ANALYSIS

Ecological and economic impacts of forest policies: interactions across forestry and agriculture

Ralph J. Alig [a,*], Darius M. Adams [b], Bruce A. McCarl [c]

[a] USDA Forest Service, Pacific Northwest Research Station, Corvallis, OR 97331, USA
[b] College of Forestry, Oregon State University, Corvallis, OR 97331, USA
[c] Department of Agricultural Economics, Texas A & M University, College Station, TX 77843, USA

Abstract

A linked model of the US forest and agriculture sectors was used to examine the economic and ecological impacts of two forest policies: a minimum harvest age limitation and a reduced public harvest policy. Simulated private responses to both policies indicate that landowners could undertake a range of adjustments to minimize their welfare impacts, but imposition of constraints on the management of existing timber stocks have particularly potent effects. Environmental changes associated with the responses include: (1) impacts on biodiversity trends and wildlife habitat conditions when economic incentives prompt afforestation of cropland in the North and less conversion of hardwood forest types to softwood plantations in the South; (2) age class distributions in all regions are 'shortened', compressing a larger inventory volume into fewer, younger age classes; (3) reductions in the area of the earliest forest successional stages, despite the concentration of inventory in the earlier ages, because of rising timber management intensity in some regions; and (4) sequestered carbon in all parts of the forest system may continue to rise even after total product volumes have begun to fall. Interregional economic impacts include higher prices for private forest land and timber products in the southern US, due to a reduced public harvest policy concentrated in the West. © 1998 Published by Elsevier Science B.V.

Keywords: Land reallocation; Forest sector; Agriculture; Interregional

1. Introduction

The US has a long history of forest policies designed to jointly pursue both economic and

* Corresponding author. Fax: + 1 541 7507329.

ecological objectives. There are numerous examples of policies affecting US forested ecosystems that act to provide improved water quality, timber, fish and wildlife habitat, recreational opportunities, erosion control and other environmental services. Unfortunately, the ecological and economic impacts of these measures are usually analyzed in isolation. Policies governing public forests often receive greatest attention in the popular press. These lands are certainly of great significance, but the largest part of US timberland, some 75% or ≈ 145 million ha, is in private ownership.[1] The responses of these private forest owners, including a majority classified as nonindustrial private forest (NIPF) owners, to forest and natural resource policies are also important considerations for policy makers. Efficacy of policy instruments may be adversely affected if owners react differently than originally envisioned, leading to outcomes markedly at odds with intended aims (Johnson et al., 1997). An integrated economic-ecologic approach can identify more than direct or first-round effects of policies targeted at improving environmental conditions. For example, ripple effects of policies may include: (i) changes in owner behavior and forest conditions in non-targeted regions (e.g. Adams et al., 1996b); (ii) externalities on forest and non-forest land uses; (iii) unintended and potentially long-term effects on investment in private timberland management (e.g. Johnson et al., 1997); and (iv) ecosystem changes at scales above the forest or landscape levels at which policies are often viewed.

Previous studies of forest policies have typically not considered bidirectional linkages in markets for agricultural and forest land or responses to policy intervention arising at and propagated through, the markets for products. Indeed, forest policies are frequently formulated using an input-oriented approach, focusing on restrictions or modifications of land or forest resources management with assumed outcomes. The present study

offers an illustration of the potential form and extent of unintended and ripple effects in the forest and agricultural sectors resulting from forest sector policies. We examine interregional and intertemporal effects on environmental conditions, using a linked model of the US forest and agriculture sectors in which market behavior and both land use and forest management investment decisions are endogenous. Because outcomes may also be heavily dependent on the policy mechanism, we consider two types of policies representing opposite extremes in terms of the focus of their initial action: (1) reduced harvests of timber from public lands which would influence private lands only indirectly through markets for products; and (2) direct regulatory constraints on the minimum age of harvest of private timber.

2. Simulations of forestry policies at a national level

In previous large-scale studies of forest policies, factor supplies are assumed to be either perfectly elastic or perfectly inelastic. For example, the Timber Supply Model (Sedjo and Lyon, 1990) has endogenous management investment decisions, but land supply in the US is assumed to be perfectly inelastic. Land is generally treated as fixed (e.g. Adams and Haynes, 1996) and conventional macroeconomic models typically have emphasized manufactured capital, labor and consumption (Daly, 1991), with little detail on a region's land and natural resources. A region's natural capital, or natural resource base, is typically not explicitly modeled. It may be possible to abandon land in some supply models, such as not regenerating it to forests by any means, but it is not possible to add land, except exogenously for timber production.

Several studies have focused on the fundamental decision problems of present-value-maximizing land owners in allocating land to alternative uses (see, Alig, 1985; Stavins and Jaffe, 1990). In either static or dynamic formulations, land owners compare rents across uses and allocate or sell their land to uses with the highest potential rents. Most studies have assumed that land prices in alterna-

---

[1] Timberland is forest land that is not reserved for other uses and is capable of producing 1.4 m³/ha per year of industrial wood. See Powell et al. (1994) for US timberland statistics.

tive uses were exogenous. Over time, however, land prices should depend on potential rents in all uses. For example, continued shifting of agricultural lands to forestry use should act to change land rents and prices in both sectors. Agricultural land rents should rise (because of shifts in markets and prices for agricultural products) while rents for forested land should fall (through changes in forest products markets in a reverse fashion) until land prices in the two uses differ by the costs of land use conversion.[2] Some studies have recognized this interactive nature of land markets (Adams et al., 1993; Chang et al., 1992; Parks and Hardie, 1995) and employ rising supply functions for land in competing uses. These approaches have generally been static, however, with limited recognition of the intertemporal nature of land use decisions and rent determination. Land prices have been variable only in the 'competing' sector, with a one-way land flow (e.g. from agriculture to forestry). As a consequence, the analyses give no assurance that land prices between sectors have reached an equilibrium relation.

Because both land allocation and timber management investment have not been endogenous in previous studies, the interaction between management of existing timber stocks and land use has also not been fully captured. Given the long-term nature of forestry production, limitations represented by characteristics of existing timber stocks may influence timber flows over the next several decades. Expansion or maintenance of current levels may require addressing current irregularities for timber age class distribution or species mixtures. At a minimum, this could require 20–30 years in the South, which has one of the shortest time periods to replace existing forests with new forests having a larger production potential.

