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This study considered regional forest policies for sequestering carbon in existing forests in western Oregon. A model of log markets in western Oregon was employed to examine the impacts of forest policy changes on future carbon stock, harvests, and management activities. A carbon tax program, as a mitigation option for encouraging forest carbon sequestration, would lead to reduced harvest and increased carbon stock in timber inventory. Changes in the level of silvicultural investments vary by owner, depending on the nature of their initial inventory. In general investment under the tax is concentrated in regimes that establish faster growing plantations. Average rotation age increases, varying in extent across ownerships and site qualities. The carbon tax reduces both consumer and producer surpluses in regional timber markets. Producers are compensated by the carbon subsidies, except at low carbon tax levels. Estimates of the marginal cost of sequestering carbon in western Oregon private forests are shown to be within the range of costs for projects considering afforestation alone in some eastern regions of the United States. If the carbon tax system takes into account carbon in forest products and woody residue, the marginal costs of carbon sequestration rise substantially because of the trade-offs between carbon in the timber inventory and in product and residue pools. Raising timber harvest from western Oregon federal timberlands would cause a reduction in regional carbon flux in forests and forest products. Projections of harvests by ownership given a constraint or target for regional carbon flux show that there are significant opportunities for substituting timber harvest and carbon sequestration between federal and non-federal lands in western Oregon. A relatively small reduction in non-federal harvest would offset a substantial loss of carbon flux in federal timberlands. The same carbon flux levels obtained in the carbon target scenarios could be achieved if a carbon offset market were available for all owners including federal agencies. The marginal welfare cost derived from the shadow price of the carbon target constraint is the market price of carbon that could produce the same flux as the constraint. The analysis indicates that only modest carbon prices would be needed (< $15/tonne C) to maintain regional forest carbon flux at current (ca 2005) rates.

The Economics of Carbon Sequestration in Western Oregon Forests

by

Eun Ho Im

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APPROVED:

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Head of the Department of Forest Resources

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I understand that my dissertation will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my dissertation to any reader upon request.

Eun Ho Im, Author

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CHAPTER 1

GENERAL INTRODUCTION

1.1. INTRODUCTION

It is a common view that climate change, such as the frequency or intensity of extreme weather and climate events, would have serious impacts on both human society and the natural environment. Recent studies suggest that climate changes have been observed in many regions of the world and climate model outputs suggest further changes in extreme events for future climates (Easterling et al. 2000). International efforts to overcome climate change were launched by establishing the United Nations Framework Convention on Climate Change (UNFCCC) in 1992 and the Kyoto Protocol in 1997. The main concern of these efforts has been to reduce the contributions to atmospheric CO_2 from natural and anthropogenic sources that drive climate change.

Terrestrial ecosystems including forests and agricultural lands are important components in the biogeochemical cycle of carbon that create many of the sources and sinks of carbon. In particular, forests are major sinks among terrestrial ecosystems sequestering a huge amount of carbon in biomass (e.g., trunks, branches, foliage, roots, and understory vegetation) and soil organic carbon. Human activities, including land use and land-use change, modify carbon flows among the atmosphere, land, oceans. Studies have argued that land-use change, like conversion of forests to agricultural use, has been a major factor affecting terrestrial sources and sinks of carbon (Post et al. 1990).

There is general agreement that forests can play a significant role in sequestration to reduce the buildup of GHGs in the atmosphere. A number of alternative approaches to utilizing forestry and forest management for carbon sequestration have been examined including forest protection; the management of forests for carbon and joint products;

afforestation and reforestation; increased production of longer lived wood products; and replacing other materials with wood (Sedjo 2001). The most widely-studied option is the afforestation of marginal agricultural lands. For existing forestlands, carbon flux can be expanded by shifts in management activities such as modification of management practices, increase in rotation age, and preservation of forestland from conversion. In some regions such as western Oregon where there is little agricultural land available to afforest, these options are the only feasible approaches to increasing forest carbon flux.

For publicly-owned forestlands, changes in policies to emphasize carbon sequestration are feasible and could be implemented directly. Conceptually, a government agency can employ a policy for expanding carbon storage or reducing carbon release from these lands. However, since public forests in the U.S. are managed for multiple purposes, objectives of a carbon policy can be inconsistent with other values. Moreover, because of the interaction of public and private lands in commodity markets, the net effect of a carbon policy for public lands is unclear. A policy for reducing carbon emission from public lands, for example, may result in declining carbon on private lands due to an increase in private timber supply.

Several policy tools can be employed to enhance carbon storage on private forestlands. Direct control of carbon storage through regulation is technically possible. In practice, however, it may be infeasible because huge costs may be involved, and it restricts the right to use the lands. Without compensation for the loss of income by land-use regulation, compliance of the private owners with the policy may not be obtained. If properly designed and implemented, market-based instruments encouraging behavior through market signals are often more desirable because they stimulate individuals to undertake control efforts that are in their own interests and that collectively meet policy goals (Stavins 2003).

The research questions of this study are: (i) how market-based mitigation instruments would affect future carbon stocks on private lands and management decisions and (ii) how federal land-use decisions would affect the overall carbon sequestration in western Oregon forests and forest products. This study will employ a market modeling approach to examine the impacts of carbon subsidy and tax mechanisms (hereafter referred to as carbon tax) on carbon flux and to estimate the policy impacts on carbon stock, harvest, and management activities in western Oregon private forests. In addition, an integrated model of private and public timber supply will be developed to provide estimates of future harvest potential from both ownerships and to analyze interrelations between private and public land-use decisions and future carbon storage.

1.2. JUSTIFICATION AND EXPECTED ACCOMPLISHMENTS

This study will develop models to project the impacts of market-based mitigation instruments in the forestry sector, especially the carbon tax, on carbon stock in western Oregon private forests. It will also provide a vehicle to demonstrate how public and private owners' decision making on their forests are interrelated in the timber market context. It is important for policy makers to predict a forest owner's response to the introduction of a carbon tax or to a change in forest policy for public lands. Since a carbon tax will alter forest owners' land-use plans and thereby affect the timber market, identifying and analyzing the impacts on the future resource base and management activities are crucial to ensure the feasibility of the policy being considered.

This study will examine the potential impacts of a market-based mitigation instrument on the land-use decisions of private owners and thereby on carbon flux and harvest on private lands over time. It will also provide estimates of possible shifts of the management activities of the private forest owners due to changes in forest policy for public lands. The findings obtained by this research will serve as basic information on the potential impacts of regional forest carbon policy, which should be taken into account by policy makers. The model for estimating effects of a carbon tax on carbon flux could also be applied to other study areas or to a national level project to assess the impacts and cost-effectiveness of carbon projects.

1.3. LITERATURE REVIEW

1.3.1. Land Use, Land-Use Change, and Carbon Flux

Forest vegetation holding two-thirds of terrestrial carbon represents a major pool in the global carbon cycle which is subject to decrease or increase as a result of disturbance, harvest, regrowth, or conversion to other land uses. In particular, historical changes in land use and land-use change have played a significant role in changes in carbon accumulation in forests. During the period 1850-1998, cumulative net global CO_2 emissions from land-use change are estimated to have been 33 percent of total global emissions (Bolin and Sukumar 2000).

Mid-latitude forests of the northern hemisphere are known to provide a large sink for atmospheric CO_2 and studies suggest historical change in land use, particularly the growth of forests after agricultural abandonment, reduced harvesting, and fire suppression, as the dominant factors governing the rate of carbon accumulation in the eastern U.S. (Houghton et al. 1999, Caspersen et al. 2000). Changes in land use, especially the conversion of forests to agricultural lands and cultivation of prairie soils, released about 25 Pg C to the atmosphere over the period 1700-1990 in the United States and after 1945, largely as a result of fire suppression and forest regrowth on abandoned farmlands, about 2.4 Pg C was accumulated (Houghton et al. 1999).

Land-use decisions in natural forestlands currently occupied by closed forests or being regenerated after harvesting have been an important issue since these areas are the vast majority of the world’s forests and currently sequestering huge amounts of carbon. The Kyoto Protocol suggests that management of these natural terrestrial carbon sinks can enhance the capacities to accumulate carbon through promotion of sustainable forest management practices, afforestation, and reforestation and thus reduce atmospheric carbon dioxide (UNFCCC 1997). That is, through forest policy for existing forestlands that may affect land-use decision of forest owners, additional carbon can be sequestered. Although the costs of sequestering additional carbon in these forests may be quite low (even in comparison with intensive plantation options), increased use of natural forests for this purpose encounters several concerns about competing forest uses, biological risk, and the capacity to actually measure the incremental carbon sequestered (Binkley et al. 1997). In particular, conversion of unmanaged old-growth forests to young Kyoto forests may lead to massive carbon losses to the atmosphere mainly by replacing a large pool of tree biomass with a minute pool of regrowth and by reducing the flux into a permanent pool of soil organic matter (Harmon et al. 1990, Schulze et al. 2000). These findings on the relationship between land-use decisions on forestlands and carbon sequestration provide the primary justification for mitigation policy on existing forestlands which is the subject of this study.

1.3.2. Forests and Carbon Sequestration

Since the 1980s, studies have raised questions about whether forests could be globally or locally a net sink for atmospheric CO_2 (Cooper 1983, Cropper and Ewel 1987) and Sedjo and Solomon (1989) suggested that it would be possible to substantially offset the world’s emissions of carbon dioxide by expanding the world’s forest areas. Several opportunities to mitigate climate change in the forestry sector have been suggested: (i) increasing carbon in biomass and soil organic matter, either through afforestation and reforestation or modification of management practices in existing forests, (ii) reducing the rate of forest loss or conversion to other land uses; (iii) increasing the storage of carbon in long-lived forest products; (iv) substituting wood products for other materials; and (v) utilizing biomass energy as a replacement for fossil fuels (Sampson and Sedjo 1997, Richards and Stokes 2003, Stavins and Richards 2005). Among those options, special attention has been paid to afforestation and reforestation projects associated with land use and land-use change such as planting trees on agricultural lands and reforestation on harvested lands (Moulton and Richards 1990, Dudek and Leblanc 1990, Adams et al. 1993, Richards et al. 1993, Parks and Hardie 1995, Stavins 1999, Plantinga et al. 1999, Adams et al. 1999, Lubowski et al. 2003).

From the literature on carbon cost studies related to the afforestation projects on agricultural lands, three general approaches are identified to estimate the costs of sequestering carbon from the atmosphere: engineering cost studies; sectoral optimization models; and econometric studies of land-use. In general, those approaches are classified by the assumptions on the opportunity cost of land which is the most important factor affecting the carbon sequestration costs. Studies also can be categorized by the carbon accounting method that measures the changing amounts of carbon that are sequestered from year to year over long time horizons: flow summation; mean carbon storage; and levelization and discounting (Richards and Stokes 2004).

Most previous studies have employed an engineering cost approach (Moulton and Richards 1990, Dudek and Leblanc 1990, Richards et al. 1993, Adams et al. 1993). These studies estimated available land area, carbon fixation rates, and planting and management costs for hypothetical sequestration programs. Land costs were estimated from returns on alternative land uses. Parks and Hardie (1995) substituted land costs by foregone net returns derived from observed returns and costs for agricultural production. However, these studies did not consider either the impacts of changes in agricultural and forest products prices as land bases and product outputs change or landowners' behavioral responses to the carbon sequestration program (Stavins and Richards 2005). Some studies have estimated marginal costs of carbon sequestration ignoring land costs because it is difficult to determine the appropriate revenues and costs and acquire the relevant data (Dixon et al. 1991).

Sectoral optimization studies adopt intertemporal market models that link the forest and agricultural sectors through the market for land (Alig et al. 1997, Adams et al. 1999). They employ a joint objective function, maximizing the present value of producers and consumers' surplus in the markets of both sectors subject to the disposition of the land base that is suitable for use in either sector. Optimization studies on the global forest sector have developed the forward-looking dynamic model of global timber markets based on optimal control theory (Sohngen et al. 1999, Sohngen and Sedjo 2000). Given a timber demand function and management and access costs, the model assumes that the objective of a social planner is to maximize the present value of net market benefit.

Econometric studies have employed a response function of landowners for conversion of land into and out of forests using changes in timber and agricultural product prices (Stavins 1999, Plantinga et al. 1999, Lubowski et al. 2005). These studies assume that a landowner behaves as net present benefit maximizer facing an array of land-use options. The owner's rule for optimal allocation of land use is to choose the use with highest expected discounted net returns per unit area less any conversion costs. Thus, actual land-use changes have been analyzed to estimate relationships between land-use choices and relative returns in the forest and agricultural sectors, thereby leading to the development of carbon sequestration cost functions.

Previous studies on forest carbon sequestration costs suggest a broad range of marginal or average costs to capture atmospheric CO_2 because of the inconsistent use of terms, differences in geographic scope, underlying assumptions, and carbon accounting methods (Richards and Stokes 2004). Recent studies have reviewed these results in an attempt to derive the potential costs of carbon sequestration policies (van Kooten et al.

2004, Stavins and Richards 2005). van Kooten et al. (2004) employed meta-regression analysis to examine 55 previous studies of the costs of sequestering carbon in the forestry sector and suggest that baseline estimates of the costs of sequestering carbon through conserving existing forests are \$47-\$260 per ton C, while tree planting increases costs by more than 200%. Stavins and Richards (2005) identify 11 previous analyses of carbon sequestration costs in the United States and argue that at 300 million tons of annual carbon sequestration the marginal costs of nearly all the studies considered fall within a marginal cost range of \$25-\$75 per ton.

In this study, afforestation is not the primary concern since it is relatively limited option in the study area, western Oregon. Land use between forestry and agriculture in this region is relatively stable, about 80 percent of total area is forested, and there is little agricultural land available to afforest at reasonable prices. The carbon accounting methods employed by those studies considering afforestation on agricultural lands, however, provide basic background for this study. In addition, the marginal costs of carbon sequestration reported by previous studies are compared with those of this study in order to examine cost-effectiveness of the mitigation options in the western Oregon forestry sector.

1.3.3. Market-based Instruments and Carbon Taxes

Government can employ many different policy tools to sequester additional carbon in existing forests. These policy mechanisms can be direct or indirect. Direct policies include production (i.e., carbon sequestration) on government land, government production on leased land, input regulation (e.g., mandatory replanting after harvest), and output regulation (e.g., controlling carbon emission by harvesting). Indirect policies are comprised of market-based incentives (i.e., tax and subsidy, contracts, and marketable permits) and institutional incentives (e.g., market reforms, community-based forestry) (Richards et al. 1997). Market-based policy instruments have been considered not only in the forestry sector but also in other sectors for mitigating climate change. Stavins (2003) found that despite some uncertainties, these instruments could accomplish environmental objectives at relatively low costs.

Relatively few stand-level studies have speculated on the impacts of market-based incentives like a tax and subsidy approach as a mitigation option in the forestry sector. Some studies considering afforestation projects have employed a market-based policy tool linked to land-use changes in which a subsidy is provided for the conversion of land to forest and a tax is imposed on the conversion of land out of forests (Stavins 1999, Lubowski et al. 2005). This policy uses a market-based incentive to land owners converting to forests thereby lowering land opportunity costs not linked directly to carbon sequestration.

Some studies have considered the carbon tax on changes in carbon on forestlands to increase carbon storage in existing forests and to investigate its effects on afforestation (Hoen and Solberg 1997, van Kooten et al. 1995, Murray 2000, Tassone et al. 2004, and McKenney et al. 2004). Since under this mechanism forest owners may be taxed for the carbon they release by harvesting their forests and may be subsidized for the carbon they accumulate, estimating carbon in forests and its change over time is critical. However, previous studies only take into account carbon in standing trees and ignore carbon in understory vegetation, forest floor, dead trees, and below-ground woody debris after harvests and the dynamic of those carbon pools. The present study is based on the tax-subsidy mechanism suggested by these earlier analyses and, in addition, estimates change in all carbon pools in forests which interact with each other.

The basic model employed by the stand-level carbon tax-subsidy studies is a variant of the Hartman (1976) model based, in turn, on the static Faustmann model, which maximizes the present value of the timber and carbon sequestration benefits over all future rotations. This model describes the impacts of the carbon tax and subsidy on land-use decisions and economic returns from forestland; however, changes in social welfare of producers and consumers are not considered. An alternative model is needed to measure the gross decrease in social benefits (consumer and producer surpluses) caused by the policy together with any price and/or income changes that may result (Cropper and Oates 1992). In this study, I will develop a market-based model that captures welfare change in timber markets resulting from the carbon tax to overcome these limitations of the previous modeling approaches. Past studies have found that inclusion of the benefits from carbon uptake results in rotation ages longer than the Faustmann rotation age (van Kooten et al. 1995, Murray 2000, Tassone et al. 2004) and have provided an explicit carbon supply curve (van Kooten et al. 1995). Some studies have found the production possibility frontier between NPV from timber production and NPV from carbon uptake (Hoen and Solberg 1994). However, no studies examined the cost-effectiveness of the carbon tax in the forestry sector.

1.3.4. Public Land-Use Decisions and Carbon Sequestration

Public forestlands that are approximately 37% of forestlands in the conterminous United States have played a role as a net carbon sink with carbon stocks in increasing from 16.3 Gt in 1953 to the present total of 19.5 Gt (Smith and Heath 2004). Carbon storage in public timberlands on the Westside of the Pacific Northwest is significantly higher than other regions because of high productivity of lands and sharp drops in public timber harvest since late 1980s. Historically carbon storage on public lands in this region declined until late 1970s since federal lands were a major timber producer, but eventually rose as timber production has shifted away from federal land to state and privately owned lands (Heath et al. 2003). Consequently, the future carbon storage in these lands will also be affected by assumptions about future harvest and growth (Smith and Heath, 2004).

A few studies have examined the interrelation between public and private land-use decisions in terms of timber markets. In general, land-use decisions on public forests are determined by long-term forest plans established by public agencies and thus are not dependent on the timber market systems. Thus, previous studies on timber markets commonly assumed a fixed level of public harvest and examined impacts of raising this level on prices of logs and wood products and inventory changes of private lands among regions (Haynes 2003, Adams et al. 2002). As private forest owners can easily adjust their management activities according to market signals, the fall of log prices resulting from increased public cut may cause reduced private log supply and ultimately increase carbon in standing tree biomass through inventory build-up (Adams and Latta 2007). In contrast, carbon losses on public lands may be expected to result from increased public harvest levels. That is, private harvest is partly replaced by public harvest in timber markets and carbon in private forests rises at the expense of carbon losses on public forests. In the previous studies, however, overall impacts of changes in public cut on carbon stocks on private and public forestlands have not been examined. In western Oregon, inventory and stand age structures of public forests differ markedly from those of private forests. Younger stands (0-60 years) dominate in privately-owned timberlands, while older stands (80 years and more) predominate in public-owned timberlands and total inventory of public timber lands is about 2.6 times greater than that of private lands (Campbell et al. 2004). In this study, we will explore how these differences affect the overall regional options for carbon sequestration and timber harvest.

1.3.5 Conclusions

Studies suggest that a carbon tax imposed on existing forestlands affects land-use decisions, but its cost-effectiveness relative to other mitigation options in the forestry sector has not been examined. The model commonly adopted may provide economic impacts of the environmental policy for stand-level forest management but can not estimate the social costs of the policy. Thus, a model considering timber market conditions needs to be introduced. In addition, we found that the impacts of changes in public land-use decisions on carbon flux and market surplus have not examined in previous market models. That is, there is a need to develop a dynamic model of log markets in which market prices and timber harvest from public and private forests are explicitly modeled.

1.4. RESEARCH OBJECTIVES

Research Goal: The overall goal of this study is to estimate the impacts of forest policies related to carbon sequestration on future carbon stocks, harvests, and management activities in western Oregon forests and to analyze interrelationships between private and public forestland-use decisions in the market context.

Objective 1: Develop an approach to model the carbon tax as a policy to sequester carbon in existing forests, estimate its impacts on future carbon stocks, harvests, and management activities in the western Oregon private forests, and evaluate the cost-effectiveness of this policy as a mitigation option in forestry sector.

Objective 2: Develop an extended model for private and public timber supply to provide future harvest potential from both ownerships in western Oregon, estimate the overall impacts of change in forest policies on future carbon stock, harvest, and management activities, analyze interrelationship between public and private forestland-use decisions in the market context, and examine the implications for forest carbon policies.

1.5. METHODS

1.5.1. Overall Research Design

This study predicts future carbon flux, harvest, and management activities in western Oregon under the carbon tax and change in forest policy for public lands. The future carbon stock, harvest, and management activities are affected by several biological and economic factors. Biological and physical conditions on forestlands (e.g., species and soil quality) primarily determine the forest's capacities to accumulate carbon as biomass on public and private lands. Economic factors (e.g., timber price) are a major concern deciding resource use on private forests, while harvest timing on public lands is not dependent upon market conditions. Thus, those factors should be considered together in a modeling process.

For the first objective of this study, a market model incorporating a tax on carbon flux will be developed based on the western Oregon Timber Supply Model (Adams et al. 2002). Two subsidy mechanisms will be examined: subsidy for carbon flux in standing inventory and subsidy for carbon flux on forestlands, forest products, and fuel substitution. The carbon tax is only applied to private owners and thereby timber markets are largely influenced by the owners' responses to the carbon tax. This modeling approach allows estimating the impacts of this mechanism on regional timber markets.

For the second objective, the extended model for private and public timber supply will be devised using the western Oregon Timber Supply Model (Adams et al. 2002). Public forests in western Oregon are managed by long-term forest plans (e.g., Northwest

Forest Plan for federal forests) and classified by their roles (e.g., riparian and late-successional reserves). Thus, harvest decisions do not rely on the timber market, but depend on the land-use status within the forest plans. The private timber supply model will be extended by integrating a harvest and inventory module for public lands, which will provide overall effects of policy change and relationship between private and public land-use decisions.

