intersectoral land transfers for the base case, an afforestation scenario and three carbon target scenarios, 1990–2039.

U.S., with the largest differences on nonindustrial private lands. In the second decade, private owners add an additional 15.8 million hectares of plantations. For the remainder of the projection private plantation area rises less rapidly, increasing about 14% between 2010 and 2039. A higher proportion of investments on industry ownerships is in relatively intensive plantation management (e.g., precommercial thinning, fertilization, and commercial thinning) compared to nonindustrial lands.

Most of the projected intensification of timber management is in the South and the Pacific Northwest. The area in commercially-preferred softwood types rises, with conversion of hardwood types to planted softwood stands. Conversion of hardwoods is driven by a relative softwood shortage (and rising softwood sawtimber prices). This, in turn, causes declining harvest volume levels and rising prices for hardwoods starting around 2020. Despite type changes, only about one-third of the future private forest landscape would consist of plantations, and most timberland area in nonindustrial private ownership would still be concentrated in the two lowest management intensity classes that involve naturally regenerated stands.

4.1.4. Carbon Projections

Table III shows the projected time path of the C inventory on private timberland. The initial estimate for the C inventory (1990) is 23.71 gigatonnes (billions of

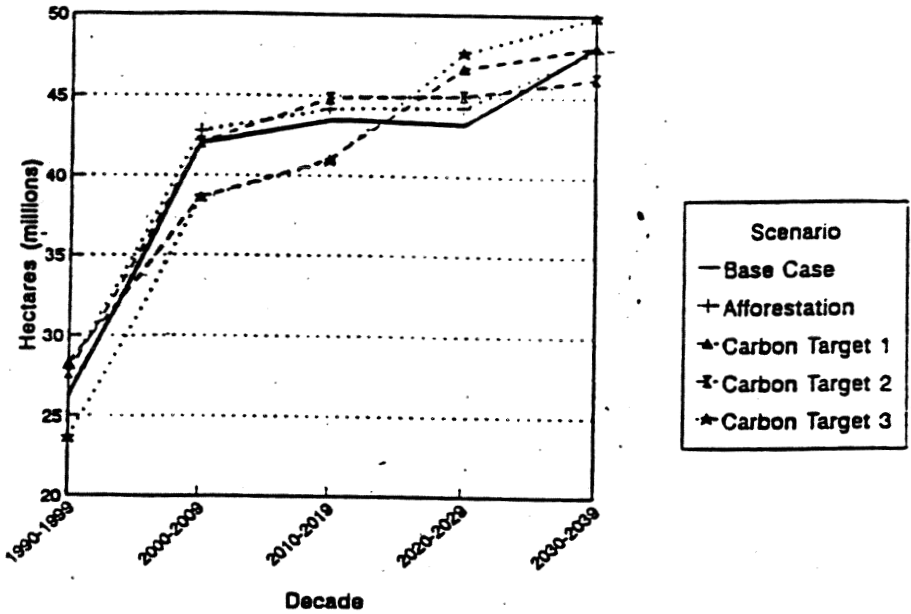


Figure 2. Projected private softwood plantation area for base case, afforestation scenario and three target scenarios, 1990–2039.

metric tonnes), similar to Birdsey's (1992) and Turner et al.'s (1993) estimates. C storage in the BASE rises at an increasing rate between 1990 and 2009 and at a decreasing rate thereafter. In the 1990s, the C stock grows by 4%, equal to a "flux" (or average change in C stock over the decade) of 0.98 gigatonnes per decade. The BASE flux then attains its maximum level of 1.611 gigatonnes per decade during 2000–2009. C fluxes remain positive over the projection, but drop to 0.7 gigatonnes by the 2030s decade.

4.2. ALTERNATIVE SCENARIOS: AFFORESTATION AREA INPUT AND CARBON TARGETS

4.2.1. Afforestation Program

Afforestation through tree planting has been proposed as one of the less expensive means of C sequestration in tree biomass (e.g., Moulton and Richards 1990). Here we simulate a "forced" land use shift from agriculture through afforestation of 4.9 million hectares of pastureland between 1990 and 1999. The model is constrained to transfer at least the specified amount of land. Once forested, however, we do not require that these hectares remain in forestry indefinitely, nor do we restrict any contemporaneous or ensuing shifts in forest or agricultural land that might occur in response to this initial transfer.