3. Modeling private land-use decisions

Landowners making decisions about use of

their lands for forestry or agriculture face a variety of physical, ecological and economic considerations. They continually face a decision whether to keep land in its current state, to convert it to another use, or to intensify management, e.g. stocking control of dense forests. In the forest and agricultural sector optimization model (FASOM), we model the aggregate actions of landowners, who are assumed to be risk-neutral and to maximize the present discounted value of a stream of expected future returns to the land (Adams et al., 1996a,b). The FASOM model is an intertemporal, price-endogenous, spatial equilibrium market model of the forest and agricultural sectors in the US. FASOM depicts the allocation of land, over time, to competing activities within and between the forest and agricultural sectors.

Because many forest policy options span both the forest and agriculture sectors (e.g. Alig et al., 1997), a linked model with endogenous consideration of inter-sectoral land shifts was essential. Further, because of the potential feedback between policy actions and land management activities, the model had to include explicit treatment of private forest management investment decisions. Solutions are found by means of a linear programming algorithm.[3] The objective function maximizes the discounted economic welfare of producers and consumers in the US agriculture and forest sectors over a nine-decade time horizon.

The FASOM modeling system draws from several existing models: in the agricultural sector, the price-endogenous, Agricultural Sector Model (Chang et al., 1992); and in the forestry sector, the Timber Assessment Market Model (Adams and Haynes, 1996), an inventory model (Mills and Kincaid, 1992), fiber model (Ince, 1994) and area change models (e.g. Alig et al., 1990). The FASOM model links the two sectors, sharing a common land base, in a dynamic framework recognizing land use and management investment and farm management programs. Other studies of

---

[2] If a subsidy or payment is used to induce the shift from agriculture to forestry, the agricultural land price should differ from the sum of forest land rents plus the present value of the subsidy by the amount of conversion costs.

[3] FASOM is coded in general algebraic modeling system (GAMS) and solutions to its segmented or linearized form are obtained by means of the CPLEX linear program optimizer (see Brooke et al., 1992).

land use transfers between the agricultural and forest sectors employ, at best, a static, one-sector (partial equilibrium) framework in which land prices between the two sectors are not allowed to resolve (e.g. USDA Forest Service, 1990; USDA Soil Conservation Service, 1989). FASOM, on the other hand, allows transfers of private land between sectors in nine regions based on the land's marginal profitability in all alternative forest and agricultural uses over the time horizon of the model, subject to the availability of resources and the specific provisions of particular policies. Projections are made for nine decades to accommodate treatment of terminal inventories (Adams et al., 1996b) but policy analysis is limited to results for the 50-year period from 1990 to 2040.

FASOM simulates the growth of existing and regenerated forest stands by means of empirical timber yield tables that give the net wood volume per hectare in unharvested stands by age class for each stratum. Harvest of a hectare 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). Typically, yields on afforested agricultural land are higher than on land that has been in tree cover for one or more rotations and these productivity differences are reflected in the growth and yield tables applied to trees on that land. Once a stand is harvested, it can be regenerated as forested land or converted to agricultural use. Regeneration can be to another forest type, driven by expected net returns from type conversions, in contrast to most previous models that have used scenarios of future shifts in timber management that were pre-set.

Timber yields vary by management intensity class (Adams et al., 1996b). Four timber management classes were identified for both private owner groups: high, medium, low and passive. The specific mix of timber management practices in a management intensity class varies by region, species and site group, but can be generally viewed as a hierarchy reflecting level of timber management intensity:

Passive–no timber management intervention of

any kind between harvests of naturally-regenerated aggregates;

Low–custodial timber management of naturally-regenerated aggregates;

Medium–minimal timber management in planted aggregates;

High–relatively intensive timber management of planted aggregates.

Shifting among management intensity classes, species groups, or (exogenous) conversion to another land use can only occur at time of harvest in the FASOM model. Lands can be allocated to the passive management intensity class in any rotation after the first. This passive class is intended to represent developments under natural successional processes on lands effectively abandoned after harvest. There are no lands classified as passively managed in the initial inventory, because they could not be distinguished from the low class based on available data and expert judgment. As a consequence, some of the movement of lands from the low to the passive class in projections may represent a 'reclassification' of passively managed lands to their proper designation. At the same time, shifts of land that were in fact passively managed in the initial inventory to the low class in subsequent periods will not be observable in the simulations because they would remain grouped in the low class.

Land-use shifts are limited to the nonindustrial private forest ownership, in which the vast majority of all historical transfers have taken place. Conversion to agriculture happens only after timber harvest. Forest land on the nonindustrial private ownership that is suitable for conversion to agriculture is classed in a three-tiered structure with varying costs of conversion in each tier and a total overall area limit, as not all forest lands can be cropped or used as pasture and conversely not all agricultural land can be converted to forest use (Adams et al., 1996a).[4]

---

[4] The total amount of forest industry timberland is assumed to remain constant over the projection period (Alig et al., 1990). Within that total industry land base, other variables such as forest type areas and management investment levels are free to vary.

4. Base case and policy scenarios

To investigate the outcomes of forest policies representing opposite extremes in terms of the focus of their initial action, we simulate two alternative forest policy scenarios—one directed at public forestlands and the other at private forestlands—and a base case (BASE) developed as a baseline for comparison. The BASE assumptions for the forest sector derive from the USDA Forest Service's 1993 updated Assessment for the Resources Planning Act (Haynes et al., 1995). Agriculture sector assumptions are discussed by Chang et al. (1992).[5] The alternative scenarios were suggested by recent policy trends and developments in the forest and agriculture sectors.

4.1. Description of scenarios

4.1.1. Reduced public harvest

Harvests from most classes of public lands in the US are established by mechanisms that are independent of markets and prices for forest products. Thus, public timber harvest is treated as exogenous and an input to FASOM. Changes in public harvests have the partial effects of changing current-period product prices and, because private forest owners in the model have perfect foresight, changing the extent and timing of all current and future harvests and management investments. Levels of public timber harvests have dropped significantly in recent years for non-timber resource protection purposes. In this scenario we assume no timber harvests from National Forest lands (Adams et al., 1996b) and reduced levels from other public lands. All public lands contributed one-fifth of the US timber harvest in 1991 (Haynes et al., 1995) and that proportion has dropped further in recent years with additional set-asides of federal timberland for threatened and endangered species habitat.

