# Socio-economic Impacts and Adaptive Responses to Climate Change: A Canadian Forest Sector Perspective

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# Table of Contents

## List of Figures

## List of Tables

## Executive Summary

There is now a consensus among the scientific community that a trend toward a general warming of the earth is inevitable. This has created heightened interest in a) the socio-economic impacts of climate change, b) the dynamic-adaptive responses of the economy to climate change, and c) the impacts of greenhouse gas reduction and climate change mitigation measures on the Canadian economy. Economists have analyzed a wide range of climate change issues. Our paper, however, concentrates on issues pertaining to assessment of economic impacts and potential adaptive responses to climate change in the Canadian forest sector. We interpret the forest sector broadly as encompassing the forest products industry and associated harvesting operations, the forest management industry, and non-market values associated with forests.

### *Objectives*

This paper has three objectives.

1. To identify the potential impacts of climate change on the Canadian forest sector and adaptation strategies.
2. To identify gaps in knowledge of the socio-economic impacts of climate change and to identify research questions that would address these gaps.
3. The third objective is to identify various methodological and analytical approaches for analysis of social and economic impacts of climate change and in particular to identify some of the approaches that are appropriate for evaluating the identified research questions.

Climate change will lead to direct economic impacts on Canadian society. However, Canadian society will respond with adaptation measures that will partially offset direct impacts. Therefore, a review of climate change impacts is not complete without an assessment of adaptation responses.

### *Summary of Impacts, Adaptations and Mitigation Policies and Challenges for Economic Analysis*

*Complexity of Interactions and Feedbacks*

- Climate change presents multiple challenges for economic impact analysis because of the complexity of the interactions and feedback between the political, economic and social systems and environmental systems.

*Economic Incentives for Adaptation*

- Impacts of climate change will impose new circumstances on firms, landowners, governments and consumers. These economic agents will consequently adapt and respond with strategies to reduce the social costs and possibly enhance benefits associated with climate change.

- The new circumstances imposed by climate change will manifest, in part, as changes in productivity and prices of inputs such as land, labor, capital and energy. In addition, the future price paths of forest products and the stream of future benefits derived from non-market goods and services provided by forests will be influenced by climate change.
- Firms, landowners, governments and consumers will respond to these changes according to their own objectives. For each economic agent, the goal will be to minimize the negative impacts on their objectives and maximize the positive impacts of climate change. The incentive to minimize the negative effects and maximize the positive effects of climate change will lead firms, landowners, governments and consumers to adopt various strategies which will allow them to either minimize impacts or exploit new economic opportunities. Table 1 is a brief summary of some of these responses.

*Adaptation Strategies of Firms*

- Adaptation may consist of firms transferring capital and business expertise to new industries, shift or substitute to inputs that are relatively less expensive under climate change, shift to less energy intensive processes if energy costs increase due to mitigation policies, and innovation of new technologies more suited to minimizing costs under new price regimes resulting from climate change. Increases in the prices of timber and energy, for example, would provide incentives for development and/or innovation of energy and resource saving technologies. This is called induced innovation.
- The ultimate outcomes of these adaptations is that while costs will increase, assuming climate change has negative impacts, the costs will not increase as much as if adaptation had not occurred. Firms, have the option of innovating new technology as a way of minimizing the cost impact of changes in relative input prices.
- While economic agents will surely adapt to climate change, they may do so under some constraints. For instance, firms operate under technological constraints that limit the degree and rate of input substitution possible. An example of this is the limited rate at which capital turnover can take place in large capital intensive industries such as the pulp and paper industry (Forest Sector Table, 1999).

*Adaptation Strategies of Landowners*

- The effect of climate change over time will be to change the types of crops or tree species that are best suited to particular sites. Well informed private forest landowners will respond to anticipated climate change by increasing harvest rates, planting new species suited to expected condition, salvaging timber, increasing or decreasing the intensity of management on their land and/or converting their land to agricultural land or pasture land. Similarly, agricultural landowners will anticipate and/or respond to climate change by changing crop types, changing their management practices, or converting their land to forest. These actions will be motivated by changes in relative land values for particular crops and particular uses at a specific location. The effect will be to increase the rate of transition from one land use to another or from one ecosystem type to another.

**Table 1.** Examples of Climate Change Impacts & Adaptations from a Forest Perspective

| Physical Impacts | Social/Economic Impacts | Who's affected? | Adaptation Policies/strategies |
|---|---|---|---|
| Forest productivity changes | Changes in timber supply and rent value. | Forest firms and land owners | Change harvest schedules (regional & annual), adjust replanting behaviour, including species planted, change land use. |
| Increased atmospheric GHGs & associated climate change | Introduction of carbon credit/permit mitigation policies, which create a carbon sequestration market. | Forest firms and land owners | Carbon sequestration in forests - change rotations, manufacturing, harvest techniques, afforestation, research & development. Reuse/recycle wood residue & products i.e. as a biofuel. |
| Increased GHGs & associated climate change | Mitigation policies which increased GHG-intensive energy prices. | Consumers and firms | Substitute GHG-intensive products i.e. steel, with wood. Increased use of bioenergy/co-generation. |
| Increased disturbances | Loss of forest stock & non-market goods. | Land owners, firms & consumers | Increased protection policies & research & development. |
| Climate change, ecotones shift northward | Changes in land values & land use options. | Land owners, firms & consumers | Changes in competition for land - forest v agriculture. New management options. |
| Climate and ecosystem changes | Climate change related economic restructuring leading to social and individual stress, & other social pathologies. | Aboriginals & other forest dependent consumers and firms | Improved communication, education, participation, conflict resolution, & removal of institutional barriers. |
| Ecosystem & specialist species changes | Changes in non-market values, especially the passive component. | Consumers, firms and land owners | Change preferences; increase forest reserves, arboreta & seed banks. |
| Ecosystem changes | Parks and natural areas dislocated; increasing land use conflict. | Consumers, land owners, firms & government | Alter park boundaries & expand into a comprehensive system. |
| Climate/forest ecosystem changes | Fixed, sunk capital dislocated. | Climate/forest dependent tourist/ forest firms | Diversification (i.e. winter ski hills, to include summer golf facilities) &/ relocation. |
| Increased atmospheric GHGs | Increased GHG-intensive energy prices. | Long-haul tourists consumers & their destination firms | Substitute with increased local tourism. |
| Warmer conditions | Increased cooling of buildings required. | Firms & consumers | Increase planting of urban trees (with co-benefits). |
| Frequency &/ magnitude of changes rise | Increasing uncertainty. | Government and firms | Increase research and development. |

*The Role of Government in Adaptation*

- The objective of government policy should be to maximize social welfare over time. Thus government adaptation to climate change should be in the form of interventions to correct market failures, income redistribution, and compensation schemes when there are asymmetries between the beneficiaries of programs and interventions and those that bear the cost of programs and interventions.
- Since information pertaining to climate change has public good characteristics an adaptive response of governments to climate change may be to facilitate science, technology and knowledge regarding climate change, climate change impacts, technologies that make adaptation easier, and public education.
- Some current research suggests that competitive markets are an important instrument for facilitating adaptation. This is an important consideration relative to adaptation on forest lands. The majority of forest land in Canada is owned and managed by government. Decisions concerning harvest rates, rotation age, stumpage value, and species selection for replanting are largely determined by physical and administrative considerations. Therefore, price signals will play a limited role in determining landowner behaviour. From an efficiency perspective an important question is; will government agencies be more or less effective in changing harvest rates, rotation ages and species choice in response to climate change, when compared with private landowners or firms?

*The Importance of Recognizing Adaptation in Impact Assessment*

- Incorporating adaptation into economic impact assessment is important both because of the impact offsetting effect of adaptation. Failure to incorporate adaptation into impact assessment will lead to overestimation of damages and underestimation of possible benefits and opportunities.
- Adaptation will also affect the rate of ecosystem transition. Both environmental variables and human interventions will determine transition rates from one distribution of ecosystem types to another. Forecasts of the future distribution of ecosystem types that rely only on biophysical influences will probably not be accurate. Thus adaptation has implications for both economic impact assessment and forecasts of biophysical impacts.

*Market Failure and Strategic Dimensions*

- Climate change presents a classic case of market failure where the actual current costs of production of goods and services underestimate the true societal costs to present and future generations. Hence, underpricing of inputs that contribute to greenhouse gas emission accumulation leads to their overuse.
- Climate change presents challenges for developing efficient and equitable mitigation policies (market failure correcting) because of strategic behavior that may lead to free riding on mitigation policies at the international level and difficulties developing market failure correcting polices at the national level.
- A fundamental characteristic of climate change and greenhouse gases is that individual countries are likely to benefit very little from their own actions to mitigate climate

change. Hence, individual nations acting on their own will bear the costs of their greenhouse gas reduction actions while reaping no rewards. This creates incentives for individual nations to reduce their mitigation efforts if other nations increase their mitigation efforts. This is known as free riding behaviour. In the context of climate change, free riding behaviour may lead to collectively undesirable, inefficient, and inadequate mitigation efforts. Canada must develop it's international negotiation strategies for mitigation and management of sinks and source in this context.

*Importance of Co-benefits*

- An important factor that may mitigate strategic free riding behaviour is the presence of co-benefits to some climate change adaptation and mitigation policies. For example, planting trees for carbon sequestration may have local aesthetic and habitat benefits. Thus climate change mitigation strategies may jointly produce several benefits simultaneously. Some economic theories suggest that this type of situation may lessen incentives to free ride on mitigation and hence co-benefits have the potential to be a highly important aspect of optimal climate change policy.

*Criteria and Considerations for Measuring Climate Change Impacts*

- Climate change policies are likely to result in transfers of wealth from one sector of society to another within the same generation or even between different generations. Hence, while the standard criteria efficiency criteria used in economic analysis is important, it may be overshadowed by the intra and inter-generational equity and distributional concerns.
- The long term nature of climate change impacts raises the question of appropriate discounting procedures for economic impact assessment. It is well known that different discount rates can generate vastly different results for projects with costs and benefits widely dispersed over long time horizons. It is important to understand that there is disagreement within the economics profession about how discounting should be conducted when costs and benefits are distributed over long time periods and thus over multiple generations. However, it is our opinion that no cost-benefit procedure or optimization model that uses any discount rate can tell policy makers how to allocate resources across generations or across the regions of the country. Given the controversy over discounting procedures we suggest the following:

    - Policy evaluations using cost-benefit analysis or other modelling approaches should be made at more than one discount rate. This will provide information to policy makers about how discount rates affect optimal policies.
    - The time path of important variables in climate change impact analyses, such as the size of the forest sector, production levels, consumption levels, forest growing stocks and sinks, should be presented as part of the analysis. In other, words the net present values of costs and benefits should not be presented in isolation of the time paths of benefits and costs. We agree with Lind and Schuler (1998) on this point.

- Other important considerations in formulating climate change policies will be uncertainty, competitiveness, and social considerations.

*Choice under Uncertainty*

- Choice criteria under pure uncertainty are related to the safe minimum standard (SMS) and the precautionary principle (Woodward & Bishop, 1997). Woodward & Bishops's (1997) maximin criterion findings under pure uncertainty, rationalize the SMS and the precautionary principle as rational choices under great uncertainty. The SMS and the precautionary principle are therefore two adaptation policy approaches that could be considered and implemented, as responses and tools to reduce the uncertainty associated with climate change.

*Social Considerations*

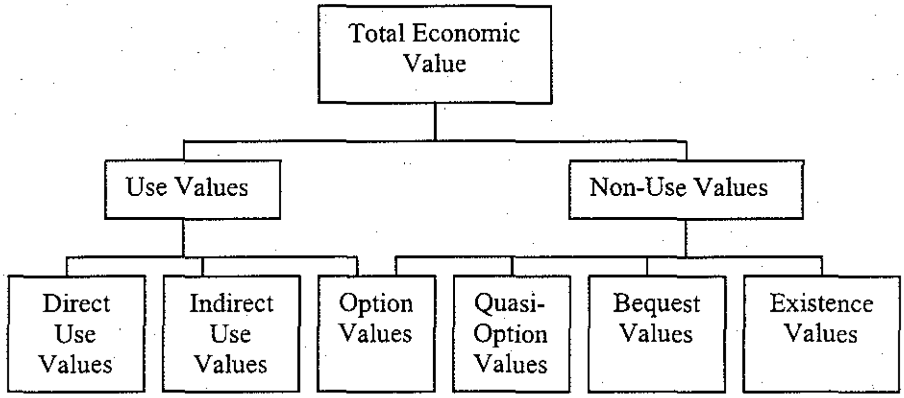
- An important consideration in evaluating climate change impacts will be to understand the social impacts of climate change on Canadian society. The costs of climate change are necessarily financial or monetary but pertain to cultural integrity, social cohesion, and community stability.
- The capacity of some groups within society to adapt to climate change may be lower than other groups and therefore the burden of impacts may be asymmetrically distributed due to existing socioeconomic circumstances. Social impact assessment can contribute to a better understanding of the nature and distribution of these costs and burdens.
- Social institutions should be designed to ensure that there is public satisfaction with policies and that the public is involved in the decision making process relative to climate change policy. New approaches may be required to resolve social conflicts which are precipitated by climate change or to anticipate the possible occurrence of conflict and take preventative steps.
- There are "attachment to place" issues for which sociologists can provide some insight. Sociological research can also contribute to developing an improved understanding of public perceptions and the development of social institutions for involving the public in the decision making process and for resolving conflict. This points to differences in beliefs and values systems within society. Failure to account for differences in beliefs and value systems relative to changes in natures attributes resulting from climate change has the potential to lead to social conflict and policy failure.

*Values impacted by Climate Change*

- Climate changes will certainly have impacts on market based forest values such as timber and forest product values. However, the concepts of economic efficiency and consumer surplus are equally applicable to non-market benefits associated with forest ecosystems. Figure 1 identifies the various types of market and non-market benefits that could be affected.
- There is limited information on the magnitude of the impact of climate change in terms of social value impacts, or on what methodological approach to employ in measuring

changes in the value of non-market goods and services. Therefore, we do not discuss or speculate on the direction of possible value changes resulting from climate change.

**Figure 1:** Use and Non-Use Values




*Impacts on timber markets*

- The ability to forecast economic impacts and adaptive responses of producers and consumers to climate change requires the development of dynamic models that integrate forecasts of ecological responses to climate anomalies with economic models of timber markets.
- One promising approach is a model developed by Sohngen and Mendelsohn (1999) who develop a dynamic partial equilibrium model of the U.S. timber market and link this model to dynamic models that simulate the effects of climate change on ecosystem distribution and productivity. The model incorporates transient changes in timber type distribution and yield (resulting from climate change) as well as period to period shifts in price (attributable to shifts in demand from population growth and growth in per-capita income).
- The model assumes that forest land owners are adaptive and respond to changes in future prices and harvest yields. These dynamic adaptive responses to climate change have the effect of "ameliorating" the economic consequences of large scale ecological changes as well as accelerating the natural rate of transition to new timber types.
- While the analytical approach employed by Sohngen and Mendelsohn (1999) is applicable to Canada, the particular findings of significant positive benefits from climate change can not be extrapolated to Canadian timber markets for a variety of reasons. There is simply no way to quantify how Canada's forest economy may adapt to climate change over time, without a dynamic-integrated ecological-economic assessment framework tailored to Canadian circumstances.

*Impacts on Non-market values*

- Passive use values are an important class of values relative to social welfare and public policy and these values will be affected by climate change. However, they are difficult and expensive to quantify and there are high levels of uncertainty relative to how the specific environmental attributes that determine passive use values will respond to climate change. Given that there is some potential for irreversible losses of certain environmental attributes without intervention there is a need for some consideration of these values in policy. These considerations will probably have to be developed in the absence of explicit measures of the impact of climate change on passive use values.

- There are two aspects where economics can make a contribution: 1) identifying the conditions and circumstances when the application of the "Safe Minimum Standard" approach for protecting ecological attributes would be appropriate, and 2) identifying social preferences and rankings for selected and geographically explicit passive use values.
- One of the main instruments for protecting non-market values and for protecting ecosystems is protected areas and parks. There may be a need for reconsideration of existing park policy in the context of climate change because climate change may result in shifts in the location of ecoystems.

*Forest Sector/ Agricultural sector interactions*

- Agriculture and forestry compete for inputs, the most obvious of which is land. Climate change may affect the relative value of land in forestry production versus agriculture production. Changes in land values should lead to changes in land use. This will be an adaptive response to climate change and it is one of the reasons why the assessment of impacts from a forest sector perspective should consider responses in the agriculture sector and vice versa.

