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Forest Carbon Sequestration Policies: Implications for Forest Management in Canada and the U.S.

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Abstract [1]

The inclusion of forest sinks as a carbon dioxide (CO_2) mitigation strategy at the international climate negotiations in Marakech (November, 2001) is expected to lead to increased investments in forest establishment and management by many developed countries. Previous studies that analyzed forest carbon policies have typically focused on market impacts in the forestry sector, such as changes in production, consumption, prices, and trade. In this study, we consider their inter-sectoral linkages to explore the policy spillover effects. Our focus is to examine the potential economy-wide, land use, welfare and trade impacts of two potential forest carbon policies in the U.S. and Canada. Specifically, we employ a dynamic computable general equilibrium (CGE) model with a global scope to simulate the policy scenarios of: 1) a global expansion of forest carbon plantations with and without U.S. participation; and 2) domestic carbon subsidies in the U.S. to motivate joint production of carbon and timber from forests by private forestland owners.

The results of our simulations suggest that implementation of either policy in the U.S. (i.e. expanding forest carbon plantations or implementing carbon subsidies) will be generally favorable to the domestic forest and agricultural sectors, but will have small negative impacts on overall welfare. The forest sector, in particular, enjoys substantial gains from increased competitiveness in relation to the other timber producing regions.

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In the case of Canada, impacts of forest carbon policies are dominated by the actions of the U.S., her largest timber trade partner. The Canadian forest sector gains only in the scenario where the U.S. chooses not to participate in a forest carbon policy. However, welfare effects from these scenarios are generally positive. The policy effects on timber trade between the two countries are dominated by the U.S.

Our model predicts that leakage effects from conversion of forestland to other uses are generally modest. Leakage occurs domestically where forests in areas outside of the carbon plantations are converted to other land uses (usually agriculture), thus reducing the policy's net effectiveness in mitigating CO_2. Leakage also occurs internationally as carbon subsidies in the U.S. crowds out the Canadian wood producers and leads to substantial conversion of forestlands in Canada. Finally, policies to expand forest carbon sequestration in the temperate regions will reduce some pressure off timber harvests from tropical regions. This outcome is obviously beneficial in the context of global warming, as it signals a potential reduction in CO_2 emissions from tropical deforestation.

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1. Introduction

The international climate negotiations that took place at the Conference of the Parties (COP) in Marrakech in November, 2001 finally resulted in an agreement that could eventually lead to a sufficient ratification of the 1997 Kyoto Protocol on Climate Change. The Marrakech agreement resolved many of the concerns regarding terrestrial sinks (UNFCCC 2001), an issue widely regarded as the stumbling block in previous negotiation sessions, and sets forth consequences for countries failing to meet their commitments. All human-induced forest, cropland and grazeland management and re-vegetation activities since 1990, or "land-use, land-use change and forestry (LULUCF) activities" in Protocol terminology, will receive credits during the first commitment period from 2008 to 2012.

As such, those nations who had previously lobbied for the inclusion of forest sinks into the Protocol, such as Canada, the Russian Federation and Australia, are now expected to expand their forestry activities as a low-cost way to achieve their CO_2 reduction targets. Canada, for example, has outlined plans for several afforestation and reforestation programs in its National Climate Change Business Plan (Canada NCCP, 2000). Similarly, Australia and New Zealand have indicated that their climate plans will incorporate a significant reliance on forest sinks to meet a substantial portion of its CO_2 emission reduction targets. It remains yet unclear what plans the Russian Federation has in terms of forest carbon policies.

The pace for action has accelerated in recent months (Rosenzweig et al., 2002). Several governments have moved forward in designing domestic trading systems even whilst international trading rules are still being developed. At the national level, the

United Kingdom and Denmark have each established domestic emissions trading programs. Some trading in these programs has already begun. The European Union (EU) and other countries are in various stages of domestic policy development. At the sub-national level, the state of Massachusetts, for example, will require reductions of CO_2 emissions from power plants and allow emissions trading as a means of compliance.

The U.S., on the other hand, rejected the Protocol last year on grounds that the treaty's emissions reduction target (7% below 1990 levels for the U.S.) would damage the domestic economy, and considered it to be "fatally flawed" for exempting developing countries from reduction targets (IISD, 2001). It has, however, created a domestic climate agenda. The most recent climate plan from the White House (released February 14th, 2001) indicated preference for a "reasonable and gradual" goal of slowing GHG emissions with emission targets indexed to economic output and achieved largely through market-based trading programs. It does also explicitly recognize the role of forest and agricultural sinks as an inexpensive near- and medium-term CO_2 reduction strategy (New York Times, February 14, 2002).

There is little consensus on the costs of inaction – previous studies have provided vastly different results depending upon their coverage and methodology. A doubling of atmospheric CO_2 levels is projected to adversely impact the U.S. timber sector by anywhere between 3.3 to 43.6 billions of 1990 US$, and the overall economy by 1.0 to 2.5% of the 1990 U.S. GNP (reported in Kolstad and Toman, 2001, p.24). Other studies however, predict positive impacts for the agriculture and forestry sectors from the expansions of productive biomes (i.e. longer growing seasons) and overall increases in forest productivity in the Northern Hemisphere. Mendelsohn et al. (2000) report gains of approximately 0.5% of the 1990 GDP for North America under a $2^{o}C$

warming scenario. Their results project positive gains of between 4 to 9 billions of 1990 US$ for forestry, and 50 to 83 billions for the agriculture sector in the region.

1.1 Study Objectives

Our objective is to contribute towards a more comprehensive understanding of the costs and benefits from policy efforts to expand the capacity for forest carbon sequestration. Climate-forest policies generally fall into one of three categories (Sampson and Sedjo, 1997):

- To increase the standing inventory of forest biomass.
- To extend the life storage of carbon in forest products.
- To substitute wood products for other materials that emit more CO_2 in their manufacture, use or disposal; or to substitute wood biomass as a CO_2-neutral energy source.

In this study, we use a dynamic computable general equilibrium (CGE) model, D-FARM (see Ianchochivina et al., 2001; Darwin et al., 1996), to examine the potential impacts of the first category of policy, that is, to increase the standing stock of forest biomass. We simulate two policy programs, namely the global expansion of carbon plantations and the provision of a carbon credit policy in the U.S. In the first set of policy simulations, expansion of carbon plantations in the U.S., Canada, Australia and New Zealand is driven by the Kyoto Protocol's CO_2 emission reduction targets (Canada NCCP, 2000; UNFCCC 1999a, 1999b). The expansion scenarios are based on the countries' existing climate plans or from the research literature (see Section 4.2, pp. 32-34 for justification and references). On the other hand, our second set of policy simulations is based on a potential U.S. domestic climate plan. As such, the carbon subsidies are only implemented in the U.S.

The primary objective of our study is to examine both the economy-wide and global impacts of forest carbon policies. In particular, we investigate:

- The interaction between expanding forest carbon plantations and other land uses, such as leakage effects and land use change.
- Forest sector impacts, including changes in forest land income, timber output and prices, and primary factor use.
- Implications for the U.S. – Canada timber trade.
- Other economy-wide impacts, such as changes in welfare and the distribution of effects.

The following chapter is a survey of different methodologies used to assess climate-forest policies. We reviewed over 15 different studies and presented a synthesis of the different strengths and weaknesses in each approach. Based on this research, we came up with a list of modeling criteria deemed necessary for climate-forest policy analysis. Details of the dynamic CGE model used in this study are presented in Chapter 3, and the base case and policy scenarios are laid out in Chapter 4. Chapter 5 is a discussion of the results. Chapter 6 concludes with policy recommendations.

2. A Critical Survey of Economic Approaches to Climate-Forest Policies [2]

Following the Kyoto Protocol in 1997, academic literature on the economics of climate change has grown tremendously (Toman, 2001). Economic ideas have played an influential role in shaping international policies for reducing greenhouse gases (GHG); examples include the design of economic incentives for developing renewable energy technologies, and international trading of carbon emissions rights. Similarly, economic approaches have been used extensively to evaluate the costs and benefits of climate policy impacts (see Kolstad and Toman, 2000 for a review).

Using forests to mitigate CO_2 emissions will obviously have direct impact on forest areas, timber harvest levels, rotation lengths and levels of management intensity (Solberg, 1997; van Kooten et al., 1995; Plantinga and Birdsey, 1994). In turn, this will affect forest product prices, consumption and trade, forest sector employment and income, and other economy-wide effects. There is a substantial body of policy studies centered on assessing the economic impacts to timber production and markets, with varying methodologies and degrees of coverage. Most are, however, limited in capturing costs outside of the market sector, such as non-market or ecological values of the forest, or for reflecting the interactions between climate change processes and the forest ecosystem (Binkley and van Kooten, 1994).

This chapter is a review of the different economic methodologies used to examine the effects of climate-forest policies – ranging in scope from stand-level landowner perspectives to global trade models, and from single-sector to macro-

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[2] This chapter is largely extracted from Wong, Alavalapati and Moulton (2002, in press).

economic models. We begin by describing the literature on use of micro or stand level assessments to analyze either climate change effects or specific carbon-related policies. These studies examine the adaptive behavior of forest owners using extended Faustmann principles for determining optimal rotation ages. The next class of studies builds on the previous by incorporating endogenous adaptation at the stand-level to regional or national assessments. Studies with a global scope are similarly constructed as the regional models, but with the incorporation of timber trade data between regions. The final group of studies is those with economy-wide linkages and/or a macro-economic perspective. The advantages of economy-wide and dynamic economic-ecologic models are reviewed to contrast with the shortcomings of single sector models. These different classes of models are then compared in their coverage of issues and their role in supporting prudent policy choices. Finally, opportunities for future integrated research are highlighted.

2.1 Micro (or stand)-level studies

Since carbon sequestration is perceived as a positive externality to timber production (a public good), there is little incentive for private investments in the production of carbon storage within a market economy (Solberg, 1997). Policies to ensure for a desired level of carbon stock in the economy will have to provide incentives to, or impose taxes on, private landowners to internalize carbon costs and benefits in their forestry practices. This will have significant impact – forestry practices that incorporate carbon storage benefits have longer harvest rotations than those that merely maximize timber revenues (Stainback and Alavalapati, 1999; Solberg, 1997; van Kooten et al., 1995).

van Kooten et al. (1995) were among the earliest to develop a methodology for internalizing the carbon sequestration benefits of growing trees into the Faustmann model. The Faustmann principle for choosing the optimal rotation age for a commercial forest plantation is based on the criteria of maximizing net present value of timber income. van Kooten et al.'s extended Faustmann model, thus, takes into account both commercial timber and carbon uptake values (carbon credits), and provides the opportunity to impose a penalty for releasing carbon into the atmosphere at harvest (carbon taxes). Their primary conclusion is that rotation ages in the U.S. Pacific Northwest are likely to increase by about 20% for the most likely range of carbon credits and taxes, but that it may be worthwhile to never harvest old-growth forests to avoid releasing the large stocks of biomass carbon into the atmosphere.

Numerous studies have applied variations of the Faustmann model to different forest types and regions, and for different objectives – Stainback and Alavalapati (1999), for example, examined the consequences of a carbon policy on management of slash pine forests in Florida. Huang and Kronrad (2001) used the difference between the Faustmann's soil expectation value of the economically optimal rotation and the biologically optimal rotation to determine the amount of annual compensation required to motivate private landowners to sequester higher levels of carbon on their forestlands in the U.S. South.

A slightly different slant was used by Hoen and Solberg (1994) in comparing the economic efficiency of sequestering CO_2 in Norwegian boreal forest stands under various forest management prescriptions. Although still within an optimizing framework, they used a linear-programming model to maximize utility from a multi-input/double-output forest production function (timber and carbon). Holding harvesting levels fixed, this approach allows the timber producer to adjust his management intensity and timing of treatments (such as fertilization, thinning, clear felling, etc.) in order to maximize carbon sequestered on the stand.

2.2 Regional or national-level studies

Early regional assessments of climate change on the socio-economic aspects of the forest sector were centered on the forest products markets – where the forest forms one component of the production function. Climate-forest policies are translated into changes in production costs, harvest rates or product prices in the timber supply function, and their movements are tracked to consequent implications on forest markets and trade. These models represent the forest sector as stock-accounting equations for changes in forest inventory or use area-based models that track land use changes in land units.

An example is Haynes et al.'s (1994) study, which used TAMM (Timberland Assessment Market Model), a forest sector model for the U.S., and ATLAS (Mills and Kincaid, 1992), the Aggregate Timber Land Assessment System, to compare the impacts of several forest carbon options. TAMM was built on earlier econometric and linear programming studies to solve spatial market concerns, and provides an integrated structure for considering the behavior of regional prices, consumption and production in both the stumpage and wood product markets. ATLAS was used to make inventory projections for all private timberland in the U.S. The study examined combinations of possible carbon policies (such as afforestation programs, recycling and reduced harvests from National Forests) and projected inevitable price increases in solidwood products and sawtimber, large-scale expansion of softwood supply in the U.S. South, and an increase in relative importance of hardwoods as a result of higher demand for fiber products.

Further developments expanded to include the agricultural sector because of their shared land base. Adams et al. (1993) linked a price-endogenous spatial equilibrium model of the U.S. agricultural sector (ASM) and TAMM to quantify the social costs of tree planting programs on agricultural land, and their effects on prices and welfare of economic agents in the agricultural and forest sectors. The model simulates competition between carbon sequestration and traditional crop or livestock activities for available land under the different carbon policy targets. The social cost associated with each target, or shadow price of carbon, is the marginal subsidy that would induce farmers to plant trees instead of crops under specific CO_2 targets. The analysis shows that the social costs are relatively low if the policy target is to sequester 10-20% of annual U.S. CO_2 emissions but these costs increase dramatically for higher CO_2 targets, suggesting that the use of agricultural land to sequester substantial amounts of carbon may be more expensive than previous estimates.