4.1.2. Extended timber rotations on private lands

In recent years regulations governing private forest practices established at the state level have been revised to protect and expand areas critical for wildlife habitat and other non-timber uses (including water yields and quality, visual characteristics and recreation opportunities; see, Adams et al., 1992). Recent policy proposals have included requiring owners to lengthen timber rotations to maintain larger areas of older stands. Longer rotations are proposed to expand habitat available for wildlife species preferring later successional stages and to increase the areas of stands with multi-layered canopies. Policy makers examining alternative forest carbon sequestration strategies for global warming mitigation have also looked to longer forest rotations as one option to increase the forest carbon stock. To examine the broad-scale application of such policies, we increased the 'minimum harvest age' constraints applied in the model to private timberland. This was done for softwood types only, with increases of 10 years in the southern US and 20 years elsewhere in the US.

5. Projected outcomes

First, we describe the BASE projections, then examine changes in environmental conditions from the imposition of policies. We consider land use, forest species and timber management aspects and resultant effects on forest structure and forest carbon. Economic impacts are represented by: land prices, forestry and agricultural product prices and distribution of welfare impacts across economic agents.

5.1. BASE projections

The BASE projections indicate that the forest sector has the potential to sustain current timber harvest amounts at the national level, with stable to declining softwood log prices in the long term (Fig. 1). This would require substantial investment in intensifying timber management on part of the timberland base and the US could conceivably concentrate timber production on fewer
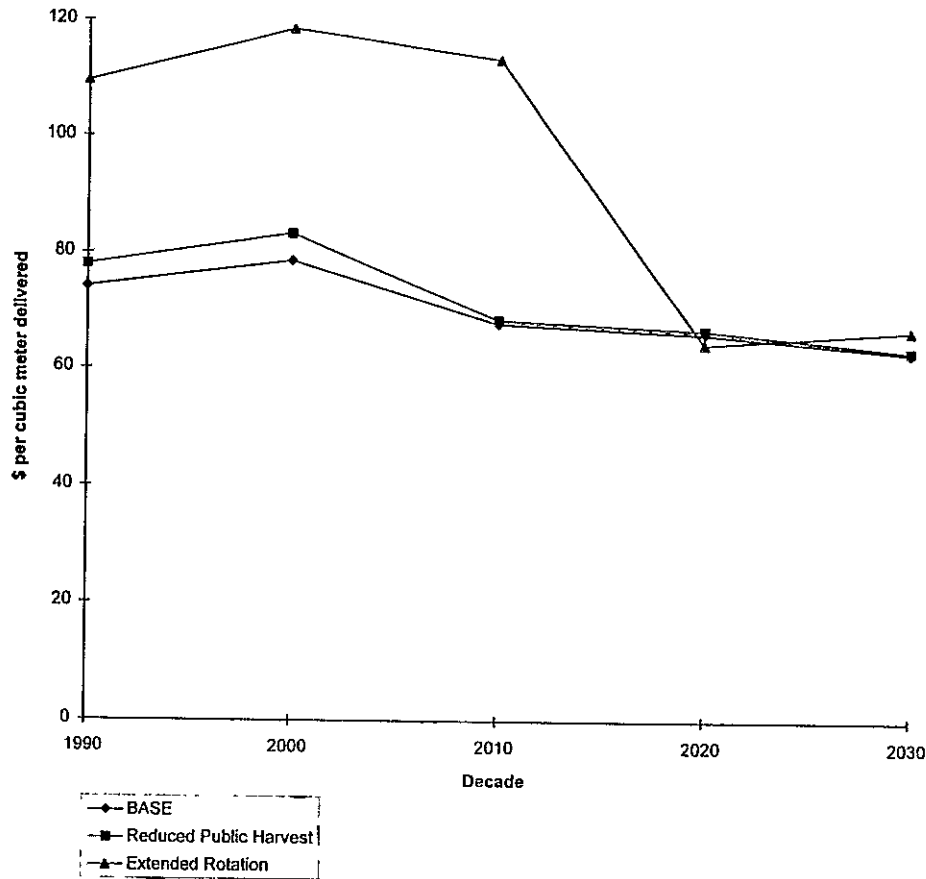
---

[5] Essentially all farm programs are eliminated in the BASE case in FASOM, reflecting the Freedom to Farm legislation of the 1995 Farm Bill.

Fig. 1. Projected softwood log prices ($/m³) by decade, for the BASE and extended rotation and reduced public harvest scenarios.

hectares. The BASE reveals numerous opportunities for shifting more area to the commercially-preferred softwood types, particularly through establishment of more softwood plantations. Softwood area is projected to rise from 33 to 51% of total private timberland between 1990 and 2040. This shift is most pronounced in the South and Pacific Northwest.

This management emphasis on softwood types, especially through expansion of softwood plantations with higher volumes per hectare, would result in softwood inventory levels increasing by more than 40% over the next 50 years (Fig. 2). Hardwood inventory volume would increase by only 1%. The projected concentration of commercial production would reduce harvest pressure on naturally regenerated forests, which could be

managed less intensively than at present. Naturally regenerated forests are projected to cover at least three-fourths of the private timberland base, with hardwoods continuing to occupy at least about one-half of the private timberland base.