*Forest Sector/Energy Sector Interaction*

- Interactions between the forest sector and energy sector are more important in the context of carbon emission abatement policies. Various instruments have been proposed to facilitate mitigation, including increasing the price of fossil fuel energy through the imposition of carbon taxes, imposing regulations to ensure minimum levels of energy efficiency, investment in afforestation projects, substitution of renewable energy for fossil based fuels, and the use of market based carbon permit systems.
- An important question relative to consideration of forests as a possible sink for sequestration of atmospheric GHG is the issue of short versus long term capacity for forest lands to store carbon. The conclusions of the Forest Sink Table (1999) suggest that forests have fluctuated from being a sink to a source and that they may, in the future, become a sink again.
- This leads to some important questions about whether credit/debit systems for carbon storage should be based on short term net carbon sequestration or based on comparisons to base lines based on forecasts of long term trends in forest carbon balances. Either method must deal with difficult carbon flux measurement issues.

*Forest Rotations and Harvest Schedules*

- The most important conclusion that can be derived from the forest rotation studies is that the effect of carbon sequestration on harvest rotation age appears to be to lengthen it (Martin, 1998, Englin and Callaway, 1995).
- A weakness in these studies, however, is that the forest rotation analyses do not include potential for increased disturbance such as fire, disease and insect attacks, which may lead to increased rates of carbon storage losses and ultimately to forest migration.
- Under climate change, forest rotation policies will have to be set based on a combination adaptive and mitigation considerations. Hence, in the context of forest management adaptation and mitigation are inseparable. This results from two factors. First, climate change may induce mitigation policy and thus a desire to use forests as a potential sink for carbon. Second, disturbance regimes are expected to increase in intensity due to climate. The forest industry will need to respond to these as an adaptation simply for the sake of timber supply management.
- Adaptive responses to increased disturbance will be on two levels – adjustment of forest rotation lengths and adjustments to forest protection policy. Forest protection may be thought of as both adaptive, in the sense of protecting timber supply for forest products production, and as mitigative in the sense of delaying carbon emissions to the atmosphere that occur as a result of disturbance.

***Knowledge Gaps and Research Themes***

- One of the objectives of this paper is to provide a guide to the systematic development of a research program that develops models and frameworks that can be used to inform policy. This is important because the government wants to create a policy environment that will provide incentives to guide or steer the forest industry, forest land owners, forest managers and forest users toward optimal responses.
- We would like to stress the need for integrated analytical frameworks. This integration can occur on two levels. First, forest sector models can be integrated in the sense that they contain linkages to climate change via connections to vegetation and ecosystem transition models, forest resource inventories and carbon budget models. Second, given the multiple linkages that the forest sector has with other sectors (e.g. the energy sector and agriculture) and with other countries via international forest products trade and given that direct climate change impacts and climate change mitigation policy impacts are likely to be widespread in the economy, it is important for models to link the forest sector to other key sectors of the economy.
- It is not necessary, feasible or even desirable to attempt to incorporate these linkages all at once. However, it is important to have an array of analysis tools, some of which contain one or more of these linkages.

*Broad Research Goals*

- The overall goal of research in this area should be to contribute to the following broad research questions:

i) What is the overall impact of climate change on the Canadian forest economy in terms of decreases in welfare of Canadian citizens directly involved in the forest sector, those that are indirectly involved, and those that use Canadian forests for recreational use or simply derive benefits from the existence of Canadian forests?
ii) How will Canadian citizens, forest products firms, environmental groups, and governments adapt to climate change impacts on Canadian forests and to what extent will these adaptations lessen the direct impacts of climate change?
iii) How will the forest sector adapt to changes in the economy brought about by mitigation policies in other sectors such as the energy sector?

- Of course these fit into an even broader research agenda that concerns the overall impact of climate change on the Canadian economy, not just the forest sector. However, even when isolated to the forest sector alone these questions are too broad for any one research program to focus on in the immediate future. Hence, we have suggested a number of more specific research themes together with some research questions that as a whole would contribute to an integrated assessment of forest sector impacts, adaptation and mitigation responses to climate change.

*Research Themes*

<u>Analysis of impacts, adaptation, adaptive land use and forest land use change</u>.

- Research questions in this theme concentrate on impacts and adaptations especially as they relate to optimal land use issues. These issues are important at both provincial and national scales.

  - Analysis of potential shifts in land use patterns and adaptive responses to climate change by consumers, firms, landowners, and governments. These are components of the broader and significantly more challenging question: What is the impact of climate change on social welfare?
  - Analysis of the rate at which adaptive measures are developed and adopted by landowners and users. An important consideration in this research is the effect of current land ownership patterns, such as the predominance of public land ownership in the forest sector, and regulatory regimes on adoption rates.

<u>Economic assessment of afforestation and forest management strategies for combined adaptation and carbon sequestration values.</u>

- Research questions under this theme are directed at how resources should be allocated among investments in afforestation, reforestation, and protection of existing forest stocks and how forest harvesting schedules should be modified to adapt to climate change and to store carbon in forests. The Kyoto agreement currently includes only afforestation and deforestation in its carbon accounting framework (National Sinks Table 1998). However, there appears to be some interest in expanding this to include reforestation and management of the entire existing forest carbon stock. Hence, the following research projects are appropriate.

- A more comprehensive analysis to determine how afforestation and future storage and/or harvest of newly afforested land area should fit into an overall forest carbon sequestration and storage management program.
- How should limited resources be allocated among investments in afforestation, reforestation, and protection of existing forest stocks from forest disturbances so as to optimise net additions or net reductions to the carbon stored in forest bio-mass together with other non-market benefits and timber benefits? Related to this question is: how forest harvest rotations and forest management schedules should be altered to account for both the fact that carbon sequestration and storage will have value and for the direct impacts of climate change – such as increased rates of fire, insect and disease disturbance or even forest migration?
- An evaluation of how assumptions about the mix of forest products produced, how quickly these forest products release carbon, how recycling policy and how management of forest products waste streams affect forest management strategy. In other words life-cycle analysis of forest products must be integrated into forest management policy analysis.

Analysis of incentive mechanisms for carbon storage and management in forests

- It is not enough to simply determine that carbon sequestration in forests is worthwhile as compared to other mitigation or sequestration options. Implementation is an important consideration that must be addressed, given that carbon values are inherently non-market values. When developing policies to encourage forest products firms and landowners to manage for carbon storage in forests, it is important that the correct economic signals are sent, so that firms and landowners are steered in the direction of optimal strategies. Some of the relevant research questions are:

  - What kinds of incentive mechanisms are suited to private land and what kinds of mechanisms are suited to forest products companies operating on public land? Incentive mechanisms should be structured to accomplish two objectives: (1) encourage increased sequestration at optimal rates and (2) to encourage forest products firms and forest owners to store carbon, once sequestered, for the appropriate (optimal) lengths of time.
  - How should carbon credit/debit systems be linked to permit or carbon tax systems that might be implemented in the energy or manufacturing sectors?
  - Given the uncertainty that still surrounds Canada's carbon budget and the uncertainties inherent in natural forest disturbance regimes, there is a need to determine how carbon credit/debit systems might operate in an environment of risk and uncertainty.

Long term timber supply and forest products supply analysis.

- This research theme is related to several of the preceding projects but should focus on timber supply at the national and provincial levels. This type of project would prove useful if it could provide projections of marginal costs of supply for comparison purposes with similar outputs from world timber supply and other regional timber supply models.

Assessment of forest product pool management strategies

- Management of forest products carbon pools will have an effect on the overall carbon flux of the Canadian economy but also the best management options for Canada's forests. Hence, there is a need to answer and analyze questions such as:

  - What is the optimal production of solid wood and paper products given market demand and supply constraints?
  - Analysis of complete lifecycle of forest products from harvest through management of waste streams via recycling and landfill management policies.
  - Comparison of forest based products lifecycle with that of possible substitutes such as steel.
  - There is a need to link lifecycle analysis with behavioural models because current product mixes, input mixes and waste streams are likely to change with changes in relative prices brought about by climate change mitigation policies.

Assessment of energy cost impacts and adaptation strategies

- Carbon taxes or carbon permit systems imposed either on the sale of fossil fuels or on carbon dioxide emissions will increase the cost of fossil fuel consumption. Manufacturing industries will have to adjust to this change. One advantage that the forest products industry has over others is a competitive advantage in the use of bioenergy from waste wood generated during the production process. This advantage gives the forest products industry the potential for substitution away from fossil fuels to biofuels more readily than other industries. Hence, a series of needed empirical studies arise.

  - Analysis of the impacts of carbon taxes or permits on optimal forest product mill energy management.
  - Analysis of the costs and benefits of increasing co-generation capacity under increased fossil fuel energy costs as well as an analysis of the impediments to co-generation and bioenergy in the forest sector.
  - Assessment of the economics of biomass plantations for energy in a high cost fossil fuel energy economy.

Analysis of inter-relationships between the forest sector, other Canadian sectors and trade responses

- This research theme is devoted to analysis of linkages of the forest sector with other key sectors of the economy such as energy and agriculture. Forest sector adaptation strategies and mitigation policies related to sequestration will ultimately have to assessed in the context of the larger economy. Some of the research questions and projects that might fall under this theme are:

- Identification and analysis of ways of linking forest carbon sequestration and storage incentive systems with carbon permit or tax systems.
- Analysis of forest sector, energy sector, agricultural sector linkages that arise through energy cost impacts and greenhouse gas emission reduction policies.
- Analysis of substitution effects between forest products and other products (such as steel beams) that arise because of changes in relative prices due to energy cost increases.
- Analysis of climate change impacts on forest products trade and changes in the forest sector's contribution to Canada's surplus balance of payments.

Analysis of non-market benefit impacts on forests.

- Climate change adds a new element to an already long list of variables that must be considered in developing and protecting non-market values and unique ecosystems. Some key research questions include:

  - Analysis of climate change adaptation strategies for parks and protected areas. Climate change is likely to have an impact on critical natural capital such as old growth and other unique ecosystems. How should Canada's network of protected areas be modified in an environment of accelerated dynamic ecosystem response to climate change?
  - Investigation of how forest harvest rotations and forest management schedules altered to sequester and store carbon impact non-market benefits such as wildlife habitat and how these management schedules should be further modified to maintain or enhance wildlife habitat
  - How should endangered species policy be formulated in an environment of accelerated dynamic ecosystem response to climate change?
  - A novel approach to cost-benefit analysis was suggested by Porter (1998) that is one attempt to deal with the discounting issues surrounding climate change. This approach inspires the following research question: What are current generations of Canadians willing to pay to assure that future generations of Canadian's can (i) have less severe climate change impacts, (ii) can more readily adapt to climate change impacts?

Analysis of Social and Cultural Impacts

- Earlier we suggested that an important consideration in evaluating climate change impacts is to understand the social impacts of climate change on Canadian society. Some possible research questions are:

  - What are the public perceptions of climate change and how should they influence climate change policy?
  - How should existing social institutions be designed or adapted to address climate change issues?
  - Determination and identification of vulnerable social groups and analysis of institutional capacity for adaptation.

## 1. Introduction: Issues of Climate Change

There is now a general consensus among the scientific community that a trend toward a general warming of the earth is inevitable. This has created heightened interest in a) the socio-economic impacts of climate change, b) the dynamic-adaptive responses of the economy to climate change, and c) the impacts of greenhouse gas reduction and climate change mitigation measures on the Canadian economy. Economists have analysed a wide range of climate change issues. These issues include the impacts of climate change on gross domestic product and measures of social welfare, taxation and carbon permit options for control of emissions, inter and intra-generational equity, spatial distribution of impacts, carbon sequestration, impacts on individual sectors of the economy and a range of other issues. Our paper, however, concentrates on issues pertaining to assessing the economic impacts and potential adaptive responses to climate change in the Canadian forest sector. We interpret the forest sector broadly as encompassing the forest products industry and associated harvesting operations, the forest management industry, and non-market values associated with forests.

The signing of the Kyoto protocol has raised questions, both about how Canada can meet its' Kyoto target, and how it should meet its target. In the context of the forest sector, this question is primarily concerned with what forest management and forest products industry strategies might contribute to the achievement of greenhouse gas emission reduction targets for Canada. From an economics perspective, the possible forest industry contribution is usually perceived as a potentially low cost means of satisfying greenhouse gas reduction targets. From an international perspective, satisfying greenhouse gas reduction targets may be interpreted as Canada's contribution to the mitigation of climate change. These questions are extremely important and our paper does address greenhouse gas reduction and mitigation policy. However, given that some degree of climate change is likely, even if the Kyoto Protocol is fully implemented, there is also a need to address the direct impacts of climate change on Canada's forest economy.

Climate change will lead to adaptation within Canadian society and these adaptations will partially offset adverse impacts. Hence, a review of adaptation strategies that might lessen the magnitude of direct impacts is warranted and this paper addresses these issues. We interpret adaptation rather broadly as strategies that reduce both the direct impact of climate change effects, such as increased disturbance levels in forests, and strategies that reduce the impact of mitigation measures that are imposed outside the forest sector but which have an indirect impact on the forest sector. For example, carbon taxes or carbon permit systems would increase energy costs. Adaptation measures would then include strategies that lessen the impacts of increased energy costs on the forest industry, such as increased use of bioenergy.

More specifically, this paper has three objectives. First, the paper attempts to identify the potential impacts of climate change on the Canadian forest sector and adaptation strategies. Our analysis is more qualitative than quantitative, concentrating more on the types of impacts and adaptations that can be expected (sections 2, 3 and 4). The second objective is to identify gaps in knowledge of the socio-economic impacts of climate change and to identify research questions that would address these gaps. The third objective is to identify various methodological and analytical approaches (section 5) for analysis of social and economic impacts of climate change. We also attempt to identify some of the approaches that are appropriate for evaluating the identified research questions. These methods range from cost benefit analysis to integrated economic-climate models.

The paper is organized into five major sections. The purpose of section 2 is to outline the various types of climate change impacts on the Canadian forests, forest management activities and the forest products industry. The section begins with a discussion of the physical and economic aspects, focusing on the issue from a national forest sector perspective. The physical dimensions include changes in temperature, precipitation, climate variability and subsequent impacts on forest growth, frequency and intensity of forest fires and other disturbances, and the potential for migration of forests to more northern latitudes (subsection 2.1). The physical and economic dimensions (subsections 2.1 and 2.2) are discussed in the context of a framework that illustrates the long-term dynamic linkages between the forest sector and global economic and atmospheric systems (see figure 1). This discussion also explores the issue of uncertainty regarding the magnitude of physical and economic impacts. Uncertainty and the long time horizons inherent in both, climate change impacts and forest management in general presents difficult challenges for formulating efficient policy responses. This aspect is explored further in subsection 3.2.

Subsection 2.3 then proceeds to a discussion of adaptation and mitigation strategy. While adaptation and mitigation are often discussed as two separate strategies we argue that adaptation and mitigation are linked in either complementary or conflicting ways. This subsection and subsequent sections describe these linkages.

A fundamental characteristic of climate change and greenhouse gases is that individual countries are not likely to benefit from their own actions to mitigate climate change. This characteristic may lead to strategic free riding behaviour in the development and implementation of international climate change mitigation policies. This is because the best national mixes of adaptation and mitigation strategies depend on the mitigation policies and actions of other nations. An important factor that may mitigate this strategic behaviour is the presence of co-benefits to some climate change adaptation and mitigation policies. These and other national and international political-economic and strategic aspects are analysed in subsection 2.4.

Section 3 is a review of the criteria and considerations for measuring economic and social impacts and for evaluating adaptation and mitigation strategies. Climate change impacts can be evaluated on the basis of traditional economic efficiency criteria. However, climate change has important implications for both intra-generational equity and intergenerational equity. While economic analysis often ignores these aspects, the impacts of climate change are potentially so far reaching that these aspects simply cannot be ignored. Subsection 3.1 outlines economic efficiency aspects of climate change as well as the potential equity and distributional impacts of climate change in both spatial and temporal dimensions. For example, the rate of discount used to evaluate climate change adaptation or mitigation measures can have a large impact on the outcome of cost benefit analyses. We outline different perspectives on discounting in the economic profession, which are related to inter-generational equity issues.

Although there is now a consensus in the scientific community that climate change is a reality, there is still uncertainty about the extent of impacts and the regional distribution of impacts. Climate policy options must be formulated given this uncertainty. Subsection 3.2 reviews various criteria for evaluating policy under uncertainty and policy ideas such as insurance schemes for dealing with climate change impact uncertainties.

Climate change may have impacts on the competitiveness of the forest industry because climate change will influence economic timber supply through a variety of direct and indirect channels. For example, timber supply will be directly affected by changes in forest growth and natural forest disturbance regimes such as fire. Moreover, competitiveness may be indirectly affected by mitigation strategies outside the forest sector such as the implementation of carbon permit systems, which will influence fuel prices and change relative prices of forest products in global markets. These issues are discussed in subsection 3.3.

Another important consideration in evaluating climate change impacts, and formulating adaptive and mitigation policies will be to understand the social and cultural impacts. These impacts range from community stability, cultural integrity, potential asymmetrically distributed impacts, impacts on social institutions, and loss of leisure and cultural opportunities. Social impact analysis may also help to evaluate the adaptive capacity of human communities as well as barriers to adaptation that might exist in some communities. These and other social considerations are discussed in subsection 3.4.