Table III. Projected carbon stocks for the BASE, afforestation scenario, and three carbon target scenarios (for each carbon target scenario, flux targets are shown in left-hand columns and carbon stock projections in right-hand columns), 1990–2039 (gigatonnes, 10^9 mt)

Start of decade	BASE case		Fixed afforestation		Fixed increment (Carbon target 1)		Fixed increment relative to BASE (Carbon target 2)		Growing increment relative to BASE (Carbon target 3)	
	Flux	Stock	Flux	Stock	Flux	Stock	Flux	Stock	Flux	Stock
1990	–	23.71	–	23.71	–	23.71	–	23.71	–	23.71
2000	0.98	24.69	1.04	24.75	1.61	25.32	1.38	25.09	0.98	24.69
2010	1.61	26.30	1.66	26.41	1.61	26.93	2.01	27.10	1.61	26.30
2020	1.47	27.77	1.49	27.90	1.61	28.54	1.86	28.97	1.47	27.77
2030	1.10	28.87	1.06	28.96	1.61	30.16	1.50	30.47	1.58	29.35
2040	0.68	29.55	0.53	29.49	1.61	31.77	1.08	31.55	1.78	31.13

* Decadal flux is computed as the difference in carbon stock levels at the start of successive decades.

Reacting to the pasture land transfer to forest plantations, the agricultural sector increases conversion of other forest land to agricultural use (Table II), demonstrating that intersectoral responses can lead to outcomes that diverge from those intended in policy formulation. Compensating adjustments result in more forest land being converted to agriculture than in the BASE. In the South, the primary region for the afforestation, the conversion of forest to pasture use almost doubles compared to the BASE, and some of the afforested land returns to agriculture when it is first eligible to transfer after timber harvest (once it reaches minimum harvest age). Thus, the net effect on land area in forest versus agriculture is significantly smaller than suggested in previous studies using static afforestation cost schedules (Moulton and Richards 1990; Parks and Hardie 1995). As a result, projected differences in timber harvest levels and timber inventory volume are relatively small between the BASE and the afforestation scenario.

4.2.2. *Carbon Sequestration Targets*

Table III shows the projected C inventory and flux rates for the BASE. In this and other studies (Birdsey 1992; Turner et al. 1993) the rate of increase in forest C storage peaks early in the projection period. But policy makers are also interested in the costs and implications of achieving constant or increasing rates of forest C sequestration in the face of greenhouse gas emissions that may grow due to rising population and energy use. To illustrate such policies we developed three scenarios in which C goals are expressed as a series of decadal C flux targets (Table III).⁵ Scenario 1 has a constant flux target, the target in Scenario 2 is a flux pattern which is a fixed amount above the BASE levels in each decade, while Scenario 3 has a rising long-term C flux pattern. Fluxes in all target scenarios must be at least as large as those in the BASE in each decade and were further constrained to meet the following targets by scenario: 1) C flux in all decades no smaller than the maximum BASE decadal level of 1.61 gigatonnes per decade; 2) C flux 0.4 gigatonnes larger than the corresponding BASE rate in each decade; and 3) C flux that starts at the first-decade BASE level and then grows each decade by an increasing amount of 0.2 gigatonnes per decade (i.e., growth accelerating by 0.2 gigatonnes each subsequent decade). All flux targets are held constant after 2040. No restrictions were placed on how these targets could be met. In light of the model objective function, the resulting solutions can be considered least social cost allocations of land and investments to meet the targets, where least social cost is defined as the minimum loss in the NPV of the welfare of producers and consumers in the agriculture and forest sectors.

4.2.2.1. *Projected Carbon Stocks and Fluxes.* Figure 3 shows projections of changes in C fluxes relative to the BASE. Scenario 1 required a constant C flux of 1.61 gigatonnes each decade, which in the first decade is 0.63 gigatonnes higher than the BASE flux. This represents a substantial increase in the size of the C

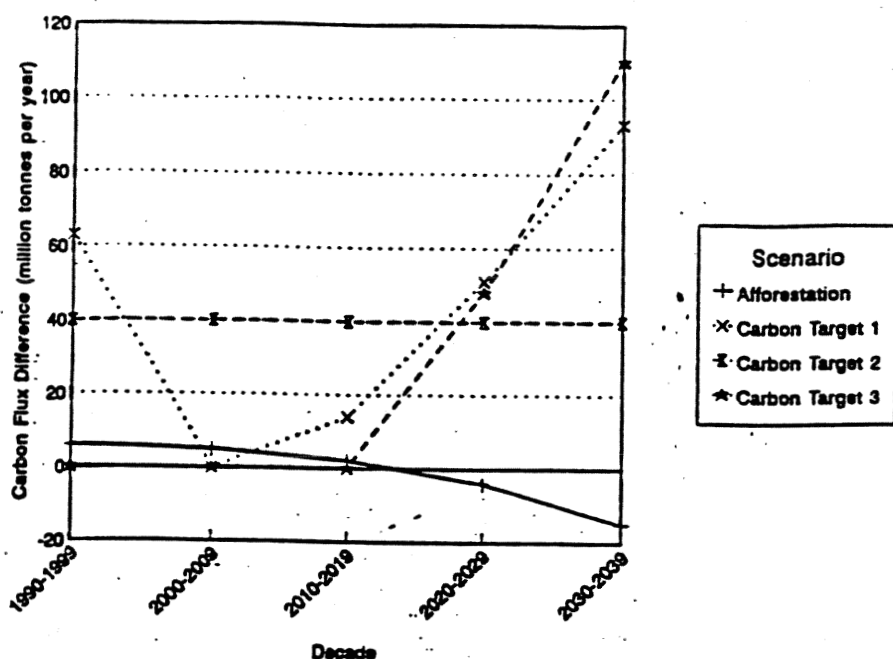


Figure 3. Projected differences (scenario-base) in annual carbon flux between the base case, an afforestation scenario and three carbon flux target scenarios, 1990–2039.