Projected land reallocation would lead to a net shift of more than 4 million ha from agriculture to forests by 2039.[6] Reallocation of land between forestry and agriculture does not follow a smooth or gradual time path. Most afforestation occurs in

---

[6] Because some timberland is converted to urban and developed uses, based on exogenous estimates from Alig et al. (1990), the overall net gain in timberland amounts to less than half of the projected net gain from agriculture. Conversions of timberland to urban and commercial uses are set exogenously at 1.5 million ha per decade and occur continually over the projection period (Alig and Wear, 1992).
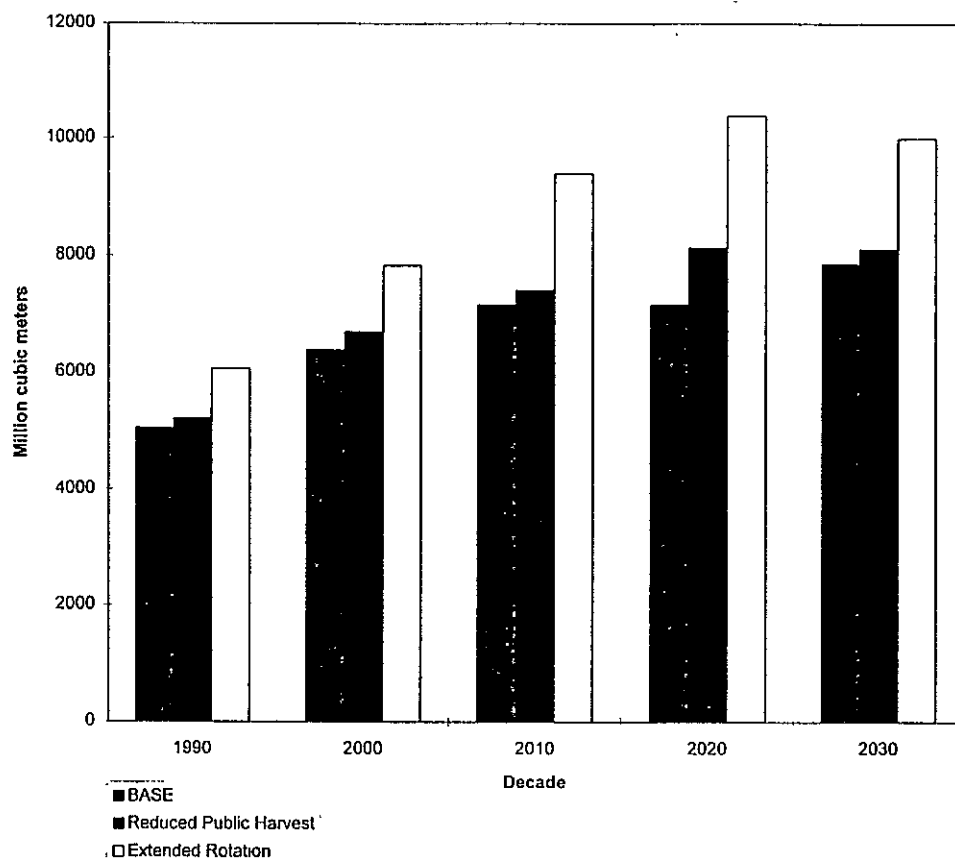
Fig. 2. Projected levels of private softwood timber inventory stocks (1 million m³) by decade, for the BASE and extended rotation and reduced public harvest scenarios.

the first two decades and in later decades there are net transfers to agriculture. Land use shifts are not necessarily 'once and for all', as some land afforested in the 1990s is transferred back to agriculture later in the projection period as the increase in derived demand from agriculture outpaces that from forestry uses.

Other land base changes include a relatively large amount of hardwood types converted to softwoods, especially in the South. Major shifts in timber management and disposition of the timberland base in the South imply changes for wildlife habitat and other environmental conditions. Conversion of several million hectares of southern hardwood types to softwood plantations may have important implications for biodiversity trends in the South and for habitat conditions for

a wide range of wildlife species (e.g. Flather et al., 1992).

Private timber harvest over the next several decades will be strongly influenced by current timber inventory characteristics, particularly relatively small areas and timber volumes in older merchantable age classes in virtually all regions. Long-term harvest is expanded through private forest management investment, especially on NIPF lands.

5.2. Environmental changes

5.2.1. Land use changes

Fig. 3 shows projected land exchanges between forestry and agriculture. The extended rotation scenario results in substantially more land use
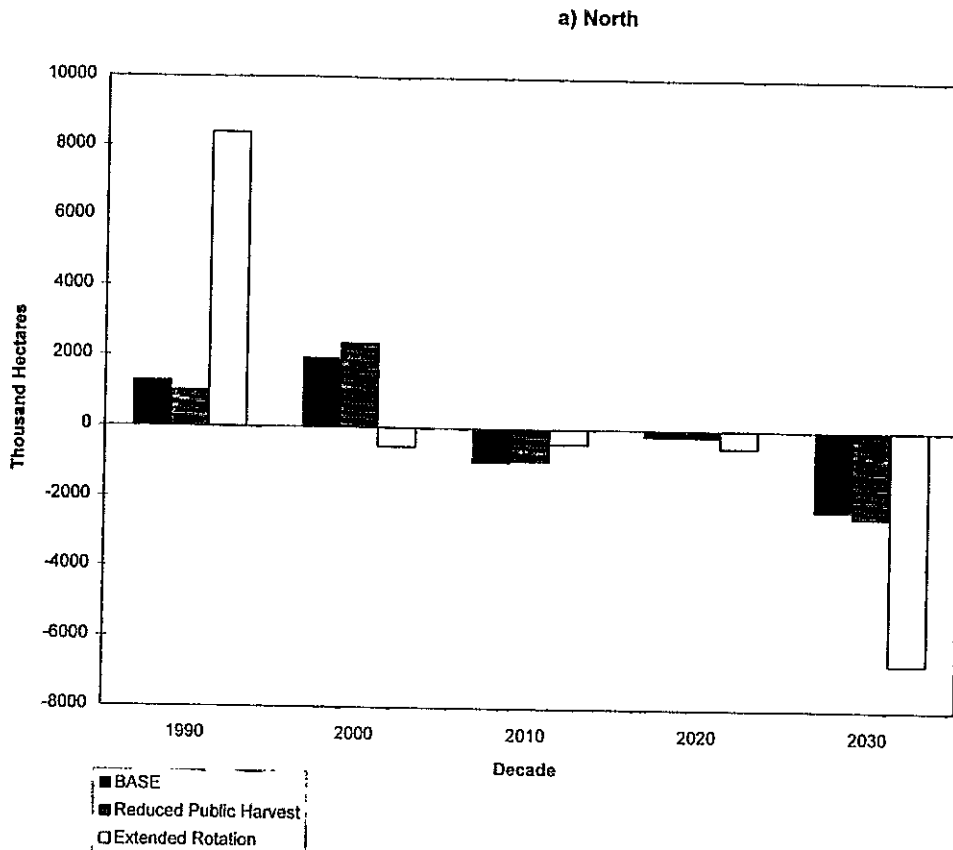
a) North

Fig. 3. Projected levels of land transfers between forestry and agriculture (1000 ha) by decade, for the BASE and extended rotation and reduced public harvest scenarios for: (a) the North and (b) the South. A positive number indicates a net transfer to forest use. Note that conversions of forest land to urban and commercial uses are not shown in this figure.

change in the first decade than the BASE or reduced public harvest scenario. The extended rotation policy leads to higher timber product prices that boost land rents in forestry. The amount of land use changes under the extended rotation policy is more than double that of the other scenarios. The intertemporal patterns of the land use projections show that the extended rotation policy leads to the largest near-term[7] amount of NIPF timberland (Table 1), but results in the lowest long-term amount as softwood log prices fall sharply after 2010 (Fig. 1).