The Forest and Agricultural Sector Optimization Model, FASOM (Adams et al. 1996; 1999), takes the research further by incorporating endogenous adaptation and dynamic stock adjustments. FASOM is a non-linear model of the forest and agricultural sectors - it has a joint spatial equilibrium market structure with the linked sectors competing for a portion of the land base. FASOM is dynamic in that it jointly solves for the equilibrium in the different markets (land, agriculture products and logs) for each model time period. Prices for agricultural and forest commodities and land are endogenously determined given demand functions and supply processes. Unlike TAMM, forestry investment decisions in FASOM are endogenous - forestland owners implement management activities to maximize their present net welfare, where the intertemporal impacts of their activities are known with certainty. The model examines the consequences of these management decisions and the market implications of “least social cost” carbon policies on forest carbon storage, fluxes and costs. FASOM results suggest that land use shifts account for the largest adjustments to meet policy targets (although these changes need not be permanent) and forest management changes involve higher intensity management and lesser forest type conversion.

An alternate method to examine land use distribution between forest and agricultural sectors under carbon subsidy programs is by using econometric land use models (Plantinga et al., 1999). This model structure has several advantages over the “engineering” or spatial equilibrium approach by capturing elements of landowner behavior such as the irreversibility of investments under uncertainty, decision-making inertia due to high costs of acquiring forest management skills and knowledge, and other private, non-market benefits derived by landowners, such as recreation. Their study of Maine, South Carolina and Wisconsin compares the marginal costs of sequestering carbon from converting up to 25% of a state’s agricultural land (upper limit) and finds that the costs are cheaper where there is lesser pressure on land conversion to urban uses, and when the harvest of more valuable timber species are permitted. These results can be used to identify regions or states where land can be converted for forest carbon sequestration activities at lowest costs.

In a similar approach, Newell and Stavins (2000) drew on econometrically estimated parameters of a land use model, and layer it upon a model of relationships that link changes in land use with changes in the time parts of CO_2 emission and sequestration. They used their model to compute the sensitivity of marginal carbon sequestration costs to changes in relative prices (between forest and agricultural products), discount rates, forest management regimes and tree species. They draw four major conclusions; first, marginal sequestration costs are greater for cases with periodic timber harvests relative to cases of permanent stands. Second, changes in the discount rate have counter-effects on the marginal costs of sequestration and quantity of induced carbon sequestration. Third, marginal sequestration costs increase monotonically and non-linearly as agricultural prices increase because the opportunity cost of land increases; and fourth, there is asymmetry between marginal costs of carbon through forestation and retarded deforestation. The last point suggests that attention should be focused on efforts to reduce rates of deforestation, particularly in the tropics.

A different method in regional studies is to explore the effect of climate change on forest productivity, and then, trace the implications on regional timber markets assuming constant demand. Integrated climate-forest assessments provide an opportunity to characterize the linkages between climate and the forests that are typically defined away or treated parametrically in traditional economic research. Bowes and Sedjo's (1993) study of the MINK region (Missouri, Iowa, Nebraska and Kansas) is an early example. The study used a stochastic model of forest growth and succession, to simulate forest development under climate conditions in the 1930s, and qualitatively measured the impacts of a 2 X CO_2 climate on the regional economy. A warmer and drier climate is generally projected for the region, leading to declines of 25% - 60% in forest biomass. Given the originally low productivity of forests in the area, the authors concluded that potential for active adaptation in forest management was unlikely unless a market for carbon exists to substantially increase the economic value of these forests. As such, these results cannot be extrapolated to other regions even though a legitimate ecological model was used to measure the effects of climate change.

Along a similar vein, Joyce et al. (1995) used the TAMM-ATLAS model to examine market effects of forest productivity under various climate scenarios projected by General Circulation Models (GCMs). Integrating TAMM-ATLAS with FORCARB (Birdsey and Heath 1996), a model of the U.S. carbon budget, provides the advantage for examining changes in forest carbon storage and flux, projected changes in forest productivity and wood product prices on the level of forest carbon sequestration in the future. Wood product markets adapt to shifts in forest productivity, inventories and harvest levels by solving for equilibrium stumpage prices and harvests based on the interactions between demand for standing timber and projected timber supply.

The more complete integrated assessments include the two expected effects of climate change on forest ecology. One is the biogeochemical effect addressed by Bowes and Sedjo (1993) and Joyce et al. (1995) – where increases in average temperatures and atmospheric CO_2 concentrations are expected to impact forest growth productivity (i.e. the photosynthesis and respiration rates), and the net gain in carbon exchange with the atmosphere[3]. Second is the biogeographical effect – simulated changes in seasonal weather patterns due to climate change could result in shifts in the geographical distribution of forest types. For the latter, Sohngen and Mendelsohn (1998) predicted a substantive shift from northern white pines to southern loblolly pines for the U.S.

A second advancement by Sohngen and Mendelsohn (1998) is the incorporation of a dynamic adjustment pathway for ecological change to climate effects, and market adaptation to these stimuli in the short and long run. A "natural change" ecological scenario was compared to an integrated model that incorporated the dynamic optimizing behavior of U.S. timber markets to illustrate how the industry endogenously adapts to minimize economic and carbon losses. The study used a GCM to model climate change, which predicts a 6.73° C temperature change and a 15% average increase in precipitation across the U.S. by 2060. These parameters were assumed to increase linearly. Combinations of biogeographic (BIOME2 and MAPSS) and biogeochemical

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[3] Early experiments into CO_2 fertilization suggest that tree productivity will indeed increase in the short-run (Eamus and Jarvis, 1989; Norby et al., 1996). It has yet to be proven whether this positive net gain can be maintained in the long-run, since other environmental factors such as nutrients, nitrogen or water may be limiting (Norby et al., 1992, DeLucia et al. 1999). The process-based terrestrial ecosystem model (TEM) by Melillo et al. (1993, p. 239) estimated that global net primary productivity of forests would increase by 20 - 26% in response to GCM-generated climate change scenarios and 2 X CO_2 conditions. Responses are most significant in tropical and dry temperate forests and least in the northern temperate ecosystems. VEMAP (1995) provides a useful review of biogeochemistry and biogeography models, and compares results obtained from these models for simulating change in the continental U.S.

models (TEM and BIOME-BGC) were used to depict the forest's ecological impacts. The natural model predicted a release of between 2.5 to 6.3 Pg[4] carbon during the forest dieback and re-distribution process, whilst the integrated model anticipated that human responses will mitigate or even reverse these fluxes by changing the timing of harvests, salvaging timber from dieback and replanting new forest types. A similar approach (Sohngen et al. 1996) expanded the geographical scope to include nine different timber supply regions in the world.

2.3 Global studies

Restricting analysis to within the region or country of study discounts the potential impact of climate-forest policies in one country on other timber-producing countries. Creation of the Kyoto Protocol is, in part, driven by issues of distribution and scale, and a global perspective is required to adequately capture those impacts. In addition, changes in the production, demand and prices of wood products in the U.S. may have implications on the international timber trade, as the U.S. is one of the world's largest importer and consumer of wood products. The single sector or partial equilibrium studies discussed earlier do not address such regional trade effects.

An early study to integrate climate impacts into a global forest assessment was carried out by Binkley (1988). Binkley used a regression model of the relationship between heat sum and forest growth to predict the effects of a 2 X CO_2 climate scenario on the growth of the world's boreal forests. Kallio et al's (1987) Cintrafor Global Trade Model was then used to predict the production, consumption, price and trade effects of the simulated climate change. The simulations projected gains for some regions and losses for others, shifts in timber revenues ranged from - 25.5% to +22.4% relative to the

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[4] 1Pg = 10^{15} g

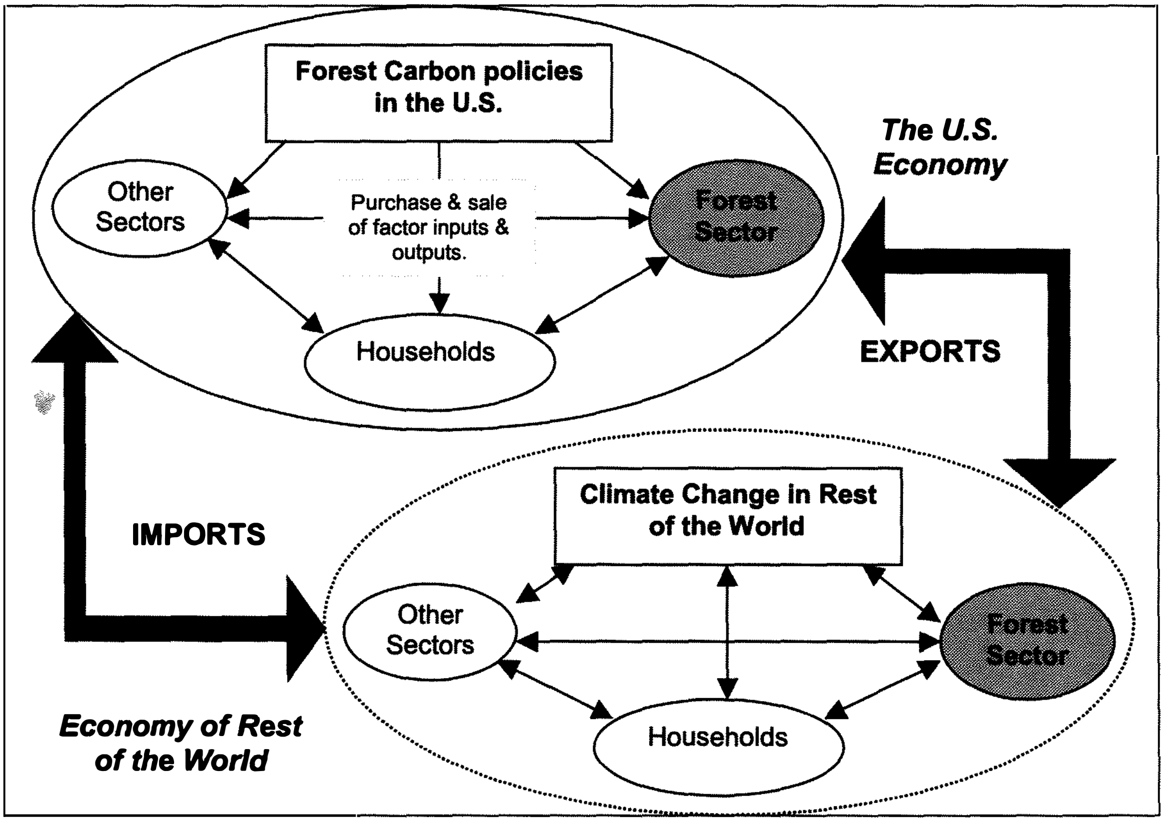
base case. However, the study is limited in that it ignored endogenous adaptation and changes in forest growth outside of the boreal region.

Similar to Joyce et al.'s (1995) study for the U.S., Perez-Garcia et al. (1997) linked climate change scenarios from GCMs with a model of global vegetation, TEM (Terrestrial Ecosystem Model; Melillo et al. 1993) to examine changes in forest productivity, and used the Cintrafor Global Trade Model to examine shifts in forest product markets. The study projected substantial shifts in global trade patterns of wood products. Under all GCM climate scenarios, Canada, China, and other Asian wood importing countries are expected to enjoy significant gains in forest productivity as increased production of pulpwood and residual chips in these countries displace pulpwood production in the Oceanic region. The U.S., on the other hand, will gain a significant cost advantage in the production of structural panels. Higher log output in the U.S. and China reduces log production in the former Soviet Union and European consumer countries, and in the process, redirects the trade flows of lumber to reduce lumber manufacturing activities in the Middle Asia, Africa and Oceanic regions.

2.4 Economy-wide approaches

The studies previously discussed have a rigorous approach to details in the forest sector and in some, a rather well-integrated structure for ecological economic analysis. They remain somewhat limited for policy analysis however, because they do not capture the overall effectiveness of a forest carbon policy beyond its impacts in the forest sector. In a national economy, the producing sectors are linked through markets in their purchase of production factors (capital, labor, and inputs) and sale of finished goods to households. Figure 1 below illustrates how the forest sector is linked to the other sectors and households in an economy. Changes in the forest sector will have implications for other producing sectors and households in the economy. An economy-wide perspective has considerable merit for public decision-making as it allows for a coherent examination of multiple objectives in identifying policy criteria and hence, provides a firm basis for making judgments on social welfare. Changes in prices (or other market conditions) can be translated into changes in aggregate well-being of consumers and producers in order to discern distributional consequences for the different groups in society.

Figure 1: Regional and sectoral linkages in the global economy



The Future Agricultural Resources Model (FARM) by Darwin et al. (1996; also Darwin, 1999) addresses the issue with a computable general equilibrium (CGE) model. FARM is composed of a geographic information system (GIS) which links climate variables with water and heterogenous land resources, and a CGE economic model which links land, water, and other primary factors with regional production, trade and consumption. FARM's CGE model simulates interactions between farmers and downstream consumers (both domestic and foreign) and so, accounts for all responses by economic agents under climate change or policy scenarios. Climate change is simulated by allowing land to shift from one land class to another based on predicted changes in length of growing season (primarily determined by regional rainfall and soil temperatures), and by changing regional water supplies.

FARM results indicate that climate change will threaten tropical forests in Southeast Asia, Latin America and Africa due to increases in per-hectare harvest rates and declining forestlands. The losses in tropical forest areas were a direct result of climate-induced effects and increased competition from crop production (Darwin et al. 1996). In addition, estimated changes in Ricardian rents indicate likely detrimental effects in Latin America and Africa, beneficial effects in the former Soviet Union, and mixed impacts on eastern and northern Europe and western and southern Asia (Darwin 1999). Benefits and losses associated with these changes are passed on to consumers. The FARM model has also been applied towards examining land-use issues as a result of policies to induce forest carbon plantations (Wong et al., 2002).

The Global Impact Model, GIM (Mendelsohn et al. 2000; Mendelsohn and Schlesinger 1999) uses an econometric[5] approach to measure the economic effects of climate change by country and market sector (agriculture, forestry, coastal resources, energy, and water). GIM combines two empirical methods to construct climate response functions for each of five sectors – a process-based analysis based on experimental approach (bottom-up) and a "Ricardian" approach using cross-sectional data (top-down).

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[5] Adams (1999) discussed the advantages and shortcomings of the two economic methodologies – econometric assessments vs. mathematical optimization – with particular reference to FARM and GIM.

For the forestry sector, the process-based analysis relies on a set of ecological models (both biogeochemical and biogeographic) and GCM simulations to construct a reduced-form model that links climate scenarios and sectoral welfare impacts to temperature and precipitation. The second method is based on a cross-sectional analysis of the effect of climate on the present value of timber grown. The GIM's advantage is that it represents strengths from both the bottom-up and top-down approaches. The first captures the response sensitivity of trees to different climates, while the cross-sectional approach includes adaptation based on where people live. Because each of the response functions is concerned with just one sector in one country however, GIM is essentially still a partial equilibrium model.