stock over a short period. To reach this objective, first-decade net afforestation is 6.4 million hectares higher than in the BASE, more than a three-fold increase. Net afforestation remains higher in later decades as the target flux stays constant while the BASE flux declines. By the 2020–2029 decade, for example, Scenario 1 requires 6.3 million hectares more afforestation than the BASE case. Viewed from the agricultural side, the cumulative amount of forest land converted to agricultural use in this scenario, and the other two C target scenarios as well, is less than in the BASE.

Scenario 2 required a flux pattern that was 0.4 gigatonnes larger than the BASE in all decades. In our simulation this entails roughly twice as much net afforestation as the BASE in the first decade. Following the BASE pattern, however, fluxes decline in decades after the second. Thus, to sustain the flux differential relative to the BASE in subsequent decades, Scenario 2 need only maintain the afforestation base through reduced conversion of forest land to agriculture use. As in Scenario 1, the relatively large amount of afforestation required upfront for the “ramping up” of C stocks in the initial period provides some added flexibility in subsequent decades. Beyond afforestation, the average harvest age of stands in some regions is also reduced in the first decade of the projection, creating more area in younger reforested age classes with higher growth and C flux.

Scenario 3 required gradually rising flux rates (though never less than the BASE). It entails a fairly steep rise in C flux relative to the BASE after 2019 (Figure 3) with rates by 2040 more than twice the BASE. To reach these higher long-term targets, Scenario 3 has the largest rates of afforestation in the later decades of the three targets and as well the largest cumulative amount of net afforestation (see Figure 1 and Table II).

4.2.2.4. Welfare Effects of Carbon Sequestration. Total net social welfare costs of the three C target scenarios – representing opportunity costs to society – range from \$20.7 billion for target 2 to \$50.8 billion for target 1. These costs reflect the size and temporal patterns of the targets and illustrate some potentially important trade-offs. While target 2 involves modest increments in C flux in the first two decades, fluxes may decline (following the BASE) thereafter. Its costs are lowest in large part because objectives in these latter periods can be achieved by husbanding initial afforestation increments with no further major additions to the forested land base. Under this scenario forest stocks are tailored to meet declining targets through expanded harvest (accompanied by declining prices) in later decades.

Target 1, in contrast, requires larger flux increments both before and after the 2000 decade peak in BASE flux. The higher (present value) of welfare losses relative to other scenarios results primarily from the sizable shift in agricultural lands needed to meet flux limits in the first decade. Additional shifts are required in later periods but amounts are smaller relative to Scenario 3 and have reduced impact due to discounting. This latter process also explains the lower costs of Scenario 3. While more acres are afforested in this scenario than in Scenario 1, it is possible to effect the use shifts in a gradual fashion over time, pushing costs into the distant and more heavily discounted future.

The impacts of the C target scenarios on welfare in the agricultural sector are consistent with expectations. Consumers' surplus falls in all of the scenarios. Losses are largest in Scenario 1 at \$76.4 billion (Table I), which involved the largest amount of first-decade net afforestation (Table II). Reducing the amount of agricultural land lowers agricultural production and drives up land rents and agricultural commodity prices. Higher agricultural commodity prices translate into losses in consumers' surplus. Producer surpluses increase because of the inelastic nature of agricultural commodity demand curves. The largest increment is \$40.1 billion in Scenario 3.

Government costs for agricultural farm and conservation programs are reduced for all three C target scenarios, which require more net afforestation than the BASE in the 1990s decade while farm programs are still in effect. More net afforestation acts to reduce agricultural land availability, increase agricultural commodity prices, raise the prices consumers pay, and narrow the gap between target prices and market prices (Callaway and McCarl 1995). This reduces the net present value of the deficiency payments to farmers, leading to reduced government payments in the range of \$0.1 to 2.1 billion across the three C target scenarios. The largest reduction

is for Scenario 1 that had the largest net afforestation in the 1990s, the decade in the model when farm programs are in effect. Unknown amounts of government expenditures to induce the necessary timber management intensification and afforestation, however, are not considered in this accounting. For example, just for the fixed afforestation case, total expenditures to induce transfer of the 4.9 million hectares are estimated to be at least \$2 billion based on analysis of costs estimates by Parks and Hardie (1995) and comparisons with FASOM intersectoral projections. Scenarios 1 and 2 would both require a substantial additional amount to induce more net afforestation in the 1990s decade, given that opportunity costs of alternative land uses and program costs are likely to increase at higher levels of afforestation.