The extended rotation policy causes a marked

change in the structure of land reallocation across the eastern regions. One large geographical reallocation is an additional 8.7 million ha of afforestation in the North (concentrated in the Lake States) compared to the BASE (Fig. 3a). More than 1 million fewer hectares are afforested in the South compared to the BASE (Fig. 3b). The North has longer timber rotations than the South in the BASE and the imposition of the extended rotation policy acts to exacerbate the relative shortage of available softwood timber supplies. The derived-demand response of the forestry sector to the policy is centered in the Lake States, where about 7 million ha are afforested to softwoods in the 1990s, compared to none in the BASE. In contrast, the area of afforestation in the

---

[7] Near-term here refers to the next two decades, while the long-term is beyond two decades.
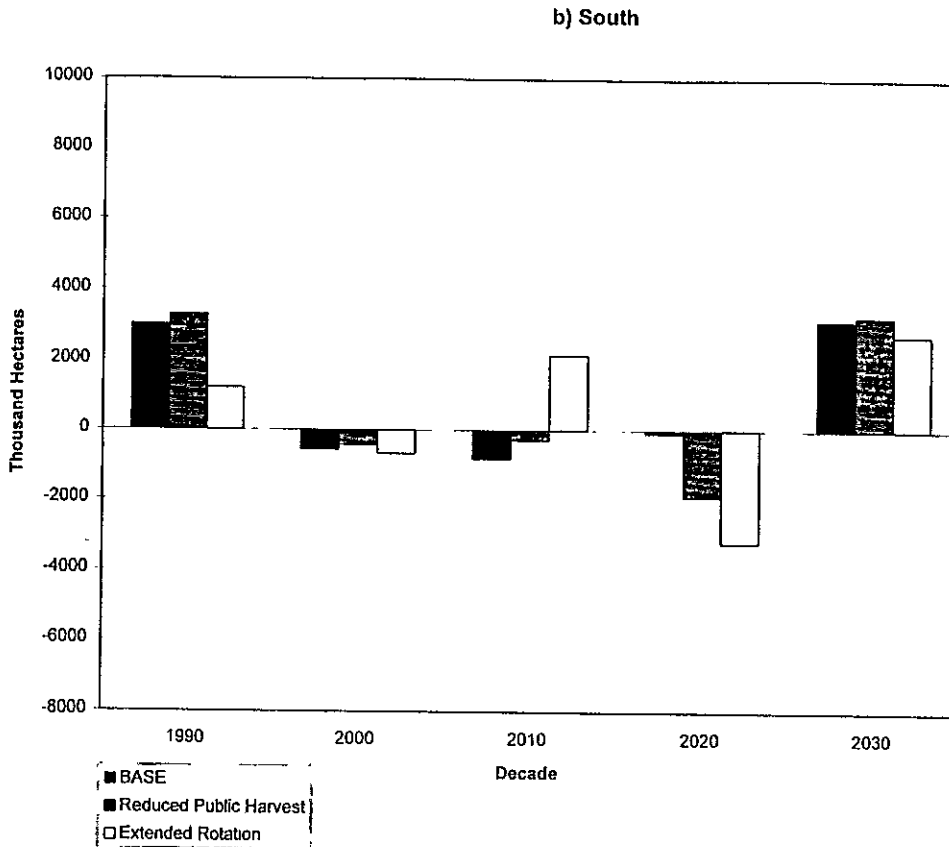
b) South

Fig. 3. (Continued)

South in that decade is lower, both for conversion of cropland and pastureland. Nationwide, this nets out to an increase in NIPF timberland of more than 5 million ha in the 1990s compared to the BASE (Table 1).

5.2.2. Changes in forest type areas

The land use changes described above are tied to some major changes in forest type areas. The total area of hardwood forest types would increase under the extended rotation policy relative to the BASE (Table 2), in both the near term and long term. The area of naturally-regenerated softwoods would change relatively little from the BASE, while the area of planted softwoods would increase in the near term (11%) but decrease in the longer term (23%). The change in afforestation rates in the Lake States resulting from the ex-

tended rotation policy would significantly increase the amount of planted softwoods in that region compared to the BASE, in a region which currently has relatively few plantations compared to the South. The South would have less plantation area under the extended rotation policy, as less area is eligible for harvest and available to be

Table 1
FASOM projections for total timberland area on nonindustrial private forests for the base case and for two policy scenarios, 1990–2040 (1 million ha)

Year	Base	Extended rotation	Reduced public harvest
1990	110.4	110.4	110.4
1999	114.1	119.5	114.1
2009	114.9	117.7	115.5
2039	112.1	110.1	111.3

Table 2
FASOM projections of softwood and hardwood private timberland areas for the base case and two policy scenarios, 1990–2040 (1 million ha)

Year	Base	Extended rotation	Reduced public harvest
Softwoods			
1990	46.4	46.4	46.4
1999	58.0	61.5	59.2
2009	64.2	64.8	67.7
2039	68.2	61.5	70.7
Hardwoods			
1990	92.6	92.6	92.6
1999	84.6	86.5	83.4
2009	79.3	81.5	76.3
2039	72.6	77.3	69.1

replanted in the first decade compared to the BASE. Overall, an increase in hardwood area would benefit those wildlife species dependent on hardwoods for habitat.

The largest gain in private softwood area by 2039 and the largest reduction in hardwood area are projected under the scenario of less public timber harvest. The policy causes an increase in softwood log prices, which prompts private owners to increase conversion of hardwood types to softwoods, especially in the South (Adams et al., 1996b).