2.5 Comparison of Model Structure and Results

The varied approaches to analyzing climate-forest policies raise two interesting questions: (1) what are the predominate theoretical and structural differences at the different scope levels; and (2) how do the theoretical differences affect predicted results? The first question is answered to some extent in the description of the different approaches in the previous section. Table 1 on page 19 presents some of the general structural points for the more prominent models.

Table 2 presents a summary of the major results from the select models under their different policy and/or climate scenarios. These results are not directly comparable given differences in model structure and features. It is not the intention to find the *best* model for two reasons: 1) economic theory and modeling is unlikely to produce the perfect predictive tool, and 2) we do not have the benefit of a historical perspective. Instead, the intention is to compare and contrasts the theoretical underpinnings and empirical results to guide future endeavors. It is useful to note that the appropriate model is one that addresses the objective at hand. A balance has to be made between the types of information gained from detailed sector analysis at the expense of those generated by broader economy-wide or integrated analyses, and vice versa. The trade-off is always driven by the question(s) that one is attempting to answer.

There are two points to clarify with regards to predictions from economic assessments. First, in addition to differences in model structure and features, the quality of regional climate forecasts contributes considerable noise to results. The science of climate change remains relatively unknown at this point, and this problem may disappear as the quality of climate information improves. Second, it should be noted that projections from economic assessment models are more accurate for short-term events. It is impossible to estimate or predict all the changes in the myriad of factors involved in shaping forestry and climate over the century, and numerical results should only be treated as useful guides.

Finally, the studies reviewed in this paper are largely focused on market goods in their evaluation of policy impacts. Non-market aspects dominate the social values of many forests, particularly on remote or unmanaged lands where the impacts of climate change may be significant (Binkley and van Kooten 1994, p. 97). Non-market benefits can be examined in the different biophysical impacts of climate change on forests, and in the valuation of those impacts. For example, changes in forest cover could affect recreational and aesthetic values, changes in forest health could affect biodiversity and wildlife habitats, and changes in vegetation could affect regional water flows. Admittedly, the incorporation of non-market values into the policy process is a daunting one and as such, policy impacts related to these issues are the least understood.

Table 1: Comparison of select models over several structural components

	Van Kooten et al. (1995)	**ASM-TAMM (Adams et al., 1993)**	**FASOM (Adams et al., 1999)**	**Perez-Garcia et al. (1997)**	**Sohngen and Mendelsohn (1988)**	**FARM (Darwin et al., 1996)**	**GIM (Mendelsohn et al., 1999, 2000)**
Theory	Optimization (extended Faustmann)	Spatial equil.	Spatial equil.	Spatial equil.	Dynamic optimization	General equilibrium	Cross-sectional analysis
Projection method	Static	Static	Dynamic (recursive)	Static	Dynamic – optimal control	Dynamic (recursive)	Static
Scope	Stand-level (Pacific NW)	U.S.	U.S. (11 regions)	Global (9 regions)	U.S. (4 ecosystem types)	Global (8 regions)	Global (7 regions)
Sectors	Forestry	Forestry-agriculture	Forestry-agriculture	Forestry	Forestry	Economy-wide	Forestry, agriculture, coastal, energy, water
Integrated climate scenarios	No	No	No	Yes	Yes	Yes	Yes
Policy scenarios	Yes	Yes	Yes	No	No	Yes	No
Endogenous management	Yes	No	Yes	No	Yes	Yes	Yes
Timber inventory	Yes	Yes	Yes	Yes	Age-delimited	No	No
Carbon flux details	Yes	Yes	Yes	No	Yes	No	No

Table 2: Comparison of select models on their main results

	Van Kooten et al. (1995)	**ASM-TAMM (Adams et al., 1993)**	**FASOM (Adams et al., 1999)**	**Perez-Garcia et al. (1997)**	**Sohngen and Mendelsohn (1988)**	**FARM (Darwin et al., 1996)[g]**	**GIM (Mendelsohn et al., 2000)**
Policy scenarios	$P_c = \$20/\text{mt}$[a] $P_t = \$15/m^3$	C stock targets	C flux and stock targets	N/A	N/A	N/A	N/A
Climate scenarios	N/A	N/A	N/A	+ 2.8 – 4.2 °C 2 X CO_2	+ 3.0 – 6.7 °C 2 X CO_2	+2.8 – 5.2 °C 2 X CO_2	+ 2°C 2 X CO_2
Rotation age	+ 20% longer	N/A	+ 0.4 – 2.4% longer	Constant	N/A	N/A	N/A
Timber prices	Constant	Constant	N/A	N/A	Decrease	+ 0.8 – 3.1% [h] + 1.7 – 5.8% [i]	Constant
Land-use change into forestry (in US)	Constant	+ 49.4 – 274.4 mil acres	+ 14 – 28 mil acres	Constant	Constant	- 4.5 – -16.4%	N/A
Carbon storage	Small increase	140 – 700 mil short tons C/yr	+ 440 – 800 mil mt	N/A	N/A	N/A	N/A
Carbon costs	N/A	\$18 – 55/ton	\$22 – 37/mt [c]	N/A	N/A	N/A	N/A
Welfare measures for the U.S.	N/A	- \$1.3 – -2.3 (producers) - \$7 – +0.2 (consumers) [b]	+ \$0.5 – 1.3 (producers) - \$0.7 – -1.6 (consumers) [d]	+ 1 bil/yr to 2040 [e]	+ \$2.6 – 30.1 (ecological change) [f] + \$ 3.9 – 31.2 (endog. mgt)	N/A	+ 56 – 87 bil [j] (+ 4 – 9 bil in forestry sector)
Distributional effects	N/A	N/A	N/A	+ Canada, US, Japan; - Chile, NZ	N/A	N/A	+ North Amer, Asia, East Europe; Rest uncertain

Notes accompanying Table 2:

:

[a] mt = metric tonne; P_c = price of carbon; P_t = price of timber

[b] in billion US dollars. Welfare measures reported are for the case where timber harvesting from carbon plantations is permitted.

[c] Average cost, carbon is discounted. Marginal cost = \$11 – 15/mt/yr

[d] in billion 1990 US dollars, simulation from 1990-2039. Welfare measures reported are for the forestry sector only.

[e] in 1980 US dollars, simulation from 1990-2040.

[f] in billions 1982 US dollars, relative to base case, 2060.

[g] Although the FARM model has a global scope, the results reported in Darwin et al. (1996) are for the Southeast Asian region.

[h] change in export prices.

[i] change in timber harvest rate.

[j] in 1990 US dollars. The expected welfare benefits reported here are for the North America region, and are approximately 0.53 – 0.83% of GDP.

2.6. Criteria for Future Research

A challenge for economic research is to provide policy makers with succinct information to make socially equitable, and economically and ecologically sound decisions. Research that fails to conceptualize multiple concerns or fails to generate information at the level appropriate to the problem at hand will provide biased results and hence, inefficient policies. From our reviews of previous research, we identified the following criteria as crucial for analysis of any climate-forest policy:

- *An objective of any policy analysis is to discern the economy-wide impacts.* As such, policy assessments should link forest sector impacts to the larger macroeconomic picture, as climate change does not impact the forest in isolation from the rest of the economy. Intersectoral linkages allow for a comparison of relative impacts incurred by different groups within a society. Also, studies interested in distributive justice should also have a global scope in order to discern welfare effects between developed and developing, and forested and non-forested countries.

- *A dynamic analysis.* Given the large capital stock involved, the dynamic nature of ecological changes and adaptive market response, static comparisons provide poor approximations of the resulting adjustment path and their welfare outcomes. A dynamic analysis can also account for issues of timing and lagged effects with regards to policy implementation and adaptation by producers.

- *An integrated linkage between the forest and climate systems.* Ecological and social systems co-evolve through time, each providing feedbacks on the other. As shown by Sohngen et al. (1998, p. 514), the integrated ecologic-economic analysis can provide insights that contradict results from the simple ecologic assessment.

- *The economic framework should be linked to a carbon cycle model.* In this way, CO_2 emissions are tied to levels of economic production and energy consumption, and CO_2 sequestration to growing forests. This information is useful for estimating cumulative gains (or losses) in carbon storage over the long term, and for comparing the overall efficiency of different forest management activities in mitigating CO_2 emissions.

- *The treatment of uncertainty is crucial*, given the lack of scientific consensus and the non-linear linkages between the climate and terrestrial systems. The two types of uncertainties that should be made explicit are: 1) uncertainties in model structure and parameter values, and 2) structural uncertainties because of expert disagreement of climate change processes. Sensitivity analyses should be carried out to account for some of the randomness in parameter values and to increase confidence in the model results.

Thus, given these demanding criteria, a suitable research path is to integrate climate and ecologic models with a forest sector model into a dynamic general equilibrium framework. Recent developments such as the FARM model (Darwin et al. 1996), integrated efforts by Sohngen et al. (1996, 1998, 2000), and the Global Impact Model (Mendelsohn et al. 2000) each have desirable elements, but there still remains work to be done to achieve a truly comprehensive policy analysis.

3. Modeling Framework

In this study, we use a dynamic version of the Future Agricultural Resources Model (FARM), originally developed at the USDA Economic Research Service (ERS) to evaluate the impacts of global climate change on agriculture systems (Darwin et al., 1996). Dynamic FARM (D-FARM) is an integrated ecologic-economic model, linking information on classes of land productivity within a computable general equilibrium (CGE) framework. The model meets many of the rigorous criteria detailed in the previous chapter as essential for integrated forest-climate analysis, but remains slightly short of meeting the criteria regarding forest dynamics (see Section 3.2.1 below).

3.1 Model Segregation

The model is segregated into 12 regions, 18 commodities and 11 sectors (see Table 3 on following page). All sectors except for agriculture produce one commodity. The agriculture sector produces 8 different crop goods.

3.2 Ecological Framework

The ecological features in D-FARM are derived from its characterization of land resources. A Geographic Information System (GIS) was used to disaggregate land into six heterogeneous classes based on length of growing season, defined as the longest continuous period of time in a year that soil, temperature and moisture conditions plant growth. The GIS has grid cells with spatial resolution of 0.5 degrees by 0.5 degrees and contain data describing the associated area's climate, natural vegetation and current land use (see Darwin et al., 1996 for more details). Thus, the land class structure captures some broad differences in land production possibilities and ecosystem types, as shown in Table 4.

Table 3: Regions, sectors and commodities

Regional aggregation	**Commodity/Sectoral aggregation**
1. ANZ: Australia – New Zealand	1. – 8. Agriculture: Paddy rice; Wheat; Other grains; Vegetables, fruits, nuts; Oilseeds; Sugar cane/beets; Plant-based fibers; Other crops
2. CAN: Canada	
3. USA	
4. JPN: Japan	
5. OEA: Other East Asia	9. LIV: Livestock
6. SEA: Southeast Asia	10. FOR: Forestry
7. EU: European Union	11. COG: Coal, oil, gas
8. FSU: Former Soviet Union	12. MIN: Other minerals
9. OEU: Other Europe	13. FMM: Fish, meat, milk
10. LAM: Latin America	14. OPF: Other processed foods
11. AFR: Africa	15. TCF: Textiles, clothing, footwear
12. ROW: Rest of World	16. NMM: Non-metallic manufactures
	17. OMN: Other metallic manufactures
	18. SRV: Services and utilities

Table 4: Land features

Land class	Length of growing season (days)	Principle crops and cropping patterns	Major ecosystem types	Sample regions [a]	% of total land in US (sample area)
1	0 – 100 *	Sparse forage for rough grazing	Tundra and alpine areas	Greenland	13.14 (Northern Alaska)
2	0 – 100 **	Millets, pulses, sparse forage for rough grazing	Desert and semi-desert shrub and grasslands	Sahara	32.88 (Mojave Desert)
3	101 – 165	Short season grains, forage, one crop per year	Boreal forests	Southern Manitoba	12.68 (Western Nebraska)
4	166 – 250	Maize, some double cropping possible	Temperate and tropical dry forests	Northern European community	32.69 (Corn belt)
5	251 – 300	Cotton, rice, double cropping common	Broadleaf, tropical dry and seasonal forests	Zambia, Northern Thailand	7.52 (Tennessee)
6	301 – 365	Rubber, sugar cane, double cropping common	Tropical rain-forests	Malaysia, Brazil	12.14 (Florida)

Notes: Soil temperatures are above 5° C for * 125 days or less, ** over 125 days in a given year.
Source: Darwin et al. (1996); [a] Olson (1989-1991).

3.3 Economic Framework

The general equilibrium core in D-FARM is based on the Global Trade Analysis Project (GTAP) framework. GTAP is well-documented and widely applied towards analysis of global trade issues (Hertel, 1995). This model retains all the features from GTAP and dynamic GTAP (Ianchovichina and McDougall, 2000).

3.3.1 Primary factors

Regional endowments of the primary factors are determined exogenously and cannot be transferred to another region. Skilled and unskilled labor, capital and water are homogenous and perfectly mobile across sectors within a region. Each factor has its own regional price, determined by the intersection of a downward sloping demand curve and a perfectly inelastic supply curve (exogenous endowments). Water is supplied to the agriculture, livestock, forestry and services sectors. Land, labor and capital are supplied to all sectors.

Demand for the primary factor land is more complicated. The land class structure which captures broad productivity differences, also restricts the range of economic activity possible within each land class. This implies that there is a unique set of commodity outputs for each region-land class combination. Land is supplied to the different sectors based on constant elasticity of transformation (CET) functions with Allen partial elasticities less than zero (see Figure 2 below). CET functions restrict land mobility between sectors, and imply that a land class is not equally productive for all uses. D-FARM allows land to respond to changing economic conditions by shifting into new uses without losing sight of its inherent productivity differences.

3.3.2 Production

The commodity markets in D-FARM are assumed to perfectly competitive, implying that the supply price equal marginal costs, and demand equals supply in all markets. Producers are profit-maximizing with a constant returns to scale technology in each sector. There are two broad categories of inputs: primary factors and intermediate inputs. Firms are assumed to choose the mix of inputs which minimizes production costs at their level of output.