In the forest sector, the projected effects on welfare of consumers and producers are reversed between Scenario 2 and Scenarios 1 and 3. While Scenario 2 had the smallest area of land use shift from agriculture to forests, it followed declining flux targets after the 2000 decade, allowing higher timber harvests than in the BASE. As a result, consumers could gain \$5.4 billion under this scenario. Consumer gain is larger than producer loss, resulting in a net gain to the forestry sector of \$1.2 billion. While Scenario 3 had far more land shifted from agriculture, more of the forest inventory had to be reserved to meet the higher terminal C flux target. Given the need to increase C storage, product harvest falls and prices rise relative to the BASE and consumer welfare declines. Projected welfare impacts under Scenario 1 are similar to those for Scenario 3 with respect to general types of effects on producers and consumers, but the timing is switched with most impacts in the first two decades.

5. Discussion and Conclusions

Policy makers are currently debating the role of forest C sinks in achieving reductions in atmospheric carbon dioxide. Candidate programs to promote terrestrial C sequestration can produce complex interactions between the forest and agricultural sectors as a result of land use changes and alter inter-owner and inter-regional patterns of investment in forest management. Past studies have examined the impacts of potential policies with models that: (i) ignore spillovers in the other sector, or (ii) simply "add up" impacts across the two sectors, ignoring feedbacks or interactions through the markets for land, or (iii) treat forest management investment as exogenous. The present study applies a linked model of the U.S. forest and agriculture sectors that treats both land use and forest management investment decisions as endogenous.

In the C target Scenarios 1 and 3, with a constant or growing flux increment relative to the BASE, afforestation of agriculture land is an important source of the C inventory increases. These land use shifts were not, however, "once and for all" shifts. In some cases, large areas shifted from agriculture to forestry early in the projection and were subsequently allocated back to agriculture in later years.

This suggests that minimum social cost strategies need not involve smooth or gradual trajectories of change in C fluxes or in patterns of implementing actions. Such strategies have more complex intersectional welfare implications than schemes commonly considered. In contrast, Scenario 2, with a flux target tied directly to the BASE, relied more on a combination of retaining land in forest (i.e., smallest amount of deforestation) and higher amounts of intensively managed forest land in several of the decades.

The structure of forest management investment is also modified (relative to the BASE) to grow or retain more wood to meet the C flux targets. Land shifting from agriculture must first be planted and is placed either into medium or high intensity management classes. In subsequent periods when these lands are harvested, they are regenerated into a mixture of the medium and passive management classes. Areas harvested from the passive class in some cases then shift back into agriculture. Softwood areas in the original forest inventory are managed in a modestly more intense fashion, with less area shifted to the passive management class. There is little change in the general pattern of management intensity allocations within hardwoods, but substantially fewer hectares are converted from hardwood to softwood types compared to the BASE. Over the projection period of 1990 to 2039, average softwood and hardwood rotation ages are significantly longer.

Among the carbon target scenarios, the present value of surpluses in the forest sector increases only under target 2, which involves declining flux targets and rising harvests in the long-term. The (declining) flux pattern of this scenario is similar to the types of afforestation policies examined in most previous studies of forest carbon sequestration, as exemplified in our analysis by the fixed afforestation case. Past studies have generally concluded that such policies would increase net welfare in the forest sector, a result in accord with our findings for target 2 and the fixed afforestation case. The remaining cases with stable or rising flux targets, however, have generally not been considered in previous studies and portray a rather different prospect. In these scenarios, forest sector welfare declines. Despite relatively large transfers of land into the forest sector, aggregate harvest output declines, prices rise, and losses in consumers' surplus outweigh producers' gains.

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Notes

1. Milling residues generated in sawlog processing can substitute for pulpwood.
2. The four management intensity classes are: "passive" – no management intervention 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 treatments in planted aggregates. Specific practices vary by region, site quality, forest type, and agricultural suitability.
3. Land is also exogenously shifted from both forest and agricultural uses of nonindustrial owner-ships to urban/developed uses along with some timberland reclassified to reserved uses (Adams et al. 1996b; Alig and Wear 1992).
4. Future climate conditions in the BASE are assumed to approximate those of recent decades. Using FASOM, Burton et al. (1995) projected relatively small national and regional economic impacts for timber growth changes of less than 10 percent, as might occur under some global climate change scenarios.
5. None of the parameters in the scenarios are tied specifically to a projected rate of increase in emissions since there is no consensus on that projected rate of increase.

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