Section 4 discusses impacts, adaptation, and mitigation strategies in 3 sub-sectors of the forest economy: the timber market, forest management, and the non-market sector. First, subsection 4.1 examines the potential adaptive responses to climate changes in timber markets, using an important US study by Sohngen & Mendelsohn (1999). Second, non-market impacts and adaptations to climate change are evaluated in subsection 4.2. Third, forest sector interactions with two other important sectors that may also be dramatically affected by climate change are assessed. These sectors are agriculture and energy. The analysis of the agriculture sector interactions emphases potential land used changes at the margin between agricultural land use and forest land use (subsection 4.3). The discussion of the energy sector will concentrate on how changes in the energy sector are likely to impact the forest sector (subsection 4.4). Subsection (4.5) discusses the possible roles of the forest sector for emission reductions and carbon stock enhancement. This subsection concentrates on the potential for forest management to adapt to climate change by: contributing to greenhouse gas reduction targets via carbon sequestration, adapting to possible increases in energy costs, and related policy options.

Section 5 of this paper is primarily concerned with methodologies for measuring potential impacts and for evaluating adaptation and mitigation strategies. The primary purpose of this discussion is to examine the types of physical, biological, and ecological models that have been developed and to evaluate the usefulness of these models for economic analysis of forest sector impacts and evaluation of adaptation and mitigation strategies. The section begins with a discussion of various physical, biological and ecological models used in climate change research (subsection 4.1). These models include general circulation models (GCMs), regional climate models, global biome models, regional ecosystem models, vegetation models, and Paleo models. The second part of section 4 is an evaluation of various economic and integrated assessment frameworks and models, including cost-benefit analysis, optimal forest rotation analysis, optimization models, partial equilibrium analysis and general equilibrium analysis. The need for integration of economic models with the physical, biological, and ecological models of climate change is discussed throughout the latter part of section 4.

The sixth and final section of the paper identifies some broad gaps in current social science capacity and suggests future directions for research. This section begins with a synthesis and problem analysis, which highlights the major problems for analysis that climate change presents and the major knowledge gaps (subsection 6.1). Finally the paper ends with an outline of the major priorities for policy evaluation (subsection 6.2) and a proposed set of research needs designed to improve the capacity of policy makers to evaluate policy options (subsection 6.3).

## 2. Impacts and Adaptation to Climate Change

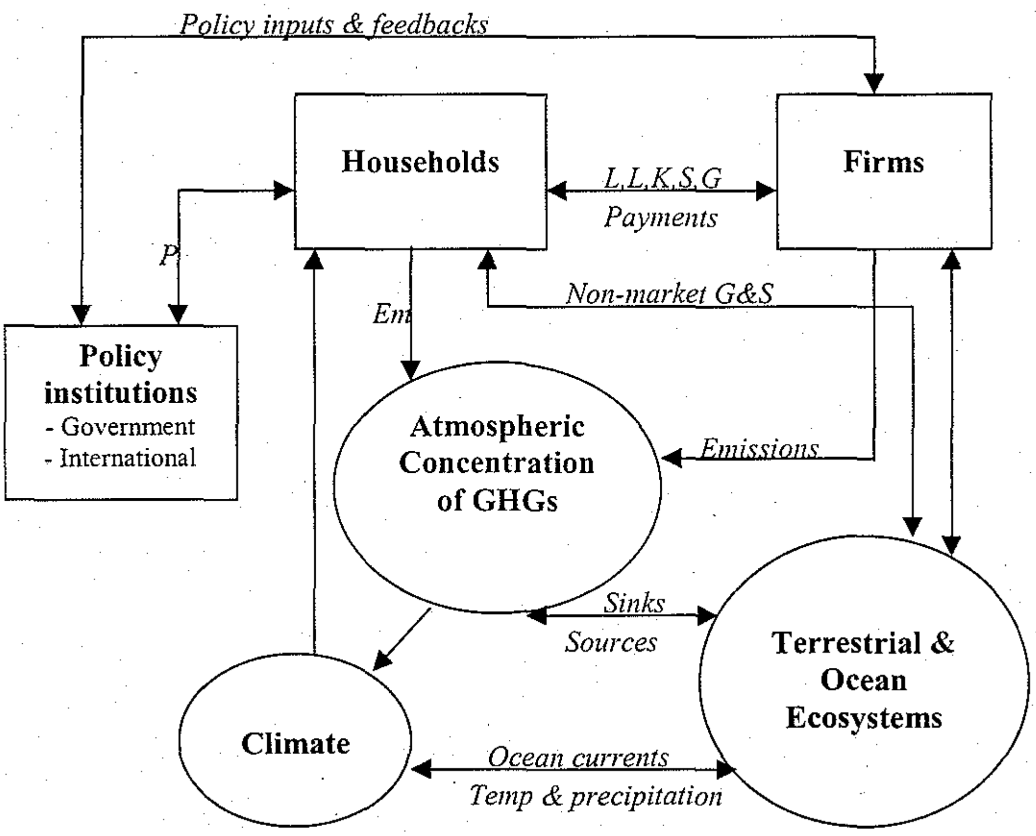
This section outlines some physical, economic, and international strategic dimensions of climate change. It also provides a general overview of how firms, landowners, governments and consumers will respond and adapt to new climatic conditions and consequent changes in land rents, production costs, and prices for goods and services. To understand the causes of climate change, the socioeconomic impacts and the consequent adaptive responses of society(s) and sectors over time, requires recognition of the interactions and complex feedbacks, between the human socio-economic, political, and institutional systems, and the atmospheric, climatic, ocean and biospheric systems.

Figure 1 provides a simple illustration of the interactions between the different systems involved in climate change. Human systems are displayed in boxes and environmental/physical systems are displayed in circles. Forest ecosystems are a subsystem of terrestrial ecosystems while forest products and forest sector policies are subsystems of human systems. Terrestrial and ocean systems supply environmental goods and services to human socio-economic systems. Human socio-economic systems in some cases consume these goods and services directly (i.e. non-market values) and in other cases transform environmental goods and services into products for consumption.

These processes of production and consumption result in changes to environmental systems (from either extraction and/or reintroduction of industrial by-products into the environment). These in turn, affect the stock of environmental goods and services, and the ability of the environmental system to provide inputs to the human systems. Thus, the figure illustrates the complex web of interactions and feedbacks between the political, economic and social systems and environmental systems.

In the case of climate change, a by-product of the transactions between firms and households at the global scale, is a measurable increase in atmospheric concentrations of greenhouse gases (GHGs). In the long term, these GHG emissions are expected to cause an increase in global temperatures and other meteorological anomalies. Climate change, in turn, impacts household preferences, the productive capacity of renewable natural resources and the mix of goods and services that can be efficiently produced by firms. In some cases climate change may have positive social welfare impacts in other cases it may have negative welfare impacts. If overall social welfare after a shifting climate regime is lower than it would have been without a change, then market failure has occurred and mitigation policies may be warranted. However, in order to evaluate the existence and/or magnitude of changes in social welfare attributable to climate change, policy makers require some understanding of the long-term impacts on society under various climate change scenarios. Moreover, since climate change may occur gradually, and over long time periods, it is necessary to evaluate the transient responses of ecosystems, households and firms as well as interactions between these systems over time. Adaptation may have the effect of mitigating many of the negative economic impacts of climate change. The challenge for economists and other social scientists, therefore, is to identify and measure impacts and adaptive responses to climate change over time. In some cases, these adaptive responses are triggered by changes in relative prices, by changes in the physical environment, or by behavioural changes in response to policy interventions. A complicating factor relative to measurement of impacts is uncertainty. There is a high degree of uncertainty concerning the complex, continually evolving and continually interacting systems portrayed in figure 1. These interactions would be difficult enough to comprehend even if it were possible to abstract to a set of static interrelationships at a single scale. However, the flows and transactions occur at multiple scales within and between the systems and they occur over long time frames.

**Figure 1:** Interactions Between the Different Systems Involved in Climate Change




*L,L,K,S,G* = labour, land, capital, services & goods. *P* = Policy inputs and feedbacks. *Em* = Emissions. *G&S* = goods & services. *C&N* = carbon & nitrogen. *Temp* = temperature.

## *2.1 Physical Dimensions of Climate Change*

The focus of this report is on the various socioeconomic dimensions of climate change impacts, adaptation and mitigation. Therefore, a detailed discussion of Canadian forest ecosystem responses to climate change is beyond the scope of this report. However, the assessment of climate change impacts is dependent on predictions of ecosystem responses to both climate change and to human management and adaptive responses. Therefore, the following subsection provides a brief overview of some physical dimensions of climate change relative to Canada's forests. For a more complete discussion of these facts, the reader is referred to (Saporta, Malcolm & Martell, 1998; IPCC, 1996a; Singh & Wheaton, 1991).

Increased concentrations of greenhouse gases in the atmosphere will cause Canada's climate to change. Predictions for global temperature change range from 1 degree to 3.5 degrees centigrade by the year 2100 (IPCC, 1996a). Other general predicted changes in climatic variables include; a lengthening of the growing seasons, changes in seasonal temperature averages and ranges, changes in precipitation and relative humidity, and possible changes in storm frequency and intensity (Maxwell, Mayer & Street, 1997; Saporta, Malcolm & Martell, 1998). Due to any number of factors (for example mountain ranges, large water bodies, continental influences, circulation patterns) these changes are expected to vary from region to region. For example, mid-continental areas are likely to become drier while other areas may become wetter, and northern latitudes are predicted to experience larger temperature increases than southern latitudes (Sedjo & Sohngen, 1998).

Canada's forests are susceptible to climate change influences (Singh & Wheaton, 1991). Climate change will have direct influences on site productivity, tree survival and regeneration capacity (Saporta, Malcolm & Martell, 1998). The physiological response of tree species will depend on the magnitude of climate change in particular locations, the rate of climate change and the ability of certain species to adapt to climate change over time. In some cases climate change could have a positive influence on site productivity due to increased growing seasons, increased precipitation, and increased growth rates due to higher temperature. Species more suited to warmer temperatures will expand their range. In other cases, species may suffer negative impacts in terms of their distribution and productivity.

Changes in disturbance regimes associated with climate change will also be a determining factor in ecosystem responses to climate change. Increases in the frequency and severity of wildfires (Weber & Flannigan, 1997), insects (Fleming & Volney, 1995) and disease (Krauchi & Xu, 1995) are predicted for some locations. Increasing disturbances may contribute to changes in species composition (Saporta, Malcolm & Martell, 1998), a decrease in average tree size and volume, and a decrease in average age (Rothman & Herbert, 1997).

The distribution of forest ecosystems is likely to change over time with climate change (Lenihan & Nelson, 1995). Different species may be unable to evolve to new climate conditions in the time available (Krauchi & Xu, 1995). This is particularly true when changing climatic conditions do not correspond to those required for flowering, pollination, seed formation, germination and competitive success (Singh & Wheaton, 1991). If climate change is beyond the limit of trees physiological tolerance, forest diebacks and ecosystem changes are inevitable, particularly at the margins of the different forest ecosystems (Singh & Wheaton, 1991).

Different ecosystem models have been used to simulate changes in forest distribution, species composition, and productivity (see subsection 5.1). However, these models provide conflicting results. For example, Lenihan & Neilson (1995) predict an expansion in the area of Canadian boreal forests, while Maxwell, Mayer & Street (1997) predict a contraction. Although model results vary, a northward shift in the distribution of the different Canadian forest types is generally expected (Lenihan & Neilson, 1995). However, poor northern soils and limitations in their ability to develop (Singh & Wheaton, 1991) may limit migration of the northern forest boundary, as may the inability of species to migrate rapidly enough (Maxwell, Mayer & Street, 1997). This suggests the general possibility of a northern migration of the southern boundary of the boreal forest and more limited expansion of the northern boundary of the boreal forest.

Integrated assessment of socioeconomic impacts requires a linking of dynamic economic models with dynamic ecosystem models. There are currently some limitations in existing integrated climate-ecosystem assessment frameworks and forecasts relative to their applicability in an integrated assessment framework across Canada. These limitations include; a) climate-ecosystem models are course and do not take into account important local influences such as mountain ranges and large water bodies, b) they provide some indications of how ecosystems may look after some period of adjustment but they provide limited insight into the dynamic responses of ecosystem over time to dynamic changes in climatic regimes, and c) they do not cover all of Canada's forest area. Canadian Forest Service climate change researchers and other researchers are currently developing improved and more comprehensive predictions of how Canadian forest ecosystems may respond to climate change over time.

### *2.2 Economic Dimensions of Climate Change*

The post-industrial revolution accumulation of greenhouse gases (GHGs) in the atmosphere[1] has occurred largely as a result of human activities and more specifically as a result of human commerce. The primary sources of increased GHGs are carbon dioxide emissions (resulting from the burning of fossil fuels), emissions of other trace gases (i.e. methane, nitrous oxide and CFCs) from a variety of sources including livestock rearing, coal mining, and natural gas leakage; and biomass reduction (largely attributable to deforestation of tropical rainforests). The consequent potential for future climate change resulting from greenhouse gas accumulation, therefore, is an economic phenomena. In fact, climate change presents a classic case of market failure, where the actual current

[1] 1900 - 300 ppm; 1965 - 320 ppm; 1985 - 345 ppm; 2100 – 618 ppm to 723 ppm (Cline, 1992).

costs of producing goods and services, (or the prices paid for inputs, such as land and fossil fuel), underestimates the true societal costs to present and future generations (this is assuming that climate change will have negative effects on aggregate welfare). Underpricing of inputs that contribute to GHG accumulation leads to their overuse.

Although this report concentrates on methodological issues pertaining to the evaluation of economic impacts of, and adaptive responses to climate change from a Canadian forest sector perspective, we begin by presenting a broader context for consideration of the dynamic interrelationships between climate and economic development over time. Since climatic processes are global in scale, the only legitimate way to portray the economic dimensions of climate is to start with a view of the inter-relationship between climate and the economy at a global level. This is provided in figure 1. In an ideal world of perfectly competitive markets, complete knowledge by households and firms, rational behaviour, and no externalities; goods, services and factors of production are efficiently priced and social welfare is maximized. If overall social welfare (i.e. aggregate consumer and producer surplus) after a shift in the climatic regime is lower than it would have been without a change, then market failure has occurred and mitigation policies may become warranted. Mitigation polices are intended to introduce new signals into the circular flow of transactions between households and firms in a way that adjusts behaviour in order to eliminate distortions caused by underpricing inputs, goods and services. The purpose of integrated assessment models is to evaluate the extent to which climate change affects the social welfare functions.

What relevance does the preceding discussion have with respect to understanding the economic dimensions of climate change from a Canadian forestry perspective? The relevancy lies in the fact that the Canadian forest sector can be viewed as a system nested within the broader framework provided in figure 1. With 10% of the worlds' forests, Canadian forest ecosystems play an important role in the global carbon cycle. As the world's dominant forest products exporting nation, the Canadian forest sector is closely linked to the global economy. As a northern nation with a large land mass, Canadian forests may be exposed to an above global average series of meteorological anomalies.

There are three main implications of the interactions shown in figure 1. First, they indicate that a comprehensive approach to impact assessment should consider the magnitude and interrelationships between impacts due to changes in underlying forest values, impacts caused by various policies to mitigate global warming, and impacts caused by structural changes in global forest products markets. This is primarily because all these influences occur simultaneously and are in many cases interlinked. Second, they indicate that any efforts to model climate change effects from a Canadian forest sector perspective will need to include linkages between the Canadian forest economy, other segments in the Canadian economy, and the global forest economy. As Fankhauser (1995, pp. 16) states; "Climate change is imposed on a system of interacting markets. Initial impacts on one sector may then also have higher order effects and spill over to other sectors of the economy." The forest sector will be impacted by changes in other sectors and impacts on the forest industry will in turn impact other sectors. Third, they indicate that the scope of Canadian impacts requires a-priori assumptions about what other countries will do relative to what Canada will do. This is discussed in more detail in subsection 2.3.

Figure 1 provides a static representation of the linkages and feedbacks between climate and the global economy. In the short run climate is constant. Climate ***change*** occurs over long time horizons. Evaluation of climate change impacts must therefore be evaluated over similar long time horizons. The long time scales over which climate change impacts are realized presents a number of challenges for the economic analysis of these impacts. First, increases in the price of goods and services and increased costs resulting from climate change will be dampened or moderated by technological innovation, relocation, substitution and changes in investment patterns. The nature and speed of these adaptive responses have an important influence on the total impact. Second, the long time horizon of effects results in considerable uncertainty in a) predicting the magnitude, direction, and pace of climate change at regional levels, b) predicting how natural ecosystems will respond to changing climate regimes, and c) predicting how households and firms will respond to, or be impacted by either a changing climate, changing natural resource endowments, or both. Impact measures will at best only be **expected** values and additional qualitative information will be necessary to take account of aspects that are non-measurable. Third, because mitigation costs and benefits and climate change impacts occur over time, for comparability it is necessary to convert all future monetary measures to a present value using a suitable discount rate. Selection of discount rates have major effects on the magnitude of impacts - particularly over long time horizons, and therefore, a suitable discount rate is imperative for providing meaningful estimates. Fourth, the long time horizons associated with the issue of climate change raise a number of issues regarding inter-generational equity and how inter-generational inequity should be measured and reflected in the evaluation of impacts. These issues are discussed in more detail in sections 3 and 5.