Figure 2: Land supply structure

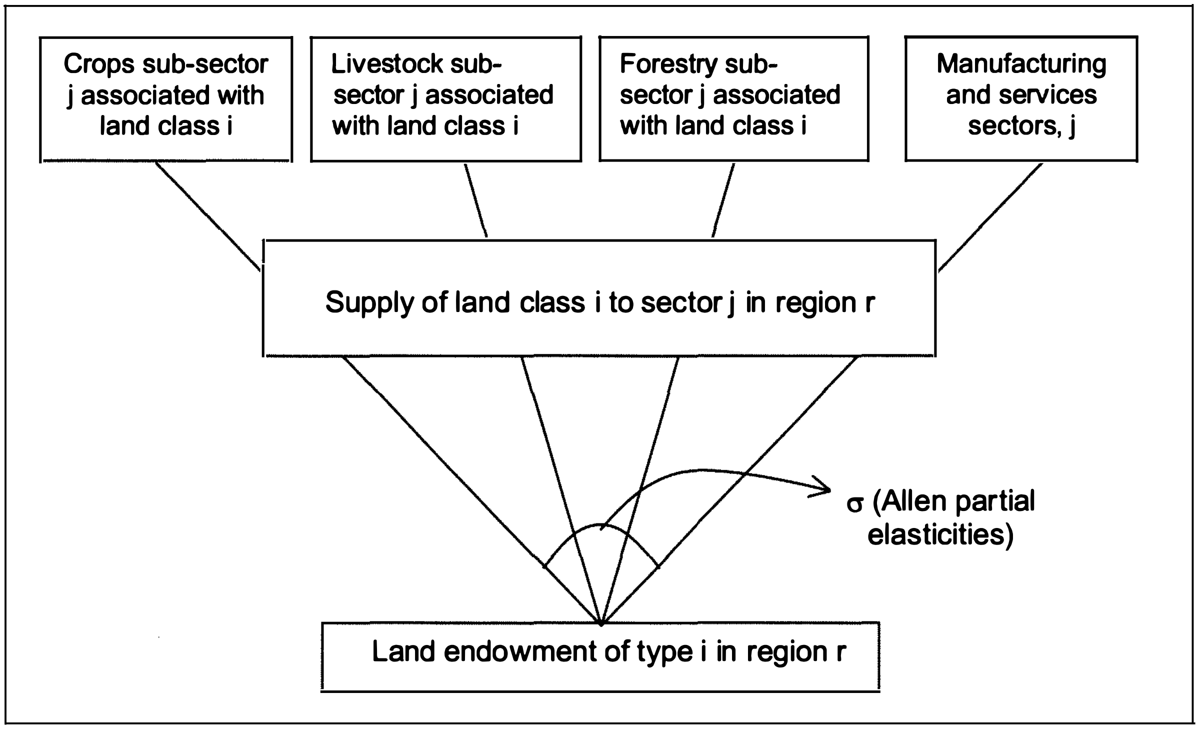
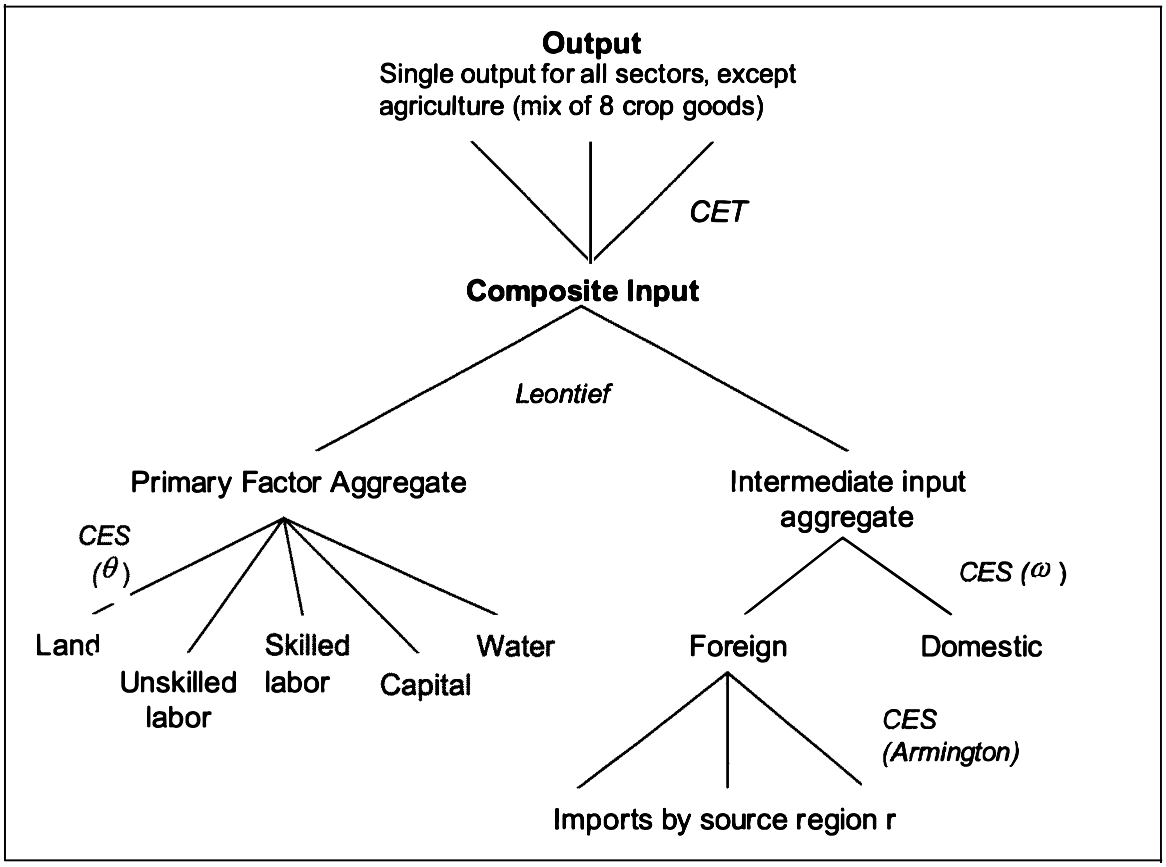


Figure 3 on the following page shows the three-level nested production structure. At the first level, the primary factor aggregate is a CES combination of skilled and unskilled labor, capital and land. The intermediate input aggregate consists of 18 possible commodities, both imported and domestic. These bundles are derived from nested constant elasticity of substitution (CES) functions – one for choosing the import-domestic mix, and an Armington determination for choosing the amount to be imported from each source region. Allen partial elasticities of substitution used in these CES functions are presented in Appendix 1. At the second level, the intermediate input aggregate and primary factor aggregate are used in fixed proportions to output following the Leontief technology. The third level of production is relevant only to the agriculture sector as all other sectors produce a single output. The agriculture sector produces a mix of 8 different crop commodities, determined by CET functions with Allen partial elasticities less than zero. The elasticities determine how supplies of crop commodities respond to changes in their relative prices.

Figure 3: Production structure



3.3.3 Consumption

Consumption is modeled using a utility-maximizing representative household. The household owns all primary factors of production and receives income through payments for use of the factors. The household maximizes utility from private consumption, government purchases and savings. Utility is modeled using per capita Cobb-Douglas utility functions, implying that income shares of private consumption, government purchases and savings within a region are constant (but not equal) across all income levels. Private household demands are represented by a constant difference of elasticities (CDE) expenditure function. The CDE structure is less restrictive than the CES in that elasticities of substitution between pairs of commodities can differ, and income elasticities are not restricted to equal one. These are presented in Appendix 1. Private consumption of imported goods follows an Armington structure analogous to the production demand for intermediate inputs.

3.3.4 Investment theory

The investment theory, which drives the dynamics in D-FARM, is described in detail in Ianchovichina and McDougall (2000). It links economic activity over time to keep track of the regional accumulation of physical capital, financial wealth and liability, and international income and investment flows.

3.3.5 Limitations in the forest sector

The major limitation of the model is that D-FARM does not contain details on the dynamics of forest growth. As similar with most CGE approaches, timber supply is interpreted as a steady-state output period by period. This short-run adjustment path implies that the amount of land in forests and the harvest regime on existing forestlands can adjust more quickly than the amount of physical capital in the forest sector. In addition, the absence of information on forest stocks suggests the forestry sector does not respond to changes in the standing stock of trees, only changes in relative prices between sectors and regions. These assumptions are clearly somewhat unrealistic. We address this issue in the last section of this report (p.55).

4. Model Scenarios

The CGE model is a system of non-linear equations and is solved using GEMPACK, a suite of programs for implementing and solving economic models. This method produces a sequence of recursive results representing changes in the endogenous variables. Solutions in the sequence maintain all equilibrium conditions embodied in the data and other restrictions imposed by the economic theory. See Harrison and Pearson (1995) for details of algorithms available in GEMPACK.

The core economic data are from the GTAP version 4E database (McDougall et al., 1998), enriched with financial data required for the investment theory (Ianchovichina, 1998)[6]. The ecological data on land classes and productivity is derived from FARM's geographic information system (Darwin et al., 1996).

4.1 Base Case Scenario

The first step is to develop and run the base case. We rely on external estimates for the macroeconomic details and use the CGE model to determine sectoral and trade results by projecting the world economy into the future. A calibrated equilibrium database for the year 2000 (Ianchochivina, 2000) serves as the starting point for our base case and policy projections. The first three years of the base case projection (2000 - 2003) captures the recent global economic slowdown and its projected recovery period. The policy shocks are applied from year 2003 onwards.

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[6] Complete documentation of the GTAP data and their sources can be found at the GTAP website: http://gtap.agecon.purdue.edu/databases/v4/v4_doco.asp.

The base case scenario utilizes estimates of annual growth rates in regional population, skilled and unskilled labor, gross domestic product (GDP), and gross domestic investment (GDI). These estimates are based on a review of the literature and include most recent estimates of population growth (Population Division of the UN, 2001) and GDP projections (World Bank, 2001). It should be noted that the base case scenario projected here is very general; it only considers standard macro aggregates and does not provide alternative optimistic or pessimistic growth scenarios. All estimates used for the base case projection are presented in Appendix 2.

To address what has been termed as "double exposure" [7], the base case scenario also includes a slow decline in tariffs to reflect the global trend in liberalizing trade. These include tariff reductions implemented during 2000 by China prior to, and after, her accession to the World Trade Organization, implementation of the Agreement of Textiles and Clothing, and decrease in tariffs after the completion of the Uruguay Round (Walmsley et al., 2000 and references within).

4.2 Policy Scenarios

We simulated two sets of policy scenarios: 1) the exogenous establishment of tree plantations to sequester carbon at a global scale, and 2) the implementation of domestic carbon subsidies in the U.S. to induce private forestland owners to consider joint production of timber and carbon in their decisions regarding timber harvests.

---

[7] Researchers have argued that the two global issues of climate change and economic globalization be examined together (see for example, O'Brien and Leichenko, 2000). *Double exposure* refers to the fact that certain regions, sectors, ecosystems and social groups will be confronted by impacts of both climate change and globalization simultaneously.

4.2.1 Policy Scenario 1 (PS1) – Expansion of carbon plantations

The first set of policy scenarios involves a global expansion of carbon plantations as driven by the Kyoto Protocol. We exogenously increased the amount of land dedicated to forest plantations in the U.S., Canada, Australia and New Zealand beginning in the year 2003 onwards. The model is extended to 23 years for longer term projections.

Table 5 presents the policy scenarios and their supporting rationale. These scenarios are well within the estimates of land considered to be technically suitable for establishing forest plantations to sequester carbon[8]. Estimates of potential land area for carbon plantations range from 345 million to 510 million hectares (ha) globally (Kolshus, 2001; Dixon et al., 1994a, 1994b).

Timber is expected to be harvested from the carbon plantations on a financially optimal rotation and sold on the global timber market, but these impacts are not adequately captured by this model. Since there are no forest growth dynamics in the model, we assume the policy shocks to take effect immediately and timber harvests are interpreted as steady-state output in each period. We implement the policy shocks at different rates according to the average rotation ages in the regions, in order to capture some of the differential regional effects.

The percentage form of the CES equation for supply of land is (lower case letters represent percentage change in variables):

---

[8] Studies that estimate the potential for forest sink activities largely focus on the amount and suitability of land available for implementing reforestation or afforestation programs, and typically ignore the various socio-economic and political factors that complicate the practicality of implementing such programs.

```
qendf(i,j,r) - aqendf(i,j,r) = qend (i,r) - ETRAE(i)*[pemf(i,j,r)
                                   + aqendf(i,j,r) - pem(i,r)]
```

where

qendf (i,r) = Supply of endowment i to sector j
aqendf (i,r) = Productivity change of factors in each industry
qend (i,r) = Endowment of primary factor i in region r
ETRAE (i) = Transformation elasticities between alternative uses of the heterogeneous land factors
pemf (i,j,r) = Market price of endowment i used by sector j in region r
pem (i,r) = Market price of endowment i in region r

To implement this policy, we made the supply of land to forest sector [***qendf ("land class", region, "forest")***] exogenous by switching the corresponding productivity change variable [***aqendf ("land class", region, "forest")***] to be endogenous.

4.2.2 Policy Scenario 2 (PS2) – Carbon subsidies

We simulated a second policy scenario of a carbon subsidy program in the U.S. The policy is designed to induce private landowners to consider joint production of timber and carbon in their decisions regarding timber harvests. This approach simulates a payment from the Government to forestland owners through the creation of a wedge between the supply (or producer) price and the market price in the supply price linkage equation:

```
PS (i,r) = TO (i,r) x PM (i,r)
```

where:

PS (i,r) = supply/producer's price of output i in region r
PM (i,r) = market price of output i in region r
TO (i,r) = ad valorem tax or subsidy; TO (i,r) > 1 in the case of a subsidy

By taking total differentials on both sides and denoting generically for variable X, $\frac{dX}{X} * 100 = x$, the equation in percentage change form becomes (again, lower case letters represent percentage change in variables):

```
ps (i, r) = to (i,r) + pm (i,r)
```

The subsidy, ***TO (i,r)***, is calculated based upon the amount of CO_2 embodied in a single unit of wood output. We assume an average carbon content of 0.2 tons per cubic meter (m^3) of wood (van Kooten et al., 1995). To convert the carbon content to CO_2 units, we use a conversion factor of 3.664 (Clark, 1992). Thus, the average CO_2 content in wood is calculated to be 0.7328 ton CO_2/m^3 wood. We assume the subsidy policy to take effect immediately upon implementation and hence, used the model to project only 10 years into the future. The levels of carbon subsidies considered in our study range from between US$ 3 – 27 per ton CO_2 sequestered[9], see Table 5.