The basic timber inventory data is provided by the Forest Inventory and Analysis of the USDA Forest Service (Azuma et al. 2002). Using these data, yield projections for existing and regenerated stands are developed by ORGANON (Hann et al. 1997) for private and state forests, while Forest Vegetation Simulator (FVS, Dixon 2003) will be used to generate future yield potentials for federal forests. A variety of management regimes is applied for private forests, while relatively few silvicultural practices will be employed for public lands according to the existing forest plans.

1.5.2. Description of Study Area

Forests and ownerships

Western Oregon has an estimated 19 million acres of land. About 80 percent of this land (15.4 million acres) is forested with 71 percent being timberland. Table 1.1 shows the estimated area of forestlands and nonreserved timberland by ownership and forest type. About 48 percent of the timberland is administered by two federal agencies, the U.S. Department of Agriculture, Forest Service, National Forest System (NFS) and U.S. Department of the Interior, Bureau of Land Management (BLM). Industrial land owned by private companies that grow timber for industrial use is the second largest portion of the timberland, and other private owners including Native American and farmers own 14 percent. The majority of western Oregon forestland (and timberland) is dominated by softwoods (conifers), with Douglas-fir accounting for 80 percent of the conifers. The national forest has a variety of forest types relative to the other ownerships.

Table 1.2 shows that western Oregon forests are heavily concentrated on relatively young stands (< 60 years), while a significant difference is found among ownerships, especially within federally owned forests, National Forests and BLM's forests. Nearly half of National Forest administered by USDA Forest Service is old growth forests (>150 years), while BLM's forest is composed of relatively young stands (< 80 years) and has no old-growth forest (>150 years). This reflects the differences of their historic timber harvests and reserve systems of old growth forests. Since private forestlands have been managed for timber production with relatively short rotation ages, they are dominated by younger forests.

Under the Forest Land Management Classification System, about 60 percent of the timberlands administered by the National Forest System are set aside as reserve areas exempt from regular scheduled timber harvest by law, regulation, or forest plan requirement (Table 1.3). Most BLM and State forests are classified as multiresource forests where restrictions on timber harvesting have been implemented through forest plans, state laws, or agency policies. Active forests managed for timber production include all private lands where scheduled timber harvest may occur and where sustainable supplies of timber are anticipated.

Past timber supply

Figure 1.1 provides harvest volume by owner class in western Oregon between 1962 and 2002. Over this period, the timber production from federal land has declined sharply, while harvest from state and privately owned land has been relatively stable. Before the 1990s, national forests and BLM forests had provided roughly half of the aggregate harvest of western Oregon with an annual average harvest of more than 3 billion board feet. In the 1990s, federal harvest dropped to 685 million board feet per year, which is only 18 percent of total harvest in western Oregon. Other public and private land averaged 3.3 billion board feet per year (i.e., half of total harvest) before 1990 and decreased 8 percent to 2,807 million board feet in the 1990s. As a result, private lands have become the primary timber supplier and their share of total harvest has risen to more than 80 percent. The change in harvest behavior on federal lands is not forced by the resource condition of these lands, but is evidence of changing availability of land for timber production based on new management decisions such as the Northwest Forest Plan (NWFP) (Campbell et al. 2004).

1.5.3. Data

Forest inventory

Timber inventory data for private and public forestlands in western Oregon derive from the USFS Forest Inventory and Analysis (FIA) periodic forest survey (Azuma et al., 2002). Because the inventories (collected between 1994 and 1998) were 9-12 years old, we attempted to update the private data to a common 2005 starting point using a timber harvest scheduling model that selected plots for harvest to maximize the present net worth of timber returns over the period from inventory date to 2005. Harvest was constrained to actual historical cut at the county level and the area clearcut and partial cut by year and owner at the half-state (western Oregon) level based on data from the Oregon Department of Forestry (ODF).

Management regimes

In cooperation with the Oregon Forest Industries Council (OFIC) during early 1998, the Oregon Department of Forestry (ODF) surveyed industrial forest land owners regarding their current management practices and future management intentions for lands in Oregon. A similar survey of ODF forest practice and service foresters was also completed to provide information on current and potential management actions of nonindustrial owners. Using these survey data, for private forests, seven management regimes including three partial cutting options will be defined for existing stands, while ten management activities including partial cutting will be applied for planted or naturally regenerated stands.

For public lands, choice of management regimes is limited since all forestlands are already allocated for certain purpose by the forest plan. For state forests, we apply the same management regimes as those of private owners. Since federal forests in western Oregon regulated by the NWFP are classified by land allocations which have specific management direction regarding how those lands are to be managed, there are relatively few options that can be applied. In this study, therefore, we have chosen relatively simple regimes, consistent with the guidelines that are suitable for our model specification.

1.5.4. Specific Methods

Objective 1: Develop an approach to model the carbon tax as a policy to sequester additional carbon in existing forests, estimate its impacts on future carbon stocks, harvests, and management activities in the western Oregon private forests, and evaluate the cost-effectiveness of this policy as a mitigation option in forestry sector.

Timber and carbon supply model

A theoretical model of a private forest owner's response to the carbon tax will be developed to describe the effects of the carbon tax on future harvest. For a policy maker's perspective, a model that links timber markets and a carbon accounting process will be devised to estimate policy impacts. The model is a variant of the Western Oregon Timber Supply Model developed by Adams et al. (2002). The western Oregon Timber Supply Model was developed to provide estimates of future timber supply potential from private lands under a variety of alternative scenarios on public regulatory policies and timber market conditions (Adams et al. 2002, Schillinger et al. 2003). This model was comprised of five elements including inventory, growth and yield, management options, land base, and harvest simulator.

A carbon accounting module including policy options is incorporated in this model (Figure 1.2). Initial inventory is provided by the FIA database and forest land base is exogenously given. Based on these data, the model generates future yield potential for each management unit using ORGANON (Hann et al. 1997). Management options including management regimes and land allocation are endogenous variables linking harvest simulator and growth and yield module. Carbon in trees will be estimated by converting the merchantable yield projection provided by the inventory module. Since carbon in the other components of the forest ecosystem depends on management activities and harvest, this will be estimated by linking the data reported by the previous studies and decision variables of the model. The harvest simulator will generate the optimal land allocations and management regimes using the data from the other elements that maximize net social surplus and carbon benefits.

Simulation scenarios

Two subsidy scenarios will be examined using the timber and carbon supply model. First, we assume that subsidies are paid to forest owners or taxes are paid by forest owners according to the change of carbon stock on standing timber inventory. In this scenario, we examine the potential impact of the carbon tax on carbon-harvest trade-offs, management activities, and welfare costs. In the second scenario, we assume that forest owners will be paid for carbon sequestration in forests and forest product and residue pools. With this scenario along with the first case, the effect of including residue and product carbon pools in the carbon tax on carbon sequestration and cost-effectiveness will be analyzed.

Objective 2: Develop an extended model for private and public timber supply to provide future harvest potential from both ownerships in western Oregon, estimate the overall impacts of change in forest policies on future carbon stock, harvest, and management activities, analyze interrelationship between public and private forestland-use decisions in the market context, and examine the implications for forest carbon policies.

Public and private timber supply model

A model developed for the objective 2 considers both private and public harvest behaviors since both owners' land-use decisions are interrelated in the market context. The model developed by Adams et al. (2002) assumed a fixed timber supply from public forests and only private harvest was endogenous. This study relaxes the assumption about constant public harvest and allows it to vary depending on forest policies. The harvest potential from public forests, however, will be an exogenous shock for the timber market. Change in forest policy for public lands affects the timber markets and thereby harvest behaviors of the private forests are also adjusted by the timber market signals.

The public and private timber supply model consists of seven components: inventory, growth and yield, management regimes, land base, public forest plans, carbon accounting, and market model (Figure 1.3). Based on the inventory and land base data, future yield potential for each management unit is generated using FVS and ORGANON. Management options including management regimes and land allocation are endogenous variables linking harvest simulator and growth and yield module.

For public forests, silvicultural practices and harvest decisions are restricted by the existing forest plan such as Northwest Forest Plan for federal lands, i.e., the management option will be determined according to the land-use goals by the forest plans. Given the data from other components, the public and private harvest simulator will generate the optimal solution. That is, the expected harvest volume from public forests will be provided from the public harvest module under various policy scenarios and then the market model will find the optimal management options that maximizes consumer and producer surplus in the timber markets. Carbon flux on forests and forest products will be estimated using the previous studies' approaches.

Simulation scenarios

The baseline projection represents the future resource and market conditions in western Oregon forests under no change in current policies for public lands, forest growth conditions, or land allocation. Two scenarios will be simulated. First, we examine the potential impacts of raising federal timber harvest to NWFP levels on carbon flux and the markets for logs in western Oregon. In the second scenario, we explore the impacts of regional carbon flux targets on regional harvest and carbon sequestration under a flexible public harvest level.

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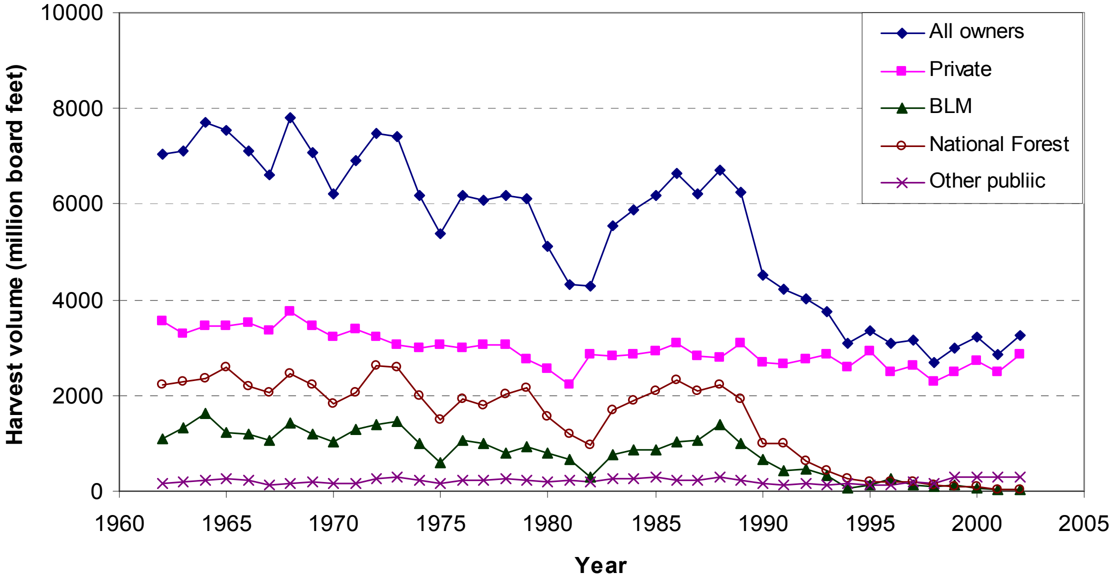

Figure 1.1. Harvest volume by owner class, western Oregon, 1962-2002 (from Oregon Department of Forestry 2003).

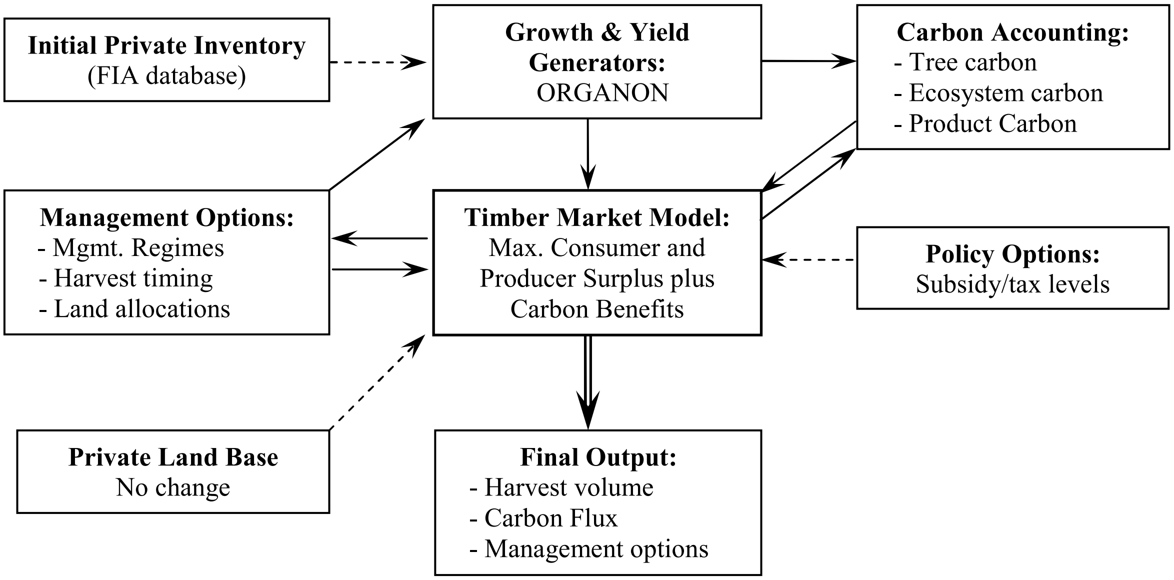

Figure 1.2. Components and structure of the timber and carbon supply model.

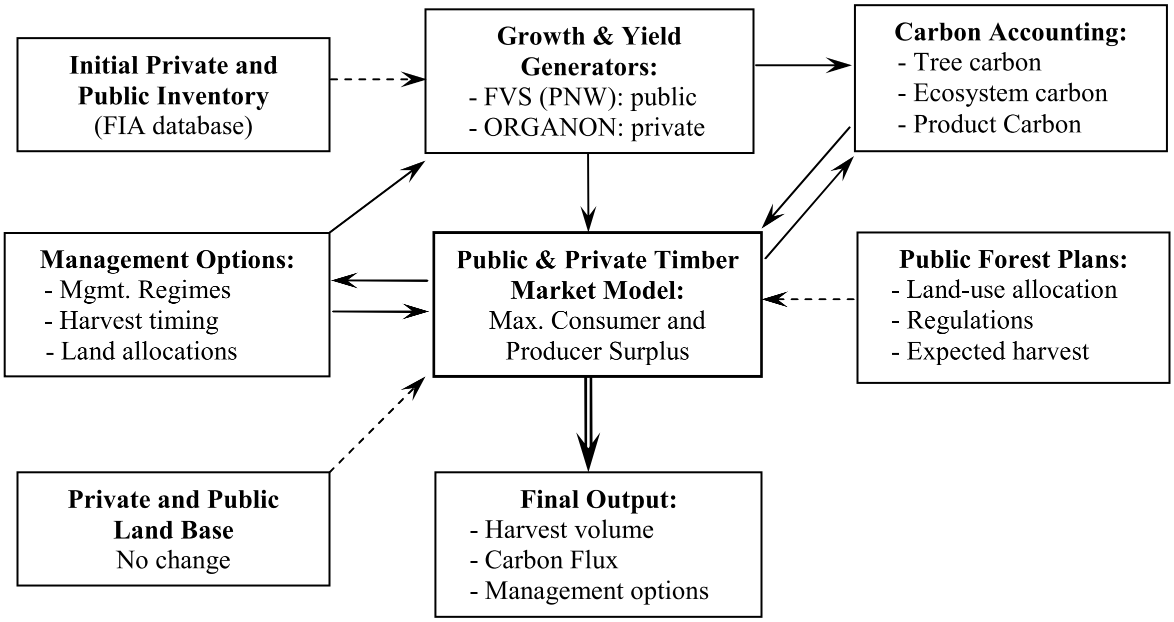

Figure 1.3. Components and structure of the public and private timber supply model

Table 1.1. Estimated area of forestland and nonreserved timberland, by owner class, and forestlands, by forest type and owner class, western Oregon, 1999.

	Public lands				Private lands		
	National forest	BLM	State	Other public	Forest industry	Other private	All owners
	Thousand acres						
Forestland	5,523	2,288	825	198	4,377	2,244	15,454
Timberland	4,327	2,182	739	112	4,177	1,882	13,418
Softwoods	3,820	1,670	570	72	3,407	1,141	10,679
- Douglas-fir	3,004	1,513	514	58	2,792	947	8,830
- Fir-spruce	335	15	-	6	120	24	503
- Hemlock-Sitka	297	83	55	4	416	71	927
- Others	184	57	-	3	79	98	419
Hardwoods	336	455	164	38	678	663	2,334

Source: Campbell et al. (2004).
Note: - = less than 500 acres found.

Table 1.2. Estimated area of nonreserved timberland, by owner and stand age class, western Oregon, 1999.

	Public lands				Private lands		All owners
	National forest	BLM	State	Other public	Forest industry	Other private	
	Thousand acres						
0-59 years	562	1,942	581	63	3,648	1,417	8,215
60-99 years	738	151	101	37	324	304	1,655
100-200 years	1,525	7	51	10	69	80	1,741
200+ years	1,314	-	-	-	43	2	1,359

Source: Campbell et al. (2004).
Note: - = less than 500 acres found.

Table 1.3. Estimated area of timberland, by reserve status and owner class, western Oregon, 1999.

Reserve status*	All timberland	Active forest (%)	Multiresource (%)	Reserved (%)
			Thousand acres	
National forest	5,297	-	2,152 (41)	3,145 (59)
BLM	2,267	-	1,334 (59)	933 (41)
State	748	-	730 (98)	18 (2)
Other public	118	105 (89)	7 (6)	7 (6)
Forest industry	4,177	4,177 (100)	-	-
Other private	1,882	1,882 (100)	-	-
All owners	14,489	6,164 (43)	4,223 (29)	4,103 (28)

Source: Campbell et al. (2004).
Note: - = less than 500 acres found.
* = definition of the Oregon Department of Forestry.

CHAPTER 2

POTENTIAL IMPACTS OF CARBON TAXES ON CARBON FLUX IN WESTERN OREGON PRIVATE FORESTS

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2.1. ABSTRACT

This study considers a carbon tax system as a policy tool for encouraging carbon sequestration through modification of management in existing forests and examines its welfare impacts and costs of the carbon sequestered. The simulated carbon tax leads to reduced harvest and increased carbon stock in the standing trees and understory biomass. Changes in the level of silvicultural investments vary by owner, depending on the nature of their initial inventory. In general investment under the tax is concentrated in regimes that establish faster growing plantations. Average rotation age increases, varying in extent across ownerships and site qualities. The carbon tax reduces both consumer and producer surpluses in regional timber markets. Producers are compensated by the carbon subsidies, except at low carbon tax levels. Not all rates of carbon tax will attract interest from private owners if participation is voluntary. Estimates of the marginal cost of sequestering carbon in western Oregon private forests are shown to be within the range of costs for projects considering afforestation alone in some eastern regions of the United States.

2.2. INTRODUCTION

Human activities have increased the atmospheric concentrations of greenhouse gases, including carbon dioxide, primarily through the combustion of fossil fuels, agricultural production, and land-use changes (IPCC 2001). Terrestrial ecosystems have been important sources and sinks of atmospheric carbon. Roughly half of terrestrial carbon is stored in forest vegetation as biomass and in organic soil, carbon pools which are subject to decrease or increase as a result of harvest, regrowth, or conversion to other land uses. Historically, changes in land use have been major factors affecting terrestrial carbon sinks. From 1850 to 1998, global changes in land use resulted in net cumulative CO_2 emissions estimated to have been 33 percent of total global emissions (IPCC 2000). In the United States, Houghton et al. (1999) estimate that changes in land use released about 25 Pg of carbon to the atmosphere over the period 1700-1990 largely from the conversion of forests to agricultural lands.

Several policies associated with forest land use and land-use change have been suggested as approaches to climate change mitigation. Particular attention has been given to afforestation projects on marginal agricultural lands (see Richards and Stokes 2004). Shifts in management activities in existing forests can also enhance carbon uptake, through modification of silvicultural practices, longer rotation ages, and preservation of forestland from conversion. In regions where there is little agricultural land available to afforest and where land-use patterns are relatively stable, modifying management practices in existing forests may be the only feasible approach to significantly increasing forest carbon flux.

This study examines the welfare costs of a carbon tax and subsidy program (hereafter referred to as carbon tax) for enhancing the sequestration of carbon on the existing private forest land base. Under the carbon tax, forest owners are subsidized for the carbon they accumulate and taxed for the carbon released by harvesting. We develop a theoretical model of a forest owner's response to the carbon tax and demonstrate how the forest owner will adjust harvest in various circumstances. To develop specific case estimates of the impacts of the carbon tax on harvest and management actions and to examine the cost-effectiveness of the carbon tax as a mitigation option in the forestry sector, we employ a model of the log market in the western part of the state of Oregon, USA. This is a region with very limited options for afforestation. We derive the marginal costs of carbon sequestration in existing private forests in western Oregon and compare our results with those of previous studies that have looked solely at afforestation projects.

2.3. PAST STUDIES

Some past studies have included options for modifying management practices in existing forests as well as afforestation projects in their estimates of carbon sequestration costs. For the U.S., Adams et al. (1999) showed that large near-term carbon increments could be obtained by changing management actions in existing forests, while reaching long-term carbon flux targets depended heavily on afforestation. In a global study of carbon pricing, Sohngen and Mendelsohn (2003) projected that under the "expected' case of rising carbon prices, 36 percent of the incremental carbon sequestered in mid-high latitude forests would result from shifts in management activities on existing forests by 2100. The remainder would be due to afforestation.

Several policy mechanisms can be employed to sequester carbon in existing forests, which Richards et al. (1997) classify as either direct or indirect. Direct policies include production (i.e., carbon sequestration) on government land, government production on leased land, and input and output regulation on private lands (e.g., mandatory replanting after harvest or limiting carbon emitted through harvesting). Indirect policies are comprised of market-based incentives (e.g., taxes and subsidies and marketable permits) and institutional incentives (e.g., market reforms). On private lands, direct control of carbon storage through regulation is technically possible. In practice, however, it may entail high costs of monitoring and control and it imposes unwelcome restrictions on the owners' rights to use the land. The environmental economics literature suggests that, if properly designed and implemented, market-based instruments are often a more desirable approach, because they encourage individuals to undertake mitigation efforts that are in their own self-interest and that collectively achieve policy goals (Stavins 2003).