Given the complexity and uncertainty described in the previous subsection, and given the fact that most of the developed countries of the world have agreed notionally to reduce the rate of emissions of GHG under the Kyoto protocol, a legitimate question might be: Why bother to undertake impact assessments? There are two important reasons. First, even if all developed countries ratify their Kyoto commitments before their domestic legislatures (an outcome which many believe will not occur because of the unrealistic level of the targets (Portney, 1999)), climate change is still expected to occur and will have impacts on the Canadian forest sector and on the Canadian economy[2]. Therefore, in addition to mitigation policies, policies to ensure efficient and equitable transformations of the Canadian economy (and forest sector) to new climate regimes will be important, and impact assessments can provide valuable information for the development of adaptation policies. A second reason or application for impact assessments is that they can lead to measures of the "marginal social costs per unit of GHG emitted" - or in essence the marginal benefit per unit not emitted due to mitigation. Determination of the

[2] At the World Conference on the Changing Atmosphere (1988) it was suggested that a reduction in global GHG emissions of at least 50% is required to stabilize the atmospheric concentration of $CO_2$ (Fankhauser, 1995).

marginal benefits of mitigation actions is a requirement for determining the optimal level of intervention at a global scale (see subsection 2.3).

We close this overview of the economic dimensions of climate change with the question - What is the justification for a separate and unique assessment of climate change impacts for the forest sector? The justifications are numerous. First, Canada's forests provide a broad range of both market and non-market goods and services, and changes in forest ecosystem distributions resulting from climate change have important implications for both these broad classes of values. For example, visual aesthetics, the existence of unique and rare flora and fauna, ecological services from forested wetlands are generally not priced in markets but humans place a high value on these services. Changes in the availability and quality of these services needs to be considered in impact assessments. Various cost-benefit exercises have been undertaken to economically value the market and non-market impacts of climate change on forestry (IPCC, 1996c) and these approaches are discussed in subsection 5.2, along with other economic impact analysis tools.

Another reason for impact assessment from a forest sector perspective is that the uncertainty associated with predicting forest ecosystem responses to climate change, result in uncertainties for the forest economy and for forest management and policy (this is further discussed in subsection 3.2). The inherent sensitivities of forest ecosystems to climate and the uncertainties of ecosystem responses create unique sectoral policy and management problems (Duinker, 1991). For example, long-term rotations for Canadian timber means that decisions are being made today under the assumption that environmental conditions at the end of the rotation will be similar to current conditions (Singh & Wheaton, 1991). Such an assumption may not be valid.

Other sector unique impacts resulting from global warming include modified fire regimes with consequent changes in forest landscapes (Weber & Flannigan, 1997). Any changes in Canadian and global forest endowments are likely to have international trade and forest products price implications (van Kooten & Arthur, 1989). Changes in product prices and changes in timber supply will impact government resource revenue (Thompson, van Kooten & Vertinsky, 1997) and the cost of management and resource development (e.g. increased protection costs are probable). Changes in Canadian forests are also likely to impact other forest dependent sectors, such as recreation (Thompson, et. al, 1997). Some activities are likely to benefit (e.g. summer outdoor recreation opportunities) while others will become worse off (e.g. winter sports) (Mendelsohn, 1998). Changes in the distribution of forests may contribute to premature obsolescence of infrastructure and change the underlying economics of recreation and forest product enterprise locations. These changes, may in turn, have implications for the economic performance of resource reliant communities and for the economic welfare of residents within these communities. Finally, forestry mitigation activities such as afforestation and intensive management of forests have been suggested to counter the build up of GHG emissions in the atmosphere through carbon sequestration (Sedjo et. al, 1995; Nilsson & Schopfhauser, 1995; Hoen & Solberg, 1994).

### *2.3 Adaptation and Mitigation Strategies*

There are two different types of approaches that can be used to respond to and moderate climate change impacts. One is adaptation or protection measures, and the other is mitigation or abatement measures. Mitigation measures are those that limit the net amount of GHGs emitted either by source-orientated measures, or sink enhancement measures (IPCC, 1996c). Examples of source-orientated mitigation measures include fossil fuel switching (i.e. from carbon-intensive coal to less carbon-intensive gas), energy conservation and efficiency improvement, and renewable energy (i.e. bio-energy, see subsection 4.5 for further details). Sink enhancement mitigation measures include capturing and disposing of GHGs, and enhancing global GHGs sinks, such as carbon sequestration in forests and soils. In the past, mitigation options have received far more attention than adaptation options (IPCC, 1996c). Adaptation strategies are those strategies which respond to climate change impacts, to increase the resilience of anthropogenic and physical systems to climate change impacts, to reduce the associated damages (Fankhauser, 1995) and to increase the possible benefits. Adaptation measures can be divided into; protection approaches (i.e. protection against forest fires), retreat approaches (i.e. relocation away from areas of forest diebacks) and accommodation approaches (i.e. replanting with species suitable to future climate predictions). However, the focus of the majority of current climate change socioeconomic research is on mitigation and little attention has been given to adaptation strategies.

The effectiveness of adaptive responses to climate change will depend on the ability of consumers, firms and governments to predict and anticipate climate change impacts. If impacts can be anticipated then proactive adaptive strategies may be formulated. For example, if one knew that the future climate would not be suitable for previously harvested tree species, then one conceivably might try to plant species or develop hybrids that are more adapted to the new climate regime. On the other hand, if one does not or cannot anticipate climate change impacts, then adaptive measures will be reactive instead of proactive and the costs of the impacts would likely be more severe.

Damages from climate change will be a function of the magnitude of physical impacts, the rate of change, and the degree of continuity of change. For example, Saporta, Malcolm & Martell (1998) point out that some research indicates the possibility of "abrupt climatic change" and that this may result in "unanticipated and possibly catastrophic ecosystem changes." Adaptation strategies and responses are also sensitive to the pace and consistency of change over time. Adaptation will be most effective if climatic change and ecosystem changes are gradual, predictable and relatively constant over time. Rapid changes and/or discontinuous changes over time will decrease the predictability of responses and increase uncertainty. This may result in sudden lurches from one dis-equilibrium to another rather than gradual convergence to a dynamically stable equilibrium.

There are four main groups that will be impacted by climate change, (either positively or negatively), and who will consequently adapt and respond over time to the new circumstances they face: firms, landowners, governments and consumers[3]. Climate change and mitigation policies will affect current and future prices for inputs (land, labour, capital, and energy). Climate change and mitigation policies will also affect the future price path for forest products and the future stream of utilities provided by non-market goods and services. Increased uncertainty associated with climate change effects will also affect the behaviors of firms, landowners, governments and consumers. Each of these groups has a unique objective function, which defines their behaviour and actions over time. For example, economics assumes that firms strive to maximize their profits and/or returns on shareholder capital. Firms, therefore, will evaluate current and future costs and product prices and will respond to actual and/or anticipated changes in these streams by adopting new competitive strategies. It is generally assumed that landowners strive to maximize the stream of rents provided by their land over time. Expectations of future changes in the stream of rents will provide an incentive to change land use or adopt new land management methods. Governments strive to maximize net social welfare over time and to ensure an equitable distribution of income. They intervene when market failures become apparent or when there is demand for the provision of public goods that the private sector would not provide. Consumers, purchase a bundle of goods and services, which maximizes the utility they obtain from their fixed budget. Thus, relative changes in costs and prices will lead to changes in behaviors depending on what goals a particular agent is attempting to achieve. The goal of the agent will be to minimize the negative impact of the change on their objective function and maximize the positive impact of change. Therefore, the incentive to minimize the negative effects and maximize the positive effects of climate change will lead firms, landowners, governments and consumers to adopt various strategies which will allow them to either minimize negative impacts or to exploit new economic opportunities. Firms, landowners, governments, and consumers have a range of alternative strategies they can employ to achieve this. These adaptive responses will have the effect of mitigating some of the scarcities and social costs associated with climate change. The following paragraphs and table 1 briefly review some of these responses.

There are a number of adaptive strategies which forestry firms may employ in response to climate change. This discussion concentrates on situations where adaptation is in response to increasing costs. We focus on this as a possibility because it is the aspect that is of particular concern from an impact and adaptation perspective. One option is to transfer their capital and business expertise to new industries. If the profit potential of the new investment opportunity under climate change, is higher than the profit potential of the firm in the existing location under climate change, then this strategy may mitigate the social cost of climate change to some degree. However, changing industries is not the only option available to firms. For example, the current technology may allow firms to substitute relatively lower priced inputs for inputs that are relatively more expensive. If energy costs increase, firms may substitute capital for energy by using more capital intensive but less energy intensive processes. The marginal costs will still be higher with

[3] This classification is somewhat arbitrary because in some cases firms and/or consumers are also landowners and their adaptive responses will be based on complex objective functions.

the new input mix but not as high as if the firm used the previous input mix. Firms, have the option of innovating new technology as a way of minimizing the cost impact of changes in relative input prices. Increases in the prices of timber and energy for example would provide incentives for development and/or innovation of energy and resource saving technologies (i.e. induced innovation). Firms may adopt hedging strategies in response to perceived uncertainties in future product and input prices. For example they may choose to produce a diverse range of products (and accept a lower return on capital) instead of producing a single product (where the potential return on capital is higher but future prices are uncertain) (Smith, 1982). Some constraints on the ability of firms to use the above strategies to adapt include: technological constraints which limit the degree of input substitution possible, long rates of capital turnover in large capital intensive industries such as the pulp and paper industry (Forest Sector Table, 1998), and globalization of the world economy (which is contributing to a trend of national specialization in the production of fewer products and services, international product standardization, increasing trade and increasing plant sizes).

Climate change and mitigation will affect revenue streams, price paths for renewable natural resources, and the rent value of land in particular uses. Relative changes in rent values and price paths will affect land use and land management. Landowners will adapt to climate change and mitigation by either selling their land, changing its use, or changing how it is managed. These adaptations are constrained by physical limitations such as soil, landform, hydrology, etc. Sohngen & Mendelsohn (1999) show that adaptive responses by landowners to changes in price paths (caused by climate change) include changes in harvesting behavior and replanting decisions. These responses result in an acceleration of the transition from one ecosystem distribution to another.

The objective of government policy should be to maximize social welfare over time. Thus, government adaptation to climate change should be in the form of interventions to correct market failures, income redistribution and compensation schemes - when there are asymmetries between the beneficiaries of programs and interventions and those that bear the cost of programs and interventions. Since information pertaining to climate change has public good characteristics an adaptive response by governments to climate change may be to facilitate science, technology and knowledge regarding climate change, climate change impacts, technologies that make adaptation easier, and public education.

Climate change and mitigation will lead to a new price paths for goods and services. This will have substitution and income effects. The price of some goods and services may decline while the price of other goods and services will increase. The net effect will be a change in the basket of goods and services purchased by consumers. The opportunity to substitute products means that the impacts of climate change on aggregate welfare are dampened. The degree to which climate change and mitigation reduces (or increases) aggregate welfare will depend on the elasticity of demand of particular goods and services. If goods and services with relatively inelastic demand (i.e. fewer substitutes) are affected to a greater degree than goods and services with elastic demand (i.e. more substitutes) then adaptive capacity of consumers will be more limited and the welfare effects of climate change more pronounced.

Mitigation and adaptation options are interlinked (IPCC, 1996c). For example, mitigation options, such as carbon sequestration in forests, are likely to result in adaptation responses by forest managers to changes in economic incentives and policy environments. Further, some strategies are likely to be implemented, because of the benefits they yield in terms of mitigation, and the benefits they yield in terms of adaptation. For example, afforestation and other forest management activities designed to preserve forest stock could be thought of as both mitigation and adaptive policies. In other words, there is joint production between the two objectives. Another example is in the forest products production sector itself. In this sector mitigation policies designed to reduce emissions such as carbon taxes or carbon permit systems will lead to higher energy input prices. The forest sector will then be likely to react to these mitigation policies and subsequent price stimulus with adaptive responses including substitution away from carbon-intensive energy sources. For example, further development and implementation of co-generation and bio-energy options would be probable.

Theoretically this is achieved by a simultaneous optimization process which minimizes mitigation costs, climate change damage costs and adaptation costs (which can also be viewed in terms of their opportunity costs, IPCC, 1996c) (Fankhauser, 1995). The optimal solution occurs when the marginal net benefits per dollar spent on adaptation equals the marginal net benefits per dollar spent on mitigation. Figure 2 provides a theoretical illustration of the 'optimal mix' of adaptation and mitigation from a Canadian perspective. It shows that the optimal mix depends on the marginal net benefits of adaptation ($MB_A$) and the marginal net benefits of mitigation ($MB_M$). The marginal net benefits of adaptation are usually local or in other words, Canadian benefits. This aspect is important when considering the international strategic dimensions, which are discussed in subsection 2.4.

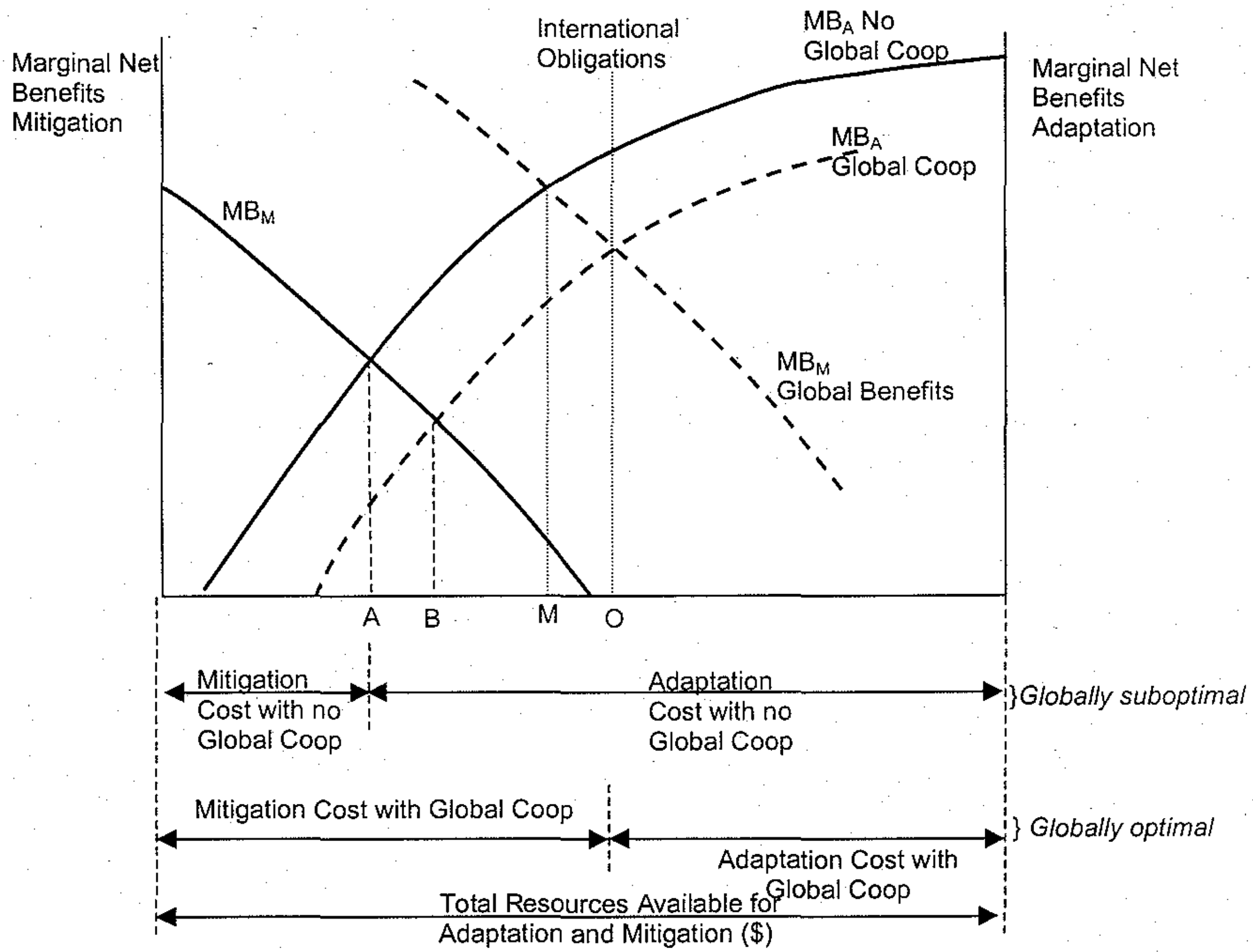
The effective design of institutional structures can be a powerful tool for promoting adaptive behaviour. Climate change introduces a new variable in decision making. However, existing institutional arrangements have not been designed to account for this new variable. Thus, the ability of Canadian society to effectively adapt to climate change and mitigate negative social consequences may require some review and modification of existing institutional mechanisms. Assuming that mitigation and adaptive responses can be separated; the optimal combination of adaptation and mitigation strategies are those that maximize net benefits.