Softwood areas are projected to increase in the short term under all scenarios, reflecting timber investment opportunities primarily in the South and less so in the Pacific Northwest Westside. Within the softwoods group, the primary species involved are southern pine in the South and Douglas fir in the Pacific Northwest Westside. A longer-term exception to the expanding area of softwoods is when the extended rotation policy leads to a reduction in softwood area after 2010. Similar to the land use situation, the extended rotation policy results in the largest near-term changes in forest type areas, but the relative build-up of softwood inventory under the policy then leads to longer-term moderation of softwood accretion relative to the other scenarios.

Forest industry acts to convert proportionately more hardwood areas to softwoods in the first part of the projection period, especially in the era

of relatively tight timber supplies before 2020. Subsequently, longer-term hardwood conversion is largely on NIPF lands, concentrated in the South.

5.2.3. Timber management intensity

Projected BASE changes in forest cover areas described above are tied to shifts in timber management intensity in the FASOM projections. Establishment of more softwood plantations, classified as receiving either medium or high timber management levels (Table 3), means that such areas will be managed more intensively and produce higher timber volumes per hectare. This allows other hectares to be regenerated naturally in the BASE and managed in a passive mode. The extended rotation policy leads to fewer hectares under passive management than in the BASE, both in the near term and longer term. Timber stocks in the extended rotation scenario are managed more intensively in the near term than in the BASE because of higher timber product prices and timberland values. In the longer term, a substantial area of older timber accumulates after the first three decades because of the harvesting restriction. When that timber can be harvested, a relatively high volume of timber per unit area is available and this lessens the further need for plantations and reduces the area harvested that is available for regeneration to the passive management class.

Similar to the land-use and forest type situations, the peak in the projected amount of planted area under the extended rotation policy comes sooner than in the other two scenarios. The early build-up of softwood inventory and sustainable longer-term levels of higher timber volumes at the extended rotation age lessen the longer-term need for plantations compared to the other scenarios. Although near-term levels of private harvest are lower than the BASE, longer-term levels are higher. Changes in private harvest levels under the scenario of reduced public harvest are not as large as under the extended rotation policy. The reduced public harvest policy increases product and private timberland prices and private land owners expand their inventory holdings in line with product demands.

i

Table 3
FASOM projections of private timberland area in plantations (medium and high timber management intensity classes) and naturally regenerated stands (low and passive classes) for the BASE and for two policy scenarios, 1990–2040 (1 million ha)

Year	Base	Extended rotation	Reduced public harvest
	Medium and high management intensity (planted stands)		
1990	10.8	10.8	10.8
1999	26.9	30.0	28.7
2009	41.8	40.0	45.4
2039	48.6	37.3	49.3
	Low management intensity		
1990	128.2	128.2	128.2
1999	95.5	102.6	95.9
2009	70.9	85.0	69.7
2039	56.3	78.1	56.0
	Passive management intensity[a]		
1999	20.3	15.4	18.1
2009	30.7	21.3	29.0
2039	35.8	23.3	34.6

[a] No lands in the initial inventory (1990) are classified as passive, since they could not be distinguished from the low management class based on the available data and expert opinion (Adams et al., 1996b).

Impacts of the extended rotation policy on timber management of the two private owner groups differ in some ways. Forest industry owners would plant less area to softwood plantations in the 1990s than in the BASE (−18%), while NIPF owners increase plantation areas compared to the BASE (25%). The NIPF owner class has the largest potential for expanding plantation area, including afforestation opportunities and is of considerable interest to policy makers as in other major timber producing regions (e.g. Lonnstedt, 1989). In the longer term, both private owner groups would reduce the area of softwood plantations relative to the BASE and would increase hardwood area. An increase in low-intensity reversion of softwood cut-over areas to hardwoods late in the projection period would contribute to the larger hardwood area compared to the BASE.

Industry lands are concentrated in the South and Pacific Northwest Westside and the most private plantations are established under the scenario of reduced public harvest. The public harvest policy is centered in the Pacific Northwest Westside region that contains a large portion of the National Forests affected by revised harvest plans to address non-timber concerns, while the

South has the largest area of forest industry lands. The policy reducing public harvest indirectly affects private forest management through altering market prices. In the short term, the policy would increase industry plantation area by ≈1% compared to the BASE and by 10% in the longer term. Higher log prices elicit more investment in conversion of hardwood types to softwoods.

5.2.4. Forest structure

The structure of forest stands in terms of species composition and seral stage is (among other attributes) important in determining their suitability and quality as wildlife habitat. Forest type changes were described earlier and now we look at projected stand conditions represented by a combination of stand age, forest type and management intensity attributes that reflect seral stage development. A critical concern in recent years has been maintenance of areas in later successional stages for wildlife species particularly adapted to these habitats.

Areas of the earliest forest successional stages are reduced, despite the concentration of timber inventory in the earlier age classes. Rising timber management intensity in some regions accelerates progression of stands through seral stages. For

example, a 20-year-old stand under low intensity management may be an open sapling-pole stand; however, under high intensity management, it can be a closed sapling-pole-sawtimber stand.

Age class distributions in all regions are 'shortened,' compressing a larger inventory volume into fewer, younger age classes. Relative to the BASE, only the extended rotation scenario has much impact on age class distributions by 2020, producing distributions with more trees in the older classes (and fewer in the younger). Under the extended rotation scenario, in the Pacific Northwest Westside the 2020 age distribution is extended to include the 70–79 and 80–89 classes. The area in classes over 49 years is greater under the extended rotation case than in the original 1990 distribution. In the South, the extended rotation requirement would increase the area in the 20–29 and 30–39 classes by 2020 compared to the BASE, while decreasing the area in stands < 20 years of age. The projected area of southern stands in the 20–39 age group would be larger than the existing area in 1990.

5.2.5. Timber inventory and sequestered carbon

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., 1993; Alig et al., 1997). This is an example of the broader-scale impacts of regional/national policies. Forcing harvest at older ages through the extended rotation policy increases the carbon sequestered by forests in the first decade by 17% compared to the BASE, but the forest carbon addition under the policy is less than under the BASE for the next two decades. The reduced public harvest policy would increase private forest carbon by 7% more than the BASE in the first decade, then by lesser percentages over the next two decades. 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, projected carbon levels can continue to rise even after the total merchantable bole volume has stabilized or begun to fall. The three classes of products in the present

model (sawlogs, pulpwood and fuelwood) have markedly different patterns of carbon storage and release in consumption, which is reflected in the FASOM model's carbon accounting.