Several studies have considered the carbon tax in the context of a single stand (van Kooten et al. 1995, Hoen and Solberg 1997, Murray 2000) and have investigated its effects on carbon sequestration and management activities in existing stands (Alavalapati et al. 2002) and on afforestation projects (Tassone et al. 2004, McKenney et al. 2004). At the forest level, Backéus et al. (2005) derived a trade-off curve between timber harvest and carbon storage over a large region, in a model where harvest is determined so as to maximize net present value given fixed future wood prices and carbon taxes. These studies find that inclusion of the subsidy revenues from carbon uptake results in longer rotation ages than in the absence of the carbon tax. To explain harvest decisions, these studies have commonly employed a variant of the Hartman (1976) model, which maximizes the present value of net returns from timber and carbon sequestration over all future rotations. This approach describes the impacts of the carbon tax on decisions and economic returns at the stand level, but does not consider impacts broadly on producers and consumers in a market where the tax is applied to all landowners over multiple time periods. Further analysis is needed to measure the change in social benefits (consumer and producer surpluses) caused by the carbon tax together with any price and/or income changes that may result (Cropper and Oates 1992).

For policy makers, some measure of the cost-effectiveness of carbon sequestration programs suggested for the forestry sector is critical in considering the role of forest carbon policies in regional or national strategies to meet net emission targets. As Parks and Hardie (1995) argue, direct monetary incentives should be provided for the program that accomplishes the greatest sequestration of atmospheric carbon per dollar spent. Hoen and Solberg (1994) estimated the marginal cost of sequestering an additional unit of carbon in terms of the present value of timber revenues foregone from producing different levels of discounted carbon sequestration in existing forests. Murray (2000) also estimated the stand level marginal opportunity costs of the carbon tax for three forest types as the ratio of reduction in timber value to the change in carbon storage. Both of these approaches demonstrate how much present income from timber production would be lost to sequester an additional unit of carbon. Like the studies noted above, however, they do not provide information on costs incurred by other market participants or reflect market adjustments to harvest changes.

2.4. A THEORETICAL MODEL OF PRIVATE OWNER RESPONSE TO THE CARBON TAX

Suppose a forest owner holds forests across a range of ages and its goal is to maximize present net income from growing trees over time.[1] Initial inventory is given by v_0 and a fixed amount of inventory of standing trees, $\bar{v}$, remains at the end of the final period. The timber growth is represented by a strictly concave function of the post-harvest stock of standing trees, $F(v)$. Assume that government introduces the carbon tax that pays a subsidy for carbon uptake in the standing trees, but levies a tax for carbon emission by harvesting, with a specific tax level at each time t. Under this mechanism, the forest owner's problem is to find the optimal harvest schedule, (H_1^*, H_2^*, H_3^*), that maximizes present value of income from timber production plus the net subsidy from carbon sequestration over time subject to constraints on the growing stock of timber and harvest limits for each period. That is,

$$\begin{aligned}
\underset{\{H_1,H_2,H_3\}}{MAX} \quad & \pi = p_1H_1 + \frac{1}{1+r}p_2H_2 + \frac{1}{(1+r)^2}p_3H_3 + p_1^c\alpha F(v_0) - p_1^c\alpha H_1 \\
& + \frac{1}{1+r}p_2^c\alpha F(v_1) - \frac{1}{1+r}p_2^c\alpha H_2 + \frac{1}{(1+r)^2}p_3^c\alpha F(v_2) - \frac{1}{(1+r)^2}p_3^c\alpha H_3 \\
s.t. \quad & v_1 = v_0 + F(v_0) - H_1 > 0 \\
& v_2 = v_1 + F(v_1) - H_2 > 0 \\
& v_3 = v_2 + F(v_2) - H_3 = \bar{v} \\
& H_1, H_2, H_3 \geq 0
\end{aligned} \tag{1}$$

where p_t is the stumpage price at time t, p^c_t is the tax level (\$/tonne) at time t, α is tons of carbon per unit tree biomass, and r is the discount rate of the owner. The first three terms of the objective function represent the present value of net income from timber production and the remaining terms indicate the present value of subsidies and taxes on carbon flux. The tax in this case is levied on the "observable" or simple periodic carbon change in the forests.[2]

In problem (1), constraints on the first and second harvests are nonbinding, only the third constraint is active, and the third-period harvest can be expressed in terms of the first and second harvests. Thus, by substitution, problem (1) can be expressed as a function of H_1 and H_2 alone. Differentiating with respect to H_1 and H_2 and setting the results equal to zero, the first order conditions appear (after rearrangement) as:

$$p_t - p_t^c\alpha = \frac{1+F'(v_t)}{1+r}[p_{t+1} - p_{t+1}^c\alpha] + \frac{1}{1+r}p_{t+1}^c\alpha F'(v_t) \quad for\ t = 1,2 \tag{2}$$

With a non-zero carbon tax, the left-hand side of condition (2) is the marginal revenue of current harvest expressed as timber income less the tax for carbon emission by harvesting and the right-hand side is marginal cost of delaying current harvest which is the discounted after-tax income from harvest plus the subsidy for incremental carbon accumulated by postponing current harvest.

When stumpage prices are the same as the no-tax baseline (as is assumed in past studies at the stand-level), condition (2) indicates that the optimal harvest is determined by the carbon tax levels in current and future periods. If the carbon tax level is constant over time, condition (2) can be expressed as follows.

$$p_t = \frac{1 + F'(v_t)}{1 + r} p_{t+1} + \frac{r}{1 + r} p^c \alpha \qquad \text{for } t = 1, 2 . \tag{3}$$

Since the fraction $0 < \frac{r}{1 + r} < 1$ for $r > 0$, equation (3) indicates that the marginal opportunity cost (the right-hand side) increases relative to the base under the constant tax. Thus, the following conditions should be satisfied.

$$F'(v_t^*) < F'(v_t^B), \quad v_t^* > v_t^B, \quad \text{and} \quad H_t^* < H_t^B \quad \text{for } t = 1,2,$$

where v^B and H^B are the post-harvest stock of standing trees and harvest without the carbon tax and v_t^* is the optimal stock with the carbon tax. Since the growth function is assumed to be concave (i.e., $F''(\cdot) < 0$), the post-harvest stock of standing trees under the carbon tax is greater than that of the baseline. That is, the forest owner will reduce harvest relative to the baseline level in a process similar to lengthening the optimal rotation age at the stand level. In addition, as the carbon tax increases, harvesting appears less profitable.

Now suppose that the carbon tax rises at the compound rate $\delta > 0$, so that $p_t^c = p^c (1 + \delta)^t$. Rising rates might be introduced if anticipated damages from global climate change rise in the future (see, for example, Table 6.11 in Pearce et al., 1996, and Sohngen and Mendelsohn, 2003). Then, condition (2) can be rewritten as follows.

$$p_t = \frac{1+F'(v_t)}{1+r} p_{t+1} + \frac{r-\delta}{1+r} p^c \alpha \qquad for\ t = 1,2. \tag{4}$$

If the rate of increase of the carbon tax is equal to the discount rate, equation (4) indicates that the optimal conditions both with and without the carbon tax are identical and the harvest levels of both cases are equal. If the rate of increase of the tax level is less than the discount rate, then the net subsidy is positive and harvest is smaller than the baseline. In contrast, when the carbon tax rises faster than the discount rate, the marginal opportunity cost of postponing harvest decreases and more harvest will occur than in the baseline. That is, at least in the short-run, if the rate of increase of the carbon tax is greater than the adjusted discount rate, forest carbon stock will decline.

Similar results obtain for an owner that maximizes utility derived from consumption of both priced and non-priced goods, if the utility function is additively separable in the utility derived from both goods (for an example see Ovaskainen 1992, p. 48). In this case the carbon tax reduces harvest relative to the no tax baseline, and the same conclusions hold as for the present value objective when the tax level rises. In more complex utility formulations, it is often not possible to establish signs of responses to the tax *a priori*.

2.5. EMPIRICAL MODEL

In timber markets, forest owners' decisions on management under the carbon tax are realized as changes in total supply of timber from private lands. From a policy maker's perspective then, timber market responses are an important concern in evaluating the overall impacts of a carbon policy. In this paper, we developed a market-level model integrated with the carbon tax based on the western Oregon portion of a timber market model described by Adams and Latta (2006).

The regional willingness to pay for logs by wood processors is computed under the derived demand function for logs in the production of lumber and plywood in western Oregon. Producer surplus for forest owners is implicitly obtained from revenue from timber sales less all costs for timber production such as harvesting, log transport, and silvicultural practices. Thus, the total area under the demand curves less costs of management, harvesting, and transport yields Samuelson's (1952) "net social surplus" denoted by

$$NSS_t(Q_t, K_t, S_t) = \int_0^{Q_t} P_t(q, K_t)dq - CH_t(S_t) \qquad (5)$$

where $P_t(q, Kt)$ is the timber demand function in period t, Q_t is total western Oregon timber consumption in period t, K_t is the quantity of capital stock in period t measured as maximum log processing capacity, and S_t is total supply of timber from western Oregon private forests in period t. Timber supply or harvest, in turn, is determined by the combination of land and management regime allocations to two categories of land: X_t, the area of existing stands at the start of the projection allocated to various management regimes that are to be harvested in period t, and N_t, the area of new stands regenerated after the start of the projection allocated to the various management regimes that are to be cut again in period t.

Ignoring current and future emissions of carbon in woody debris and dead trees already on the ground, subsidies (or taxes) would be paid to (or by) forest owners according to the change of carbon stock in the standing trees and understory. We assume that all private forest owners in western Oregon will participate in the carbon tax program and overall social welfare can be computed simply as the sum of net social surplus in timber markets and social benefits from carbon sequestration. That is, net subsidy at period t, $NS_t(X_t, N_t)$, is expressed as

$$NS_t(X_t, N_t) = \sum_{j=1}^{J} p_t^c [CS_{j,t}^F(X_t, N_t) - CS_{j,t-1}^F(X_{t-1}, N_{t-1})] \tag{6}$$

where $CS^F_{j,t}$ is the carbon stock in the post-harvest stock of the standing trees and understory biomass in the management unit j at period t. Carbon stock is estimated by combining forest inventory data on merchantable stand characteristics with biomass/merchantable volume ratios and carbon densities for various components of stand biomass and the soil (Hoover et al., 2000).

We assume that regional wood processors can adjust their mill capacity (capital stock) to changes in regional factor costs to ensure their competitiveness in national wood products markets. Capacity adjustment is assumed to entail costs following a two-tier scheme. All operating capacity which limits log consumption by wood processors incurs a minimum per unit maintenance expenditure, k_m, in each period. Capacity expansion or investment, E_t, entails higher costs per unit, k_u. Both costs are deducted from the market surplus objective function.

The market equilibrium problem, therefore, comprises a discrete time optimal control problem with control variables X_t, N_t, and E_t and dynamics given by the constraints on the disposition of the total inventory area among management-harvesting activities, demand-supply balance, and capacity adjustment.[3] A simple mathematical form of the intertemporal market model is:

$$\begin{aligned}
&\underset{\{X_t, N_t, E_t\}}{Maximize} \quad \sum_{t=0}^{T} \left[NSS_t(Q_t, K_t, S_t) + NS_t(X_t, N_t) - k_m K_t - k_u E_t \right] (1+r)^{-t} \\
&s.t. \quad \sum_t X_t = A && \text{Allocation of existing area} \\
&\sum_{t<j} N_{t,j} \le X_t + \sum_{k<t} N_{k,t} \quad \forall\, t && \text{Future area of even-aged stand} \\
&S_t = X_t V_t^X + \sum_{k<t} N_{k,t} V_{t-k}^N \quad \forall\, t && \text{Harvest} \\
&Q_t = S_t \quad \forall\, t && \text{Demand-supply balance} \\
&K_t = (1-\tau) K_{t-1} + E_t \quad \forall\, t && \text{Capital stock investment} \\
&\lambda K_t \ge Q_t \quad \forall\, t && \text{Log consumption limit}
\end{aligned} \tag{7}$$

where *A* is the total inventory area, $V^X{}_t$ is the vector of volume for existing stands at period *t*, $V^N{}_t$ is the vector of volume for regenerated stands before *t* periods, τ is depreciation rate of capital stock (capacity), and λ is the minimum capital stock utilization rate.

The market model described to this point treats both industrial and nonindustrial private forest (NIPF) owners as present value maximizers, setting rotation ages so as to maximize the land expectation value of stands. Previous studies of NIPF management objectives, however, have found that non-market outputs of forests are an important concern for these owners as well as net discounted revenues (Kuuluvainen et al. 1996, Kline et al. 2000). To mimic the effects of these more diverse objectives, we assume that NIPF owners restrict their harvests so as to maintain larger proportions of older stands in their inventory than is the case for industrial owners. This restriction is implemented by constraining the proportions of both young and mature forests in future inventories to fall within the bounds observed in historical NIPF inventory data.

Projections are made for 100 years with a 5-year time step. In this paper, however, we examine only the first 60 years of the projection as the policy-relevant period and to avoid undue influence of the terminal conditions. The simulations reported here use a real discount rate of 6 percent for all owners. Lower discount rates (e.g., 4%) lead to a reduced near-term harvest in the baseline case (Adams et al. 2002) and thus smaller amount of carbon would be sequestered under the non-zero carbon tax.

2.6. RESULTS

Using the empirical model described in section 2.5, we projected harvest, prices, timber management investment, and wood and carbon inventories on western Oregon private forest lands under a range of fixed levels of the carbon tax (p^c_t \$/tonne) and varying rates of carbon tax growth. These results provide the basis for estimating the impacts of the carbon tax on timber harvest and the costs of carbon sequestration.

2.6.1. Current Carbon Stocks and Baseline Projection

We first consider our model's estimate of the current carbon stock on private lands. Several studies have reported estimates of forest carbon stock for regions that included our study area, but they have all included public as well as private ownerships. As a consequence Table 2.1 shows estimates by carbon pool on a per hectare basis. Methods differ widely across studies. Heath et al (2003) and Birdsey et al (2003) use carbon density approaches based on merchantable inventory similar to ours, while Law et al. (2004) produced a carbon budget for the forested region of western Oregon using a spatially nested hierarchy of field and remote-sensing observations and a process model, Biome-BGC. Our estimates are within the range of previous studies for live biomass and soil carbon but well below the range for dead biomass. Apart from differences in the estimation processes used in all studies to approximate the size of this pool, our value may be lower due to the exclusion of public lands with their large areas of undisturbed old-growth stands and high volumes of large woody debris. Summing across all pools, estimates of the total carbon stock from past studies range from 220 to 388 tonnes/ha. Our total is 214 tonnes/ha.

The baseline projection provides an estimate of carbon stock and harvest potentials of western Oregon private forests when there are no changes in current regulatory policies or market conditions and no carbon tax. Simulation results show that total estimated carbon stock of western Oregon private forests in 2000 is 561 million metric tonnes (Mt) gradually rising to 635Mt by 2065, a 13 percent increment. There is a large net accumulation in the woody debris pool since harvest volumes increase steadily in the near future. At the owner level, carbon stocks on industrial and nonindustrial lands are estimated at 384 Mt and 177 Mt, respectively, in 2000, increasing to 430Mt for industrial lands and 205Mt for non-industrial lands by 2065. For the standing tree and understory biomass which is the pool subject to subsidization and taxes, about 153 Mt and 89 Mt of carbon are stored on industrial lands and nonindustrial lands, respectively, in 2000, increasing to 161 Mt for industrial lands and 99 Mt for nonindustrial lands by 2065.

2.6.2. Change in Average Harvest and Carbon Storage

Implementing the carbon tax system, Table 2.2 illustrates that there is some reduction in harvest and increase in average carbon stock in the standing tree and understory biomass for both owner groups at all tax levels. For low carbon tax levels, average harvest declines only modestly because large near-term reductions are offset by harvests in excess of base levels in later periods. Harvest rises in the longer-term, in part, because of rapidly accumulating inventory. At higher tax levels, harvest remains below the base for most or all of the first 50 years of the projection.

Several factors including management intensity, catastrophic mortality, and harvest can affect carbon in forests. Ignoring uncertainties (e.g., forest fire and insects) and holding all inputs constant, the only way to expand carbon storage in standing trees relative to the baseline is to reduce harvests. Timber production and carbon sequestration are multiple outputs competing for the same land base resource. Table 2.2 provides a trade-off relation between average carbon in standing trees and average timber production. Inspection of the table reveals that industrial lands accumulate more carbon than nonindustrial lands for the same reduction in timber harvest. This is due primarily to the relative productivity of the lands (industry ownerships have higher average site index) and existing age distribution of forests (industry lands have more area in younger age classes).

2.6.3. Change in Investments, Management Activities and Rotation Ages

Additional carbon can also be sequestered, without reducing harvest, by modifying forest management practices and investments such as the species of trees planted, fertilization, and site preparation after harvest. From a carbon perspective, planting is preferable to natural regeneration because it allows earlier forest establishment and growth in total biomass (Turner and Long, 1975). In the market model, however, altering management regimes to increase carbon storage involves costs which lower net social surplus (see equation [5]). Thus, the *a priori* effects of the modification of management regimes and investments caused by the carbon tax are ambiguous.

The distribution of existing and newly planted area (X_t and N_t) across silvicultural regimes over time is endogenous in our model. Projected discounted total investments for silvicultural activities by ownership are shown in Table 2.2. These include costs for site preparation, planting, and management for precommercial thinning and fertilization. As private forest owners reduce harvest in the presence of the carbon tax, total private investment also contracts, but the responses differ by ownership. Industrial owners, owning younger and higher productivity forests, reduce their investment primarily by abandoning regimes that involve treatment beyond regeneration. For a carbon tax of $100, anticipated investments decline by nearly 40 percent relative to the base case, shifting more regeneration activity into plantations rather than natural seeding. Carbon sequestration benefits also encourage NIPF owners' to concentrate activity in plantations, but the result is an expansion of investment by nearly 20 percent relative to the baseline at the $100 tax level. Note that Sohngen and Mendelsohn (2003) found a net increase in private investment in mid-high latitudes in their global analysis.

To illustrate the effects of the carbon tax on management activities, Table 2.3 shows the projected percentage of area by broad type of silvicultural regime for existing and new stands in 2065. For new stands, the proportion of lands allocated to intensive management regimes declines because of the higher near-term carbon taxes even though these promise higher yields and more carbon subsidies in future years. Area allocation to "Regen only" plantation stands increases to more than 50 percent at a $100 carbon tax, since the potential subsidies overweigh plantation costs. In contrast, natural regeneration is less costly but carbon returns are delayed, so this regime is less preferable at high carbon tax levels. The large increases in the share of "Grow only" in existing stands reflect these same considerations. Partial cutting rises, in part, because it allows higher rates of carbon sequestration while avoiding a clearcut and the high tax payment.

Given the benefits of carbon subsidies, forest owners reduce harvest relative to the baseline and, as the carbon tax level rises, the optimal rotation increases. Our results on the area-weighted average rotation ages for various carbon tax levels are shown in Figure 2.1. With the exception of low site quality lands, there are significant differences in rotation age changes by owners and land quality.[4] Rotation age on industrial lands is more sensitive to the carbon tax than on nonindustrial lands. Rotation is particularly sensitive to changes in the tax on low site quality lands at low tax levels. Some single stand studies have found that it may be socially optimal never to harvest stands under very high carbon tax levels. This effect can be seen in Table 2.3 as larger and larger percentages of the total private land base remaining in “Existing stands” in the “Grow only” regime as the tax level rises.

2.6.4. Change in Welfare and Cost-Effectiveness of the Carbon Tax

In this study we differentiate between the direct and indirect costs induced by the carbon tax.[5] Direct costs are the net subsidies or net financial input of the government for achieving a specific level of carbon sequestration, while indirect costs are changes in net social surplus in timber markets which are not intended by the carbon tax policy. The simple theoretical model of the forest owner’s harvest decision in section 2.4 showed that, at least in the short-run, the forest owner will reduce harvest levels under the carbon tax. As a result the aggregate supply of timber from western Oregon private forests is expected to decline. In regional timber markets, this reduction causes a loss of net social surplus (i.e., indirect cost) which is offset by the net subsidy from carbon sequestration (i.e., direct cost) transferred to forest owners.

Under the carbon tax, the regional timber supply curve shifts leftward since forest owners reduce their harvest levels. Responding to a decrease in timber supply, regional wood processors adjust their milling capacity, which leads to a leftward shift in the timber demand curve. As a result, there is a change in the welfare (surplus) positions of market participants. As shown in Table 2.4, introduction of a carbon tax leads to reductions in both consumer and producer surplus. In regional timber markets, timber consumers (wood processors) are always made worse off due to contracting timber supply and rising prices, while timber producers (forest owners) are better off despite lower harvest as a result of the net subsidy payments (producer surplus + net subsidy > 0) except at carbon taxes of $20 per tonne or less. In this latter case, producer losses exceed the subsidy (Table 2.4). If the program were voluntary it presumably wouldn't be adopted for carbon prices in this range.

The hypothetical carbon tax in this study pays owners for changes in the carbon in standing trees and understory biomass, what we've termed "observable" carbon. But some of this carbon would have been sequestered in the absence of the program, so estimating the program's actual carbon costs requires comparison of expenditure with any carbon increments above the baseline or "additional" carbon. Specifically, marginal costs are estimated by the ratio of change in discounted costs to the change in additional carbon sequestration. We compute two marginal costs: marginal project costs and marginal social costs. The former represents the marginal cost of actual government spending (i.e., direct costs) to achieve a given level of carbon sequestration, while the latter indicates the marginal cost that society (including regional wood processors) face. It is computed as the change in net social surplus (i.e., direct and indirect costs). Table 2.4 provides estimates of both average and marginal costs computed in both ways. Marginal and average social costs are substantially higher than the marginal project costs because of the inclusion of consumer and producer losses.