Current research suggests that competitive markets are an important instrument for facilitating adaptations by the forest sector and other sectors in general. This is an important consideration relative to adaptation on forest lands. The majority of forest land in Canada is owned and managed by government. Decisions concerning harvest rates, rotation age, stumpage value, and species selection for replanting are largely determined by physical and administrative considerations. Therefore, price signals will play a limited role in determining landowner behaviour. From an efficiency perspective an important question is; will government agencies be more or less effective in changing harvest rates, rotation ages and species choice in response to climate change, when compared with private landowners?

**Table 1.** Examples of Climate Change Impacts & Adaptations from a Forest Perspective

| Physical Impacts | Social/Economic Impacts | Who's affected? | Adaptation Policies/strategies |
|---|---|---|---|
| Forest productivity changes | Changes in timber supply and rent value. | Forest firms and land owners | Change harvest schedules (regional & annual), adjust replanting behaviour, including species planted, change land use. |
| Increased atmospheric GHGs & associated climate change | Introduction of carbon credit/permit mitigation policies, which create a carbon sequestration market. | Forest firms and land owners | Carbon sequestration in forests - change rotations, manufacturing, harvest techniques, afforestation, research & development. Reuse/recycle wood residue & products i.e. as a biofuel. |
| Increased GHGs & associated climate change | Mitigation policies which increased GHG-intensive energy prices. | Consumers and firms | Substitute GHG-intensive products i.e. steel, with wood. Increased use of bioenergy/co-generation. |
| Increased disturbances | Loss of forest stock & non-market goods. | Land owners, firms & consumers | Increased protection policies & research & development. |
| Climate change, ecotones shift northward | Changes in land values & land use options. | Land owners, firms & consumers | Changes in competition for land - forest v agriculture. New management options. |
| Climate and ecosystem changes | Climate change related economic restructuring leading to social and individual stress, & other social pathologies. | Aboriginals & other forest dependent consumers and firms | Improved communication, education, participation, conflict resolution, & removal of institutional barriers. |
| Ecosystem & specialist species changes | Changes in non-market values, especially the passive component. | Consumers, firms and land owners | Change preferences; increase forest reserves, arboreta & seed banks. |
| Ecosystem changes | Parks and natural areas dislocated; increasing land use conflict. | Consumers, land owners, firms & government | Alter park boundaries & expand into a comprehensive system. |
| Climate/forest ecosystem changes | Fixed, sunk capital dislocated. | Climate/forest dependent tourist/ forest firms | Diversification (i.e. winter ski hills, to include summer golf facilities) &/ relocation. |
| Increased atmospheric GHGs | Increased GHG-intensive energy prices. | Long-haul tourists consumers & their destination firms | Substitute with increased local tourism. |
| Warmer conditions | Increased cooling of buildings required. | Firms & consumers | Increase planting of urban trees (with co-benefits). |
| Frequency &/ magnitude of changes rise | Increasing uncertainty. | Government and firms | Increase research and development. |

**Figure 2:** The Optimal Mix of Mitigation & Adaptation, & International Obligation




Government also has a role in enhancing adaptive behaviour. These roles include assisting vulnerable groups and facilitating efficient markets (e.g. reviewing and revising property rights where appropriate - i.e. private versus public land). Market failures need to be corrected (e.g. the value of knowledge on climate change, and incorporating inter-generational welfare considerations into decision making). Independent research on adaptation issues should be promoted (e.g. through non-governmental organisations). Finally, government should ensure that existing public institutions for dealing with market failure are not too rigid to adapt to changing climate conditions (e.g. allowable annual cut policies, tenure length issues, access policies and species regeneration polices - i.e. those that require sites to be regenerated with the previous species mixture).

*2.4 Strategic & Political Economic Dimensions of Climate Change*

Various impacts of climate change at the international levels may induce nations, firms or groups to behave strategically in a way that leads to less than optimal outcomes from the perspective of maximizing society's welfare. There are two types of strategic behaviour discussed below. One type of strategic behaviour occurs when corporate, provincial or national climate change policy making is conditioned by the actions and/or policies of other corporations, provinces or nations. For example, Canada might condition its ratification of the Kyoto agreement on what the United States does and the United States might condition its ratification of the agreement on what developing countries are willing to do. Strategic behaviour of this sort is important at all levels of jurisdiction but the discussion here will focus on the international level. Another type of strategic behaviour is the expenditure of resources by interest groups (environmental groups, firms and other groups) to influence policy development so that the resulting policy environment satisfies the group objectives to the fullest extent possible. This type of behaviour is referred to as rent seeking.

*International strategic dimensions*

We first focus on the international strategic dimension. A fundamental characteristic of climate change and greenhouse gases is that individual countries are likely to benefit very little from their own actions to mitigate climate change. Hence, individual nations acting on their own will bear the costs of their greenhouse gas reduction actions while reaping no rewards. In addition, this creates incentives for individual nations to reduce their mitigation efforts if other nations increase their mitigation efforts. This is known as free riding behaviour. In the context of climate change, free riding behaviour may lead to collectively undesirable, inefficient, and inadequate mitigation efforts (Sandler 1997, Nordhaus & Yang, 1996). This is illustrated in table 2. When other countries do not mitigate climate change, Canada's climate change impacts will be high regardless of what Canada does. Hence, if Canada employs costly mitigation strategies and other countries do not cooperate then Canada will incur large climate change impacts in addition to the mitigation costs – clearly not a desirable outcome. Hence, if other countries do not mitigate, Canada's optimal strategy is to keep mitigation costs low. On the other hand, if other nations do cooperate then Canada will incur smaller climate change impacts.

However, these lower impacts will occur regardless of Canada's mitigation policy which contributes very little to the overall reduction of greenhouse gas output and hence climate change. Therefore, Canada's optimal mitigation strategy is to do as little as possible. In other words, no matter what other nations do Canada's best strategy (from a purely self-interested perspective) is to do as little mitigation as possible. The problem is that all nations face similar types of payoff and hence the best strategies for all countries is to minimize mitigation action, hoping that other countries will take the lead on mitigation. The result is a mutually undesirable outcome; countries do not cooperate and reduce greenhouse gas output. The desirable outcome is for all countries to cooperate in the mitigation of climate change.

This result is essentially the free rider problem that accompanies any public goods or common pool resource problem. Since non-mitigating countries cannot be excluded from enjoying the benefits of other countries' emission reductions, there is a tendency to attempt to let other countries bear the bulk of the mitigation costs. Climate change therefore creates a strategic environment that is conducive to free riding – where the dominant strategy is to let other countries take care of the problem.

**Table 2.** Alternative Scenarios for Evaluation of Forest Sector Impacts. This table suggests the magnitude of mitigation costs, direct climate change impacts, and adaptation costs for Canada, with Canadian actions, given the actions of other countries.

| Canada | Other countries | |
|---|---|---|
| | Fail to fulfil Kyoto commitments | Fulfil Kyoto commitments |
| Fails to meet Kyoto commitment | Low mitigation cost<br>Potential large climate change impacts<br>Potential high adaptation benefits | Low mitigation cost<br>Smaller climate change impacts<br>Low adaptation benefits |
| Fulfils Kyoto through a mix of interventions<br>- improve energy efficiency<br>- substitution/fuel switching (e.g. natural gas for coal)<br>- increase renewable energy use<br>- clean development credits<br>- carbon sequestration | High mitigation cost<br>Potential large climate change impacts<br>Potential high adaptation benefits | High mitigation cost<br>Smaller climate change impacts<br>Low adaptation benefits |

At the international level, agreements or treaties that incorporate international obligations can be constructed to try to overcome this free rider problem. In figure 2 this is illustrated by the vertical line at point O, which is at the intersection of the global marginal net benefit of mitigation curve ($MB_M$) and the marginal net benefit curve of adaptation (with international cooperation). Point O is the intersection between the local, Canadian marginal net benefits of adaptation with global cooperation, and the aggregate marginal netbenefits of Canadian GHG reductions to all countries ($MB_M$ Global). It should be the objective of policy makers to choose the level of obligation that is illustrated by point O. However, at the international level truly binding treaties are difficult to construct and enforce. Hence, maintenance of cooperation at the international level is extremely difficult.

It is important to understand this aspect of international climate change policy from an adaptation perspective, because the best mixes of adaptation and mitigation strategies at the national level then depend on the mitigation policies of other nations. Both figure 2 and table 2 illustrate this point. In figure 2 the optimal mix of adaptation and mitigation from a global perspective is at point O. This is the optimum when all countries cooperate, and all countries take the benefits to other countries in account when formulating mitigation policy. However, if other countries do not cooperate the optimum mix is at point M, where Canada still considers the benefits to other countries of its own mitigation efforts. However, from Canada's own perspective, when no other country cooperates to reduce emissions then the optimal amount of Canadian mitigation and adaptation is at point A.

Free riding is fundamental to the climate change problem and it arises because all countries benefit from the mitigation actions of any other country or countries. In other words, benefits of mitigation action include benefits for all countries, not just the country that is making the mitigation effort. The same is true for only a very limited number of adaptation strategies, for example, those which could be implemented to safe guard endangered species with existence values (see subsection 4.2). On the other side of the coin, countries that do not emit significant levels of GHGs still incur damages from climate change, along with those countries with high GHG emission levels.

In reality, the decisions on the choice and weight given to adaptation and mitigation strategies are usually made at different political levels. Mitigation measures are often decided at international conferences, such as the Kyoto protocol, whereas adaptation strategies are more likely to be decided on national, regional, local or individual levels. Therefore adaptation strategies are usually decided by "climate takers", who consider climate change to be exogenous (Fankhauser, 1995), whereas mitigation strategies are more likely to be decided by "climate makers", at a global level where strategies can influence climate change. Nevertheless, the economic, social, political and environmental viability of different strategies, and combinations of strategies are important to the choice of strategies that are actually implemented.

An important factor that may mitigate strategic free riding behaviour is the presence of co-benefits to some climate change adaptation and mitigation policies. For example, measures to reduce fossil fuel emissions of greenhouse gases may lead to other local benefits such as improved health and/or decreased health costs. Planting trees for carbon sequestration may have aesthetic and habitat benefits. Thus, climate change mitigation strategies may jointly produce several benefits simultaneously. Cornes & Sandler (1986) develop an economic model with public goods that also yield some private benefits. The situation is similar to the case of co-benefits. Cornes & Sandler (1986) then show that private, or in this case national incentives, may lead to less free riding on public goods. Hence, co-benefits have the potential to be a highly important aspect of optimal climate change policy.

*National strategic dimensions*

Individuals, environmental groups and industrial/manufacturing groups will attempt to influence government and the policy making process so that policy outcomes leave them as well off as possible. This is known as rent seeking in the political economy literature. By participating in the formulation of policy, and ultimately making the final decision for the most important stakeholder, which is the general public, it is important for governments to keep the politics of interest groups in mind. This type of behaviour may manifest itself in a number of policy-making arenas.

For example, in the formulation of carbon permit systems that place a cap on national emissions it is important to consider how permits are distributed among the emitters of carbon (see Table 3 for a description of permit trading systems). The two main categories of distribution systems are auctions and grandfathering (Cramton & Kerr 1998a, 1998b). These two systems have different implications for the distribution of scarcity rents that are generated when a cap and carbon allowance trading system is implemented. These differences, in turn, create incentives for rent seeking. Rent seeking may occur in several stages of the development of a carbon permit system. First, before the final decision about the type of system is made, firms are likely to lobby for a grandfathering system because it limits the transfer of income from their shareholders to, the government or general public. Environmental groups, conceivably, might lobby for an auction system so that rents can be captured by the government and possibly redirected toward energy saving or new clean energy technologies. Second, if it was decided that a grandfathering system for permits was to be implemented, the government would expose itself to further rent seeking as various companies argue for the largest possible share of the total number of permits. In addition, a policy would have to be carefully crafted to avoid possible perverse incentives that might signal corporations to emit as much greenhouse gas as possible before the allocation of permits is decided. As in the case, where the permit allocations to firms are decided by historical emission levels. There will also be concerns about the freedom of entry into the market by new firms.

Credit trading systems, which are particularly relevant to forest carbon sequestration options, may also be prone to rent seeking behaviour. In credit trading systems, credits are given for emissions reductions from a projected baseline (Rolfe, 1998a). There are several potential difficulties with this type of system. The first is in predicting the baseline. Any predictions are likely to have a wide band of alternative paths around them because of the regular market supply and demand cycles and uncertainties. For example, policy makers would have to decide whether they wish to give credit for emissions reductions that are simply a result of market downturns, which are part of regular business cycles. Another example of the difficulty in determining a baseline relates to forest management. Suppose, for a moment that carbon storage policy was expanded from afforestation and deforestation as in the current Kyoto agreement, to reforestation and management of existing forests. Determining a baseline in this environment is particularly difficult for several reasons. First, forest disturbance regimes such as forest fire, insect and disease attacks are highly erratic, making it difficult to establish a baseline

(Armstrong, 1999). Second, disturbance regimes are partly determined by forest protection policy and by forest harvesting practices. Third, emissions of carbon resulting from forest harvesting depend on the particular harvesting scenario selected. Hence, the baseline is dependent on management practice, which is likely to change in the future. This dependence of the baseline on management practices further complicates the implementation of a credit trading system by introducing the possibility of rent seeking. In the case of credit trading systems, individual firms may have incentives to argue that their baselines are as high as credibly possible so that the maximum amount of future credit can be attained.

### *2.5 Summary*

This section has provided the context and background for the rest of our paper. It has outlined the different physical and socioeconomic impacts and their complex interactions, using a framework. Our definition of adaptation and mitigation strategies was provided, along with examples, and the belief that these two types of strategies are interlinked, and can not be viewed in isolation. Finally, strategic dimensions of stakeholders impacted by climate change and/or climate change polices were given. These included the problems of free riding and rent seeking. Many of the impacts and strategies/policies described above can be applied to the economic criteria and social considerations outlined in the following section.

## 3. Socioeconomic Criteria & Considerations for Measuring Impacts

Measurement of the socioeconomic impacts of climate change and associated policy responses must be evaluated using some criteria. In general, when we evaluate a set of policies, whether they are climate mitigation policies, adaptation policies or carbon sequestration policies, we want to choose one from a set of alternatives that is best by some definition. In economics, the objective of impact assessment, policy evaluation or project analysis is to determine whether an action makes people affected by the policy better or worse off. In the case of adaptations, we want to know whether adaptive strategies reduce the negative impacts on welfare caused by direct climate change impacts. This requires two things: a way of measuring welfare change and a means of aggregating the welfare changes for the people affected by policy changes. This section provides a variety of criteria, approaches and considerations for assessing climate change impacts and related adaptation strategies. These include efficiency, equity, uncertainty and competitiveness criteria, as well as social considerations. These are the key considerations, but are by no means an exhaustive set.

### *3.1 Efficiency & Equity*

The purpose of this subsection is to examine economic criteria for assessing impacts and for evaluating short and long term actions undertaken as a result of climate change or to prevent climate change. The first part of this discussion is a review of basic economic criteria used in cost benefit analysis and other forms of economic analysis – namely the Pareto criterion or efficiency criterion. In addition, the compensation principle is discussed. Equity in both intra and inter-generational contexts is then examined in the second part. Essentially, this is an examination of the appropriateness of employing discounting for evaluating climate change policies. The three approaches for the evaluation of investments involving intergenerational transfers that have been suggested in the literature are discussed. The discussions are important because the use of discounting will be crucial to analysis of long term adaptation and mitigation policies. Finally, some suggestions for use of discounting are made.

Economic efficiency is the focus of economic cost/benefit analysis and more sophisticated variants such as dynamic general equilibrium analysis. While efficiency is an important criterion, climate change policies related to forests are likely to result in transfers of wealth from one sector of society to another within the same generation or even between different generations. Hence, equity, both intra and intergenerational, must be an important consideration in evaluating climate change adaptation and mitigation policies. Economists have traditionally been uncomfortable speaking about equity. However, this appears to be changing and some economists have suggested that equity considerations, at least under climate change, are more important than any concern about efficiency (Lind & Schuler, 1998). Perhaps this arises because efficiency can be defined rigorously without appealing to strong equity norms (Boadway & Bruce, 1989). However, economists are often in the best position to point out the equity consequences of policies or policy changes, and are in a position to make policy makers aware of redistributional impacts of various policies. In the case of climate change, fundamental equity issues pertain to the allocation of welfare across the regions of Canada, across interest groups, and across generations.