5.3. Economic changes

5.3.1. Product prices

The two policies both act to reduce the near-term supply of timber compared to the BASE, lower total US timber harvest and raise log prices (Fig. 1). The policies exacerbate conditions of limited merchantable private inventory in the US during the first three decades of the projection and amplify the log price increases observed in the BASE in this period. In the reduced public harvest scenario, higher log prices elicit more private forest investment, gradually forcing prices back toward BASE levels and raising total wood consumption above the BASE by 2020. In contrast, the major market effects of the higher minimum harvest ages in the extended rotation scenario are concentrated in the first few decades. In effect, this scenario forces postponement of harvest of some lands that were 'financially mature' in the first decades of the BASE. When these hectares do move above the higher age minimums, their volumes are larger and consumption and prices return quickly to BASE levels. The extended rotation scenario forces the retention of land in lengthened forest rotations for the first three decades of the projection.

Although both policies lead to higher first-decade log prices than in the BASE, log prices under the extended rotation policy remain highest through 2010 (Fig. 1). The required lengthening of rotations prolongs the shortage of merchantable timber, thereby further muting supply-side responses that are outstripped by growth in demand. This drives up log prices to almost 70% higher than BASE levels.

Agricultural product prices are likewise most affected by the extended rotation policy. The grain price index (Adams et al., 1996a) for the 1990s is 3% higher under that forest policy compared to the BASE, while less public timber harvest leads to a price increase of < 0.1%. The agricultural price differential due to the extended

Table 4
Present value of selected economic welfare components in FASOM for the base case and percent changes from base case for two policy scenarios

Welfare component	Base (trillion $)	Extended rotation (% change)	Reduced public harvest (% change)
Forest sector domestic consumer surplus	2.388	−9.7	−1.4
Forest sector domestic producer surplus	0.230	83.2	10.1
Forest sector net surplus	2.754	−1.6	−2.0
Agriculture sector net surplus	38.965	−0.1	0.0

All future benefits and costs are discounted at 4%. Surpluses associated with foreign trade, terminal inventory valuation and other miscellaneous are not shown in Table 4 (see Adams et al., 1996a for discussion of surplus accounting).

rotation policy grows to 5.4% in the 2000s, before approximating the BASE index in the 2010s. The large quantity of near-term afforestation under the extended rotation policy causes grain production to drop between 1 and 2% during the first two decades, forcing up grain prices.

5.3.2. Land prices

The effects of the policies on the value of land as a factor of production vary across regions and over time, with changes in land prices reflecting changes in relative returns. The extended rotation policy greatly increases the amount of agricultural land afforested in the North in the 1990s (Fig. 3a), resulting in an increase in the value of agricultural land that can be converted to forest use in the North by about 20% in the 1990s compared to the BASE. In contrast, that same policy reduces the demand for convertible agricultural land in the South and associated land prices drop by ≈ 20% relative to the BASE. After 2000 some price differentials are reversed, with the extended rotation policy resulting in prices for southern forestland that are larger than BASE ones in the 2010s and 2020s.

Possible differences in land price impacts across forest types are illustrated with the extended rotation policy for the Lake States. Land with softwood types has a lower price than under the BASE, while the reverse is true for hardwood land prices. The policy increases the supply of softwood land relative to hardwood land.

5.3.3. Economic welfare

The largest impacts of the policies are in the forestry sector (Table 4). Forestry producer surplus would increase by 83% under the extended rotation policy and 10 percent under the reduced public harvest policy, relative to the BASE. Consumers of forestry products would sustain relatively large losses under the extended rotation policy, equal to 10%.

Impacts on the agricultural sector from imposition of forest policies are greatest for the extended rotation policy. Given that the policy causes additional afforestation of agricultural land and a reduction in US grain production, the higher agricultural prices lead to increased agricultural producer surplus. However, the larger loss by agricultural consumers leads to a $24 billion welfare reduction for the agricultural sector.

6. Discussion and conclusions

Policy simulation results indicate several potential avenues for unintended economic and ecological consequences and ripple effects across regions, owner groups and sectors that might not have been anticipated with traditional input-oriented policy analysis. With endogenous land markets and management decisions, changes in product and land prices and profitability stimulate changes in investment or land use that act to counter in some cases the intended effects of the two policies. It is important to note that the projected extent of some of these effects depends in part on the assumptions of perfect foresight and perfect capital markets employed in our model. Uncertainty regarding policy outcomes in markets or limits on

investment would act to heighten market (price) responses while limiting offsetting land use and management changes. Characteristics of the existing timber stocks, such as a relative shortage of timber stands with merchantable age classes, also have important influences on the type of projected responses to policy imposition. Thus, an extended rotation age policy on private lands would exacerbate the limitations of existing timber stocks, particularly the limited amount of older timber in merchantable age classes. The result is large near-term increases in log prices and reductions in near-term timber harvest relative to the BASE.

The simulations indicate several potential future developments impacting the forested environment under the two policies.

(1) Net land shifts to the forestry sector may be substantial under an extended rotation policy, especially afforestation of cropland in the Lake States region. Some land use shifts are transitory, in that many afforested hectares are converted back to agriculture later in the projection period.

(2) Both policies have consequences for the forest environment through changes in forest cover type areas and investment in management applied to private forest lands. Economic incentives to convert hardwood forest types to softwood plantations in the South are reduced by the relatively large amount of afforestation in the North. In the BASE 7 million ha of hardwood lands are converted to softwoods in the 1990s, but under the extended rotation policy that amount is reduced by more than half. These changes in forest types 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 some wildlife species dependent on habitat in later seral stages. The extended rotation scenario suggests that minimum harvest age restrictions alone may be insufficient to broaden the age distribution significantly in some regions.