Most past studies on the costs of carbon sequestration in the forest sector differ markedly from ours in methods, geographic scope, and assumptions and nearly all have focused on afforestation of agricultural land as the vehicle for raising net carbon flux. Recent reviews have surveyed these results in an attempt to draw some generalizations about the potential costs of forest carbon sequestration policies (van Kooten et al. 2004, Richards and Stokes 2004, Stavins and Richards 2005). To compare the cost effectiveness of the carbon tax policy for existing private forests in western Oregon, the marginal cost curves in Table 2.4 were recalculated using the normalization procedure suggested by Stavins and Richards (2005).[6] Figure 2.2 shows the marginal cost curves for this study and two previous studies on carbon sequestration costs at the state or regional level using afforestation alone (Stavins 1999, Newell and Stavins 2000, Plantinga et al. 1999). The costs of sequestering carbon in existing private forests in western Oregon lie between Plantinga et al. (1999) for Wisconsin and above those of Newell and Stavins (2000) for Mississippi Delta counties at very low rates of sequestration and in the general range of the Plantinga et al. findings for higher rates.

2.6.5. Effect of a Rising Carbon Tax

Both the total incremental carbon accumulated with the carbon tax as well as the timing of the flux increments are important. Since the benefits and costs obtained from carbon sequestration are discounted, a constant carbon tax level over time implies that carbon sequestered in current or near term periods is more valuable than in the future. In contrast, future carbon uptake is emphasized by a rising carbon tax over time. Several studies using integrated assessment models to compute economically efficient policies to mitigate climate change have estimated that marginal damages from carbon emissions would rise over time (Pearce et al. 1996, Sohngen and Mendelsohn 2003). Van ’t Veld and Plantinga (2005) argued that these findings may support mitigation policies that employ carbon prices rising at roughly the same rate as damages. Our simple model for a forest owner’s harvest decision shows that if the carbon tax level is expected to increase over time above a certain critical rate, at least in the short term, more harvest will occur, which leads to reducing carbon stocks relative to the baseline case. Recent studies have also found that rising carbon prices over time provide incentive to delay carbon sequestration projects and as a result, optimal carbon sequestration under rising carbon prices will supply less than that of a constant price case (van ’t Veld and Plantinga 2005).

We simulated the western Oregon model with different rates of tax growth to examine the effects on carbon sequestration and regional timber markets. Figure 2.3 presents the percent change in average and annualized carbon sequestration and market welfare (both annualized as in the previous section) relative to the constant $10 carbon tax case. Within a range of increasing rates, more carbon is sequestered relative to the constant tax case. Higher rates of increase, however, result in a net reduction in both the average and annualized carbon sequestered relative to the constant tax case, as near-term flux is reduced and long-term flux increased. Although, in initial and near-term periods, increased regeneration harvest may lower total surplus as a result of large carbon taxes, under the high rate of tax increase, future carbon benefits from these regenerated stands may be large enough to outweigh the initial loss. The impacts of a rising carbon tax on market welfare are relatively small. The net social surplus (consumer and producer surplus) in regional timber markets declines slightly as the rate of increase of the carbon tax rises.

2.7. DISCUSSION

This study considers the carbon tax as a policy tool for encouraging carbon sequestration in existing forests (no afforestation options) and examines its welfare and carbon sequestration costs. When both carbon revenues and costs are included in forest management decisions, forest owners will reduce their planned harvests and investments and lengthen the average rotation. Both regional wood processors and forest owners suffer surplus losses in timber markets, but the latter will be at least partially subsidized by carbon payments.

Our results differ from, and extend, past findings in several important ways:

i) Initial inventory conditions and growth potential (site quality) can markedly alter the carbon sequestration-timber harvest trade-offs, as we saw in comparing industrial and NIPF ownerships.

ii) Silvicultural investments will change in response to a carbon tax, with variations depending on inventory and growth potential of the land base.

iii) Modifications of management on existing forest land in western Oregon can be cost competitive with afforestation in sequestering additional forest carbon, even when costs include losses of net social surplus in regional timber markets not considered in other studies. The land productivity and high growth rates of forests in western Oregon relative to other U.S. regions provide the opportunity to consider the carbon tax as a regional mitigation policy in the forestry sector.

iv) Not all rates of carbon tax will attract interest from private owners if participation is voluntary. Results in Table 2.4 indicate that a carbon tax lower than $20 per tonne would not offset private owner losses. This obtains because a net reduction in carbon stock of the standing trees and understory biomass is expected in the baseline by 2042. As a result owners' face a steady stream of near-term tax payments that outweigh the prospect of future subsidy gains until the tax rate exceeds $20/tonne − the gains from lengthening rotation must exceed near-term tax payments. In contrast, when net carbon is sequestered in the baseline, forest owners are willing to participate in the policy even for a very low carbon tax.

This outcome emphasizes the complex and controversial nature of identifying the baseline carbon flux − as recognized in post-Kyoto deliberations − because of non-uniqueness, uncertainties, and leakage (IPCC 2000, Chomitz 2002). In practice, the baseline may be determined by a negotiation process between forest owners participating in the carbon tax program and the government implementing it (Sohngen and Mendelsohn 2003).

Finally, in considering our results it must be recognized that this study provides only partial equilibrium analysis of carbon sequestration and timber markets. The effects of the carbon tax are examined only in the western Oregon timber markets and carbon in western Oregon private forests that are directly affected. Leakage may be expected if we consider the project within a broader spatial or temporal context such as carbon in woody residue in forests, forest products and landfills and the carbon stock of other region's forests (Chomitz 2002, Aukland et al. 2003, Murray et al. 2004).

Footnotes:

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[1] The model includes only three explicit periods. Ovaskainen (1992) discusses the generalization to any number of periods.

[2] The objective function of the maximization problem (1) can also be expressed as: $\pi = p_1H_1 + \beta p_2H_2 + \beta^2 p_3H_3 + p_1^c\alpha(v_1 - v_0) + \beta p_2^c\alpha(v_2 - v_1) + \beta^2 p_3^c\alpha(v_3 - v_2)$, where it is clear that the tax/subsidy is paid on the observed period to period change in inventory.

[3] In practice, additional constraints are required in the model to represent the effects of existing forest policies. Details are given in Adams et al. (2002).

[4] Since most of the low-productivity stands are allocated to partial cutting or reserved lands at high carbon tax levels, change in the average rotation age on these lands is small.

[5] The levelization/discounting approach is employed for benefits and costs of carbon sequestration to account for the timing differences of costs and carbon capture. See Richards and Stokes (2004).

[6] All costs were converted to 1992 dollars using the U.S. Consumer Price Index. Carbon sequestration estimates were converted to equivalent annual carbon flows over a 60-year time horizon, and a 5% discount rate was applied.

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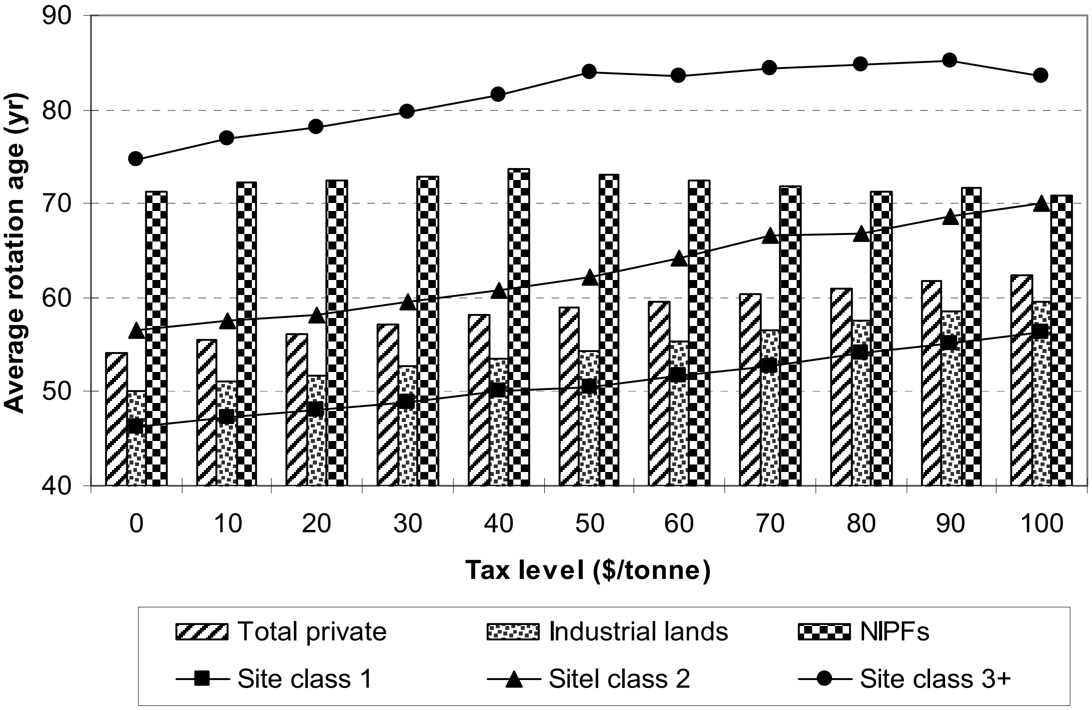

Figure 2.1. Average rotation age relative to the baseline by owners and site classes in western Oregon private forests, 2005-2065.

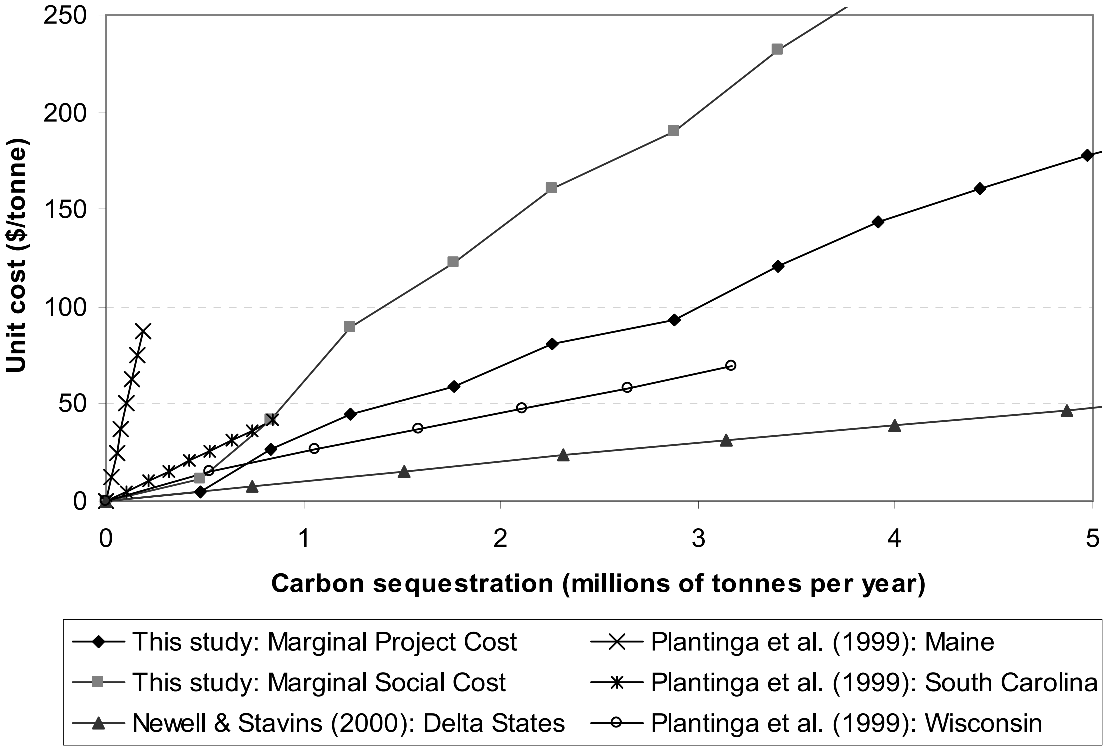

Figure 2.2. Marginal cost curves of carbon sequestration in western Oregon private forests, 2005-2065, with comparisons to results from selected studies examining states and regions.

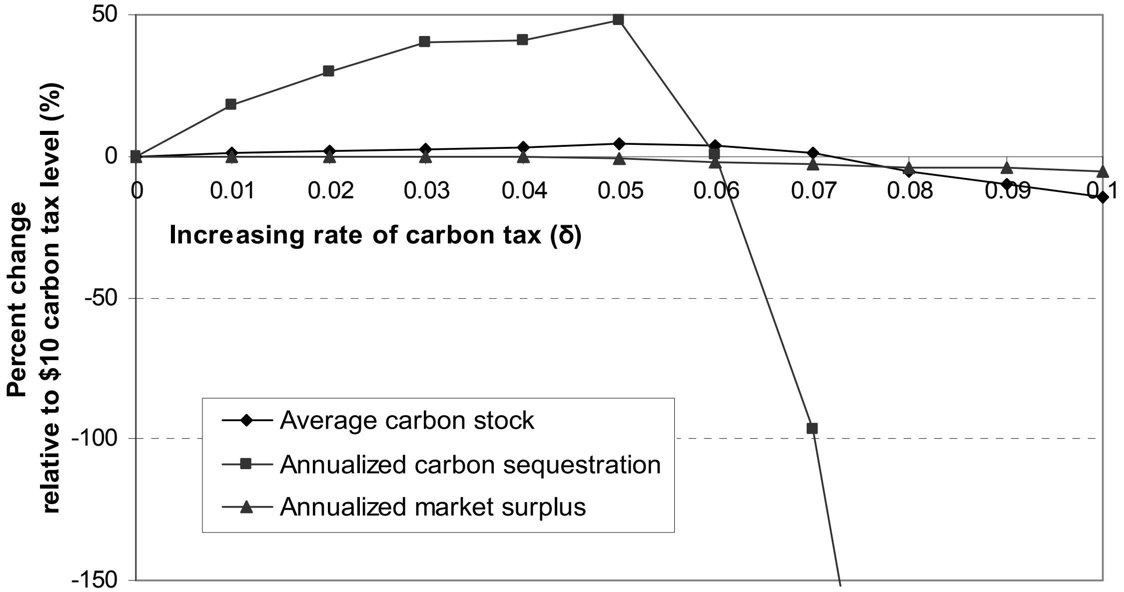

Figure 2.3. Effects of increasing carbon tax on carbon sequestration and market welfare in western Oregon private forests, 2005-2065. Tax rises at rates δ from $10/tonne.

Table 2.1. Alternative estimates of carbon stock (tonnes/ha) from previous studies.

	Region / owners	Area (1,000 ha)	Live biomass	Dead biomass	Soil
Heath et al. (2003)*	WA+OR+CA/ all	36,486	102.8	45.6	91.1
Birdsey et al. (2003)†	OR / all	12,027	82.3	42.4	95.2
Law et al. (2004)	western OR/ all	8,200	128.6 - 196.8	38.4 - 49.5	111.9 - 142.4
This study	western OR/ private only	2,677	87.5	28.4	97.7

Note: * Estimates of carbon stock for Pacific coast region in 1997; and
† Estimates of carbon stock for Oregon in 1997.

Table 2.2. Average harvest, average carbon stock, and discounted total silvicultural investment under various levels of a carbon tax in western Oregon private forests, 2005-2065.

Tax level ($/tonne C)	Average harvest (million ft^3)		Average carbon stock (million tonne C)		Silvicultural Investment (1992 $US million)	
	Industrial	NIPF	Industrial	NIPF	Industrial	NIPF
0	664.6	217.8	148.2	91.6	354.9	75.4
10	653.3	213.2	159.0	96.2	337.4	74.1
20	640.8	212.3	168.4	98.2	328.9	75.4
30	628.4	207.7	179.5	100.7	314.1	76.2
40	613.5	203.9	193.3	104.3	300.1	79.5
50	595.1	200.3	207.7	107.2	292.9	83.5
60	576.9	188.7	223.4	112.0	279.8	87.0
70	559.9	174.0	238.3	115.8	264.6	87.1
80	539.8	165.6	250.8	120.4	246.8	88.9
90	514.7	158.4	264.0	125.5	233.9	89.8
100	494.7	147.0	278.3	129.9	213.6	89.6

Table 2.3. Percent of timberland area allocated to management intensity classes in 2065 in western Oregon private forests.

Tax level ($/tonne C)	Existing stands			New stands			
				Naturally regenerated stands		Planted stands	
	Grow only	Intensively managed	Partial cutting	Regen only	Intensively managed	Regen only	Intensively managed
0	7.5	1.5	7.3	28.8	15.5	16.9	22.5
10	9.0	0.7	6.6	34.0	10.2	16.6	22.9
20	9.6	0.6	7.0	36.0	6.8	17.7	22.4
30	10.0	0.7	8.0	38.7	3.3	18.0	21.4
40	10.8	0.8	8.7	37.5	1.2	21.5	19.6
50	10.6	0.8	11.2	32.0	0.6	29.1	15.7
60	11.7	0.8	13.1	26.2	0.3	35.2	12.8
70	13.5	1.2	14.7	21.2	0.2	40.5	8.8
80	15.3	1.2	14.7	18.9	0.1	43.8	6.0
90	18.0	1.3	14.2	15.4	0.1	48.0	3.0
100	20.4	1.8	14.0	13.0	0.1	49.6	1.2

Note: “Intensively managed” represents the areas receiving precommercial and commercial thinning and fertilization, while “Regen only” represents the areas with no other management activities after regeneration. Percentages sum to 100 across the columns, reflecting the allocation of the full private land base in 2065.

Table 2.4. Annualized change in welfare, net subsidy, and carbon sequestration and the marginal and average costs under the carbon tax in western Oregon private forests, 2005-2065.

Tax level ($/tonne)	Market surplus ($ million)		Net subsidy ($ million)	Carbon sequestration (1,000's tonnes C)	Marginal project cost ($/tonne C)	Marginal social cost ($/tonne C)*	Average project cost ($/tonne C)	Average social cost ($/tonne C)
	Consumer surplus	Producer surplus						
0	0.0	0.0	0.0	-308	0.0	0.0	0.0	0.0
10	-0.9	-3.0	1.8	182	3.7	11.6	3.7	11.6
20	-1.7	-8.6	11.0	550	25.0	42.5	12.8	24.9
30	-14.0	-16.9	28.6	952	43.7	94.8	22.7	47.2
40	-38.4	-31.6	59.7	1,492	57.6	130.2	33.2	72.1
50	-66.3	-48.5	99.8	1,996	79.6	168.7	43.3	93.2
60	-104.2	-74.8	157.0	2,617	92.1	195.4	53.7	114.9
70	-139.0	-100.4	219.6	3,137	120.3	236.3	63.7	133.2
80	-175.0	-128.3	291.3	3,641	142.2	268.9	73.8	150.6
90	-215.0	-160.3	374.1	4,157	160.7	300.4	83.8	167.8
100	-260.5	-197.4	470.1	4,701	176.4	328.5	93.9	185.3

Note: All monetary amounts are in 1992 dollars; annualized consumer and producer surplus of baseline is $992 and $1,597 million, respectively; discount rate is 6%; and * marginal social cost = (decrease in net social surplus + increase in net subsidy)/(increase in carbon sequestration)

CHAPTER 3

THE EFFECTS OF RECOGNIZING PRODUCT AND RESIDUE POOLS ON THE COST-EFFECTIVENESS OF FOREST CARBON SUBSIDY PROGRAMS

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(will be submitted to *Ecological Economics*)

3.1. ABSTRACT

This study employed a market level analysis of a carbon subsidy and tax program to examine the effects of recognizing forest product and on-site residue pools on the costs of sequestering carbon in existing forests. The “instant tax” treating products and residues as instant emissions accumulates a substantial amount of additional carbon in the timber inventory. Inclusion of product and residue pools in the “extended tax” provides much less incremental carbon because of the trade-off between carbon in the timber inventory and in product and residue pools. Under both tax programs, regional wood processors and timber suppliers are made worse off by reduced private timber supply. Market welfare losses under the instant tax are barely offset by subsidy payments, while net subsidies exceed combinded welfare losses under the extended tax, suggesting that a redistribution system might make the tax attractive to all market participants. The marginal opportunity costs for private forest owners under both tax programs are similar and fall within ranges found in previous stand-level studies. Recognizing products and residues in the carbon tax substantially increases marginal project costs compared to the instant tax and relative to costs found in previous studies for afforestation projects in some regions of the eastern United States.

3.2. INTRODUCTION

Under the Kyoto Protocol and subsequent negotiations, signatories are allowed to create carbon sinks through programs aimed at modifying forest management activities, such as lengthening rotations or altering silvicultural treatments, as well as traditional afforestation actions. In all programs the Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC 1997) recommend that all carbon in products and on-site residues generated by any timber harvest be treated as a loss or “instant emission.” To motivate private owners to modify their timber management activities, economists have considered carbon subsidy and tax programs (a “carbon tax”) that provide payments when carbon accumulates and impose taxes when timber and carbon are removed. In examining the effects of carbon tax programs, most past studies have focused on the stand level, considering the changes in optimal rotation by means of the Hartman (1976) variant of the classical even-aged Faustmann model. Some of the stand level analyses have considered the ramifications of including products as long-lived pools in assessing the tax and subsidy, but most studies have treated on-site residues as instant emissions consistent with IPCC guidelines (IPCC 1997).

Inclusion of these additional pools can have an impact on stand-level management. For example, van Kooten et al. (1995) in a stand-level study with fixed prices found that more carbon is stored in timber inventory (i.e., rotation ages are extended) when these pools are treated as an instant emission than when all carbon in forest products is permanently reserved. Large scale tax programs, however, can be expected to change timber supplies and hence current and future prices in forest products markets. Fewer studies have examined the effects of carbon taxes in such a market context, and it appears that all of these have treated product and residue pools as instant emissions (Adams et al. 1999).