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[9] Subsidy levels are based on scenarios from the Forest and Agricultural Greenhouse Gas Modeling Forum, October 1-3, 2001, organized by the USDA Economic Research Service and the US EPA Methane and Sequestration Branch, http://foragforum.rti.org/

Table 5: Policy Scenarios used in the analysis

	Region(s)	Policy shocks
Policy Scenario 1 (PS1): Carbon plantations (23 year simulation, 2000-2023)	U.S. Canada (CAN) Australia (AUST) New Zealand (NZ)	▪ High scenario US: 16 mil ha CAN: 5 mil ha AUST: 100,000 ha/yr till 2020 [1] NZ: 55,000 ha/yr from 2007-2012 [2] ▪ Low scenario US: 5 mil ha [3] *All others remain same as previous* ▪ Zero scenario US: NO carbon plantations *All others remain same as previous*
Policy Scenario 2 (PS2): Carbon subsidies (10 year simulation, 2000-2010)	U.S. only	▪ \$ 3 per ton CO_2 ▪ \$ 7 per ton CO_2 ▪ \$14 per ton CO_2 ▪ \$27 per ton CO_2

Notes:

[1] Kirschbaum (2000).

[2] Ford-Robertson et al. (1999).

[3] Projected expansion of plantations with a carbon credit of \$50 per ton carbon (McCarl and Schneider, 2001).

5. Results and Discussion

The model's results should be interpreted with caution. There are three things that readers should keep in mind: first, the percentages reported for the different sectors are not equal, that is, they are relative to the size of the sector's share of the overall economy. Second, the results depict changes in real, not nominal, prices as calibration of the CGE model normalizes prices relative to a numeraire, in this case the price of a global savings commodity. Third, although the model has a global scope, we focus largely on results for Canada and the U.S. only.

5.1 Base Case Results

Given our assumptions of global economic and population growth as reflected in the macroeconomic projections in Appendix 2, the base case scenario predicts shifts in land use composition for both U.S. and Canada. These shifts are quite substantial – the total increase in forestland in Canada is approximately 8.39 mil ha, and decrease in forestland size of about 2.79 mil ha in the U.S. by the year 2023 (Figure 4). The mobility of land between the forestry and agricultural sectors is driven by the relative changes in sectoral land income (or land rents in each sector). As shown in Figure 4, forestland income grew by almost 3.5% in Canada and shrunk by approximately 0.4% in the U.S. Conversely, farmland[10] income decreased by almost 42% in Canada and increased by 3.75% in the U.S. The dramatic increase in size of forests in Canada, thus, may be more of a result of the large drop in farmland, rather than the small increase in forestland, income.

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[10] Farmland is an aggregate of crop- and grazelands.

Despite the decrease in forestland size in the U.S., timber output continues to grow as demand increases with the lower prices. In addition, there does not appear to be any shortage of food over the next two decades. The aggregate price of food crops declines about 6% relative to savings, the numeraire, while aggregate crop output increases by 24%. This growth in crop production is a result of our trade liberalization scenario built into the base case. The simulated decline in import taxes significantly lowers the price for all U.S. crops and timber on the world market (by between 6 and 17%) and encourages an expansion in U.S. exports to all other regions. The results also suggest an intensified use of capital in both the forestry and agricultural sectors in the U.S. – demand for capital increases by over 87% in 2023, whilst demand for the other primary factors (water and labor) only increases by between 7 and 8%.

Table 6: Cumulative % change in the forestry and agriculture sectors, Base Case, 2023

Variable	**USA**	**Canada**
	Forestry	
Output	31.28	0.26
Price	-11.28	6.33
Exports	148.22	-9.87
Imports	-20.30	55.44
	Agriculture	
Output	24.02	-4.27
Price	-5.96	2.69
Farm land income (crop + livestock)	3.75	-41.94

Trade liberalization does not favor Canada kindly, however. Prices for Canadian crop and timber exports increase across-the-board in the world market (by between 0.5 to over 9%), indicating that the comparative advantage for producing those goods has shifted elsewhere. Capital investment in the two sectors increased by just about 35% over the next 23 years, whilst demand for labor and water resources decreased by over 10%. Predictably then, timber trade between the two countries benefits the U.S. Exports of timber from the U.S. to Canada increases by almost 56%, whilst imports from Canada to the U.S. declines by 29%. Figure 5 on the following page shows the cumulative changes in global timber output and exports at end of the model projection period. The base case suggests that the disturbing trend of increasing timber output from tropical regions will continue over the next 23 years, indicating a continuing trend of tropical deforestation.

Table 7 below details the base case impacts on welfare in the U.S. and Canada. In general, households in Canada enjoy an improvement in welfare, although the country's crop and forest producers do not fare as well. The opposite holds for the U.S. – the benefits of growth and trade liberalization are enjoyed by the crop and forestry sectors, whilst the consumers suffer losses in welfare. The welfare indicator is a Hicksian measure of Equivalent Variation.

Table 7: Cumulative % change in select welfare variables for the Base Case, 2023

Variable	**USA**	**Canada**
Total factor income	3.71	35.8
Per capita Household utility	-7.62	26.85
Average wages	-28.11	-9.90
Regional income	13.1	41.77
Terms of trade	-18.55	19.97
Welfare (US$ millions)	-151406	172421

Figure 4: Base Case change in land use and forest sector income, 2023

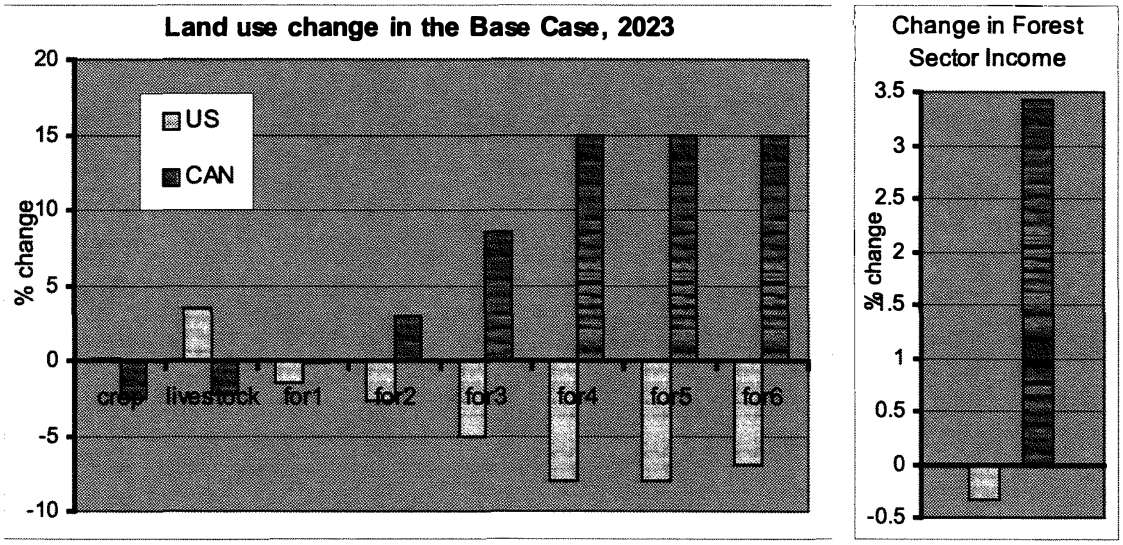
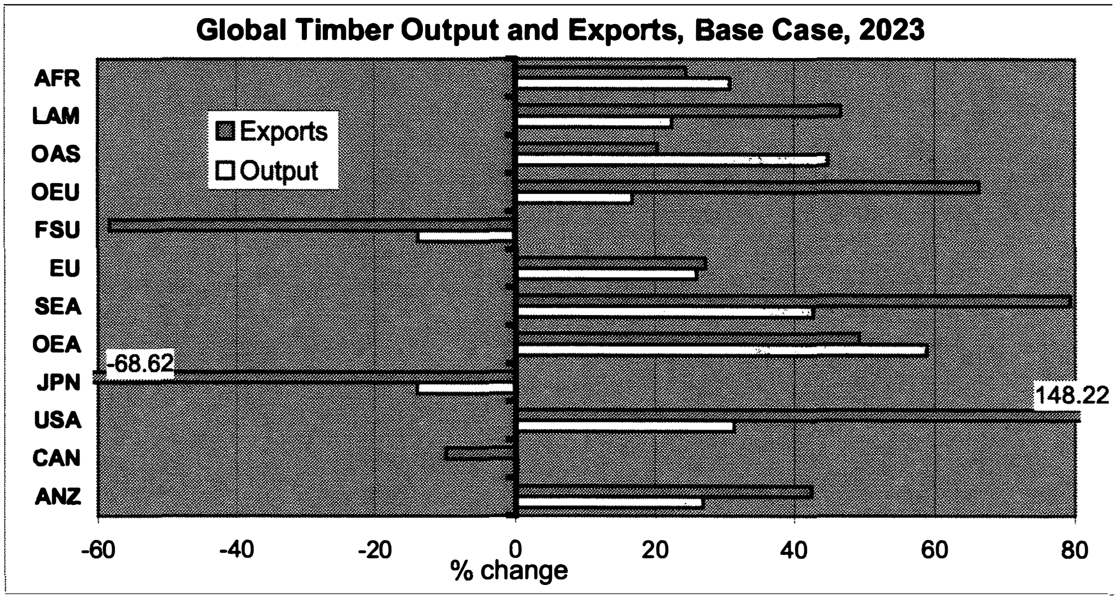


Figure 5: Base Case change in global timber output and exports, by region, 2023



5.2 Results of Policy Scenario 1

This section discusses the first policy scenario of a global expansion of carbon plantations. The results are all changes from the base case scenario, and reveal the impacts of carbon plantations.

5.2.1 Implications for the U.S.

In terms of land use shifts, expanding carbon plantations does not appear to have significant impact on the size of crop- or grazelands (see Figure 6). There are leakage effects however. The exogenous increase of forest plantations in certain land classes induces forest clearing in other areas where there were no policy shocks. The leakage effect is a trade-off from the policy, as expected influx in timber supply drives down prices and forestland income, leading to shifts to other land uses that are now relatively more profitable in those areas. The cleared forestland is mostly converted to industrial and manufacturing sectors. Leakage effects for the U.S. range from 0.67 mil ha in the *High* scenario and 0.43 mil ha in the *Low* scenario (Table 8 below).

Table 8: Cumulative leakage effects from Policy Scenario 1, 2023

	Leakage effects in carbon plantation scenario (mil ha):		
Region	*High*	*Low*	*Zero*
U.S.	0.67	0.43	-
Canada	0.23	0.35	0.11

The changes above base case for the U.S forestry sector with our scenarios of carbon plantations are very intuitive of economic theory. Magnitudes of timber output and price changes are reflective of the size of the policy shock (see Table 9). Predictably, the carbon plantations boost overall U.S. timber exports. The lower prices for U.S. timber on the global market improve its competitiveness with regards to the other timber producing regions. However, this is not a linear relationship. In the *High* scenario, the U.S. monopolizes the global timber trade but loses some of that competitive edge as other timber producing regions gain from the lower scale of carbon plantations. For the *Low* scenario, market prices for timber from the FSU and OEA decline more relative to the U.S., thus increasing exports from those regions. This explains the "blips" in Figure 7 as other countries in the region, namely OEU and OAS, replaces their exports of wood from the U.S. with exports from FSU and OEA[11]. In terms of the U.S.-Canada timber trade, U.S. exports increase by 4.25% in the *High* scenario and 1.38% in the *Low* scenario, and decrease by 0.32% in the *Zero* scenario (Figure 7).

Table 9: Interactions between the forest and agriculture sectors from Policy Scenario 1, U.S., 2023

Variable	**% changes from base case with carbon plantations**		
	High	*Low*	*Zero*
		Forestry	
Output	1.28	0.44	-0.01
Price	-1.80	-0.98	-0.004
Forest land income	-1.65	1.40	-0.23
Exports	5.22	2.32	-0.10
Imports	-3.47	-1.80	0.34
		Agriculture	
Output	0.14	0.25	0.07
Price	-0.01	-0.19	0.03
Farm land income (crop + livestock)	-0.75	-0.10	0.29

---

[11] Such differences in regional competitiveness are captured by the information on transportation costs, embedded in the economic data.

In terms of overall welfare, U.S. forest producers suffer losses from lower forestland incomes in the *High* scenario, but recover with slightly higher incomes in the *Low* scenario. This corresponds with our earlier discussion about changes in overall timber exports and relative price decreases in the two scenarios. The distribution of welfare is presented in Table 10. Households gain in the *High* scenario from lower wood prices, and greater demand for factors in the expanded forest plantations and from induced growth in the manufacturing sectors. The opposite holds in the *Low* scenario where forest producers gain but households suffer small losses in welfare. The *Zero* scenario, in which the U.S. does not participate in a policy of carbon plantations, has little impact on either land use change, the forest sector or overall welfare.

Table 10: Cumulative change in welfare variables from Policy Scenario 1, U.S., 2023

	% change from base case with carbon plantations		
Variable	*High*	*Low*	*Zero*
Total factor income	0.24	-0.26	-0.01
Per capita hhold utility	0.03	-0.03	0
Average wages	0.30	-0.39	0.003
Regional income	0.20	-0.23	-0.01
Terms of trade	0.21	-0.41	0.02
Welfare (US$ millions)	2176	-2452	4.47

5.2.2 Implications for Canada

The impacts of a carbon plantation policy on Canada are dominated by the actions of the U.S., her largest timber trade partner. Shifts in land use are quite similar in all three scenarios (see Figure 6) as carbon plantations are simulated to expand by 5 mil ha in all cases. Leakage effects are modest and range from 0.11 and 0.35 mil ha.

As in the case of the U.S., impacts on the forest sector from the different scenarios are not linear. The *High* scenario suggests that U.S. will dominate timber output and exports from the North American region. The Canadian forest sector regains some of the market share in the *Low* scenario. Timber trade from Canada to the U.S. declines in both the *High* and *Low* scenarios by 3.25% and 1.71%, respectively (see Figure 8). In the case of *Zero* scenario, Canadian wood exports to the U.S. increase slightly by about 0.5% above the base case. Exports also generally increase to the other regions except OEU, OAS and OEA. Correspondingly, forestland income improves in the *Zero* scenario but declines in the other scenarios.