(4) Management intensity trends raise concerns both where they become more intensive and more extensive. On industry ownerships, the percentage of land managed in plantations doubles, rising to 45% of the industrial land base by 2039. Under the extended rotation policy, not as many hectares are shifted to plantations (31% by 2039). Because the effect of intensive management is to move lands more rapidly into a closed canopy (full site occupancy) condition, stands reside in the earliest successional stages for a shorter time. This may, in some regions, lead to actual reductions in the area of these earliest stages despite the concentration of inventory in the earlier ages. Similar concerns attend the shifting of large areas of nonindustrial private lands into the passive management category. These are areas essentially harvested and abandoned with tree densities and species compositions that may be unlike any 'natural' stands. Imposition of the extended rotation policy decreases the area under such passive management, as a counterbalance to the reduction of lands shifted to the highest timber management classes.

(5) All simulations show continued growth in the total cubic volume of private inventory in the US, with more rapid growth under policies that act to raise prices the most. And, while total merchantable wood volume may stabilize or begin to decline at some point, sequestered carbon in all parts of the forest system could continue to rise.

FASOM's endogenous determination of the combination of land use, forest type composition and timber management investment levels is linked to parallel land base changes in agriculture. The agriculture sector would be impacted most heavily by the extended rotation policy, which would reduce US grain production by 1–2% in most decades of the projection and would drive up grain prices by several percent. The geographic concentration of land reallocation prompted by the extended rotation policy, with a large amount of land use changes in the North, is different than that typically suggested in previous studies (e.g. USDA Soil Conservation Service, 1989).

Projections of market and investment-induced changes in forest harvesting, management and

land use, as in this study, can help provide information needed when evaluating aggregative indicators of conservation and sustainable management of forest and agricultural ecosystems. For example, the Santiago Declaration (Canadian Forest Service, 1995) concludes that trends in biological diversity may be suggested by indicators such as total forest area over time, forest species composition and the extent of area by forest type by age class or successional stage. Additional work remains to better integrate analyses of coarse scale measures such as those provided here with those at finer scales of resolution, such as fragmentation of forest types. The current work provides a platform for future research in this area and as well for analysis of alternative representations of key economic elements of the projections such as the investment decision process in imperfect 'real world' capital markets.

Acknowledgements

References

Adams, D.M., Haynes, R.W., 1996. The 1993 Timber Assessment Market Model: Structure, Projections, and Policy Simulations. USDA Forest Service Gen. Tech. Rep. PNW-GTR-368. Pacific Northwest Research Station, Portland, OR, 58pp.

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

Adams, R., Adams, D.M., Callaway, J., McCarl, B., Chang, C., 1993. Sequestering carbon on agricultural land: Social costs and impacts on timber markets. Contemporary Policy Issues XI: 76–87.

Adams, D.M., Alig, R.J., Callaway, J., McCarl, B., Winnett, S., 1996a. Forest and Agricultural Sector Optimization Model: Model Structure and Projections. USDA Forest Service Research Paper PNW-RP-495. Pacific Northwest Experiment Station, Portland, OR, 60pp.

Adams, D.M., Alig, R.J., McCarl, B., Callaway, J., Winnett, S., 1996b. An analysis of the impacts of public timber harvest policies on private forest management in the US. For. Sci. 42 (3), 343–358.

Alig, R., 1985. Econometric analysis of the factors influencing forest acreage trends in the Southeast. For. Sci. 32 (1), 119–134.

Alig, R.J., Hohenstein, W., Murray, B., Haight, R., 1990. Changes in area of timberland in the United States, 1952–2040, by ownership, forest type, region, and State. USDA Forest Service Gen. Tech. Rep. SE-64. Asheville, NC, 34pp.

Alig, R.J., Wear, D., 1992. US private timberlands, 1952–2040. J. For. 90 (5), 31–37.

Alig, R.J., Adams, D.M., McCarl, B., Callaway, J., Winnett, S., 1997. Assessing effects of mitigation strategies for global climate change with an intertemporal model of the US forest and agricultural sectors. Environ. Res. Econ. 9, 259–274.

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

Canadian Forest Service, 1995. Criteria and indicators for the conservation and sustainable management of temperate and boreal forests (The Montreal Process). Natural Resources Canada Document Fo42-238/1995E, Hull, Quebec, 27pp.

Chang, C., McCarl, B., Mjelde, J., Richardson, J., 1992. Sectoral implications of farm program modifications. Am. J. Agr. Econ. 74, 38–49.

Daly, H., 1991. Toward an environmental macroeconomics. Land Econ. 67 (2), 255–259.

Flather, C., Brady, S., Inkley, D., 1992. Regional habitat appraisals of wildlife communities: a landscape-level evaluation of a resource planning model using avian distribution data. Landsc. Ecol. 7 (2), 137–147.

Haynes, R.W., Adams, D.M., Mills, J., 1995. The 1993 RPA Timber Assessment Update. USDA Forest Service Gen. Tech. Rep. RM-259. Ft. Collins, CO, Rocky Mountain Forest and Range Experiment Station, 66pp.

Hoen, H.F., Solberg, B., 1994. Potential and economic efficiency of carbon sequestration in forest biomass through silvicultural management. For. Sci. 40 (3), 429–451.

Ince, P., 1994. Recycling and long-range timber outlook. USDA Forest Service Gen. Tech. Rep. RM-242. Ft. Collins, CO, Rocky Mountain Forest and Range Experiment Station, 23pp.

Johnson, R., Alig, R.J., Moore, E., Moulton, R., 1997. NIPF landowners' view of regulation. J. For. 95 (1), 23–28.

Lonnstedt, L., 1989. Goals and cutting decisions of private small forest owners. Scand. J. For. Res. 4, 259–265.

Mills, J., Kincaid, J., 1992. The aggregate timberland assessment system-ATLAS: A comprehensive timber projection system. USDA Forest Service Gen. Tech. Rep. PNW-GTR-281. Pacific Northwest Research Station, Portland, OR, 160pp.

Parks, P., Hardie, I., 1995. Least-cost forest carbon reserves: Cost effective subsidies to convert marginal agricultural land to forests. Land Econ. 71 (1), 122–136.

Powell, D., Faulkner, J., Darr, D., Zhu, Z., MacCleery, D., 1994. Forest resources of the United States, 1992. USDA Forest Service RM Gen. Tech. Rep. 234. Ft. Collins, CO, Rocky Mountain Forest and Range Experiment Station, 132pp.

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

Stavins, R., Jaffe, S., 1990. Unintended impacts of public investments on private decisions: The depletion of forested wetlands. Am. Econ. Rev. 80 (3), 337–352.

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

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, 280pp.