This study employs a market level analysis of the carbon tax to consider the effects of including product and residue carbon pools on the costs of sequestering carbon through management changes. Under the carbon tax, forest owners are subsidized for the carbon uptake resulting from growth of the timber inventory in forestlands, while a tax for the carbon released by harvesting depends on the assumption about residue and product carbon pools. If these pools are assumed to be instantly oxidized into the atmosphere when harvesting occurs, all carbon in timber harvested is subject to taxation at the time of removal, but inclusion of these pools in the carbon tax system will lead to the tax installment over time as these pools are gradually oxidized into the atmosphere. To examine the market and carbon impacts of excluding or including residue and product carbon pools in the carbon tax mechanism, we construct a model of the log market in the western part of the state of Oregon, USA. Our results on the mass of carbon sequestered and on the marginal costs per additional unit of carbon under alternative assumptions about residue and product carbon pools are compared with those of previous studies.

3.3. A MODEL OF PRIVATE OWNERS’ RESPONSE TO THE CARBON TAX

The supply of logs to the regional markets is based on private forest owners’ decisions about harvest timing and silvicultural practices to optimize the value of their timber investments given stand growth, interest rates, management costs, and price expectations. For forest owners, since introduction of the carbon tax provides additional income and cost in management activity, their land-use decisions would be adjusted so as to maximize their management objectives under new circumstances. In the market context, forest owners' responses to the carbon tax are realized as changes in total supply of timber from private lands and, in consequence, affect the equilibrium of timber markets. To estimate these market and carbon sequestration impacts of the carbon tax, we develop a market-level model that maximizes social welfare from the carbon tax mechanism given initial inventories and assumptions about stand growth, silvicultural practices, and land-use changes. The model is based on the western Oregon portion of a timber market model described by Adams and Latta (2007). For simplification, the social welfare function is assumed to be additively separable between social surplus in timber markets and social benefits from carbon sequestration.

The social welfare from consumption and production of timber is measured as consumer and producer surplus (i.e., net social surplus) in timber markets. The regional willingness to pay for logs by wood processors (computed as the area under the derived demand function for logs in western Oregon) less the costs of timber supply such as harvesting, log transport, and silvicultural practices yields the net social surplus (Samuelson 1952). The social benefit from reducing carbon emissions to the atmosphere is represented by net subsidies paid for carbon sequestered by modifying management activities in existing forests. Current and future emissions of carbon would arise from woody debris and dead trees already on the ground, from wood and paper products in use, and from the disposal of products through burning and decay in landfills. Subsidies (or taxes) would be paid to (or by) forest owners according to the change of carbon stock on their forest lands, including woody residue and forest products originating from their harvests. When product and residue carbon pools are treated as instant emissions in carbon accounting, only the carbon flux in standing trees and understory is subject to subsides and taxes.

Log demand would shift depending on product prices, technology, nonwood costs, and mill capacity. In the arbitrage of the market, log buyers (regional wood processors) trade off possible log sources until their costs are as low as possible for their level of output. Thus, we assume that regional wood processors can adjust their mill capacity (capital stock) varying with product prices, equipment costs, depreciation, and interest rate. All costs associated with these capacity adjustments (i.e., capacity expansion and maintenance costs) are deducted from the consumers' surplus in the timber markets.

3.3.1. Mathematical Formation

Suppose private forestlands in western Oregon are divided into a number of management units, J, and each unit, j, has a homogeneous characteristic in terms of land class, forest type, stand size, tree stocking, and management prescription. Each management unit, m, is managed under some mix of silvicultural regimes composed of uneven- and even-aged management regimes. Let $X_{j,m,t}$ be the area of management unit j existing at the start of the projection allocated to management prescription m that will be cut in period t, $N_{j,m,k,t}$ be the area of management unit j that was regenerated in period k, to be cut again in period t, in management prescription m, and CE_t be the quantity of capital stock purchased in period t, where $j = 1, 2,\ldots, J$, $m = 1, 2,\ldots, M$, $k = 0, 1,\ldots, K(< t)$, and $t = 0, 1, \ldots, T$.

Then, a simple mathematical form of the intertemporal market model is as follows:

$$\begin{aligned} \underset{\left\{\substack{X_{j,m,t},\\ N_{j,m,k,t},CE_t}\right\}}{Maximize} \quad & \sum_{t=0}^{T-1}\left[\int_{q=0}^{Q_t} P_t(q,K_t)dq - k_m K_t - k_u CE_t - CH_t(S_t)\right](1+r)^{-t} \\ & + \sum_{t=1}^{T-1}\sum_{j=1}^{J} p_t^c CS_{j,t}(1+r)^{-t} + \left[\int_{q=0}^{Q_T} P_T(q,K_T)dq - CH_T(S_T)\right] r^{-1}(1+r)^{-T} \end{aligned} \tag{1}$$

subject to:

$$\sum_{m=1}^{M}\sum_{t=0}^{T-1} X_{j,m,t} = A_j \qquad \forall\ j \tag{2}$$

$$\sum_{m=1}^{M}\sum_{h=t+1}^{T-1} N_{j,m,t,h} \le \sum_{m=1}^{M} X_{j,m,t} + \sum_{m=1}^{M}\sum_{k=0}^{K} N_{j,m,k,t} \qquad \forall\ j,t \tag{3}$$

$$S_t = \sum_{j=1}^{J}\sum_{m=1}^{M} X_{j,m,t}V_{j,m,t}^{X} + \sum_{j=1}^{J}\sum_{m=1}^{M}\sum_{k=0}^{t-1} N_{j,m,k,t}V_{j,m,t-k}^{N} + Z_t \qquad \forall\ t \tag{4}$$

$$Q_t = S_t \qquad \forall\ t \tag{5}$$

$$K_t = (1-\tau)K_{t-1} + CE_t \qquad \forall\ t \tag{6}$$

$$\lambda K_t \ge Q_t \qquad \forall\ t \tag{7}$$

$$\begin{aligned} CS_{j,t} = {} & [CS_{j,t}^{F} - CS_{j,t-1}^{F}] + [\alpha_{j,t}CS_{j,t}^{H} - \sum_{k=1}^{t-1}\delta_{j,t-k}\alpha_{j,k}CS_{j,k}^{H} - \delta_{j,t}R_{j,0}] \\ & + [\beta_{j,t}CS_{j,t}^{H} - \sum_{k=1}^{t-1}\lambda_{j,t-k}\beta_{j,k}CS_{j,k}^{H} - \lambda_{j,t}W_{j,0}] + \gamma_{j,t}CS_{j,t}^{H} \qquad \forall\ j,t \end{aligned} \tag{8}$$

$$CS_{j,t}^{F} = \sum_{k=t+1}^{T}\sum_{m=1}^{M} X_{j,m,k}CS_{j,m,t}^{X} + \sum_{k=t+1}^{T}\sum_{s=0}^{t}\sum_{m=1}^{M} N_{j,m,s,k}CS_{j,m,t-s}^{N} \qquad \forall\ j,t \tag{9}$$

$$CS_{j,t}^{H} = \sum_{m=1}^{M} X_{j,m,t}CS_{j,m,t}^{X} + \sum_{m=1}^{M}\sum_{k=0}^{t-1} N_{j,m,k,t}CS_{j,m,t-k}^{N} \qquad \forall\ j,t \tag{10}$$

where Q_t is total western Oregon softwood sawlog consumption at mills in period t, Z_t is net import and public softwood harvest sawlog volume in period t, A_j is the area in existing stands that were in management unit j at the initial period, $P_t(q, K_t)$ is the derived demand for softwood sawlogs in period t, a function of quantity q and current capacity, $CH_t(S_t)$ is the costs for producing the total supply of softwood sawlogs, S_t, including all management, harvesting, and transport costs in period t, Q_T is average annual softwood sawlog consumption in the post-projection period, K_t is the quantity of capital stock in period t measured as maximum log processing capacity, k_m is the per unit cost of maintaining capital stock, k_u is the per unit cost of purchasing capital stock, τ is the depreciation rate of capital stock, λ is the maximum capital stock utilization rate, r is the discount rate, $p^c{}_t$ is the unit carbon tax at time t, $V^X{}_{j,m,t}$ and $CS^X{}_{j,m,t}$ are the softwood volume and the carbon stock in the standing tree, forest floor, and understory biomass in management unit j existing at the start of the projection allocated to management prescription m that will be cut in period t, respectively, $V^N{}_{j,m,k,t}$ and $CS^N{}_{j,m,k,t}$ are the softwood volume and the carbon stock in the standing tree, forest floor, and understory biomass in management unit j that was regenerated in period k, to be cut again in period t, allocated to management prescription m, respectively, $\alpha_{j,t}$, $\beta_{j,t}$, and $\gamma_{j,t}$ are the proportions of carbon in timber harvested in management unit j at period t stored (used) as woody residue, forest products, and fuel wood, respectively, with $\alpha_t + \beta_{j,t} + \gamma_{j,t} + \varepsilon_{j,t} = 1$ where $\varepsilon_{j,t}$ is the proportion of carbon instantly emitted at period t in management unit j, $\delta_{j,t}$ and $\lambda_{j,t}$ are the proportions of carbon emission in woody residue and forest products in (originated from) management unit j at period t, respectively, with $\sum_{k=0}^{\infty} \delta_{j,k} = 1$ and $\sum_{k=0}^{\infty} \lambda_{j,k} = 1$, and $R_{j,0}$ and $W_{j,0}$ are the initial carbon stocks in woody residue and forest products in (originated from) management unit *j*, respectively, at period *t*. Under the assumption treating product and residue carbon pools as instant emissions, equation (8) becomes:

$$CS_{j,t} = [CS^{F}_{j,t} - CS^{F}_{j,t-1}] \qquad \forall\ j,t \tag{8′}$$

The objective function (1) is comprised of three parts: (i) the net social surplus from timber markets; (ii) social benefits from carbon sequestered in forests, woody residue, and forest products; and (iii) net social surplus from a fixed periodic flow of sawlogs in all periods after *T* based on the terminal period's inventory. Constraints (2) and (3) are the dispositions of the total inventory area among existing and regenerated stands assigned to some management prescriptions. Constraints (4) and (5) are the log market balance equations indicating that total supply of timber to the market including net import and public harvest and demand-supply balance. Constraints (6) and (7) are the capacity control equations that indicate the definition of the change in capital stock over time as investment less depreciation and capacity operating rate. Constraints (8) to (10) represent the carbon in the standing trees, forest floor, understory, woody residue, and forest products.

Projections are made for 100 years with a 5-year time step. In this paper, however, we examine only the first 60 years of the projection as the relevant policy period and to avoid undue influence of the terminal conditions. The simulations reported here use a real discount rate of 6 percent for all owners. In this mathematical form, for simplification, net log imports from other regions (Z_t in equation (4)) are expressed as exogenous variables, but our model explicitly recognizes social surplus in export and import log markets and net imports are determined through interactions between these markets. Details are given in Adams et al. (2002) and Schillinger et al. (2003) along with assumptions about public harvest levels, log export and import markets, future prices of products and of labor and other variable inputs. The model is nonlinear but was solved as a linear program through a piece-wise linearization approach and a Gauss-Seidel fashion approximation (Montgomery et al. 2004, p 253).

3.3.2. Carbon Accounting in Forests and Residue and Product Pools

A number of previous studies have estimated carbon storage in the forest ecosystem by combining forest inventory data on “merchantable” stand characteristics with carbon densities for various components of stand biomass and the soil (Birdsey 1992, Turner et al. 1995, and Heath et al. 2003). To estimate carbon in forest products, several studies have employed an approach for accounting actual stocks and flows of carbon from forests to wood and paper products in use, to dumps or landfills, and to burning and emissions from decay (Row and Phelps 1996, Skog and Nicholson 2000). We followed these same approaches for estimating carbon storage in western Oregon private forests and forest products (Equation (8) to (10) in the mathematical form of the market model). Carbon budgets were constructed using the merchantable volume yield projection derived from ORGANON (Hann et al. 1997) and carbon densities and estimates of carbon in understory and soil reported in previous studies and tracking logs consumed in markets and carbon deposition trough to end uses such as housing and paper.

Carbon storage in a stand is composed of five pools: tree, understory, forest floor, woody debris, and soil. The yield projections are converted to total tree carbon using multipliers for merchantable-to-total biomass and the carbon proportion of biomass using conversion factors reported by Birdsey (1992). Estimated carbon in understory vegetation (herbs and shrubs) and in mineral soil is based on Birdsey (1992). Forest floor carbon was estimated by converting the amount of organic matter in litter and dead trees obtained from Gholz's (1979) equations to carbon stock equivalents. The current carbon storage in woody debris is calculated from the past 50 years' harvest data. We employed different decay rates for above- and belowground woody debris and forest types based on the previous studies (Edmonds 1987, Chen et al. 2001).

Carbon in western Oregon log market production and consumption was projected through 2065, beginning in 2005, tracking each period's wood harvest, import, and export through to its final disposition. The timber allocated to sawmills, pulp mills, plywood plants, and other manufacturers is divided into primary product and utilized/unutilized mill residue based on the Forest Service's timber assessment for the Pacific Northwest region (Haynes 2003) and a statewide census of Oregon's primary forest products industry and out-of-state mills that received timber from Oregon during 2003 (see Figure 8 in Brandt et al. (2006)). Carbon in solid wood and pulp products is estimated for several end-use categories to calculate the time carbon remains sequestered in these products after disposal in dumps and landfills. The current carbon sock in forest products was estimated using the past 50 years' harvest data in western Oregon.

3.4. RESULTS AND DISCUSSION

Using the market model described in section 3.3, we projected harvest, price and capacity investment behavior in western Oregon timber markets under a range of unit carbon values (p^c_t $/tonne), including and excluding products and residues in the carbon accounting. These results provide the basis for estimating the effects of the treatments of product and residue carbon pools on timber harvest, market welfare, and the costs of sequestering carbon in existing forests.

3.4.1. Carbon Sequestration, Product Leakage, and Additionality

Forest management activities with periodic harvests can sequester carbon on-site (timber inventory and residue) and off-site (forest products). If all carbon in harvested trees is assumed to be lost when harvesting occurs, however, these activities create a carbon sink only in the timber inventory. Table 3.1 illustrates the annualized discounted carbon sequestration by alternative treatments of product and residue pools under the carbon tax programs. The carbon tax case where we treat carbon in products and residues as instant emissions ("instant tax") would create a much larger carbon sink in live and dead biomass in forests compared to the case when these carbon pools are gradually released ("extended tax"). For a carbon tax of $50 per tonne, the instant tax program can accumulate nearly 2 million tonnes per year of carbon in the live and dead biomass in forests. But private forest owners in western Oregon will supply about 1.1 million tonnes C in these pools under the extended tax program. This is due primarily to the difference in average rotations and management practices between both programs. That is, longer average area-weighted rotations are obtained in the instant tax program than in the extended tax program. As a result, for a \$50 carbon tax, the average harvest in the former declines nearly 10 percent relative to the baseline, while the latter declines by only 4.6 percent. In both programs, management investment shifts so that avoiding regeneration harvests in existing stands is the preferred action relative to the no-tax case (the baseline), but more lands are set aside as this regime under the instant tax program. For newly established stands, intensive management regimes are less preferred in both programs relative to the no-tax case. Under the extended tax, however, area allocation to these regimes in planted stands is considerable because commercial thinning become less costly due to product and residue carbon pools, while promising higher yields and more carbon subsidies in future year.

Under the extended tax, carbon sequestration in forest products and woody residues declines for all carbon tax levels relative to the baseline because of reduction in timber harvests, while under the instant tax system carbon sequestered in off-site products and on-site residues is ignored. The no-tax case is expected to obtain about 2.2 million tonnes per year of carbon in product and residue pools by 2065 in western Oregon private forests, which markedly outweighs the loss of carbon sequestration in live and dead biomass (-307.9×10^3 tonnes C) on these lands. From these points, as the carbon tax rate rises, the extended tax program will expand carbon sinks in timber inventory by reducing timber harvests leading to lower carbon sinks in products and residues. For a low carbon tax level, overall carbon accumulation (trees plus products and residues) under the extended tax program is much higher than that of the instant tax program (ignoring products and residues). At tax levels of $80 or higher, however, tree carbon alone under the instant tax system exceeds tree plus product and residue carbon in the extended tax.

A carbon tax policy in western Oregon will also affect carbon fluxes in other regions through log and product trade. We estimated leakage via the log market through change in the net import of logs to western Oregon timber markets under the extended tax program. As the carbon tax rate rises, leakage from log export and import markets also increases.

The additional carbon sequestration obtained by the carbon tax programs is measured as changes in on-site and off-site carbon sinks shown in Table 3.1. The instant tax case can remove substantially more atmospheric carbon than the extended tax. For a $50 carbon tax, for instance, forest owners will sequester 2.3 million tonnes per year of additional carbon in the instant tax program, while less than one million tonnes of incremental carbon will be accumulated in the extended tax program. In fact the expansion in additional carbon as the tax rate rises (Table 3.1) in the extended tax is consistently smaller than under the instant program. This reflects the trade-off between inventory and product-residue pools faced under the extended program. Under the extended tax program, reduction in timber harvest to gain subsidies from expanding carbon in timber inventory causes reductions in subsidies from product and residue pools. Under the instant tax, in contrast, private owners can reduce their harvests ignoring carbon payment from product and residue pools.

The effect of product leakage on additionality of carbon in the extended case is relatively small in western Oregon. Note, however, that the leakage estimate in this study does not include carbon changes in woody residue or timber inventory in other regions and product substitution with other industrial materials as this study provides only partial equilibrium analysis of the regional timber markets. Recent national level analyses on forest carbon sequestration programs suggested that leakage potential could be substantial in some cases (Sohngen and Brown 2004, Murray et al. 2004).

3.4.2. Market Welfare and Carbon Subsidies

The carbon tax programs cause some direct and indirect costs to society. In this study, the direct costs are measured as financial input (i.e., net subsidies) of the government for achieving a specific target of carbon sequestration, while the indirect costs indicate an unintended change in net social surplus in timber markets. The latter is stimulated by log market adjustments between log suppliers (private and public owners and log importers) and regional wood processors. The carbon tax shifts the log supply curve of the forest owners, which affects the equilibrium prices of log markets and ultimately leads to shifts in the log demand curve for regional wood processors through adjustment of milling capacity. As a result, market participants (consumers and producers) face both welfare gains and losses. Imposition of carbon taxes lowers the net social surplus in western Oregon timber markets due to reductions in log supply from private lands as illustrated in Table 3.2. Market welfare loss in the instant tax program is substantially higher as less private timber supply is anticipated than in the extended tax program. For a carbon tax $50 per tonne, both regional wood processors and timber suppliers suffer nearly $39 million per year of the market surplus loss under the extended tax program relative to the no-tax case, but this loss rises nearly threefold in the instant tax program.

Under the carbon tax programs, subsidies are provided to private forest owners to compensate for their market surplus (timber income) losses due to management changes. For a low carbon tax, subsidies in the extended tax program are substantially larger than in the instant tax program. But for an $80 or higher carbon tax, incremental carbon in the inventory pool alone under the instant tax exceeds incremental carbon in both inventory and product-residue pools under the extended tax. Thus forest owners will receive more carbon subsidies in the instant tax program. This is another manifestation of the trade-offs between the inventory and product-residue carbon pools imposed on owners under the extended tax.

Overall social welfare (net social surplus plus net subsidy in Table 3.2) of the instant tax program is negative for many carbon tax rates because of large reductions in market surplus, while overall welfare is positive for all carbon tax levels in the extended tax program. For a $50 carbon tax, the instant tax program causes $15 million per year of social welfare loss, but under the extended tax program consumers and producers gain $108 million per year relative to the no-tax case. Thus, if there is a redistribution mechanism between market participants, the extended tax would presumably be welcomed by both regional wood process and timber suppliers.

3.4.3. Cost Effectiveness of the Carbon Tax

Cost-effectiveness has been recognized as a primary criterion to be used in formulating and implementing policies for mitigating climate change. Under the carbon tax, some of the carbon sequestered would have been accumulated in the absence of the program, so estimating the program's actual carbon costs requires comparison of expenditure with carbon increments above the baseline or "additional" carbon. That is, the carbon tax is evaluated in terms of additional carbon sequestered and the marginal costs for achieving it. Two types of marginal costs are derived in this study: the marginal opportunity cost for private forest owners in western Oregon and the marginal project cost from policy maker's perspective. The former represents the slope of the production possibility frontier between the present value of timber income and discounted (annualized) carbon sequestration. From the forest owners' perspective, it indicates how much timber income would be lost to expand carbon sinks by one unit through changes in management activities. From a policy maker's perspective, the marginal project cost depends solely on net subsidies (public outlays) of achieving a given level of carbon sequestration that may, in turn, be compared to the outlays required for other forestry-based mitigation strategies.

As shown in Table 3.2, sequestering one additional unit of carbon under the instant tax program may require forest owners to abandon between $11 and $73 per tonne C of timber income for carbon tax rates ranging from $10 to $100 per tonne C. Slightly more timber income must be given up under the extended tax program. In a stand-level analysis, Murray (2000) estimated that marginal opportunity costs for Douglas-fir in the

U.S. Pacific Northwest ranged from $4 to $45 per tonne at a carbon price ranging from $10 to $50 per tonne. As a contrast, Huang and Kronrad (2001) reported the average costs for sequestering one unit tonne of additional carbon ranged from $19 to $114 on existing loblolly pine plantation stands in the South and from $2 to $13 on unstocked lands. Our average costs for the forest owners vary from $11.0 to $52.8 depending on the form of the carbon tax, falling between their average costs of existing and plantation stands.

In our analysis, the marginal project costs of sequestering 0.5 to 5 million tonnes per year of additional carbon vary from $3.7 to $176.4 per tonne under the instant tax program. Including product and residue carbon pools in the tax system significantly increases these costs, the range rising to $78.4 to $311.3 per tonne for carbon increments from 0.3 to 2.0 million tonnes per year. Under the extended program the private owners are concerned about all carbon pools in forests and forest products and the trade-offs among those pools when they alter their management activities. As a result, a relatively small amount of additional carbon is sequestered for an increment in the carbon tax.