Table 11: Interactions between the forest and agriculture sectors from Policy Scenario 1, Canada, 2023

Variable	**% changes from base case with carbon plantations**		
	High	*Low*	*Zero*
		Forestry	
Output	-0.11	-0.37	0.12
Price	-0.2	-0.23	-0.16
Forest land income	-5.96	-4.80	0.04
Exports	-2.55	0.02	0.61
Imports	4.21	1.36	-0.32
		Agriculture	
Output	-0.08	-0.39	0.16
Price	-0.13	-0.001	-0.02
Farm land income (crop + livestock)	-0.66	-2.13	0.40

In general, Government and household welfare improves most in the *Low* scenario where benefits from expanding carbon plantations are not crowded out by the overwhelmingly cheaper timber output in the U.S. (see Table 12). Forest producers gain in the *Zero* scenario where their competitiveness in regional timber trade improves over the U.S., but there emerges increased competition from the other timber producing regions as well such as Australia-New Zealand and the Former Soviet Union. This can be observed by the lower terms-of-trade.

Table 12: Cumulative change in welfare variables from Policy Scenario 1, Canada, 2023

	% change from base case with carbon plantations		
Variable	*High*	*Low*	*Zero*
Total factor income	-0.07	0.38	-0.07
Per capita hhold utility	-0.09	0.24	-0.02
Average wages	0.09	0.07	-0.05
Regional income	-0.07	0.40	-0.07
Terms of trade	-0.25	0.55	-0.05
Welfare (US$ millions)	566	1512	-123

In general, expansion of carbon plantations in the temperate regions lowers the pressure on the tropical timber producing regions. As shown in Figure 9, the *High* scenario lowers timber output from SEA, LAM and AFR by 0.11%, 0.12% and 0.25%, respectively, and exports by 3.12%, 1.79% and 0%, respectively. For the *Low* scenario, the decreases in output are approximately 0.08%, 0.10% and 0.18% for SEA, LAM and AFR, respectively. Although these percentages appear small, their absolute values are quite sizeable given the magnitude of timber production in the tropics. Impact of the *Zero* scenario on tropical timber regions is negligible.

Figure 6: Land use change in U.S. and Canada from Policy Scenario 1, 2023

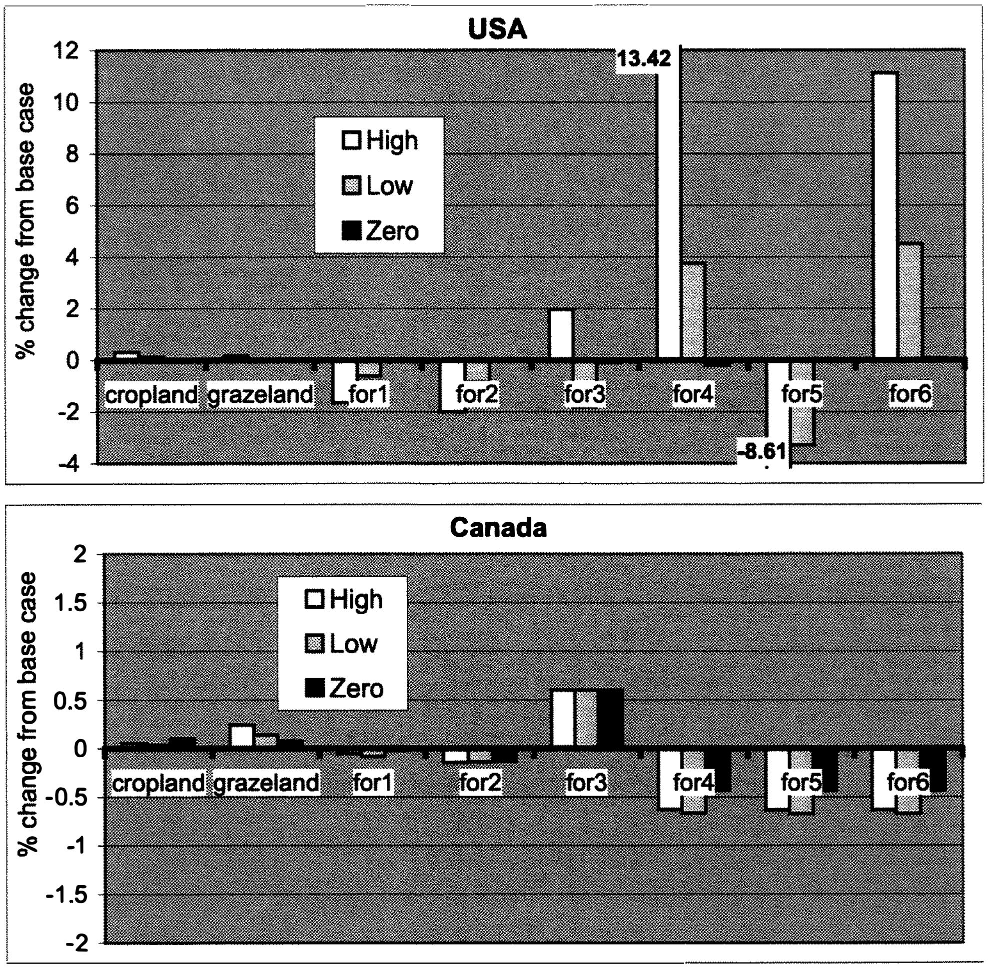


Figure 7: Cumulative change in U.S. exports of timber to other regions, Policy Scenario 1, 2023

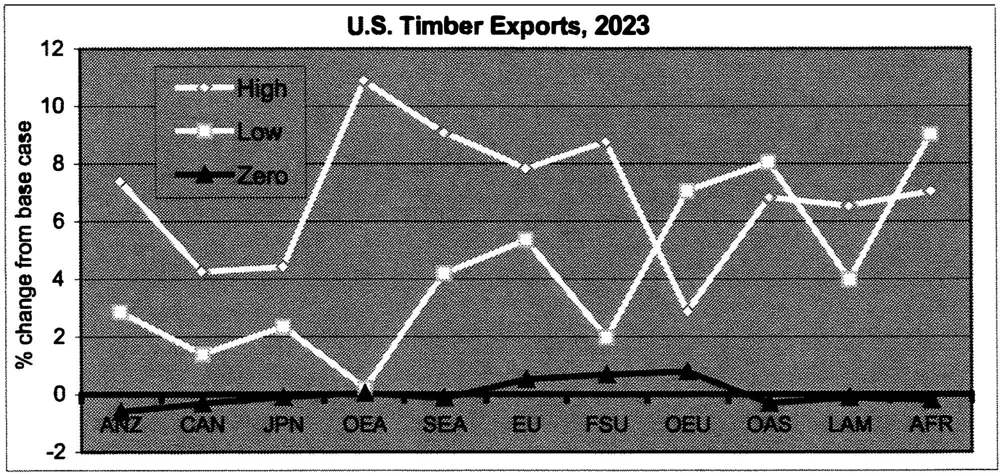


Figure 8: Cumulative change in Canadian exports of timber to other regions, Policy Scenario 1, 2023

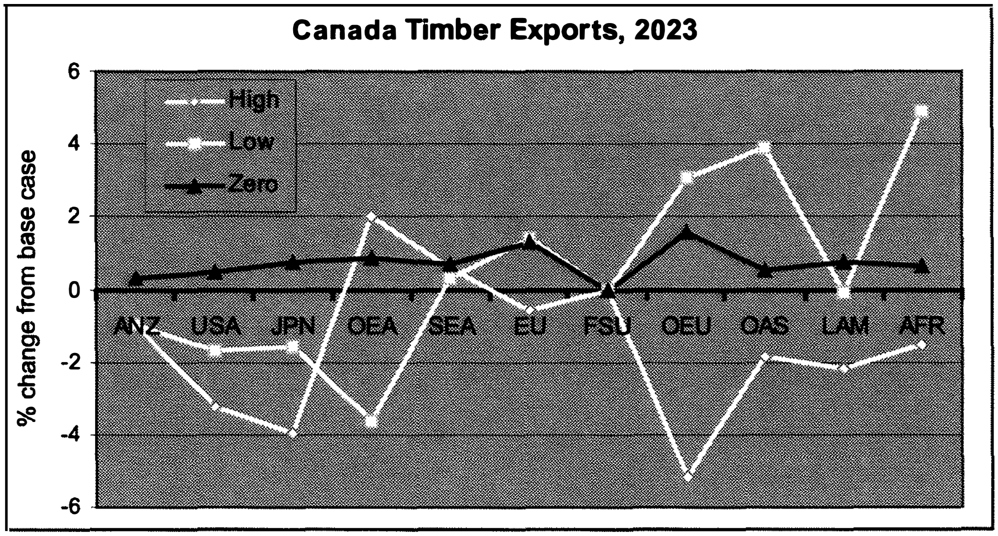
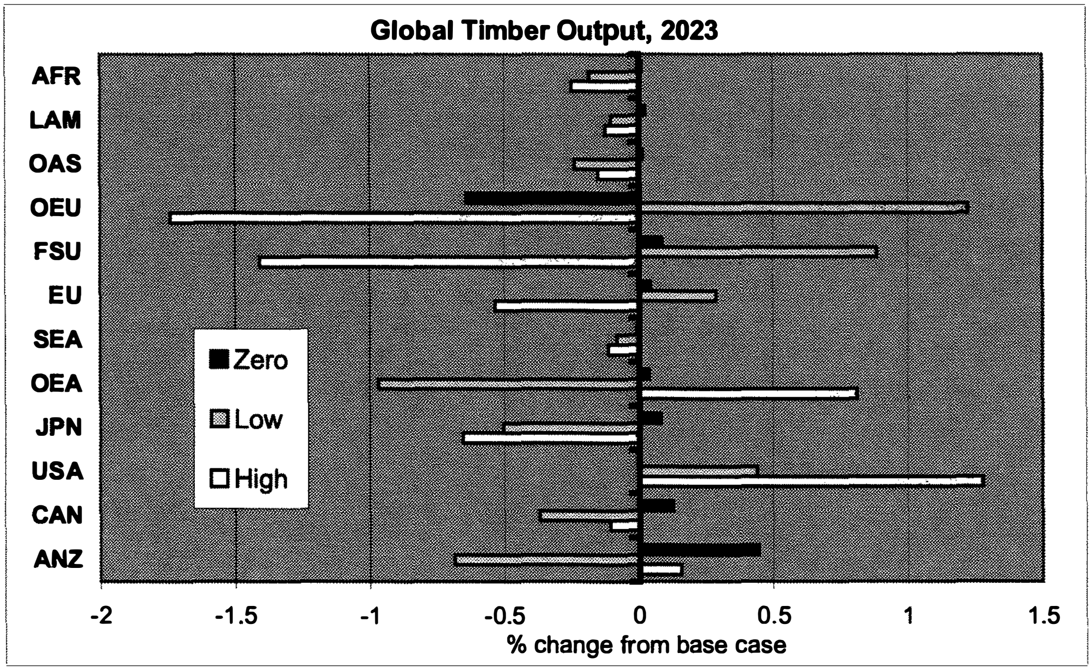


Figure 9: Cumulative change in timber output by region from Policy Scenario 1, 2023



5.3 Results from Policy Scenario 2

This section presents results from our second policy scenario of domestic carbon subsidies in the U.S. to forestland owners. Once again, results are changes above the base case scenario to highlight the impact of carbon subsidies.

5.3.1 Implications for the U.S.

Paying forestland owners to sequester carbon through subsidies generally leads to increases in timber output from U.S. forests (Table 13). This is to be expected since carbon subsidies increase profitability in the forest sector, thereby encouraging a higher intensity of timber production and supply. Correspondingly, larger areas of land shift into forestry with higher levels of carbon subsidies (Figure 10). Increases in forestland size range from about 0.92 mil ha in the $3 subsidy scenario to 6.47 mil ha in the $27 subsidy scenario. A similar pattern emerges in the timber trade relations between U.S. and Canada (see Figure 11) – higher subsidies induce greater exports of wood from the U.S. to Canada, and vice versa. Higher subsidies also lead the U.S. to significantly increase their timber exports to all regions (Figure 12).

It is interesting to note, however, that not all the effects from carbon subsidies are direct linear relationships. For example, the costs of production are predictably lower as forestland owners are compensated with subsidies of $3, $7 and $14 per ton CO_2, but surprisingly higher at the highest subsidy level of $27 per ton CO_2 (Table 13). As the large expansion of forestland in the $27 subsidy scenario is also accompanied by a substantial increase in demand for the primary factors of labor (+16.96%) and capital (+16.98%). This demand drives up as the factor prices and increases costs of production above the carbon subsidies. Forestland prices also show significant increases across all land classes at this subsidy level, from about 6% to 17% over the base case.

Table 13: Interactions between the forest and agriculture sectors from Policy Scenario 2, U.S., 2010

Variable	**% changes from base case with carbon subsidies**			
	$3/ton CO_2	$7/ton CO_2	$14/ton CO_2	$27/ton CO_2
		Forestry		
Output	2.78	6.50	12.78	23.15
Price	-5.08	-10.68	-18.24	-27.50
Costs of production	-0.72	-1.12	-0.74	2.44
Forest land income	10.13	26.43	59.56	137.26
Primary factor income from forestry	5.07	12.68	27.34	58.44
Exports	17.47	41.01	81.28	149.33
Imports	-10.56	-21.48	-34.78	-48.88
		Agriculture		
Output	-0.32	-0.39	-0.69	-1.16
Price	-0.10	0.05	0.31	0.84
Farm land income (crop + livestock)	-0.94	-0.20	0.48	2.30

The expansion of forests, however, is at the expense of farmland area. This effect can be observed with the decline in total crop output and slight increase in aggregate price from scarcity effects (Table 13). Farmland producers suffer losses at the lower carbon subsidy levels. At the higher subsidies of $14 and $27 per ton CO_2, the aggregate crop price is high enough to induce positive changes in farmland income. In terms of distribution, the U.S. forest sector benefits and households suffer small utility losses from the carbon subsidies (Table 14). The negative values for the Hicksian welfare measure are indication of the costs required to compensate forestland owners for sequestering carbon.