*Efficiency and the compensation principle*

The efficiency criterion, or the Pareto efficiency criterion, plays a central role in much of economic analysis. It is the basis of cost-benefit analysis as well as more sophisticated general equilibrium models. A new policy satisfies the Pareto efficiency criterion if it makes all parties involved at least as well off as before the policy is enacted and at least some parties better off. If a new policy makes some better off and harms others then it cannot be said to be more efficient than the existing policy environment. In these cases, it is traditional to invoke the compensation principle. The compensation principle requires that the winners in a new policy environment be able to compensate the losers at least hypothetically or in principle. The compensation must be such that the losers under the new policy are just as well off as before the policy was enacted. In addition, the winners are still better off even after the compensation is paid.

Cost benefit analysis is an extension of these principles to situations where costs and benefits occur at different points in time. With cost benefit analysis, policies (or projects) should only be accepted if discounted benefits are greater than discounted costs. In some cases, the benefits and costs may not be equally distributed among those affected by the new policies. Some individuals may be opposed to the new policy because they are actually made worse off if the policy were to proceed.

There are good reasons why only policies that satisfy the compensation test should be accepted – even if compensation is not made. The fact that compensation is not made implies that the beneficiaries of the policy do not compensate those whom the policy hurts. This is a decision to subsidize the beneficiaries of the policy, or to redistribute resources. If for some reason a decision is made to subsidize the beneficiaries, then benefit cost analysis criteria is still useful. One should undertake the redistributive policy only if it passes the cost benefit criterion – benefits > costs. Why? Because if benefits are less than costs then the beneficiaries can be made just as well off by giving them a cash payment that is less than the cost of the policy (Lind & Schuler, 1998).

Lind & Schuler (1998) suggest that there are two aspects of a decision to undertake this type of policy. The first is an ethical decision to transfer wealth from society in general to the beneficiaries. Cost-benefit analysis does not tell us how or if this should be done. This decision must be made based on values outside the scope of costs benefit analysis. The second aspect concerns the question of how best to make the transfer, via the policy or through a cash transfer. Clearly, the policy is more efficient if benefits are greater than costs and a straight cash transfer is more efficient otherwise.

All of this presumes that it is feasible to make a cash transfer. If a cash transfer is not feasible, then there may be circumstances where policies that do not meet the cost benefit criterion might be followed as a wealth transfer mechanism. This is a decision that requires a value judgement separate from the cost benefit criterion.

The above discussion provides an overview of efficiency and equity considerations relative to the assessment of climate change impacts and policies. A practical question relative to measuring impacts and evaluating policies is: What unit of measurement should be used in order to value impacts and provide empirical measures of the relative costs and benefits of policy options? In general, the economic value of a good or service is equivalent to the amount of utility that the good or service provides to a consumer minus the disutility of supplying the good or service (Sinden & Worrell, 1979). When aggregated over all consumers of a good, the measure of total utility is the sum of the area under the demand curve. The measure of disutility is the area under the supply curve. The measure of social value is the difference between these two areas. Thus, the total economic value of a good is the area below the demand curve and above the supply curve up to the point where the equilibrium price is reached. This sum is termed the net social benefit and it includes two types of values: consumer surplus and producer surplus. For long term issues such as climate change, impact assessment requires the measurement and comparison of the stream of net benefits over time, both with and without climate change and/or related policies. The difference (which may be either negative or positive) is then a measure of the impact of the event. However, since the net benefits occur over different periods, they must be discounted to a present value in order to be comparable. This raises the question of the choice of discount rates which is discussed below.

*Intergenerational efficiency and discounting*

When costs and benefits of policies or changes in the environment are distributed over time, economists use discounting techniques to account for the fact that people place relatively more importance on present consumption of goods and services than they do on future consumption. While economists tend to agree that discounting should be practiced for evaluation of policies and investments that have relatively short term implications, they do not agree on how discounting should be carried out for policies with long term implications (see Lind & Schuler, 1998). Climate change is one such long term issue.

It is well known that different discount rates can generate vastly different results for projects with costs and benefits widely dispersed over long time horizons. Investments that appear efficient if low discount rates are used in the cost-benefit calculation appear inefficient if high discount rates are used. This has led to a debate, both in the economics discipline, and other social sciences, about the appropriateness of discounting for policies (or investments) that have implications for generations that will live beyond the life span of the current generation. Within the economics discipline, this debate has focussed more on the appropriate magnitude of the discount rate to determine which investments are efficient. Here we do not try to answer the question: what discount rate should be used? Instead, we try to clarify some of the issues in this debate that exists in the economics profession. Fundamentally, the problem is how to make tradeoffs between our consumption today, and someone else's consumption tomorrow. There is some debate about whether discounting in cost benefit analysis, or other forms of economic modelling, is a reasonable approach to this problem.

First, we discuss what efficiency and equity mean in the context of intergenerational tradeoffs of wealth and resources. In the context of global climate change and long run forest management, a new policy is more efficient than the existing policy environment, if the new policy makes at least one generation better off, while making all other generations at least as well off. However, the situation is somewhat more complex when future or current generations are worse off. For example, if a new policy increases the wealth of current generations while decreasing the wealth of future generations then the policy is not more efficient than the current policy. Conversely, if a new policy increases the wealth of future generations while reducing that of current generations then the new policy is not more efficient than the current policy. These two situations may arise even if the discounted benefits of the new policy are greater than its discounted costs. In this case, we can again invoke the compensation principle. However, now the compensation must be paid across possibly widely divided generations and this may be problematic. In the following paragraph, we explore this problem and its relationship to the use of discounting in cost benefit analysis.

Traditionally economists have used discounting to evaluate investments that have long-term costs and benefits. Costs and benefits at each point in time are discounted appropriately so that they can be compared. The result of this procedure, for an individual policy (or project), is a single number called the net present value (NPV). The net present value of a policy indicates whether benefits are greater than costs for that policy. It may be compared to the net present value of other policies to determine which policy is the best or most efficient.

Most economists agree that there are two important aspects to choosing the appropriate rate of discount for policies with intergenerational implications, namely; efficiency and equity. However, there is much disagreement about the correct interpretation of discounting and the effect of discounting on intergenerational equity. IPCC (1996c) and Lind et. al (1998) discuss two general approaches to discounting: prescriptive versus descriptive. These two approaches differ in their philosophical approach – using two different questions as their points of departure. The prescriptive approach begins with the question: "How should impacts on future generations that are generated by our current actions be valued?" Thus, the point of departure for the prescriptive approach is an ethical premise. On the other hand, the descriptive approach starts with an empirical question. It asks what tradeoffs across generations and over time do people actually make. In addition, the descriptive approach deals with the question of "crowding out", where more profitable policies, in the net present value sense, may be displaced by policies with lower returns, if lower rates of discount are used to evaluate and possibly accept policies. Alternatively some economists, such as Lind & Schuler (1998) feel that there is no discount rate (zero or otherwise) that is appropriate for evaluating these policies that lead to welfare transfers across different generations.

Prescriptive approaches usually generate lower discount rates than descriptive approaches. To understand the difference in these approaches it is useful to examine the following expression.

$$d = \rho + \theta g$$

Both approaches are interested in $d$, which is the sum of the two right side terms. In the prescriptive approach $d$ is often called the social rate of time preference. The term $\rho$ is know as the pure rate of time preferences, and reflects how society discounts the welfare of future generations, or the difference in weight placed on the next generation as compared to the current generation. This is the equity component of the discount rate. The term $\theta$ is the elasticity of marginal utility, which measures how much welfare changes in percentage terms when aggregate consumption changes by 1 percent. The term $g$ is the percentage growth rate of the economy in consumption terms. Hence the complete last term measures how much subsequent generations are better off than current generations – it is the growth rate of welfare along the optimal growth path of the economy. The expression may be derived from a basic optimal growth model of the economy. The objective in such a model is to maximize the sum of weighted or discounted welfare where society is faced with a choice of consuming or saving. Saving adds to the capital stock passed on to future generations.

Most economists agree that this is a useful framework from which to begin discussions about the appropriate discount rate. However, there is disagreement about what values on the right side of the above equation should be used in evaluating these benefits. In particular they disagree on what the value of $\rho$ should be. Those advocating a prescriptive approach suggest that the value of $\rho$ should be zero based on ethical grounds. A zero social rate of time preference reflects an equal weight placed on each generation. For example, Cline (1998) makes this argument because $\rho$ reflects the rate of discount of welfare on future generations. In his view, there is no justifiable reason for choosing a $\rho$ different from zero. From the prescriptive point of view, all that remains then is to decide the last term. However, this is an empirical question because it requires a forecast of growth in welfare. Since growth rates are, in part determined by rates of technological change this must be estimated at least implicitly. Long run rates of growth are usually estimated to be between 0.5-3% depending on the rates of technological progress. Hence, since the prescriptive approach sets $\rho$ equal to zero, the social rate of discount calculated by the prescriptive approach is also between 0.5 and 3%. Note that if estimates suggested that welfare was to decrease over time then $g$ would be negative, which would then justify a negative discount rate. However, there are few who predict this.

There are two major criticisms of the descriptive approach (IPCC, 1996c). First, opportunity costs of capital are often greater than the social rate of time preference calculated by the prescriptive approach. Hence, if one was to decide to make an investment in climate change or forest management that yields a return of 2% (which exceeds the social rate of time preference derived above) but is below the market rate of 5% then the capital diverted or displaced to the lower yielding investment means less is available to invest in the higher yielding investments at 5%. This means that less capital may be passed on to future generations. This extra capital could presumably be used to offset losses due to climate change or lower volumes of forest stocks. The counter argument is that there can be no guarantee that these investments will be available to future generations to compensate them for these losses. That is the capital may be consumed by intervening or intermediate generations. The second major criticism is that society does not behave consistently with the assumption of $\rho$ equal to zero. The fact that market rates of return on capital are greater than the social rate of time preference (SRTP) is one such inconsistency. Others include low savings rates, and low levels of spending on education which represent investments in physical and human capital. One counter-argument to this is that just because the government or society fails to allocate resources on ethical grounds in one area of possible investment does not mean that it should not in another area (Cline, 1998).

Descriptive approaches suggest that the discount rate used for evaluating long term policies/investments should be based on society's actual behaviour. Those advocating this approach believe there is no justifiable reason for using welfare criterion that is different from what actual decision makers use (this includes all conceivable economic agents). To sum up the descriptive approach we make the following two points:

- Investments/policies in forest management, adaptation and/or mitigation measures for climate change that lie below the market rate of interest divert capital from investments/policies yielding higher returns. This diversion of capital to lower yielding investments/policies may make current and future generations worse off, not better off.

- If investments/policies (or lack of investment/policies) makes current generations better off at the expense of future generations, it is possible, with the correct transfers on a higher yielding investment/policy, to make appropriate transfers that would make all generations at least as well off. However, if the objective is really to make purposeful transfers that will make future generations better off at the expense of current generations then these transfers should be considered independently.

The prescriptive approach argues in return that there may not be efficient ways of transferring capital to future generations. Hence, if a policy is efficient (benefits are greater than costs) but makes current generations better off at the expense of possibly far removed future generations then the policy may not be more efficient than business as usual. Normally, if benefits are greater than costs we could invoke the compensation principle. However, if there is no way of making the transfer or guaranteeing that capital is passed on to future generations then using the market rate of return on capital is no longer valid (Lind & Schuler, 1998).

There are several problems in transferring capital over long time horizons or between widely separated generations. Transfer of capital might be accomplished by setting up a trust fund. This fund would compensate future generations with more capital, which they could then either reinvest or consume. However, setting up such a fund is difficult if not impossible. Lind & Schuler (1998) outline several specific problems in setting up such a fund:

- To implement the compensation principle there is a need to set aside dedicated resources for this purpose. These resources presumably would be invested and reinvested at the market rate of return until the time when compensation would be paid.

- Identification of individuals harmed by current actions or choices would be difficult because climate change is likely to benefit some and harm others.

- A trust fund set up would require the cooperation of intermediate generations and there is no way of guaranteeing this cooperation because circumstances and incentives will change over time. Indeed intervening generations may have every incentive to consume. Another problem is that climate change impacts and the future in general are extremely uncertain. Hence, requiring a commitment may be overly restrictive and may prevent later generations from adapting to new circumstances that can arise for a variety of reasons such as technological change and the acquisition of new information.

Hence, if we try to justify the use of cost benefit analysis and the compensation principle we must have in mind a mechanism for resources to be transferred across generations and indeed over intervening overlapping generations. The problem is that it is impossible to have confidence in such a mechanism because we cannot guarantee the commitment of intervening generations.

Lind & Schuler (1998) also argue that no discount rate based on the market rate of interest, or some kind of modified rate, can tell us how we should allocate resources across generations; or more specifically, how we either collectively or individually <u>should</u> make tradeoffs between the consumption of current generation and some future generation. This is a choice variable, not one that can be inferred from behaviour within the existing institutional structures, including markets. This is an argument for not using discount rates to evaluate climate change policies with long term implications or transfers between generations. If intergenerational equity is a goal then there is no reason to think that benefits and costs that accrue to future generations should be discounted in the same way that individuals discount benefits and costs of policies/investments that occur within their own lifetime. This is purely an intergenerational distributional question. It is the same type of question that arises when we determine if we want to make an income transfer to a community in northern Canada for the purpose of development, education, or for some other reason. This is purely a distributional choice and cost benefit analysis cannot help us make this determination.

The preceding discussion points to a number of recommendations and considerations for choice of discount rates for assessing climate change impacts. They are summarized and listed as follows:

- Equity and distributional considerations are just as important if not more important than efficiency concerns in evaluating climate change programs.

- These equity and distributional considerations cut across two dimensions – intra and intergenerational equity.

- Policy evaluations using cost-benefit analysis or other modeling approaches should be made at more than one discount rate. This will provide information to policy makers about how discount rates affect optimal policies.

- The time path of important climate change variables such as the size of the forest sector, production levels, consumption levels, forest growing stocks and sinks, should be presented as part of the analysis. We agree with Lind and Schuler (1998) on this point.

- No cost/benefit procedure or optimization model that uses any discount rate can tell us how to allocate resources across generations and across the country.

### *3.2 Uncertainty*

The long-term nature of climate change is related to the inter-generational difficulties outlined above, and is also part of the reason why uncertainty is so prevalent. Uncertainty, according to Arrow (1971) is an incomplete knowledge of the world. Without complete knowledge, the nature of climate change impacts, and the precise consequences of human actions to climate change are unknown. Examples of climate change uncertainties are discussed in section 2, and occur in the stocks, flows and systems illustrated in figure 1[4]. These uncertainties must be considered when decisions which affect climate change, including policy choices, are made.

*Sources of uncertainty*

Throughout this paper examples and sources of uncertainty related to climate change are discussed. The IPCC (1996c) divides the impact uncertainties of climate change into three main areas: scientific uncertainties (i.e. dynamic feedbacks), socioecologic uncertainties (i.e. climate change impacts on the relationship between humans and forests), and socioeconomic uncertainties (i.e. economic and social welfare effects of climatic change and associated adaptation and mitigation strategies and policies).

One of the main problems with the uncertainty of climate change, is the corresponding uncertainty of the impacts of climate change. If these impacts occur gradually and continuously, then human and ecological systems are more likely to adapt to these changes smoothly, easily and at relatively low costs. However, the more extreme and sudden the impacts are, the more likely that high cost, catastrophic and irreversible

[4] Subsection 5.2 provides a complementary discussion of uncertainty within cost-benefit/decision analysis/multi-criteria analysis.

damage will occur. Therefore, the probability associated with the likelihood of these extremes occurring is vital to decision making and policy choice.

The long time horizons of climate change further complicate analysis of related uncertainty. The complications arise, in part, because technological innovation and adoption are difficult, if not impossible, to accurately predict centuries or even decades into the future. Conversely, this long time horizon can be viewed as an opportunity for innovation to occur. Another aspect of the long time horizon is the impacts of climate change on future generations, and the likely changes in the preferences of these future generations. In the case of intergenerational equity issues then become relevant, and are discussed in the previous subsection.

*Dealing with uncertainty*

In decision analysis, the uncertainty of outcomes from alternative choices of actions are assigned probabilities, in an attempt to explicitly consider uncertainty. After these estimated outcome probabilities have been established they can be applied to alternative action possibilities, expected values can be calculated, and used to identify and select the preferred action. The choice of these probabilities can be based on either objective scientific knowledge, or on subjective personal judgment (IPCC, 1996c). However, in the case of climate change there is no objective historical or current data (either actual or experimental) which can be used to make objective estimates of the associated uncertainty. Subjective data is also limited, as there is a wide range of divergent opinions about climate change, held by various interest groups.