Subsidies are larger under the extended tax because the carbon pool subject to the program is larger than the instant case. As the tax rate rises (see Table 3.2) the increments in subsidies are larger and the increments in carbon are smaller than the instant case, leading to substantially higher marginal project costs in the extended program.

Most past studies of marginal forest carbon costs in the U.S. have not considered market adjustments and have focused on afforestation projects on agricultural lands rather than management modifications in existing forests (see, for example, Stavins and Richards, 2005, for a summary). To compare our results with these earlier studies, we recalculated our marginal project costs using the normalization procedure suggested by Stavins and Richards (2005).[1] Figure 3.1 shows the marginal cost curves for this study and two previous studies at the state or regional level using afforestation alone (Plantinga et al. 1999, Stavins 1999, Newell and Stavins 2000). The marginal project costs of the instant tax program lies between those from Plantinga et al. (1999) for Wisconsin and above those of Newell and Stavins (2000) for Mississippi Delta counties. The extended tax program, however, entails costs at or above the highest levels found in the Plantinga et al (1999) analysis.

3.5. CONCLUSIONS

This study employed a market level analysis of a forest carbon tax program to examine the effects of including product and residue pools on the costs of sequestering carbon through management changes in existing forests. The "instant tax" case, where forest products and on-site residues are treated as instant emissions, accumulates a substantial amount of additional carbon in the timber inventory by reducing harvests and lengthening average rotation. Inclusion of product and residue carbon pools in the "extended tax" system provides much less incremental carbon because of the trade-offs between carbon in the timber inventory and in product and residue pools. Under both carbon tax programs, reduced timber supply makes regional wood processors and timber suppliers worse off. Subsidy payments under the instant tax barely offset combined supplier plus processor welfare losses at only two of the tax rate levels examined. In contrast, net subsidies exceed market welfare losses at all tax rates under extended tax system, suggesting that a redistribution system might make the tax attractive to all market participants.

Our average and marginal opportunity costs for private forest owners under both carbon tax cases are similar and fall within ranges found in previous stand-level studies. This is due in part to the fact that the log demand of timber consumers (regional wood processors) shifts through capacity adjustment, hence the impact of the tax programs on stumpage prices is relatively small and the costs to log processors in both the instant and extended tax cases are similar. We find that inclusion of product and residue pools in the carbon tax substantially increases marginal project costs compared to the instant tax case and relative to costs found for afforestation projects in some regions of the eastern United States. Under the extended carbon program, net subsidies are large but a relatively small increment in carbon is obtained due to the trade-off between the inventory and product-residue carbon sinks, which produces markedly higher marginal project costs in this program.

Footnotes:

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[1] All costs were converted to 1992 dollars using the U.S. Consumer Price Index. Carbon sequestration estimates were converted to equivalent annual carbon flows over 60-year time horizon, and a 5% discount rate was applied.

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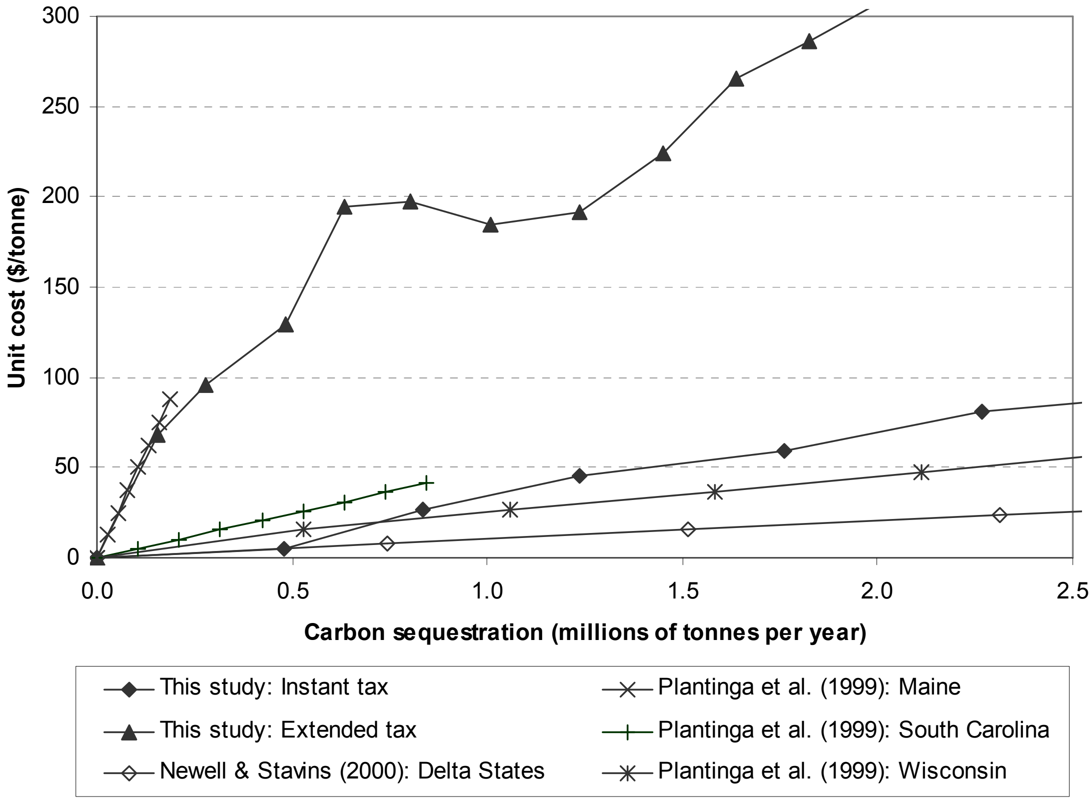

Figure 3.1. Marginal cost curves of carbon sequestration in western Oregon private forests, 2005-2065, with comparisons to results from selected studies examining states and regions.

Table 3.1. Annualized discounted carbon sequestration by alternative treatments of product and residue pools under the carbon tax programs in western Oregon private forests, 2005-2065.[*]

Tax level ($/tonne C)	Instant tax program (Excluding carbon in forest products and residue pools)		Extended tax program (Including carbon in forest product and residue pools)				
					Carbon in forest products		
	Carbon in live and dead biomass[†]	Additional carbon sequestration	Carbon in live and dead biomass[†]	Carbon in woody residue	WO private harvest	Net log trade (Imp. – Exp.)	Additional carbon sequestration[‡]
	………… 1,000’s of tonnes C per year …………						
0	-307.9	0.0	-307.9	1,132.4	1,082.2	151.7	0.0
10	182.4	490.3	53.4	1,101.6	1,038.4	158.6	279.7
20	550.3	858.1	344.1	1,071.0	994.4	167.9	486.5
30	952.3	1,260.2	566.7	1,042.5	957.0	177.5	633.5
40	1,492.0	1,799.9	808.1	1,012.1	916.6	187.0	794.7
50	1,995.7	2,303.6	1,105.7	971.0	864.7	190.4	996.0
60	2,617.0	2,924.9	1,448.0	919.8	798.9	194.1	1,217.5
70	3,137.4	3,445.2	1,772.2	870.7	736.2	199.7	1,424.4
80	3,641.4	3,949.3	2,059.7	824.3	677.4	201.7	1,604.6
90	4,156.8	4,464.7	2,348.0	778.1	619.5	206.4	1,784.1
100	4,700.5	5,008.4	2,640.8	729.1	558.9	210.4	1,963.3

Note: [*] 6% of the discount rate is applied; [†] Carbon in the standing trees, forest floor (excluding on-site harvest residues), and understory; and [‡] Product leakage from log trade is included.

Table 3.2. Annualized change in market welfare, net subsidy, and the marginal costs of carbon sequestration by alternative treatments of product and residue pools under the carbon tax programs in western Oregon private forests, 2005-2065.[*]

Tax level ($/tonne C)	Instant tax program (Excluding carbon in forest products and residue pools)				Extended tax program (Including carbon in forest product and residue pools)			
	Net social surplus in WO log markets ($ million)[†]	Net subsidy for carbon sequestration ($ million)	Marginal costs for WO private owners ($/tonne C)	Marginal project costs ($/tonne C)	Net social surplus in WO log markets ($ million)[†]	Net subsidy for carbon sequestration ($ million)	Marginal costs for WO private owners ($/tonne C)	Marginal project costs ($/tonne C)[‡]
0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10	-3.9	1.8	11.0	3.7	-2.4	21.9	11.6	78.4
20	-10.3	11.0	21.4	25.0	-6.2	48.2	24.3	126.9
30	-30.9	28.6	24.9	43.7	-10.3	77.0	33.9	195.9
40	-70.0	59.7	30.4	57.6	-18.9	109.5	39.2	201.5
50	-114.9	99.8	37.6	79.6	-38.9	147.1	40.0	186.8
60	-179.0	157.0	46.1	92.1	-64.7	190.0	47.6	193.8
70	-239.4	219.6	53.7	120.3	-91.3	236.5	56.7	224.9
80	-303.3	291.3	59.7	142.2	-119.6	284.9	62.1	268.4
90	-375.2	374.1	66.5	160.7	-147.5	337.1	70.1	290.8
100	-457.9	470.1	73.0	176.4	-179.5	392.9	78.8	311.3

Note: [*] All monetary amounts are in 1992 dollars and 6% of the discount rate is applied; [†] Annualized net social surplus in WO log markets in the baseline is $2,588 million; [‡] Product leakage from log trade is included.

CHAPTER 4

THE IMPACTS OF CHANGES IN FEDERAL TIMBER HARVEST ON FOREST CARBON SEQUESTRATION AND LOG MARKETS IN WESTERN OREGON

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4.1. ABSTRACT

This study examines the potential impacts of raising federal timber harvest on carbon sequestration in forests and forest products and log markets. We construct a dynamic model of western Oregon log markets in which market prices and timber harvests from private, federal, and state forest in western Oregon are explicitly modeled. Simulation results suggest that regional carbon flux in forests and forest products will gradually decline as harvest rises from federal timberlands. Higher federal cut leads to increments in consumer and total producer surplus. Payments to federal agencies rise faster than the losses of private and state forestland owners, so aggregate producer surplus expands. Projections of harvest by ownership given the constraint of a regional carbon target show that there are significant opportunities for substituting timber harvest and carbon sequestration between federal and non-federal lands in western Oregon. A relatively small reduction in non-federal harvest would offset a substantial loss of carbon flux on federal timberlands. This is possible in part by lengthening rotation ages, shifting the concentration of harvest within an ownership toward stands with lower levels of carbon storage, and by modest reduction in cut. Similar levels of carbon sequestration could be achieved if a carbon offset market were available for all owners, including federal agencies. The marginal welfare cost derived from the shadow price of the carbon target constraint is the market price of carbon that could produce the same flux as the constraint.

4.2. INTRODUCTION

The Northwest Forest Plan (NWFP, also called the “President’s Plan”) was established in the mid-1990s at the request of President Clinton to meet the need for late-successional forest habitat for certain endangered species, while providing some level of federal timber harvest to support Pacific Northwest processing industries. In western Oregon alone, the NWFP authorized annual harvests from federal lands of approximately 600 million board feet (USDA and USDI 1994a: 3&4-265). This timber harvest level has never been implemented, however, due to changes in agency policies and court challenges of federal timber sales offerings by environmental and other groups. As a result, federal harvest in western Oregon averaged about 140 million board feet per year over the period 2000-2004. Some industry and local government groups continue to urge federal agencies to raise cuts to NWFP levels, citing growth in regional wood processing needs, employment benefits, and (most recently) as a means to reduce fire hazards.[1] At the same time, the objections to federal harvest raised in the early 1990s--loss of wildlife habitat, impaired fisheries production, and deterioration of amenity values--remain important today, and continued restrictions enjoy wide support.

As the U.S. moves toward a national policy of controlling greenhouse gas emissions, a further concern may potentially be added to this list—that increased harvest could reduce rates of carbon sequestration in public forests, particularly if cutting involves older stands with large carbon stores in both standing trees and downed woody debris (Harmon et al. 1990, Schulze et al. 2000). Public forest lands in the West are important carbon sinks with significant rates of net carbon uptake. For the combined region of western Oregon and western Washington, Heath and Smith (2004) estimate that the net non-soil carbon flux for all public timberlands was roughly 200 million metric tonnes of carbon (MMTC) between 1953 and 2000, nearly 10% of the estimated net flux for all public timberlands in the coterminous U.S. over this period. Sequestration has increased since timber harvest on federal timberlands was constrained in the late 1990s. This study examines the potential impacts of raising federal timber harvest to NWFP levels on carbon flux and the markets for logs in western Oregon. Two specific questions are considered:

(i) How would increased timber harvest on federal timberlands change regional forest carbon flux? We develop a set of market scenarios in which timber harvest from public forests rises by stages from recent levels to the highest volume that can be sustained within the bounds of current federal forest land-use allocations and harvest guidelines. Regional and owner-specific carbon fluxes associated with each alternative federal harvest level are projected.

(ii) Could timber harvests from federal and private timberlands be coordinated in ways that reduce the carbon flux impacts of higher federal cut, and at what cost? In these scenarios, federal and private forests are assumed to be "jointly" managed so as to meet the regional carbon flux levels found for the several stages in scenarios (i). That is, we estimate the market clearing timber supplies from private and federal lands subject to a set of alternative lower bounds on regional forest carbon flux corresponding to the alternative federal harvest levels in scenarios (i). Costs are estimated as the differences in market surplus between the case with maximum sustainable federal harvest and the specific flux target cases.

To simulate these cases, we construct a dynamic model of western Oregon log markets in which market prices and volumes together with harvest, growth, and inventory on both private and public forests are explicitly modeled. This approach is unique in the forest market modeling literature. Previous dynamic models have either ignored inventories on public forestlands (e.g., Adams et al. 1999), merged public and private timber inventories and timber harvest decisions as if they shared common management (e.g., Sedjo and Lyon 1990, Sohngen and Mendelsohn 1998), or treat public timber harvest and forest management as exogenous (Adams and Latta 2005, Depro et al. 2006). Similarly, static econometric models have either ignored public timber inventories (e.g., Wear and Murray 2004) or treat all timber harvest and forest management decisions as strictly exogenous (e.g., Haynes 2007). In our model, federal timber harvest levels are assumed to be proscribed by agency policies (such as the NWFP) independent of market behavior, but the selection of stands to be harvested and modes of forest management over time can be varied (given the harvest bound) so as to alter the impacts on carbon flux. Thus silvicultural regimes, timber harvest timing, and growth are endogenous.

4.3. METHODS

Future timber supplies and carbon sequestration are simulated by means of five basic components: (i) initial inventory data; (ii) assumptions about the potential range of future silvicultural practices that might be applied to public and private lands; (iii) projections of future timber and carbon yields under the several management regimes; (iv) assumptions about changes in timberland areas and land-use restrictions on private and public timberlands; and (v) a market model describing current and future regional timber market conditions. In this process, the market model projects future timber harvest and prices based on initial inventory and other assumptions, selects the management regimes to employ which are consistent with the objective, and updates growing stock inventory and carbon storage over time.

4.3.1. Inventory

Timber inventory data for private and public forestlands in western Oregon derive from the USFS Forest Inventory and Analysis (FIA) periodic forest survey (Azuma et al. 2002). Because the inventories (collected between 1994 and 1998) were 9-12 years old, we attempted to update the inventory data to a common 2005 starting point using a timber harvest scheduling model that selected plots for harvest to maximize the present net worth of timber returns over the period from inventory date to 2005. Harvest was constrained to actual historical cut at the county level and the area clearcut and partial cut by year and owner at the half-state (western Oregon) level based on data from the Oregon Department of Forestry (ODF).[2] Federal timber harvest was assumed to occur in the areas assigned as “Matrix” and “Adaptive Management Areas” in the NWFP (see discussion land classes in following section). Tree lists from the original plots were updated using a version of the ORGANON model for private and state forestlands and the Forest Vegetation Simulator (FVS) for federal lands (Hann et al. 1997, Dixon 2003).

4.3.2. Management Intensity Classes (MICs)

Regimes of silvicultural practices are applied to private, state, and federal timberlands over the projection period—in some cases more than one for stands harvested more than once during the projection. For private lands, seven MICs including three partial cut options were defined for existing stands that are part of the original inventory at the start of the projection. Stands established during the course of the projection could employ either natural or artificial regeneration and one of four regimes of subsequent treatments (a total of eight options). Details of the MICs for private timberlands are given in Adams et al. (2002). We followed the same approach to the MICs for state lands. Three partial cutting regimes were allowed in existing stands, corresponding to light, moderate, and heavy thinning, and regeneration harvest (clearcutting) is not applied to hardwood stands. A minimum rotation age was introduced at 40 years for existing stand and 50 years for new stands.

For federal timberlands, the choice of management regime is limited because all federal timberlands are allocated to management areas (each with different management guidelines) by the NWFP. Categories include: Congressionally Reserved area (CR--wilderness, national parks, etc.), Late-Successional Reserves (LSR), Adaptive Management Areas (AMA), Managed Late-Successional Areas (MLSA), Administratively Withdrawn Areas (AW), Riparian Reserves (RR), and Matrix (the remaining area lying between the preceding allocations). Allowable management practices based on our interpretation of the management standards and guidelines (USDA and USDI 1994b) in each area are summarized in Table 4.1. The NWFP guidelines provide general management directions, including prohibited actions and spatial considerations of silvicultural practices based essentially on the desired future conditions of forests in each area. They do not suggest specific silvicultural actions or regimes. We have chosen relatively simple regimes, consistent with the guidelines that are suitable for our model specification.

There are two commercial thinning (CT) MICs for softwood stands in LSR-related categories, with a different regime where LSR and AMA overlap. Three partial cutting (THIN LO, ME, and HI) regimes are defined for Matrix, AMA, and RR categories. Regeneration harvest (clearcutting) is allowed only in softwood stands allocated to the Matrix and AMA designations. Unlike private and state timberlands that can potentially move through more than one silvicultural regime over the projection period, a parcel of federal forest once allocated to a regime remains in that regime for the full projection.

4.3.3. Yield Projection

Timber yields for private and state timberlands were generated using methods similar to Adams et al. (2002). The individual tree simulation model, ORGANON (Hann et al. 1997), was used to model stand development over time for each MIC in each stand. The actual tree lists from the FIA inventory data were input to ORGANON for existing stand types. New stand tree lists were generated using the young stand simulator SYSTUM1 (Ritchie 1993) for a range of site classes for each ecological region and for

Douglas-fir stands and other conifer stands. Subsequent yields for all stands were developed with ORGANON.

Inventory update and yield estimates for each MIC in federal forests were derived from the Forest Service FVS stand projection system (Dixon 2003). Growth for each stand (plot) was simulated using one of six regional variants of FVS. Tree lists for existing stands were obtained from the FIA inventory and simulated for each MIC. Ingrowth of mixed species was assumed to occur naturally at the time of thinning with density that varies according to the number of trees removed by harvesting. To mimic new planted stand development, the densities of regeneration harvest are derived from averages for all young private stands from the FIA database by forest type and ecoregion.

4.3.4. Carbon Estimation

Carbon storage in the forest ecosystem comprises five pools: live and dead trees, understory, forest floor, woody debris, and soil. Carbon in standing trees was estimated using tree lists projected by ORGANON and FVS and tree biomass equations. Stem biomass calculated from volume equations in the FIA inventory was converted to stem carbon. Carbon in bark, live and dead branches, and foliage was obtained from biomass equations multiplied by biomass-carbon conversion factors (Gholz et al. 1979; Ter-Mikaelian and Korzukhin 1997).[3] Because most species do not have a root biomass equation except for Douglas-fir, the amount of root carbon was estimated by the amount of above ground carbon multiplied by the ratio of above and below ground biomass (Table 1.1 in Birdsey 1992). Future biomass in snags is based on tree mortality, as predicted by the individual tree simulation models, which is gradually oxidized with constant rate over time (Turner et al. 1995, Chen et al. 2001). Understory carbon by forest type was estimated as a constant percent of live tree carbon as suggested by USEPA (2003) for the Pacific Northwest Region. Forest floor carbon is assumed to be 10 percent of the carbon pools in the foliage and dead branches of the live trees. Half of above and below ground woody residues is assumed to remain after site preparation and is gradually oxidized using constant decay rates (Edmonds 1987, Chen et al. 2001). Estimated carbon in mineral soil is based on Birdsey's (1992) estimates. Carbon in current snags and woody debris is calculated from the FIA inventory data.

Following Row and Phelps (1996) and Skog and Nicholson (2000), we estimate carbon in forest products by accounting for stocks and flows of carbon from forests to wood and paper products in use, to dumps or landfills, and to burning and emissions from decay. Carbon in western Oregon log market production and consumption was projected through the projection period, beginning in 2005, tracking each period's wood harvest, import, and export through to its final disposition. The timber allocated to sawmills, pulp mills, plywood plants, and other manufacturers is divided into primary product and utilized/unutilized mill residue based on the Forest Service's timber assessment for the Pacific Northwest region (Haynes 2003) and a statewide census of Oregon's primary forest products industry and out-of-state mills that received timber from Oregon during 2003 (see Figure 8 in Brandt et al. (2006)). Carbon in solid wood and pulp products is transferred to several end-use categories and future carbon remains sequestered in these products after disposal in dumps and landfills are calculated. Current carbon in forest products in use and landfills was estimated using the past 50 years of harvest data for western Oregon.

4.3.5. Land Area Changes and Land-Use Allocation

In western Oregon, private owner groups have realized small gains in timberland area since the late 1970s; for industry owners through transfers from other private, and for other private owners through afforestation of land in non-forest uses. State and federal timberland areas have also been relatively stable for several decades. In the absence of any significant historical area base trends, we assumed constant timberland area by owner during the projection period in this study.