It appears that the U.S. policy of carbon subsidies could lead to a monopolization of global timber market. U.S. timber exports to all regions increase dramatically as carbon subsidy levels approach $27 (Figure 12), and lead to a reduction in timber output by practically all regions (Figure 13). The pressure on tropical forests is considerably lessened as timber output from tropical regions drop from 0.27% to 1.66% in SEA, 0.20% to 1.39% in LAM and 0.43% to 2.92% in AFR.

Table 14: Cumulative change in welfare variables from Policy Scenario 2, U.S., 2010

	% change from base case with carbon subsidies			
Variable	\$3/ton CO_2	\$7/ton CO_2	\$14/ton CO_2	\$27/ton CO_2
Total factor income	0.07	0.03	0.18	0.32
Per capita hhold utility	-0.01	-0.03	-0.03	-0.05
Average wages	0.03	-0.03	0.09	0.16
Regional income	0.02	-0.04	0.02	0.28
Terms of trade	-0.11	-0.17	-0.15	-0.16
Welfare (US$ millions)	-972	-2347	-2294	-3942

5.3.2 Implications for Canada

The case for Canada is almost the mirror image of impacts incurred in the U.S. Forestland size in Canada declines over all the scenarios, shifting to farmland and industrial uses (Figure 10). The loss of forestlands ranges from 1.13 mil ha in the $3 scenario to 12.48 mil ha in the $27 subsidy level, and is a form of international leakage from the policy. However, this may not be as severe an impact given the large projected increase of forestland in the Base Case. As carbon subsidies increase in the U.S., the Canadian forest sector is increasingly crowded out of both the regional and global timber markets (Table 15). The waning trend in timber output, exports and forestland income does not bode well for the forest industry. Exports to the U.S. decline from 10.54% to almost 49% across the different subsidy levels. Decline in forest sector profitability encourages development in the other sectors in the Canadian economy, particularly in the coal-oil-gas, minerals and services sectors. Canadian society, however, appears to gain in this policy scenario (see Table 16 below). The indicators of household utility, regional income and Hicksian measure of welfare improve for all the different subsidy levels, at a constant rate.

Table 15: Interactions between the forest and agriculture sectors from Policy Scenario 2, Canada, 2010

	% changes from base case with carbon subsidies			
Variable	$3/ton CO_2	$7/ton CO_2	$14/ton CO_2	$27/ton CO_2
	Forestry			
Output	-0.83	-1.69	-3.05	-5.02
Price	-0.34	-0.66	-1.07	-1.66
Forest land income	-3.95	-6.79	-11.49	-17.58
Primary factor income from forestry	-1.60	-3.03	-5.22	-8.27
Exports	-6.86	-14.38	-24.17	-48.88
Imports	12.73	30.10	60.04	149.34
	Agriculture			
Output	-0.32	-0.08	0.04	0.41
Price	-0.28	-0.25	-0.29	-0.24
Farm land income (crop + livestock)	-2.0	-1.43	-1.69	-1.12

Table 16: Cumulative change in welfare variables from Policy Scenario 2, Canada, 2010

	% change from base case with carbon subsidies in U.S.			
Variable	$3/ton CO_2	$7/ton CO_2	$14/ton CO_2	$27/ton CO_2
Total factor income	0.17	0.12	0.18	0.19
Per capita hhold utility	0.08	0.08	0.09	0.09
Average wages	0.09	0.01	0.10	0.12
Regional income	0.17	0.13	0.19	0.20
Terms of trade	0.14	0.18	0.17	0.18
Welfare	482	506	549	526

Figure 10: Land use change in U.S. and Canada from Policy Scenario 2, 2010

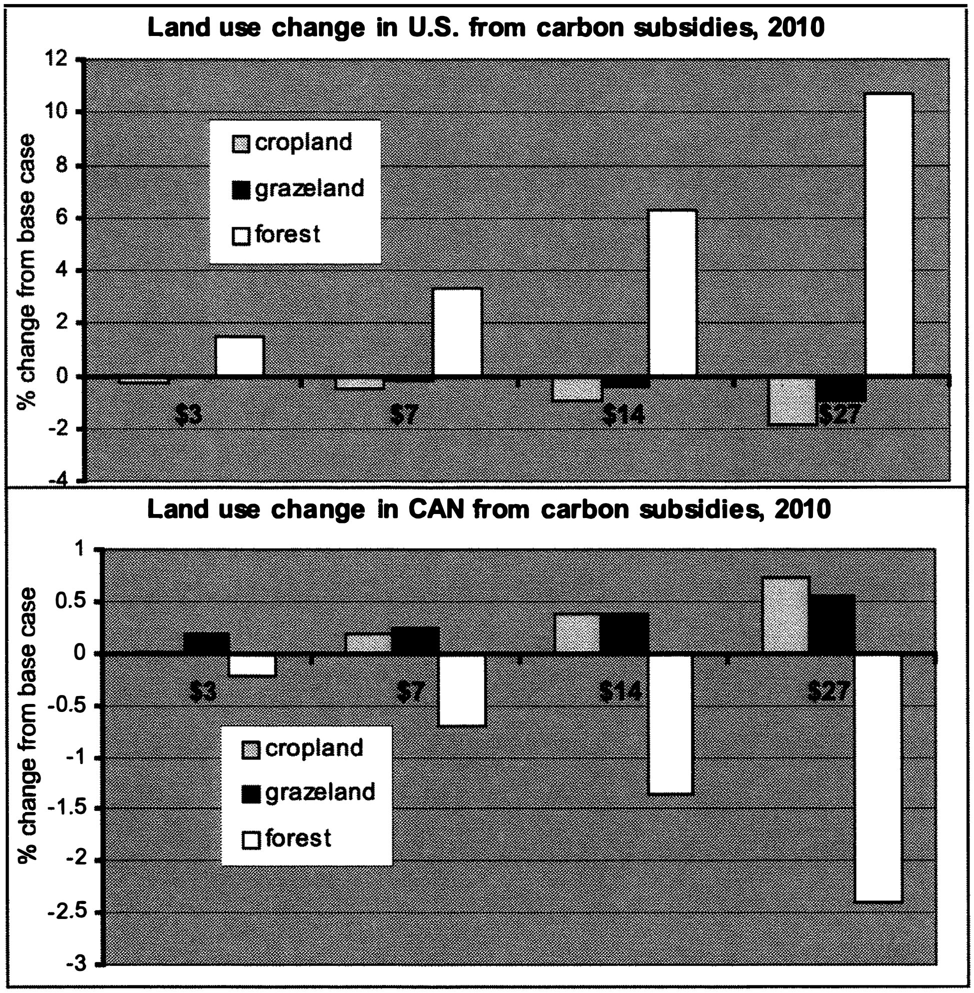


Figure 11: Cumulative change in U.S.–Canada timber trade from Policy Scenario 2, 2010

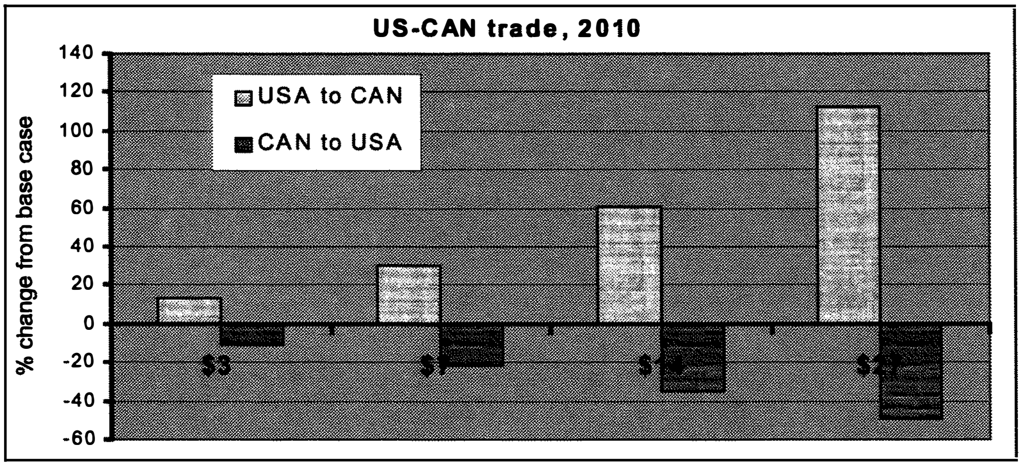


Figure 12: Cumulative change in U.S. wood exports to other regions from Policy Scenario 2, 2010

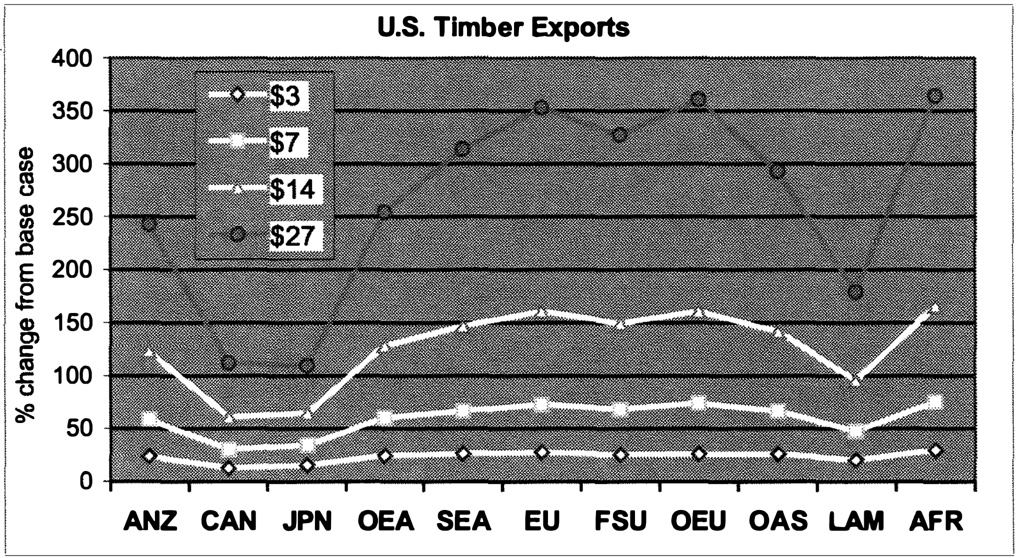
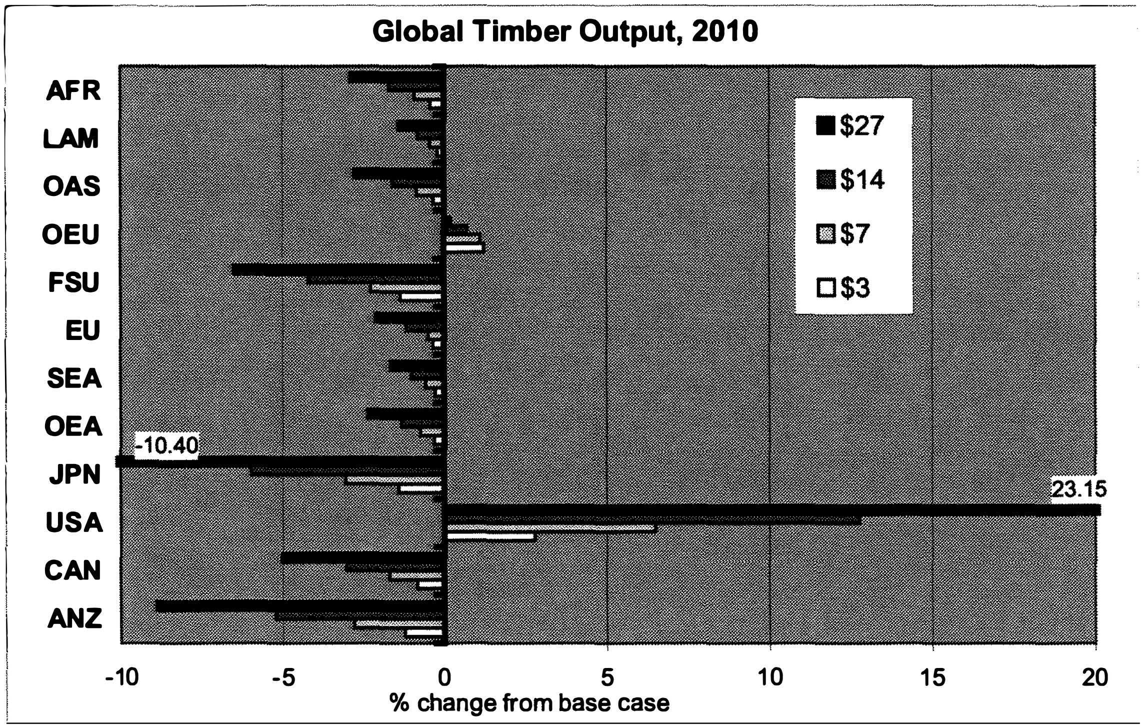


Figure 13: Cumulative change in global timber output, by region, from carbon subsidies in the U.S., 2010



6. Conclusions and Policy Recommendations

This study uses a dynamic computable general equilibrium model to examine the policy spillover impacts of two different CO_2 mitigation strategies using forest sinks. It is useful to keep in mind that our study results are characteristic of our choice of approach. The general equilibrium framework generally projects smaller impacts by taking into account the "crowding out effects" that is not captured in either single-sector models or other policy analysis tools such as the fixed coefficient input-output and social accounting matrix models. Unlike those approaches, the general equilibrium framework has considerable advantage by allowing input and output prices to vary with respect to changes in their demand, and accounting for economy-wide substitutability among factor inputs and commodity outputs.

Results from our policy simulations with the dynamic CGE model suggest the following implications:

- The use of carbon subsidies may be a more effective way of expanding the forest carbon sequestration capacity in the U.S. as compared to exogenous increases in the area of carbon plantations. In comparing results from the *Low* scenario of carbon plantations and the $27 per ton CO_2 subsidy level[12], performance of the U.S. forest sector and household welfare levels are considerably better in the case of carbon subsidies.

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[12] The *Low* scenario simulates an expansion of 5 mil ha of carbon plantations, whereas implementation of $27 per ton CO_2 will lead to an increase of approximately 6.5 mil ha in total forestland area.