The uncertainty associated with climate change can therefore be described as "a case of choice under pure uncertainty" (Woodward & Bishop, 1997, pp. 492). Pure uncertainty occurs when there is a well-defined state space of outcomes, but the decision maker is unable to assign probabilities to the different outcomes (Woodward & Bishop, 1997)[5]. One such example is found in Nordhaus (1994b), where the widely diverse opinions of different scientific and economic experts of climate change, very aptly indicate that a consensus of opinion on likely climate change impacts would be impossible to reach. Therefore, the applicability of probabilistic analysis and, by association, expected values in climate change decision making may be limited. The Principle of Insufficient Reason, whereby each expert would be assigned the same probability may also be limited. This is because there is no objective way of assigning probabilities to the differing opinions (Woodward & Bishop, 1997).

Nevertheless decisions concerning climate change need to be made, and therefore an appropriate way to include uncertainty is required. One possible approach for including uncertainty is provided by Woodward & Bishop (1997) in their pure uncertainty application to climate change decision making. Their approach uses the axioms from the Arrow-Hurwicz (1972) framework. When a policy maker or manager's decision making process is consistent with these axioms it is Arrow-Hurwicz rational. The result of

[5] Whereas, in the case of risk, probabilities can be assigned to different outcomes. Some authors therefore distinguish between risk and uncertainty in this way.

applying these axioms to decision making under uncertainty is that the choice of criteria is limited to either the maximin and maximax criteria.

**Figure 3.** Illustration of the Maximin Criteria.

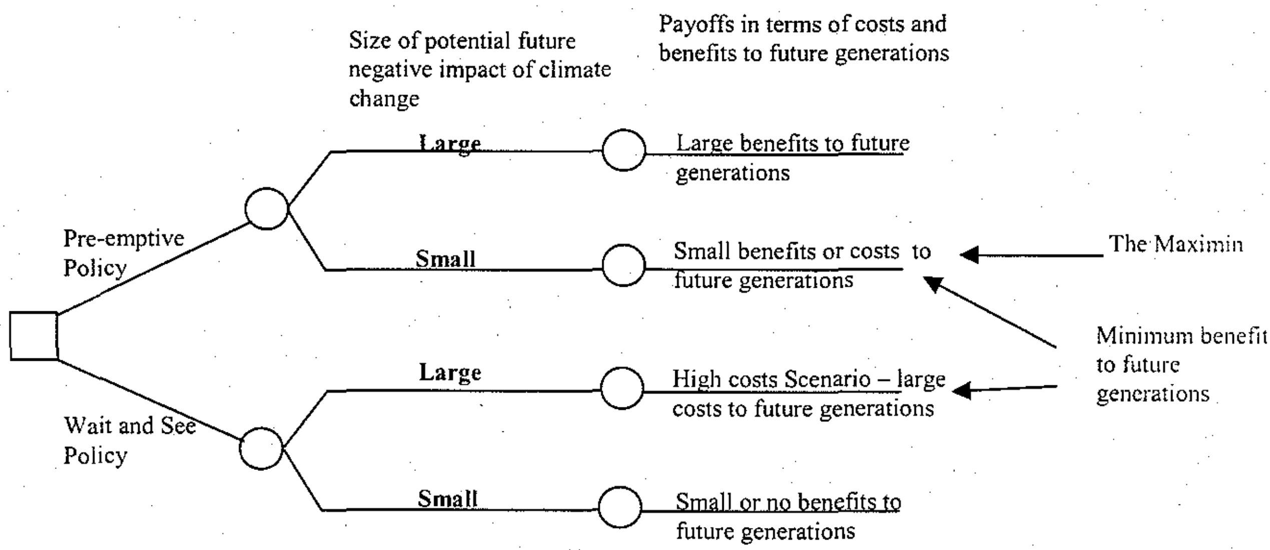



Figure 3 illustrates the choice of the maximin criteria. In this figure current generations may choose between climate change pre-emptive policies or wait and see policies. The payoffs of these policies to future generations depend on the size of the uncertain climate change outcome. If impacts are large, payoffs to the pre-emptive policy to future generations are large. However, if impacts are small then the pre-emptive policy will yield small or possibly negative benefits to future generations. On the other hand, if the impacts are large and a wait and see approach is followed costs to future generations will be very large and if impacts are small costs or benefits will be negligible. The maximin criteria identifies the worst possible outcome for each policy choice and then chooses the policy that gives the maximum of the worst possible outcomes. This is the pre-emptive policy in this case. (Note, this is an example only and is meant for illustrative purposes)

With the addition of the axiom of uncertainty aversion (which is related to extreme risk aversion) the maximin criteria (where maximisation of the minimum occurs) is preferred. Woodward & Bishop (1997) apply this theoretical finding to a climate change example and find that a rational, risk averse policy maker should indeed maximize the minimum payoff (the maximin criterion). In their case study, this suggests that an aggressive abatement policy should be implemented, with the option of switching to a more moderate policy, if future knowledge indicates that this is appropriate.

Choice criteria under pure uncertainty are related to the safe minimum standard (SMS)[6] and the precautionary principle (Woodward & Bishop, 1997). Woodward & Bishops's (1997) maximin criterion findings under pure uncertainty, rationalize the SMS and the precautionary principle as rational choices under great uncertainty. The SMS and the precautionary principle are therefore two adaptation policy approaches that could be considered and implemented, as responses and tools to reduce the uncertainty associated with climate change.

Woodward & Bishop (1997) findings also support Schelling's (1992) suggestion that research should focus on the extreme possibilities of climate change. Further, Woodward & Bishop (1997) argue that the use of the midpoint of the outcome space or the central-case scenario should not be presumed to approximate the mean, particularly given the uncertainty and potential adverse effects of climate change. Even if extreme events and impacts are thought to be highly improbable, there is an element of surprise with uncertainty, when such extremes could become reality. Therefore, it may be appropriate for society to adapt and prepare for, as well as to mitigate against, such extreme events, to reduce their vulnerability. Even if an extreme event is highly improbable, the chance of a surprise could be unacceptably high (IPCC, 1996c).[7]

Uncertainty allows for increased strategic behaviour by stakeholders affected by climate change, particularly as the issue is both dynamic and long-term. Strategic behaviour is discussed in subsection 2.4. One approach to reducing the problems associated with it is a sequential decision process, where the dynamic nature of collective decision making is acknowledged and incorporated (IPCC, 1996c). The application of sequential decision making under uncertainty to the climate change issue is likely to reach a similar conclusion to the application of pure uncertainty by Woodward & Bishop (1997). Namely, short-term strategies are chosen, then the outcomes of these decisions are evaluated, and incorporated into future decisions, and so on. This strategy is known as the "act-learn-act" approach. The decision to act, then learn, then act, is intuitive, given the lack of perfect knowledge to support long-term decision making and the potentially high cost of delay, when mitigation and adaptation strategies to reduce vulnerability are not initiated. Especially given some of the issues discussed in subsection 5.2, which include stock characteristics and irreversibility. A decision tree with decision points, choices and possible outcomes is used for sequential decision process analysis. However, this approach may lead to a less aggressive choice of climate change policies than the pure uncertainty approach (IPCC, 1996c).

The issue of imperfect knowledge is very much related to the value of information. In sequential decision making, new and more accurate information can increase the appropriateness of decisions and actions with respect to possible impacts and outcomes. The value of information can be estimated, using expected values of decision options.

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[6] The SMS suggests that critical resource levels, below which degradation of the resource is economically irreversible, should be avoided by policy makers, unless costs of achieving this are immoderate.
[7] Gjerde, Grepperud & Kverndokk (1998) provide a discussion and application of the possibility of a catastrophe resulting from climate change, and how this affects the optimal climate change policy.

Information is valued as the difference between the expected value, when the state of the world is known before the policy is implemented - so that there is a potential to apply a different policy for every possible state of the world; and the expected value when a single policy is adopted without knowledge of the state of the world (Peck & Teisberg, 1997).

Another means of including uncertainty within economic climate change models, is the Monte Carlo technique. The Monte Carlo technique is used in simulation models. Uncertainty or risk are represented for certain variables in the model by a series of random draws from probability distributions, which may or may bot be conditional distributions based on policy choices or external factors. Schimmelpfennig (1996) argues that the Monte Carlo technique more adequately represents uncertainty than decision analysis techniques, which tends to use only a few possible values from the full range of outcomes of the variable whose uncertainty is being modelled.

Other strategies for dealing with uncertainty and risk in a climate change context include insurance options. There are a number of different insurance approaches which could be implemented, including mutual insurance contracts (where parties with similar risk levels agree that those who suffer losses will be compensated by those who do not); and risk securities (where each different possible outcome is assigned a "risk security" which is only paid out if that particular outcome occurs, these risk securities would be tradable to be efficient) (IPCC, 1996c). However, insurance approaches are particularly difficult to implement in the climate change context. This is partly due to the long-term nature of the issue – whereby insurance may theoretically need to be provided across generations, which is likely to be impossible (see the discussion in the previous subsection). Further, the high degree of uncertainty associated with climate change is likely to severely hinder the quantification of risk securities and risk levels.

One further problem with climate change policy decisions is that decision makers have relatively short tenures which create friction with the long-term nature and policy requirements of climate change. Further, the uncertainty of climate change can be used to provide a justification for short-term inaction, which could be costly in the long-term, but politically and economically desirable in the short-term. Instead, decision makers should explicitly consider decision uncertainties and the long-term implications of short-term inaction (IPCC, 1996c). A portfolio of climate actions would then be likely, which would include the implementation of both mitigation and adaptation measures (as discussed in subsection 2.3), as well as the need for future research.

### 3.3 *Competitiveness*

An area of concern to policy makers is the potential impact of climate change and mitigation on industrial output from particular strategic sectors. Changes in industrial output and in the mix of goods and services produced by an economy are generally the result of a change in the competitive circumstances of particular industries. Changes in competitive circumstances may be attributable to market forces, changes in regulation and policy, and other factors.

The main reason that policy makers are interested in monitoring changes in competitive circumstances is to develop an appreciation of the impact of policy on industrial output. Declining competitiveness and lower rates of economic growth can have undesirable social impacts including possible under employment of factors of production (including labour), social conflict and political instability. It is important to note, however, that the impacts of climate change on industrial competitiveness may be positive or negative. Also, even if competitiveness impacts are negative, consumer benefits might be positive. Therefore, competitiveness analysis provides only a partial picture of the socioeconomic implications of climate change. Moreover, in small open economies such as Canada's, the competitiveness of particular industries is constantly changing in response to global market forces. Interventions to reverse the decline in competitiveness of a particular industry would not only be operationally impractical but may result in inefficient use of societies resources. Thus, changing competitiveness in a particular industry is not in and of itself meaningful, however, changing competitiveness in a particular industry, attributable to a policy intervention or to a particular market failure is meaningful, especially if there is specificity in terms of the affected industries.

The impacts of climate change on the competitiveness of the forest industry are a function of many factors including:

- the magnitude of climate change impacts on the availability and price over time of key inputs used by the forest industry,
- the types of mitigation policies that are adopted,
- the technologies available to the industry and the options these technologies provide relative to adapting to climate change and mitigation by input substitution (e.g. if the relative price of energy or timber increase over time then firms will strive to substitute relatively lower priced inputs such as capital, labour and bio-energy for higher priced inputs), and
- the degree of exposure to changes in the structure of global markets resulting from climate change.

Structural analysis of the effect of climate change on competitive factors, combined with assessment of the capacity of industries to respond, will help to provide an understanding of the impacts and the adaptive responses to climate change and climate change policy. Thus, competitiveness analysis provides a useful and possibly necessary complement to the development of large economy-climate modelling exercises because if the models are improperly specified they will provide inaccurate representations of industry responses. Also, competitiveness analysis can provide supporting information for accurate interpretation and analysis of model results.

Competitiveness is a vague term with many definitions. Its origins are in the administrative and business sciences (Jacques, 1995; Coffin et. al, 1993). Changes in competitiveness may occur as a result of a number of factors including:

- changes in product demand factors (e.g. price);
- changes in the availability and price of inputs (e.g. land, labour, capital and energy);
- changes in institutional factors (e.g. regulatory burden and taxes);

- technological changes, and
- market factors (e.g. market structure, consumer control, supplier control and strategies of rival).

The measurement and analysis of competitiveness occurs at three levels: firms, industries or sectors, and countries. However, interpretations and the measures used to evaluate competitiveness at these levels vary. At the industry or sector level (the level of greatest relevance for this report) competitiveness is a measure of "the ability of a group of like firms to compete with another group of firms in another sector or with the same sector in another country." (Coffin et. al, 1993, pp. 460). Examples of direct measures or indicators of industry or sector level competitiveness include market share and competitiveness indices (composite indices comprised of a number of determinants of competitiveness). Market share is generally viewed as a proxy indicator of future profit earning potential. In situations where market share and profitability are not correlated, then market share may provide a misleading indicator of competitiveness. Measures such as total factor productivity, factor share analysis, and cost of production are determinants of competitiveness and as such provide indirect indicators or measures of competitiveness (Coffin et. al, 1993). Finally, competitiveness is a dynamic and a forward-looking concept. It is not the absolute value of any particular measure that is relevant for assessing competitiveness, but instead, relative changes in measures over time. Therefore, if market share is declining over a period of 20 years in a particular industry, it is a sign that the competitiveness of the industry is declining and that in the future, the profitability of the industry may decline (if it is not declining already).

A related idea to competitiveness is the concept of comparative advantage. The theory of comparative advantage was introduced by David Ricardo (1817) as an improvement on the theory of absolute advantage developed by Adam Smith (1776) (Jacques, 1995). Its purpose is to explain gains from trade and trade flows. The theory of comparative advantage says that a country will not necessarily produce all products where it has an absolute cost or efficiency advantage. Total output is increased when countries specialise in producing and trading those products where their efficiency is higher, while allowing other countries to produce and trade products where their efficiency is relatively lower (even though costs of production are lower in the country in question). The country can then export those products it produces and import products that it requires. The net result of specialization and trade is a higher level of aggregate income for the international economy. The theory of comparative advantage describes the motivations, incentives and directions for trade in international markets[8].

[8] This is a very cursory and incomplete description of the theory of comparative advantage. The reader should refer to other economics textbooks on international economics and the gains from trade for a more complete discussion of the theory of comparative advantage.

The theory of comparative advantage was extended by the development of the Hecksher-Ohlin-Vanek Theorem (HOV) which Prestemon and Buongiorno (1997)[9] describe as follows:

> "According to the classical Heckscher-Ohlin-Vanek theorem of international trade, the comparative advantage of a region can be traced to its level of endowments of immobile factor inputs, other things being equal. For example, if the determinants of competitiveness in the economies of two regions are equal in every respect except endowment of land, the region with the greater land endowment should be more competitive in exporting products that use land intensively in production...It predicts that a region's net exports of a given good are a positive function of its resource endowment and a negative function of its income."

Thus, the relative endowment of a particular natural resource in a country is an important determinant of the comparative advantage of industries that rely on the resource. This concept can be quantified using a revealed comparative advantage index. This index has been applied by Jacques (1995), Bonnefoi & Buongiorno (1990), and Prestemon & Buongiorno (1997) to evaluate trends in the comparative advantage of regions in forest trade.

*The effects of forest ecosystem change*

Climate change will affect the distribution of ecosystem types and productivity within these ecosystems types (see subsection 2.1). As noted above, changes in the relative endowment of forest resources in a country can be expected to have an impact on the comparative advantage of that country in the production and export of forest products (all other factors equal). Some industries where forest resources are an important input include forest products industries, the tourism industry, the trapping industry, outfitters, and recreation and vacation camps and lodges. However, since the forest industry is larger than these other industries, it is export based, and the link between resource endowment and production is tangible the remainder of this discussion focuses on timber supply.

A global shift in the distribution and productivity of ecosystems has significant implications for the level and distribution of global timber supply. However, the future level and distribution of timber supply also depends on land use and management choices (i.e. future timber supply will be a function of both environmental factors and economic and political decisions). Changes in comparative advantage can be expected to occur where there are relative shifts in resource endowments (i.e. Country A's timber supply goes up (or down) relatively more than country B's timber supply).

[9] These authors note that there are a range of limiting assumptions embedded in the HOV model which have led to the development of alternative models for describing trade flows. However, according to Prestemon & Buongiorno (1997) the HOV model does seem to have explanatory power in explaining trade in forest products.

Thus, in summary, economic theory suggests that the comparative advantage of a nation in forest products trade is a function of relative resource endowment. Climate change will lead to environmental changes and changes in economic choices that will translate into global shifts in the level and distribution of forest resources. These shifts will cause changes in the distribution of production and in patterns of trade. Evaluating the future impact of climate change on export capacity requires a) an understanding of the impact of climate change on Canada's long term timber supply, and b) an understanding of changes in Canadian timber supply relative to supply responses in other countries. Valuable supporting information would include a) measures of the relative factor intensity of various forest products in Canada and in other countries, and b) measures of the elasticity of substitution of raw materials for other factor inputs.

*The competitive effects of mitigation*

As noted above, one reason for undertaking competitiveness analysis is to evaluate the impacts of policy and regulation on industrial competitiveness. An important criteria in policy evaluation is measuring the extent to which a domestic policy imposes a competitive disadvantage on the domestic industry compared to foreign producers. It is also important to have an understanding of the distributional impacts of policy. Policies that disproportionally affect the competitiveness of particular industries may also have disproportional regional impacts.