Federal and state timberlands are divided into several land-use categories according to existing forest plans. For each federal stand (inventory plot), proportions of land-use allocations designated by the NWPF are identified using land-use allocation maps provided by the Regional Ecosystem Office and stand location coordinates in the FIA inventory database. Table 4.2 presents a comparison of the land distribution under the NWPF and our approximation by land-use allocation and watershed type based on the inventory plots. Timberland classified as CR, AW and ND was excluded from harvest. As a result, the total timberland area in this study that may receive some form of harvest is 4,124 thousand acres (54 percent of total USFS and BLM timberlands). Of these areas 45 percent (1,849 thousand acres) is designated in the Matrix and AMA categories which may receive regeneration harvest and/or thinning regimes. Riparian Reserves comprise 788 thousand acres and are eligible for three types of partial cutting. About 1,487 thousand acres in LSR and LSR+AMA lands could be prescribed by some form of thinning to develop multistoried stand structure. State-owned timberlands are also divided into several use categories: non-forest, reserved forests, multi-resource forest, and active forest. We estimated the actual land base available for timber production from the proportion of harvestable area for seven of the largest state districts reported by the Oregon Department of Forestry (2006). State land classified as reserved area in the FIA inventory was removed from the harvestable acreage.

4.3.6. Market Model

Future levels of timber harvest and prices are determined by interactions among producers and consumers in the regional timber market. In this study, we construct a model of the log market in western Oregon that is similar to that described by Adams and Latta (2007). Demand is derived from lumber and plywood production and log exports, all of which are sensitive to the delivered price of logs. The supply of logs from private forests is based on land owners' decisions about harvest timing and silvicultural practices to optimize the value of their timber investments given stand growth, interest rates, management costs, and price expectations. Oregon law directs that state lands are to be managed so as to maximize timber values along with social and environmental values (Oregon Administrative Rules 629-035-0000 through 629-035-0110). Thus state owners are assumed to maximize net timber revenues subject to constraints on achieving future forest conditions described in the state forest plans. On federal lands, the NWFP is supposed to provide timber production at predictable levels while protecting and managing long-term health of forests, wildlife, and waterways. In this study, the base case projection assumes that federal owners chose areas to harvest to minimize management costs subject to some policy-based constraint on the maximum level of harvest.[4]

A simplified version of the regional log market model (recognizing only private and federal lands) is show in the Appendix. Market equilibria for all periods in the projection are found where the present value of consumers' willingness to pay less the costs of timber management, log transport, and capacity adjustment (equation [A.1]). Log demand shifts depending on product prices, technology, nonwood costs, and capacity. Capacity decisions (ΔK) are endogenous, depending in part on equipment costs, depreciation, and interest rate (equation [A.1] and [A.6]). Regional harvest is derived from both private/state and federal lands (equation [A.2]). Inventories are characterized in terms of areas in existing and regenerated stands (E, R) and the management regimes applied to both (I). Federal cut is constrained by an "allowable cut" that varies with harvest policies (equation [A.3]). All existing stands on private/state and federal lands must be allocated to some management regime and either harvested or reserved from harvest over the projection. Newly created stands (by clearcutting) can occupy no more area than was clearcut harvested over the projection and must be either harvested again during the projection or reserved from harvest (equation [A.4] and [A.5]). Regional forest carbon flux depends on harvest and growth in private/state and federal forests and may or may not be constrained to meet some minimum flux target (equation [A.7]).

4.3.7. Additional Assumptions

In the projections, assumptions about future prices of processed products and of labor and "other" variable inputs were derived from the 2005 Resource Planning Act Timber Assessment Update (Haynes et al. 2007). The existing management plans for both state and public forestlands require that these lands provide sustainable and predictable production of forest products in the future. These requirements are mimicked by imposing non-declining flow of timber harvests and limitations on period-to-period fluctuations of area clearcut and thinned. In addition, public log supply is assumed to be at least as high as recent (2000-2004) average levels through the projection. A multi-species habitat conservation plan (HCP) has been established by the state to ensure that state forest land management complies with the federal Endangered Species Act (16 U.S.C 1531 et seq.). We approximate this management objective by requiring that 50 percent of state forest land be composed of complex stand structures (layered and older forest structures)[5] by 2035 rising to 60 percent by 2065.

4.3.8. Analysis of the Impacts of Changing Federal Harvest

We examine the impacts of changing federal timber harvest on forest carbon flux in western Oregon using sets of simulation scenarios. Two major questions guide the analysis.

(1) What are the potential carbon flux changes resulting from increased timber harvest on federal lands? The concern here is to identify the trade-off between expanded

federal timber harvest and federal carbon flux when no efforts are made to modify the carbon flux impacts of harvest changes. Future market behavior and carbon flux are projected in a series of scenarios with rising minimum levels for federal harvest. In the simplified model structure used in the Appendix, this would correspond to rising levels of $c_{F,MAX}$ in equation [A.3]. For example, $c_{F,MAX}^{(1)} < c_{F,MAX}^{(2)} < \cdots < c_{F,MAX}^{(M)}$, where $c_{F,MAX}^{(1)}$ is the current or "baseline" harvest computed as the average of recent historical levels, and $c_{F,MAX}^{(M)}$ is the highest average harvest volume that can be sustained within the bounds of current federal forest land-use allocations and timber harvest guidelines under the NWFP. For each timber harvest bound, $c_{F,MAX}^{(i)}$, the model will project an associated total regional forest carbon flux, $T_C^{(i)}$, for scenarios $i = 1,\ldots,$M. The total carbon flux $T_C^{(1)}$ associated with the current or baseline harvest level, $c_{F,MAX}^{(1)}$, is termed the baseline carbon flux. We expect that federal forest carbon flux will fall from the baseline level as cut rises, but the overall impact on total regional flux given possible substitution of federal for private/state cut is unclear *a priori*.

(2) Could timber harvests from federal and private/state lands be coordinated in ways that reduce the carbon flux impacts of higher federal cut, and at what cost? We develop M scenarios, each corresponding to one of the scenarios in (1), where total regional carbon flux in scenario *i* is constrained to be at least $T_C^{(i)}$ from the i^{th} scenario in (1) but the levels and mix of federal and private/state harvest are free to vary (so long as federal cut is no larger than $c_{F,MAX}^{(M)}$). In effect federal and private/state lands are "jointly" managed so as to meet the total regional carbon flux target, $T_C^{(i)}$, with minimum market impact. Costs, measured as changes in market surplus, are estimated relative to the case

in (1) with maximum sustainable federal harvest, $c_{F,MAX}^{(M)}$. Regional harvest is expected to fall as the flux target rises, but given some flexibility in federal cut (below $c_{F,MAX}^{(M)}$) and the significant differences between private/state and federal inventories, possible changes in the mix of federal and private/state cut and the levels of total regional carbon sequestration are not clear.

4.4. RESULTS AND DISCUSSION

4.4.1. Current Carbon Stocks and Baseline Projection

Our model's estimate of current carbon stock on forestlands and forest products in use and landfills is 1,388 MMTC. About 902 MMTC is sequestered in live biomass followed by carbon in dead biomass accumulating 247 MMTC and in forest products sequestering 239 MMTC.[6] Several studies have reported carbon estimates in these pools for regions that included our study areas. Table 4.3 presents our estimates of carbon densities on forestlands and in forest products with previous studies' estimates. Heath et al. (2003) and Birdsey and Lewis (2003) used carbon accounting approaches based on merchantable inventory. Law et al. (2004), using eddy flux methods, produced a carbon budget for the forested region of western Oregon by ecoregion. It is noteworthy that our estimates of forest carbon densities are within the ecoregion ranges reported by Law et al. (2004). Average carbon storage per hectare in western Oregon forests is much higher than that of Pacific Northwest region. Note that our forest carbon accounting method using biomass equations and stand tree lists generated by ORGANON and FVS widely differ from these studies. National forests in western Oregon are sequestering a huge amount of carbon in standing trees since more than 65 % of national forests are concentrated on old-growth forests (>100 years). Current forest product carbon pools originating from private lands are higher than from other owners reflecting that private owners have been a dominant timber supplier in western Oregon log markets since early 1990s.

The baseline represents the case where the future timber harvest from federal timberlands is sustained at the recent average between 2000 and 2004 and there are no changes in current regulatory policies or market conditions. Simulation results show that total estimated carbon stock of western Oregon forests and forest products gradually rises to 1,994 MMTC by 2065, a 44% increment. At the owner level, carbon stocks of private, federal, and state lands are estimated at 479 MMTC, 809 MMTC, and 100 MMTC, respectively, in 2000, increasing to 555 MMTC (16% increment) for private lands, 1,253 MMTC (55% increment) for federal lands, and 186 MMTC (86% increment) for state lands by 2065. There is a large net carbon increase in federal lands, 444 MMTC, and, on average, these lands sequester 7.4 MMTC annually during the projection period. This is 14.8% of annual carbon flux on all U.S. federal lands predicted by Depro et al. (2006). Smith and Heath (2004) predict that public forests of Pacific Northwest Westside could additionally accumulate about 400 MMTC by 2040 while our estimate of carbon increase in western Oregon federal lands alone is about 300 million tonnes by 2040. Carbon stock of dead biomass in federal forests will double by 2065 because of high mortality of live tree biomass. In contrast, carbon in forest products transferred from federal forests will drop by nearly half of the current storage.

4.4.2. Change in Carbon and Harvest under Expanded Federal Harvests

In our first question, changes in federal timber harvests might impact near-term and long-term private and state timber harvests and carbon sequestration and, in consequence, the overall impact on total regional carbon flux is unknown *a priori*. Figure 4.1 presents the overall trade-off relation between regional average annual timber harvest and annualized regional carbon sequestration.[7] Under the baseline (CURRENT FEDERAL CUT AND REGIONAL ΔC in Figures 4.1 and 4.2) assuming current federal cut is maintained in the future, western Oregon forestlands will supply about 3.6 billion board feet of harvest volume to the regional timber markets and 12.4 MMTC is sequestered in forests and forest products. As average regional harvest rises due to increased harvest from federal timberlands the regional carbon flux declines steadily with an elasticity of about -0.5. That is, a 1% increase in average annual regional harvest is associated with a -0.5% reduction in regional carbon flux. At the maximum sustainable federal cut (MAX SUSTAINABLE FEDERAL CUT in Figure 1), regional harvest is about 4.4 billion board feet (increased 751 MMBF over the baseline) against a 1.2 MMTC reduction in regional carbon sequestration.

Non-reserved federal timberlands that may receive some form of harvest sequester 4.8 MMTC in the baseline. We estimate an additional annual carbon flux of 2.8 MMTC for reserved federal forestlands (ΔC ON RESERVED AREA in Figure 4.2). The remaining share of annual regional carbon sequestration, 4.8 MMTC, is obtained from private and state forestlands. As illustrated in Figure 4.2, non-reserved federal timberlands will trade federal carbon sequestration with harvest increase from these lands. The maximum sustainable federal harvest (MAX SUSTAINABLE FEDERAL CUT in Figure 4.2), 885 MMBF, which is higher than the level authorized by the NWFP, could be achieved at a loss of 1.2 MMTC of carbon sequestration. The federal owners' response is smaller than the regional aggregate with a carbon flux/harvest elasticity of -0.2, a 1% increase in federal harvest leads to a -0.2% reduction in annualized carbon flux on federal lands. There is very little substitution of federal for private and state cut over the range of changes in federal harvests examined here. The near-term reduction in average private and state harvests which results from the maximum federal harvests is 0.05 % by 2035 rising to 0.07% between 2035 and 2065 relative to the base case. As a result, average annual harvest from these lands is nearly the same as the baseline level.

4.4.3. Change in Carbon and Harvest under Carbon Target Alternative

Under the carbon target scenario, regional forest owners will make joint efforts to achieve regional carbon sequestration targets given timber market and resource conditions. Stand age distributions and timber inventories among forest owners in western Oregon are markedly different (Campbell et al. 2004) and, as shown in Table 4.3, initial carbon stocks also are diverse across owner groups. Given these discrepancies of resource bases and flexibility in federal cut below the maximum sustainable level, imposing a regional carbon flux target would likely cause some reduction in regional timber harvest, but changes in the mix of owner group's cut are not clear.

As presented in Figure 1, higher regional carbon sequestration targets lead to less average annual timber harvest from western Oregon forests, but the trade-off is limited. The equivalent of the baseline carbon flux could be obtained with a reduction of only 35 MMBF in regional cut below the sustainable maximum. The steep slope of the trade-off curve for carbon flux target scenarios in Figures 1indicates that carbon flux is highly sensitive to small changes in regional timber harvest when the cut can be optimally allocated among ownerships. From the baseline perspective, more regional timber harvest would be attainable while not reducing regional carbon sequestration (CURRENT REGIONAL ΔC in Figure 4.1).

We found that although the total timber harvest reduction between the sustainable federal maximum and baseline carbon target level is small, there are significant opportunities for substituting timber harvest and carbon flux between federal and private/state lands. Changes in harvest and carbon flux on federal lands are less responsive to the carbon flux target scenarios compared to those of the other lands. To reach regional carbon flux at the baseline level, federal owners reduce 15 MMBF of federal timber harvest to sequester an additional 0.15 MMTC of carbon sequestration, while about 20 MMBF of private and state timber harvest is converted to 1.1 MMTC of additional carbon sequestration.

This substitution comes about in part by shifting the concentration of harvest within an ownership toward older stands and toward stands with lower levels of carbon storage. Figures 4.3 and 4.4 present percent of average annual harvest by stand age class and by carbon density class in private and federal forests under the baseline and the baseline carbon flux target scenario. Less private harvest occurs in younger stands with the target since these have relatively high carbon sequestration rates. That is, average rotation ages are lengthened. In contrast, as shown in Figure 4.4, under the baseline carbon target scenario, timber harvest from private forests having high carbon densities slightly declines relative to the base case. That is, regeneration harvest originating from stand ages less than 50 years declines 274 MMBF but 50 and higher age classes provide about 115 MMBF of additional harvest relative to the baseline, while about 92% of private harvest reduction occurred in stands with carbon density over 100 tonnes per acre. This means that relatively younger stands (<50 years) having high carbon densities are less preferred under the carbon flux target scenarios. Federal cuts between the scenarios differ substantially, but we can see similar trends on harvest concentrations by stand age and carbon density class. Not all federal forest is densely stocked old-growth with large volumes of both standing timber and down woody debris. Some areas have relatively low stocking, low levels of woody debris, and low growth. In the simulations, harvests on these federal areas are substituted for cut from more rapidly growing private stands.

4.4.4. Market surplus impacts

Increased timber supply from federal timberlands or regional carbon target scenarios may affect the equilibrium of timber markets resulting in changes in market prices of logs and welfare position of market participants. Table 4.4 presents the annualized net social surplus in regional log markets under the baseline, carbon target at the baseline carbon flux, and the maximum sustainable federal cut scenario. Under the baseline, market surplus is expected to be about $2.3 billion divided into $836 million for regional log processors, $54 million for federal agencies, and $1,407 million for private, state, and log importers, respectively. The maximum sustainable federal cut scenario is expected to earn over $2.8 billion of net social surplus. From the expanded federal cut, log consumers and federal agencies enjoy higher surplus and timber profits, but other producers including private and state forest owners and log importers are worse off due primarily to near-term harvest reduction and log prices. The welfare cost of shifting from the sustainable maximum federal cut level to the carbon target at baseline flux level like the harvest change is modest at -$28.8 million and is born primarily by log users, while net gains in log markets shifting from the baseline to the carbon target is substantial at $496.5 million.

The shadow price of the carbon sequestration constraint in the market clearing solution under the carbon target scenarios represents the marginal cost of producing the regional carbon flux target (Hoen and Solberg 1994). It represents the marginal welfare cost to market participants (consumer and producer) for sequestering an additional unit carbon in forests and forest products in western Oregon under the regional market system. Simulation results show that the carbon flux targets above carbon flux at the maximum federal cut yield positive marginal costs and a higher carbon flux target produces a higher marginal cost. When the model is constrained to accumulate at least the carbon flux at the baseline level, the shadow price is about $12.26 per tonne. If all lands had access to a “carbon offset sales system” in which owners received payments for net additions to flux and paid a fee for net flux reductions, the baseline carbon flux would be achieved at about $12.26 per tonne of carbon price. In this case, forest owners would receive $152.5 million per year by selling carbon offsets at the expense of a $10.4 million of losses from the log markets.

4.5. SUMMARY AND CONCLUSIONS

In this study, we developed market model of logs in western Oregon to examine the impacts of the expanded timber supply from federal timberlands on carbon sequestration and log markets. Simulation results suggest that regional carbon flux in forests and forest products will gradually decline as harvest rises from federal timberlands. A higher federal cut given land-use designations by the NWFP leads to lower federal land carbon sequestration. Substitution of federal for private and state timber harvests is very limited in our projections even for the maximum sustainable federal cut level. Our analysis of market surplus impacts of the highest federal cut finds that regional log processors would realize increment in surplus through expanded log consumption and a slight drop in log price relative to the base case. Federal agencies would also enjoy higher surplus (profits) as their market share rises, but private and state forestland owners would be consistent losers under the expanded federal timber harvests.

The regional carbon flux target scenarios present a very different view. The market clearing solutions with flexible federal cut show that the same level of regional carbon flux can be achieved with a higher regional timber harvest through coordinating harvests on federal and non-federal lands. Carbon sequestration equivalent to the baseline could be obtained with a limited reduction in regional cut relative to the maximum regional cut level. That is, there are significant opportunities for substituting timber harvest and carbon sequestration between federal and non-federal lands in western Oregon. A relatively small reduction in non-federal harvest would offset a substantial loss of carbon flux in federal timberlands. This is possible in part by lengthening rotation ages, shifting the concentration of harvest within an ownership toward stands with lower levels of carbon storage, and by modest reduction in cut. The steep slope of the trade-off curve (Figure 4.1) for this case indicates that carbon flux is highly sensitive to small changes in regional timber harvest when the cut can be optimally allocated among owners.

For a policy maker considering an array of regional mitigation options for climate change, a harvest coordination program as envisioned in the carbon target scenarios would be attractive since a regional carbon flux target could be obtained by joint efforts of all forest owners while minimizing its impact on regional log markets. But, such a program may entail significant issues of management and control. Our results suggest that similar targets could be achieved that if a carbon offset market were available for all owners including federal agencies. The marginal welfare cost of carbon sequestration derived from the shadow price of the carbon target constraint is the market price of carbon that could produce the same flux as the constraint. Thus, the regional forest carbon flux and harvest under the baseline carbon target case could be mimicked at a \$12.3 per tonne of carbon converted to \$45 per tonne CO_2 as well in carbon price.[8]

In developing this analysis, we have assumed that western Oregon federal harvest would be allowed to rise from current levels. The options considered are hypothetical to demonstrate potential trade-offs. Highly controversial, though, there are proposals to raise federal cut from several groups (For example, Association of O&C Counties and Forest Service Employees for Environmental Ethics).[9] In our welfare accounting, only log market values are represented and impacts on other resources have not been considered.

Footnotes:

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[1] See, for example, testimony of Tom Nelson on behalf of the American Forest and Paper Association (AFPA) before Agriculture, Nutrition, and Forestry Committee of the United State Senate in June 26, 2003 and testimony of the AFPA submitted to the House Appropriations Subcommittee on Interior, Environment, and Related Agencies in March 16, 2006. (http://www.afandpa.org/) and the National Forest Counties and Schools Stabilization Act submitted by Douglas County in western Oregon (Proposed Safety Net Solution is available from: http://www.co.douglas.or.us/NFCS%20Stabilization%20Act%201-15-07.pdf).

[2] Oregon annual timber harvest reports from 1986 to 2005 are available from the ODF website, http://egov.oregon.gov/ODF/STATE_FORESTS/FRP/annual_reports.shtml.

[3] We estimate carbon in trees from biomass equations since individual tree information is available from ORGANON and FVS yield projections. In addition, it allows avoiding potential bias in using constant conversion of merchantable volume into total tree biomass (Johnson and Sharpe 1983).

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[4] We also assume that a stand on federal lands would not be eligible for harvest unless all costs for harvesting, hauling, and regeneration could be offset by timber revenue.

[5] We employ stand structure classes defined by stand attributes as suggested by Latta and Montgomery (2004).

[6] Since carbon in mineral soil is assumed to be constant, it is not included in our analysis of carbon sequestration.

[7] Annualized carbon sequestration represents the amount of carbon sequestered in the present that would be equivalent to the reported flow, assuming constant marginal benefits of sequestration (Stavins and Richards 2005).

[8] 1 tonne of carbon = 3.67 tonnes of CO_2.

[9] See proposals at: http://www.co.douglas.or.us/NFCS%20Stabilization%20Act%201-15-07.pdf and http://www.fseee.org/eactivist/oregonsolution.pdf.

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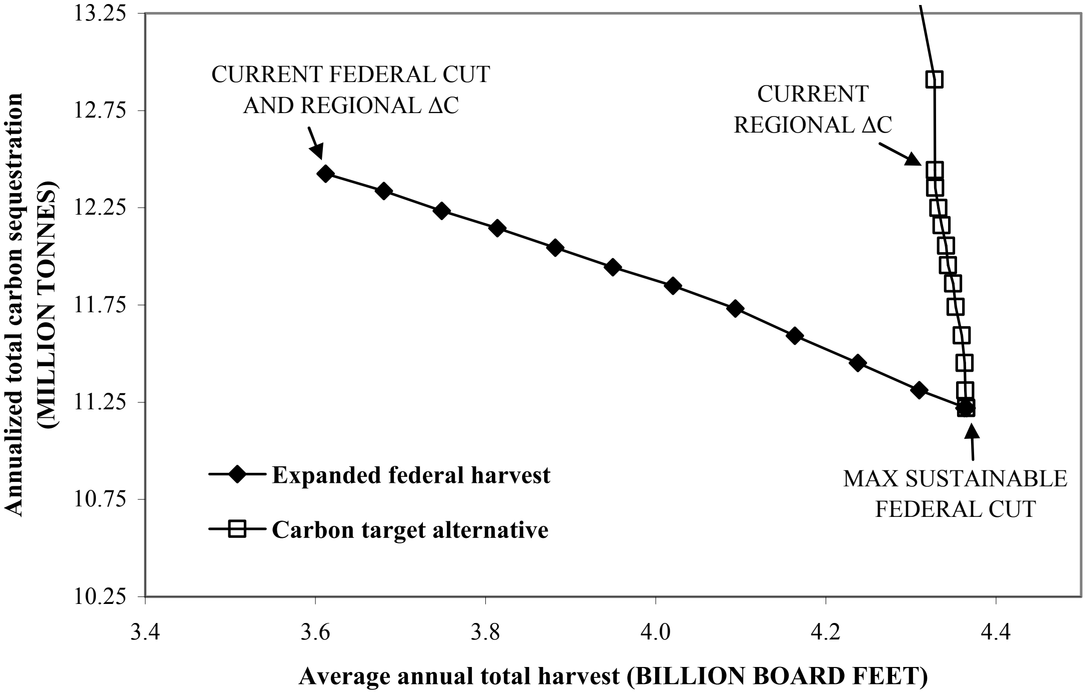

Figure 4.1. Trade off curves between average annual harvest and annualized carbon sequestration for all ownerships in western Oregon under two policy scenarios (2005-2065). ΔC is carbon sequestration.