- Canadian forest producers lose competitiveness in the scenario of domestic carbon subsidies in the U.S. across all subsidy levels, whilst Canadian households benefits from higher utility and welfare. In the case of the policy to expand carbon plantations, Canadian forest producers gain only when the U.S. decides on the *Zero* policy. This suggests that Canada will have to take steps to improve their competitiveness in the global timber markets if the U.S. undertakes any type of forest carbon policy. A possible action could be in the form of improving forest productivity.

- Leakage effects are generally modest, depending on the policy scenario. Our model captures both domestic and international leakage effects. The former when forests in areas outside of carbon plantations are converted to other land uses. International leakage effects occur in the case when carbon subsidies in the U.S. crowds out the Canadian forest sector from regional trade, causing the conversion of forestlands in Canada to industrial and agricultural uses.

- In all the scenarios (except the *Zero* scenario without U.S. participation), policies to expand forest carbon sequestration in the temperate regions will reduce some pressure off tropical deforestation. This is beneficial in the context of global warming through the conservation of existing carbon stocks in tropical forests and preventing CO_2 emissions from deforestation.

Finally, we address the two main weaknesses of the model in its current form. First is the limitation in modeling dynamic stock changes in the forest sector. The current approach of optimal steady-state output needs to be improved upon because the short-run adjustment path implies the unrealistic assumption that the amount of land in forests and the harvest regime on existing forest lands are assumed to adjust more quickly than the amount of physical capital in the forest sector. An advancement has to be made to treat the forest sector as moving along a transition path to steady state, and achieving it only in the long run. This can be carried out by linking the CGE framework to a timber supply or inventory model such as TAMM (described on p.8) or Sohngen and Mendelsohn's dynamic timber supply model (p.12).

A second weakness of this model for our analysis is in its characterization of economic sectors. The *Forestry* sector only covers the production of logs from the forests. The value-added sectors, such as wood processing or pulp and paper, are lumped together in the *Non-metallic manufacturing* sector and their effects from the policy shocks are not as clear. Since much of the U.S.-Canada timber trade are in value-added products, details of their impacts from the carbon policies are not fully fleshed out in this analysis. However, the overall economic effects are adequately captured by the other welfare-related and trade balance variables.

These limitations form a basis for future research in this area. The Dynamic FARM framework already meets several of the important criteria laid out in pp.22-23 as crucial for climate-forest policy analysis – it is an economy-wide model with a global scope, has dynamic features (except in the forest sector) and an ecologic-economic linkage. In addition to the two requirements discussed above, another advancement would be to incorporate on levels of CO_2 emissions and sequestration, in order to observe the net effects of carbon policies and to compare their overall cost-efficiency.

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Appendix 1: Elasticities

The following tables display, respectively: 1) the Allen partial elasticities of substitution for primary factors and differentiation between domestic and imports in the CES functions of the production structure; 2) income, and 3) own-price elasticities of household demand. All elasticities used in the CGE model are from the GTAP Version 4E database (http://www.gtap.agecon.purdue.edu/databases/v4/v4_doco.asp).

Allen partial elasticities for primary factors (ϕ), and between domestic and imported commodities (ω)

Sectors	ϕ	**Commodities**	ω
		PDR	2.20
CRP 1 to 6	0.24	WHT	2.20
		GRO	2.20
LIV 1 to 6	0.24	VF	2.20
		OSD	2.20
FOR 1 to 6	0.24	CB	2.20
		PFB	2.20
		OCR	2.20
		LIV	2.78
		FOR	2.80
COG	0.20	COG	2.80
MIN	0.20	MIN	2.80
FMM	0.29	FMM	2.29
OPF	1.12	OPF	2.45
TCF	1.26	TCF	3.32
NMM	1.26	NMM	2.05
OMN	1.26	OMN	3.33
SRV	1.40	SRV	1.94

Income elasticities for private consumption, by region

	ANZ	CAN	USA	JPN	OEA	SEA	EU	FSU	OEU	OAS	LAM	AFR
PDR	0.131	0.130	0.168	0.162	0.435	0.174	0.147	0.187	0.206	0.313	0.195	0.686
WHT	0.137	0.130	0.168	0.162	0.435	0.370	0.185	0.187	0.205	0.301	0.267	0.353
GRO	0.135	0.130	0.168	0.162	0.413	0.365	0.177	0.187	0.200	0.311	0.183	0.384
V-F	0.194	0.128	0.141	0.355	0.734	0.635	0.291	0.543	0.499	0.593	0.527	0.642
OSD	0.134	0.128	0.141	0.355	0.641	0.634	0.236	0.543	0.445	0.732	0.504	0.641
C-B	0.380	0.128	0.141	0.355	0.527	0.661	0.276	0.543	0.284	0.723	0.580	0.633
PFB	0.270	0.128	0.141	0.355	0.420	0.662	0.226	0.543	0.347	0.734	0.529	0.650
OCR	0.273	0.128	0.141	0.355	0.815	0.479	0.291	0.543	0.415	0.661	0.537	0.637
LIV	0.262	0.153	0.118	0.689	1.054	0.650	0.253	0.281	0.357	0.637	0.447	0.624
FOR	1.121	1.114	1.118	1.089	1.321	1.167	1.129	1.151	1.342	1.524	1.221	1.514
COG	0.992	0.998	1.004	0.992	1.102	1.022	0.994	0.920	1.147	1.013	1.030	0.915
MIN	1.121	1.114	1.118	1.089	1.183	1.183	1.121	1.151	1.385	1.343	1.232	1.535
FMM	0.155	0.138	0.117	0.611	0.668	0.570	0.236	0.297	0.290	0.557	0.403	0.618
OPF	0.624	0.450	0.520	0.498	0.667	0.597	0.551	0.627	0.637	0.691	0.621	0.689
TCF	0.927	0.925	0.941	0.881	0.934	0.919	0.922	0.875	1.018	0.909	0.943	0.939
NMM	1.120	1.114	1.118	1.089	1.285	1.263	1.123	1.151	1.333	1.289	1.216	1.343
OMN	1.068	1.076	1.128	1.065	1.180	1.066	1.055	1.063	1.185	1.148	1.145	1.215
SRV	1.079	1.075	1.046	1.112	1.155	1.223	1.078	1.117	1.103	1.221	1.182	1.256

Own-price elasticities of demand at initial equilibrium, by region

	ANZ	CAN	USA	JPN	OEA	SEA	EU	FSU	OEU	OAS	LAM	AFR
PDR	-0.076	-0.071	-0.116	-0.070	-0.072	-0.059	-0.075	-0.058	-0.010	-0.046	-0.067	-0.116
WHT	-0.082	-0.071	-0.116	-0.070	-0.069	-0.074	-0.113	-0.058	-0.078	-0.048	-0.082	-0.062
GRO	-0.080	-0.071	-0.116	-0.070	-0.067	-0.071	-0.105	-0.058	-0.067	-0.057	-0.053	-0.066
VF	-0.110	-0.066	-0.070	-0.268	-0.222	-0.172	-0.190	-0.167	-0.179	-0.163	-0.190	-0.141
OSD	-0.069	-0.062	-0.067	-0.264	-0.226	-0.174	-0.151	-0.167	-0.182	-0.135	-0.202	-0.123
CB	-0.237	-0.061	-0.067	-0.264	-0.283	-0.173	-0.167	-0.167	-0.188	-0.135	-0.172	-0.115
PFB	-0.159	-0.061	-0.067	-0.264	-0.214	-0.174	-0.147	-0.167	-0.206	-0.135	-0.186	-0.136
OCR	-0.161	-0.062	-0.069	-0.264	-0.202	-0.151	-0.189	-0.167	-0.192	-0.148	-0.188	-0.137
LIV	-0.165	-0.095	-0.066	-0.598	-0.217	-0.185	-0.173	-0.085	-0.113	-0.129	-0.147	-0.130
FOR	-0.782	-0.785	-0.885	-1.00	-0.407	-0.520	-0.880	-0.398	-0.616	-0.316	-0.501	-0.295
COG	-0.659	-0.710	-0.776	-0.898	-0.280	-0.435	-0.728	-0.310	-0.364	-0.320	-0.339	-0.351
MIN	-0.782	-0.787	-0.885	-1.00	-0.784	-0.498	-0.870	-0.398	-0.532	-0.313	-0.400	-0.277
FMM	-0.104	-0.094	-0.079	-0.516	-0.254	-0.163	-0.174	-0.095	-0.124	-0.168	-0.146	-0.180
OPF	-0.348	-0.246	-0.317	-0.401	-0.227	-0.165	-0.354	-0.185	-0.317	-0.179	-0.215	-0.164
TCF	-0.590	-0.590	-0.668	-0.756	-0.371	-0.361	-0.634	-0.266	-0.497	-0.213	-0.343	-0.209
NMM	-0.728	-0.725	-0.834	-0.939	-0.460	-0.444	-0.676	-0.369	-0.691	-0.353	-0.443	-0.360
OMN	-0.669	-0.680	-0.782	-0.893	-0.467	-0.448	-0.755	-0.311	-0.661	-0.328	-0.407	-0.297
SRV	-0.155	-0.175	-0.174	-0.229	-0.278	-0.204	-0.326	-0.102	-0.284	-0.188	-0.206	-0.173

Appendix 2 – Estimates for the Base Case Projection

The following tables list our estimates used to project the base case scenario into the future. They are obtained from GTAP (Walmsley et al., 2000 and references within) and other institutional sources (IMF, World Bank, UN Population Division).

Annual % change in Gross Domestic Product (GDP) and Gross Domestic Investment (GDI)

Region	**2000–01** [a]		**2001–02** [a]		**2002–03** [a]		**2003–23** [b]	
	GDP	**GDI**	**GDP**	**GDI**	**GDP**	**GDI**	**GDP**	**GDI**
ANZ	3.4	3.2	2.3	2.2	3.0	2.9	2.9	2.8
CAN	4.4	6.2	1.4	1.9	0.8	1.1	2.9	4.1
USA	4.1	3.9	1.0	0.9	0.7	0.7	3.1	2.9
JPN	2.2	2.2	-0.4	-0.4	-1.0	-1.0	2.2	2.2
OEA	8.0	8.5	6.0	6.4	6.0	6.4	6.3	6.7
SEA	6.8	1.8	3.0	0.8	3.5	0.9	5.5	1.5
EU	3.4	4.3	1.7	2.1	1.3	1.6	4.1	5.1
FSU	7.9	26.3	6.1	20.3	3.9	13.0	3.5	11.7
OEU	4.8	8.1	0.2	0.3	3.4	5.8	4.4	7.5
OAS	5.5	6.1	4.5	5.0	3.8	4.2	5.4	6.0
LAM	4.1	7.2	1.0	1.8	1.7	2.9	4.3	7.5
AFR	2.8	4.2	3.5	5.2	3.5	5.2	3.6	5.4

<u>Sources</u>: [a] IMF (2002). Details for 2000-2003 accounts for the overall economic slowdown from the global recession and its projected recovery.

[b] The longer range forecasts are from the World Bank (2001).

Annual % change in population growth

Region	2000–01	2001–02	2002–03	2003–08	2008–13	2013–18	2018–23
ANZ	0.96	0.96	0.96	0.81	0.66	0.47	0.28
CAN	0.8	0.8	0.8	0.76	0.71	0.67	0.62
USA	0.89	0.89	0.89	0.85	0.81	0.78	0.74
JPN	0.14	0.14	0.14	0.02	-0.11	-0.23	-0.35
OEA	0.78	0.78	0.78	0.78	0.78	0.78	0.78
SEA	1.03	1.03	1.03	1.03	1.03	1.03	1.03
EU	-0.37	-0.37	-0.37	-0.37	-0.37	-0.37	-0.37
FSU	1.03	1.03	1.03	1.03	1.03	1.03	1.03
OEU	-0.37	-0.37	-0.37	-0.37	-0.37	-0.37	-0.37
OAS	1.03	1.03	1.03	1.03	1.03	1.03	1.03
LAM	0.88	0.88	0.88	0.88	0.88	0.88	0.88
AFR	1.85	1.85	1.85	1.85	1.85	1.85	1.85

Source: UN Population Division (2001)

Annual % change in supply of skilled labor *

Region	2000–01	2001–02	2002–03	2003–08	2008–13	2013–18	2018–23
ANZ	0.36	0.36	0.36	0.30	0.25	0.18	0.11
CAN	1.01	1.01	1.01	0.96	0.90	0.84	0.78
USA	1.16	1.16	1.16	1.11	1.06	1.01	0.97
JPN	-0.11	-0.11	-0.11	-0.02	0.08	0.18	0.27
OEA	3.61	3.61	3.61	3.61	3.61	3.61	3.61
SEA	5.19	5.19	5.19	5.19	5.19	5.19	5.19
EU	-0.98	-0.98	-0.98	-0.98	-0.98	-0.98	-0.98
FSU	2.62	2.62	2.62	2.62	2.62	2.62	2.62
OEU	-1.13	-1.13	-1.13	-1.13	-1.13	-1.13	-1.13
OAS	3.03	3.03	3.03	3.03	3.03	3.03	3.03
LAM	3.67	3.67	3.67	3.67	3.67	3.67	3.67
AFR	2.67	2.67	2.67	2.67	2.67	2.67	2.67

Annual % change in supply of unskilled labor *

Region	**2000–01**	**2001–02**	**2002–03**	**2003–08**	**2008–13**	**2013–18**	**2018–28**
ANZ	1.06	1.06	1.06	0.89	0.73	0.52	0.31
CAN	0.80	0.80	0.80	0.76	0.71	0.67	0.62
USA	0.92	0.92	0.92	0.88	0.84	0.80	0.77
JPN	-0.14	-0.14	-0.14	-0.02	0.11	0.23	0.35
OEA	0.54	0.54	0.54	0.54	0.54	0.54	0.54
SEA	1.27	1.27	1.27	1.27	1.27	1.27	1.27
EU	0.54	0.54	0.54	0.54	0.54	0.54	0.54
FSU	1.46	1.46	1.46	1.46	1.46	1.46	1.46
OEU	-0.30	-0.30	-0.30	-0.30	-0.30	-0.30	-0.30
OAS	1.35	1.35	1.35	1.35	1.35	1.35	1.35
LAM	0.90	0.90	0.90	0.90	0.90	0.90	0.90
AFR	2.03	2.03	2.03	2.03	2.03	2.03	2.03

Note: * The shares of skilled and unskilled labor are constant proportions of population growth, and are obtained from Walmsley et al. (2000).