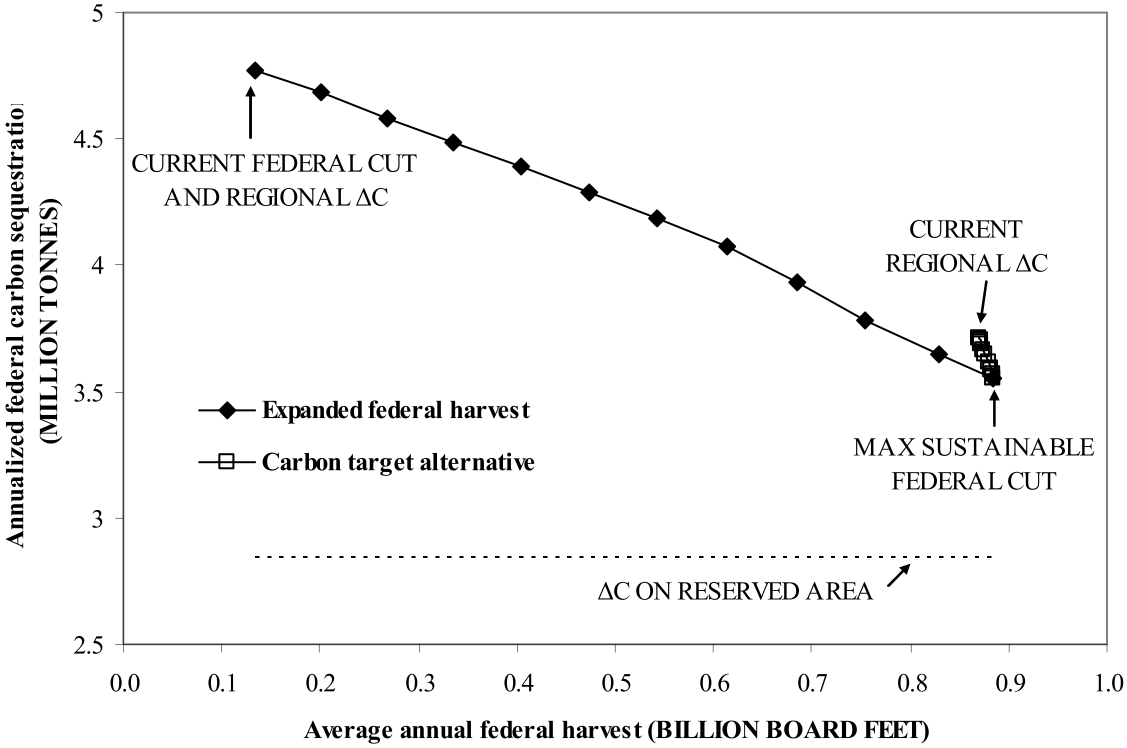

Figure 4.2. Trade off curves between average annual harvest and annualized carbon sequestration on federal lands in western Oregon under two policy scenarios (2005-2065). ΔC is carbon sequestration.

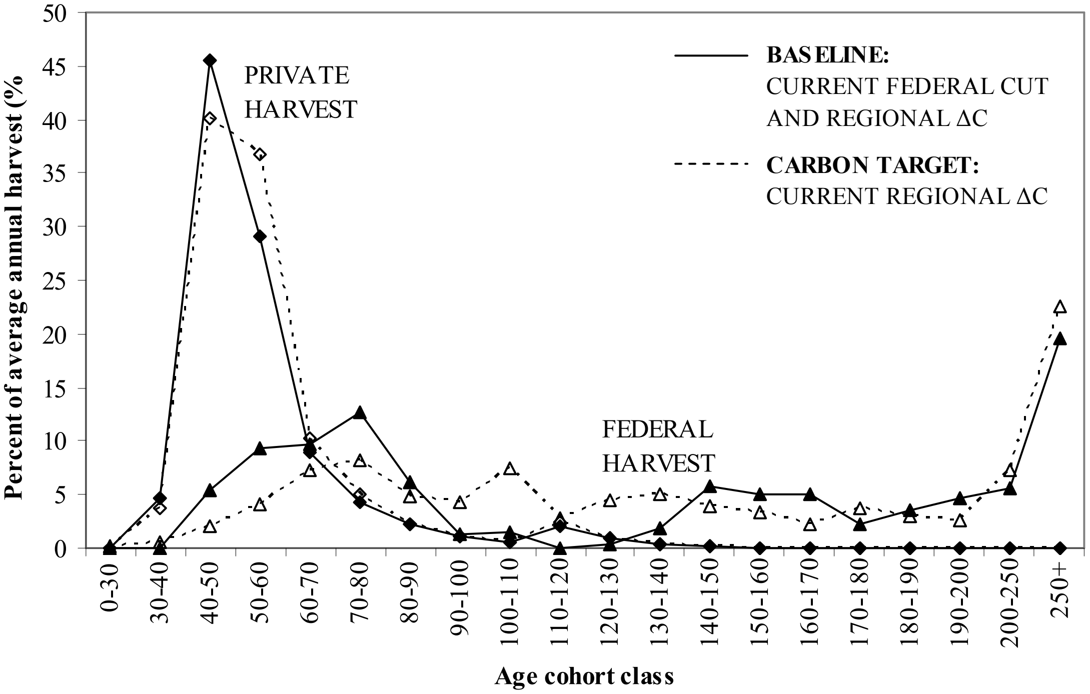

Figure 4.3. Percent of average annual harvest by stand age class in private and federal forests under the current federal harvest baseline and carbon target alternatives corresponding to this baseline.

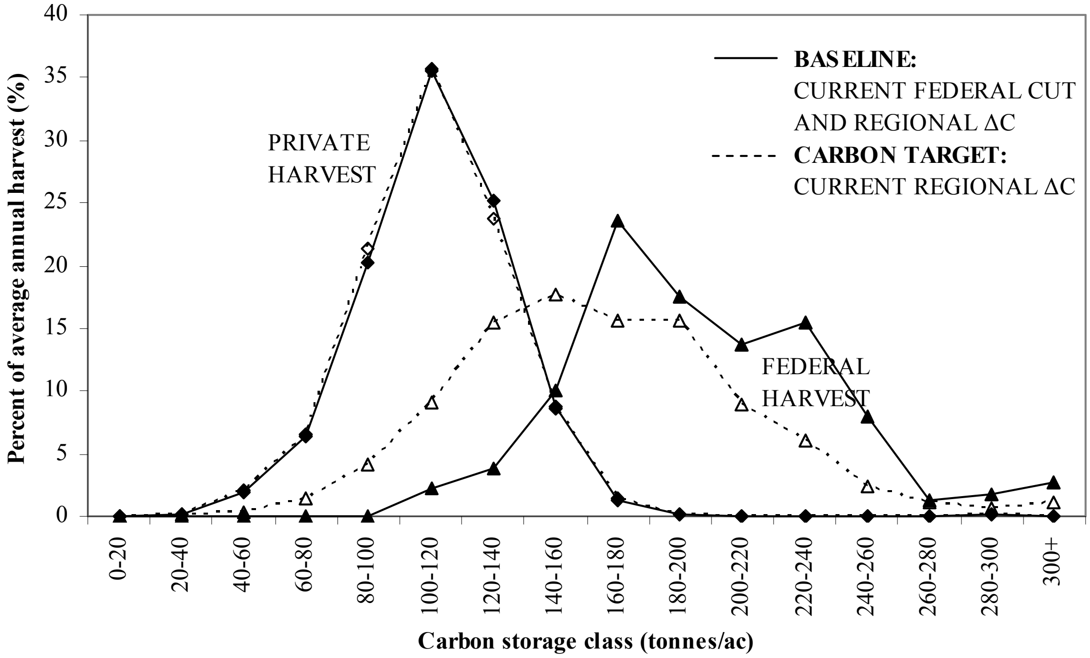

Figure 4.4. Percent of average harvest by carbon storage class in private and federal forests under the current public harvest baseline and carbon target alternative corresponding to this baseline.

Table 4.1. Management practices and management intensity classes for public stands in the model

Definitions of management practices based on NWFP Standards and Guidelines

Management action	Land-use allocation	Criteria
Commercial thinning (CT)	LSR	if > 9 mbf/ac and volume percent (DBH ≥ 30 inches) < 40 % remove 40 % thinning across diameter classes (> 7 inches and < 36 inches)
	LSR+AMA	if > 9 mbf/ac and volume percent (DBH ≥ 30 inches) < 60% remove 40 % thinning across diameter classes (> 7 inches and < 36 inches)
THIN LO	Matrix/AMA/RR	if > 9 mbf/ac remove 20 % thinning across diameter classes (> 7 inches)
THIN ME	Matrix/AMA/RR	if > 10 mbf/ac remove 40 % thinning across diameter classes (> 7 inches)
THIN HI	Matrix/AMA/RR	if > 10 mbf/ac remove 60 % thinning across diameter classes (> 7 inches)
Regeneration harvest (REGEN)	Matrix/AMA	if > 12 mbf/ac and stand age ≥ 100 [or volume percent (DBH ≥ 30 inches) ≥ 60 %] remove all trees after remaining 16 live tree/ac

Management intensity classes

MIC	Timing applied
Grow only	Initial period
CT + Grow only	Any period (no additional practices after thinning)
THIN LO + Grow only	Any period (no additional practices after thinning)
THIN ME + Grow only	Any period (no additional practices after thinning)
THIN HI + Grow only	Any period (no additional practices after thinning)
REGEN + Grow only	Any period (no additional practices after regeneration)

Note: mbf = thousand board feet, a board foot is a measure of sawtimber volume (approximately 6.74 m^3, Spelter (2004))
ac = acre (approximately 0.405 ha)
"volume percent" is the fraction of total volume in stems at least 30 inches (2.54 cm) DBH

Table 4.2. Comparison of areas administered by the USFS and BLM under the NWFP and as approximated in this study by land-use allocation and Key and non-Key Watersheds.

Land-use allocation	Northwest Forest Plan			This study		
	Key Watersheds			Key Watersheds		
	Tier1/Tier2	non-Key	Total	Tier1/Tier2	non-Key	Total
		1,000 acres			*1,000 acres*	
CR+AW+ND	657	767	1,424	618	694	1,312
LSR	1,318	1,756	3,074	1,360	1,764	3,125
AMA	76	497	573	82	500	583
Matrix+RR	684	2,359	3,043	679	2,415	3,094
Total	2,735	5,379	8,114	2,740	5,374	8,113

Note: Areas include forest (timberland + non-timberland) and non-forest lands; ND represents non-designated areas.

Table 4.3. Alternative estimates of non-soil carbon stock density (tonnes/ha).

Previous studies	Region/owners	Carbon in forestlands		Carbon in forest products
		Live biomass	Dead biomass	
Heath et al. (2003)[a]	WA+OR+CA/all	102.8	45.6	-
Birdsey and Lewis (2003)[a]	OR/all	82.3	42.4	26.4
Law et al. (2004)[b]	Western OR/all	128.6 - 196.8	38.4 - 49.5	-
This study[b]	Western OR/all	144.2	39.5	38.2
	Western OR/private	82.7	35.3	61.0
	Western OR/USFS	204.9	45.3	19.8
	Western OR/OPUB	161.4	34.1	21.9
	Western OR/state	176.2	48.3	26.5

Note: [a] Estimates in 1997; [b] estimates in 2002; OPUB represents other federal lands; and state represents non-federal lands that are owned by state and local governments and other non-federal public owners.

Table 4.4. Annualized market surplus and potential carbon payments under the baseline and two alternative policy scenarios (2005-2065).

Policy scenarios	Consumer surplus	Producer surplus		Total surplus (+C payment)
		Federal	Others	
	1992 $US million			
Baseline: current federal cut and regional C flux	836.3	53.6	1,406.7	2,296.5
Carbon target: regional C flux = baseline	1,126.4	314.7 (80.3)	1,351.9 (72.2)	2,793.0 (152.5)
Federal cut at maximum sustainable, no C flux limits	1,144.6	317.5	1,359.8	2,821.8

Note: A 6% of the discount rate is used; figures in parenthesis are net subsidy for carbon sequestration at a $12.6 per tonne of carbon; and others include private and state forest owners and log importers.

APPENDIX. Simplified Representation of Model Structure

The time subscript is omitted in most cases to simplify the notation.

$$MAX \quad \sum_{t=0}^{T}(1+i)^{-t}[\int P(C,K)dC - c_K \Delta K - M(E_P,R_p,I_P) - f(E_F,R_F,I_F)] \qquad [A.1]$$

$$C - c_P(E_P,R_p,I_P) - c_F(E_F,R_F,I_F,pol) \leq 0 \qquad [A.2]$$

$$c_F(E_F,R_F,I_F,pol) \leq c_{F,MAX} \qquad [A.3]*$$

$$P_P(E_P,R_p,I_P) \leq A_P \qquad [A.4]$$

$$P_F(E_F,R_F,I_F) \leq A_F \qquad [A.5]$$

$$K_t - (1-\delta)K_{t-1} - \Delta K \leq 0 \qquad [A.6]$$

$$\sum_{t=0}^{T}(1+i)^{-t}[\Delta C_W(C) + \Delta C_P(E_P,R_P,I_P) + \Delta C_F(E_F,R_F,I_F)] \geq T_C \qquad [A.7]*$$

where

t and T are time period and the length of the projection period, respectively;

i is the discount rate;

E_P, R_P, E_F, and R_F are the areas of existing and regenerated stands in private/state (*P*) and federal (*F*) ownerships;

I_P and I_F represent the arrays of management regimes (or management intensities) available on private/state and federal lands;

$P_P(E_P,R_P,I_P)$ and $P_F(E_F,R_F,I_F)$ are land area accounting equations that control the relationship between areas of existing (*E*) and regenerated (*R*) stands, their allocation to management regimes (*I*), and insure that no more than the available land base (*A*) is used for private/state and federal ownerships, respectively;

A_P and A_F are the timberland areas of private/state and federal ownerships;

C is log consumption in milling processes;

$P(C,K)$ is the inverse derived demand curve for logs by processing industries;

K and ΔK are capital stock (represented as capacity) and capital stock change;

δ is the capital depreciation rate;

c_K is the unit cost of new capital;

$M(E_P,R_P,I_P)$ and $f(E_F,R_F,I_F)$ are the cost of timber harvesting, transportation and management on private/state and federal lands;

$c_P(.,.,.)$ and $c_F(.,.,.)$ give the volumes of timber harvested on private/state and federal lands as functions of land area in existing and regenerated stands and area allocations to the various management regimes;

pol represents the effects of federal timber harvest policies (as in the NWFP standards and guidelines) in specifying the timber can be harvested and how it can be cut;

$c_{F,MAX}$ is the upper bound on federal timber harvest, only employed in the expanded federal harvest scenarios;

$\Delta C_W(.)$, $\Delta C_P(.)$, and $\Delta C_F(.)$ are sets of functions that compute the net carbon flux in forest products (W) and on private/state and federal forest lands;

T_C is an optional lower bound on regional forest carbon sequestration, only employed in the carbon target scenarios; and

p_C is the optional unit price of forest carbon, only employed in the carbon market scenarios.

The objective function is the customary maximization of the present value of producers' plus consumers' surpluses net of transport and other costs and including returns from net sales of carbon offsets. Endogenous variables are E_P, R_P, E_F, R_F, and ΔK.

After linearization of *P(C,K)*, the problem can be solved as a linear program for a given sequence of *ΔK*, yielding values for *E* and *R* and a new series of *ΔK*. This new series is used in a second solution, and so on in an iterative fashion until the *ΔK* stabilizes within some tolerance. This Gauss-Seidel approach eliminates the need to solve the overall system [A.1] – [A.7] as a nonlinear programming problem. The elements with *'s are only used in certain scenarios: equation [A.3] is used in expanded federal harvest scenarios and equation [A.7] in the carbon target scenarios. Linear programming solutions were obtained with the GAMS system employing the CPLEX solver.

CHAPTER 5

GENERAL
CONCLUSIONS

This study considered regional forest policies for sequestering carbon in forests in western Oregon. A model of log markets in western Oregon was employed to examine the impacts of forest policy changes on future carbon stock, harvests, and management activities. Two research questions were considered: (i) how a carbon tax on carbon flux in private forests would affect future carbon stock and management decisions on these lands and whether the carbon tax could be cost-effective; and (ii) how federal land-use decisions would affect overall carbon sequestration in western Oregon forests and forest products and log markets. These policy questions were simulated using the market model developed in this study and analyzed in the market context.

The first policy addressed is a mandatory carbon tax program that pays a subsidy for carbon uptake or levies a tax for carbon loss in timber inventory as a regional mitigation option for encouraging sequestration of carbon in existing private forests. The analysis examined its welfare and carbon sequestration costs. Including both carbon revenues and costs in forest management decisions, private forest owners would reduce their planned harvests and investments and lengthen the average rotation. Market impact analyses under the carbon tax showed both regional wood processors and forest owners would suffer surplus losses in timber markets, but the latter would be at least partially subsidized by carbon payments.

Simulation results differ from, and extend, past findings in several important ways: (i) initial inventory conditions and growth potential (site quality) can markedly alter the carbon sequestration-timber harvest trade-offs, as seen in comparing industrial and NIPF ownerships; (ii) silvicultural investments will change in response to a carbon tax, with variations depending on inventory and growth potential of the land base; (iii) modifications of management on existing forest land in western Oregon can be cost competitive with afforestation in sequestering additional forest carbon; and (iv) not all rates of carbon tax will attract interest from private owners if participation is voluntary. The land productivity and high growth rates of forests in western Oregon relative to other U.S. regions provide the opportunity to consider the carbon tax as a regional mitigation policy in the forestry sector.

The market and carbon impacts of excluding or including residue and product carbon pools in the carbon tax program were also examined using the log market model in western Oregon. Compared to the case where these polls are ignored, their inclusion provides much less incremental carbon because of the trade-offs between carbon in the timber inventory and in product and residue pools. Under both cases, reduced timber supply makes regional wood processors and timber suppliers worse off, but net subsidies exceed market welfare losses at all tax rates when products and residues are included, suggesting that a redistribution system might make the tax attractive to all market participants. In addition, we found that the marginal costs of carbon sequestration are substantially higher than in the case when all carbon in timber harvested is assumed to be immediately lost as an atmospheric emission.

To address the second research question, we construct a dynamic model of western Oregon log markets in which timber harvests from public as well as private forests are endogenous. The market model of private and public timber supply is simulated to examine the impacts of changing timber supply from federal timberlands on carbon sequestration and log markets. Simulation results suggest that regional carbon flux in forests and forest products will gradually decline as harvest rises from current level of federal timberlands. In our projection, a higher federal harvest would substitute for only a limited amount of non-federal harvest even for the maximum sustainable federal cut level. Our analysis of market surplus impacts of the highest sustainable federal cut level finds that regional log processors would realize increment in surplus through expanded log consumption and a slight drop in log price relative to the base case. Federal agencies would also enjoy higher surplus (profits) as their market share rises, but private and state forestland owners would be consistent losers under the expanded federal timber harvests.

If federal and non-federal lands were jointly managed so as to meet a regional carbon flux target, the market solution provides a higher regional cut than in the base case. That is, there are significant opportunities for substituting timber harvest and carbon sequestration between federal and non-federal lands in western Oregon while not reducing regional carbon sequestration. A relatively small reduction in non-federal harvest would offset a substantial loss of carbon flux in federal timberlands. This is possible in part by lengthening rotation ages, shifting the concentration of harvest within an ownership toward stands with lower levels of carbon storage (this is particularly marked on federal lands), and by modest reduction in cut. For a policy maker considering an array of regional mitigation options for climate change, a harvest coordination program as envisioned in the carbon target scenarios would be attractive since a regional carbon flux target could be obtained by joint efforts of all forest owners while minimizing its impact on regional log markets. But, such a program may entail significant issues of management and control. Our results suggest that similar targets could be achieved that if a carbon offset market were available for all owners including federal agencies. The marginal welfare cost of carbon sequestration derived from the shadow price of the carbon target constraint is the market price of carbon that could produce the same flux as the constraint.

In considering these results, some limitations should be recognized. The outcomes emphasize the complex and controversial nature of identifying the baseline carbon flux and harvest. In the model, the baseline or no policy flux pattern is known. In practice, the baseline would have to be established in some way, perhaps by a negotiation process between forest owners participating in the carbon sequestration program and the government implementing it. It must also be recognized that this study provides only partial equilibrium analysis of carbon sequestration and timber markets. The effects of the carbon tax and increased federal cut are examined only in the western Oregon timber markets and carbon in western Oregon forests that are directly affected. Leakage may be expected if we consider the project within a broader spatial or temporal context. Finally, in our welfare accounting, only log market values are represented and impacts on other resources and values have not been considered.

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