The Forest Sector Table (1998) notes the following:

> "Pursuant to the Kyoto Protocol, Canada undertook to reduce its greenhouse gas (ghg) emissions by six percent with respect to the 1990 level of 599 megatonnes (Mt) C02 equivalent by 2008 - 12. Analysis by NRCan suggests that Canada's net annual ghg emissions will have to be reduced by 20 to 25 percent, or about 140-185 megatonnes (Mt) CO2-equivalent, compared to the level expected to occur in 2010 under a business as usual (BAU) scenario. This is recognized as a very difficult challenge".

There are basically six types of policy options for achieving the Kyoto targets including: a carbon or GHG tax, tradeable permits, emission caps, regulation, sinks/offsets and joint implementation/clean development mechanisms (subsection 4.6). The implications for the competitiveness of the Canadian forest industry will vary depending on:

- the option or mix of options is used and the net costs (or benefits) on particular segments of the forest industry[10] (the exposure of particular segments to mitigation policies may depend on the relative energy intensity of particular forest industries),

10 Some types of mitigation policies could make positive contributions to forest industry competitiveness. For example, afforestation sink programs could result in lower timber costs in the future. Higher prices for fossil fuels along with regulatory changes could increase opportunities for forest companies to produce and sell electrical energy (produced from organic materials) to electrical utilities.

- the extent to which competitor firms in other countries will face similar costs (or benefit) impacts, and
- the ability of industry to substitute other inputs (such as bio-energy, capital, labour, and raw materials) for the expected higher priced, fossil fuel based energy supplies. Evaluation of the short-term competitive impact of mitigation policies on the forest industry requires additional research on these key questions.

Measurement of the effects of mitigation policy on forest sector output would require the development of a general equilibrium model that captures the linkages between the energy sector, the forest sector, and other sectors. The GE model would need to be designed to capture the effects of energy price increases on the forest sector and other sectors. Moreover, the model would be required to have the capacity to evaluate the potential implications of various carbon/GHG trading system options. These modeling efforts would be complementary to more detailed structural analysis of the adaptive capacity of various industries (i.e. factor intensities, substitutions elasticities).

*Effects of global market responses to climate change on Canadian competitiveness.*

Canada is the world's leading forest products exporting nation accounting for about 20% of global trade, with a total value of exports of about $32 billion in 1994 (Canadian Forest Service, 1996). Thus, changes in supply, demand and global forest products prices attributable to climate change would impact the competitiveness of suppliers - particularly high cost marginal producers. However, the interrelationships are complex and the economic impacts are dependent on elasticities of supply and demand.

Perez-Garcia, Joyce, Binkley and McQuire (1997) link various climate change response scenarios (based on a double CO2 concentration) to a process-based biogeochemical model and a global trade model, to simulate the impacts of climate change on the global forest products market. Their findings suggest that climate change will increase the productivity of the global forest resulting in significant welfare gains by producers and some welfare losses to timber owners. Their findings for the U.S. indicate that "large gains to U.S. consumers and a smaller gain to U.S. mill owners more than offset the losses to timber owners[11]."

Van Kooten and Arthur (1989) used a much simpler analytical framework to estimate the welfare effects of climate change on Canada's boreal forest. Their approach was based on estimation of linear supply and demand curves in the U.S. and Canada. They concluded that welfare losses to Canadian producers exceed welfare gains to Canadian consumers and that market responses to climate change lead to a net welfare loss to Canada. This analysis is old and overly simplified and therefore the specific findings have limited applicability in the context of current policy needs. However, the approach illustrates a) that climate change impacts are transmitted through international markets and they should be taken into account, and b) the significance of market structure and supply and demand elasticity in evaluating domestic climate change impacts transmitted through global markets.

[11] US timber owners incur a net loss because the decreases in price outweigh output effects.

### 3.4 *Social & Cultural Considerations*

The majority of this report focuses on the economic dimensions of climate change impacts and adaptation. Economic analysis has much to offer in evaluating climate change impacts and assessing adaptation, however, such analysis cannot be relied on exclusively. Issues pertaining to socioeconomic impacts and adaptive responses to climate change are broad, complex and subject to high levels of uncertainty. Therefore, it is important to also examine social and cultural considerations.

*Social dimensions*

Castle (1996) argues that economists need to recognise the requirement for a pluralistic approach to evaluate "complex social problems" which are subject to uncertainty. Pluralism "refers to the use of multiple viewpoints or intellectual approaches". An important consideration in evaluating climate change impacts will be to understand the social impacts of climate change on Canadian society. Social impact analysis falls into the discipline of sociology. There are equity oriented, pragmatic and technical reasons for broadening the scope of social science analysis relative to climate change. First, as noted in subsection 3.1, there are ethical/inequity tolerance questions pertaining to the distribution of costs of mitigation and adaptation that need to be considered when developing policy responses. In some cases these costs are not financial or monetary but pertain to cultural integrity, social cohesion, and community stability. Also, for any number of reasons the capacity of some groups within society to adapt to climate change may be lower than other groups and therefore the burden may be asymmetrically distributed due to existing socioeconomic circumstances. Social impact assessment can contribute to a better understanding of the nature and distribution of these costs and burdens.

A pragmatic reason for requiring sociological analysis is that for policy to be effective it will need to be generally acceptable to society (IPCC, 1996c). Therefore, in addition to considering the technical dimensions of climate change from biological and economic viewpoints, the public policy process will also need to account for public perceptions regarding climate change and acceptable policy responses. Moreover, it will need to ensure that social institutions are designed to ensure that there is public satisfaction with policies and that the public is involved in the decision making process relative to climate change policy. Also, new approaches may be required to resolve social conflicts which are precipitated by climate change or to anticipate the possible occurrence of conflict and take preventative steps. There are "attachment to place" issues that sociologists can provide some insight on. Sociological research can also contribute to developing an improved understanding of public perceptions and the development of social institutions for involving the public in the decision making process and for resolving conflict.

A third reason for broadening the scope of social science analysis relative to climate change is technical in nature. Economics as a consequentialist[12] doctrinaire has certain

[12] "The worth of an action is judged in terms of its consequences." (Castle, 1996)

limitations relative to accounting for the views of some about the value of natures attributes (Castle, 1996). That is to say, economics is particularly anthropocentric relative to the value and worth of natural resources[13]. There are a number of people in society, who are of the belief that natures attributes have "intrinsic merit" (Castle, 1996). Natures attributes are important for what they are and not in terms of the value they contribute to humans. This points to differences in beliefs and values systems within society. Failure to account for differences in beliefs and value systems relative to changes in natures attributes resulting from climate change has the potential to lead to social conflict and policy failure. Economics has other limitations that need to be recognized. Economic models of human behaviour generally assume some level of consistent and rational behaviour on the part of individual consumers and producers (i.e. Sohngen & Mendelsohn, 1999) and that consumers and producers are fully informed about the consequences of their choices. However, in reality, these decision makers may not always be rational and given the high levels of uncertainty that surround climate change they are probably not well informed about the consequences of their decisions. Finally, the objective functions in most economic models of climate change impacts are based on measures of welfare impacts[14]. There has been a history of discussion in the economics literature of the relevancy of adding individual utility to determine aggregate social preferences. The IPCC (1996c) report notes the following:

> "Arrow (1951) addressed the fundamental question of whether individual preferences can be aggregated in a reasonable way into overall societal preferences. He concluded that, in general, it is impossible to add individual preferences together to produce a social welfare function if we require the resulting aggregation to satisfy some very natural and reasonable conditions, such as preventing individuals from holding dictatorial powers. ......However, if it is known that these preferences are restricted to certain types, then it may still be possible to combine them in a consistent and reasonable way to form a social ordering (see Sen, 1984)."

The intent of the previous discussion is not to downplay the applicability of economics in assessing climate change impacts and adaptation but to emphasize the need for complementary analysis in other social sciences. The remainder of this section discusses various dimensions of social and cultural aspects of climate change impact and adaptation from a forest sector perspective.

*Social impacts*

Climate change has the potential to affect social interaction and the quality of life in various ways. First, changes in precipitation and temperature regimes can affect human behaviour. For example, changes in average temperature, cloudiness, amount of

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[13] The worth or value of a natural resource is a consequence of the value that individuals obtain from either using or experiencing the resource (use values) or from having the knowledge that the resource is being maintained in some form that they value (passive use values).

[14] The objective function for Nordhaus (1994a) is maximization of the "discounted sum of the utilities of consumption...summed over the relevant time horizon". Sohngen & Mendelsohn (1999) adopt an objective function of maximized present value of net consumer and producer surplus.

snowfall, season length, severity of seasons, and higher incidence of extreme weather events can cause higher levels of stress and other social pathologies (Farhar-Pilgram, 1985). Second, changes in climate has implications for human health (e.g. heat stress, disease, higher incidence of pollen related illnesses. Third, climate change will lead to ecosystem change and changes in ecosystem productivity that in turn may require economic restructuring and adaptation. Rapid restructuring of economic systems can lead to social stress and/or social dysfunction (especially for human settlements that are relatively immobile and/or where there is a strong sense of attachment to place). Fourth, ecosystem changes can reduce opportunities for undertaking traditional activities (e.g. hunting, fishing and gathering). Fifth, the establishment of policies to mitigate climate change is likely to result in higher costs to individuals (e.g. higher energy costs and possibly higher food costs[15]). The elasticity of demand for energy and food is inelastic (when considered as aggregate commodity groups) which means these goods have relatively few substitutes. Thus, increased cost of energy and food may cause greater declines in purchasing power for some members of society than others. For example, rural incomes tend to be lower than urban incomes, however, rural residents may face relatively higher costs due to mitigation policy. Declines in purchasing power can have social impacts and these impacts may be more pronounced in human settlements dominated by resource industries (agriculture, forestry, mining communities). These influences may be aggravated by climate change impacts.

The types of social impacts that are possible from climate change or mitigation policy include increased poverty, family breakdown, income instability, declines in purchasing power, social conflict, loss of leisure and cultural opportunities, and changes in "sense of place" (Farhar-Pilgram, 1985). The magnitude of social impacts attributable to climate change and climate change mitigation depends on many factors including a) the magnitude, rate, and continuity/discontinuity of climate changes, b) the types of ecological responses that will occur, c) the relative sensitivity or exposure of particular social communities to climate change, climate change impacts, and mitigation policy, d) the economic circumstances of affected social groups and e) the ability or capacity of these groups to adapt or respond. Human communities at risk from a forest sector perspective include a) Aboriginal settlements, b) residents of economically undiversified rural communities reliant on forests for their economic livelihood, and c) social groups where forest access contributes to their "sense of place". (Farhar-Pilgram, 1985).

The ability of communities or social groups to respond and adapt to climate change will depend on their institutional capacity. Adaptive capacity will be enhanced if a) affected parties are satisfied with their level of involvement in decision making, and b) if they are well informed relative to what to expect and what their options are. Some social groups face significant barriers relative to their ability to respond. These barriers come in the form of institutional rigidities that reduce their mobility. For example, Aboriginal peoples living on established reserves may find themselves facing unstable ecosystems

[15] Note that if climate change increases agricultural productivity, there will be downward pressure on food prices. This may not apply in all agricultural communities given that some landowners may respond to higher energy and food costs by increasing production for home consumption. Alternatively, higher energy costs mean higher transportation costs which account for a higher proportion of the cost of food in rural locations.

on reserves but will have limited opportunity to relocate or search for alternative opportunities. Thus, the existence of institutional rigidities can reduce adaptive capacity of some forest based social groups. This issue requires further exploration.

Kusel (1995) notes that adaptive capacity is related to physical capital, human capital, and social capital at a community level. He describes these concepts as follows:

> "Community capacity is the collective ability of residents in a community to respond (or communal response) to external and internal stresses; to create and take advantage of opportunities; and to meet the needs of residents, diversely defined. It also refers to the ability of a community to adapt and respond to a variety of different circumstances. Community capacity depends on three broad areas: 1) *physical capital* - which includes physical elements and resources in a community (e.g. sewer systems, open space, business parks, housing stock, schools), including financial capital; 2) *human capital* - which includes the skills, education, experiences and general abilities of residents, and 3) *social capital* - which includes the ability and willingness of residents to work together for community goals...social capital appears to be one of the most important determinants."

### *3.5 Summary*

This section has provided descriptions of important socio-economic tools and considerations that are relevant to the study of climate change. Approaches to analyse and respond to inter and intra-generational equity, and associated discounting issues, decision making under pure uncertainty and risk, and changes in Canadian competitiveness are given. Many of the economic approaches discussed can, and should, be applied to the study of climate change and Canadian forestry. Possible negative social impacts are also examined, and the key social issues and problems that could arise with climate change are identified. The following section describes some important forest sector specific considerations relevant to the application of the principles and concepts described in this section. Many of the approaches outlined above could be applied to these case studies. Linkages back to this section provide some indication of where these approaches are of particular relevance.

## 4. Forest Sector Considerations in Assessing Impacts, Adaptation & Mitigation

The previous two subsections provide a general description of the physical, economic and strategic dimensions of climate change, and an overview of various criteria which can be used to assess the socioeconomic impacts and implications of climate change and climate change policies. However, these discussions are general and do not identify many of the specific considerations and factors which are important for applying the concepts to the special and unique problem of climate change as it relates to forest sector impacts. In order to apply the concepts it is necessary to identify a) what forest values are affected by climate change, b) how climate change impacts these values over time, and c) what effects adaptive responses by forestry firms, consumers, forest landowners and governments have on the flow of forest values over time. Moreover, impacts and adaptive responses in the forest sector will be conditioned by the nature of interactions with other sectors (primarily agriculture and energy) and by policy changes (e.g. mitigation policies). This section provides an overview of these considerations. The first subsection (4.1) provides an illustrative case study of impacts and adaptations in timber markets in the United States. Although the results of this study can not be extrapolated to Canada (due to differences in institutional structures between Canada and the U.S.) the study does provide an illustration of the linkages between ecosystem change and timber market responses and adaptations. The second subsection (4.2) identifies non-market values that may be impacted, and discusses how climate change may affect these values. Subsections 4.3 and 4.4 consider the interactions of the forest sector with the agriculture sector and the energy sector. Subsection 4.5 considers the role of the forest sector in mitigation, and associated adaptive responses to mitigation policies.

### *4.1 A Case Study of Timber Market Impacts & Adaptations*

The ability to forecast economic impacts and adaptive responses of producers and consumers to climate change requires the development of dynamic models that integrate forecasts of ecological responses to climate anomalies with economic models of timber markets. Furthermore, timber market models could be linked to economic models of the forest products manufacturing sector to evaluate downstream effects. Some of these impacts were discussed in subsection 3.3 pertaining to competitiveness. This case study concentrates on timber markets. Climate change impacts are measured in terms of a comparison of the stream of benefits occurring with climate change minus the stream of benefits expected to occur without climate change (i.e. baseline cases). Although such integrated assessment models have not been developed to forecast climate change impacts in Canada, they have been undertaken at a global level (e.g. see Nordhaus, 1994a; Cline, 1992) and for the United States. This subsection summarizes the approach and results of a recent study that assesses the impacts of climate change on U.S. timber markets and evaluates this study in terms of two questions: 1. To what extent can the results of this study be extrapolated to Canada?, and 2. What can be learned from this study in terms of the development of analytical frameworks in Canada? The particular study considered is: Sohngen & Mendelsohn (1999) The impacts of climate change on the U.S. timber market.

*Summary of Sohngen and Mendelsohn (1999) methodology and results*[16]

The majority of forested land in the U.S. is held by private land-owners (by either large corporations or by a large number of smaller individual forest land owners). Sohngen and Mendelsohn (1999) develop a dynamic partial equilibrium model of the U.S. timber market and link this model to dynamic models that simulate the effects of climate change on ecosystem distribution and productivity. The authors argue that landowners in particular locations will adjust their harvest schedules and replanting decisions in response to expected changes in future prices and yield[17]. These decisions in turn will affect regional timber supply as well as the price path for timber over time[18]. Thus, price and harvest levels are endogenous. Timber supply, management intensity, and land use (i.e. forestry versus agriculture on lands suited to both) are price and risk responsive and it is relative changes in current and expected future prices as well as risk of future loss that will trigger adaptive responses on the part of land owners to climate change. These dynamic adaptive responses to climate change have the effect of "ameliorating" the economic consequences of large scale ecological changes as well as accelerating the natural rate of transition to new timber types.

Sohngen & Mendelsohn (1999) begin their analysis with steady state predictions of climate, ecosystem distribution, and ecosystem biomass accumulation after a doubling of atmospheric C02. They utilize the outputs of various combinations of general circulation models (Oregon State University, Geophysical Fluid Dynamics Laboratory, and United Kingdom Meteorological Office), ecosystem distribution models (MAPPS, BIOME2, and DOLY), and ecosystem production models (Terrestrial Ecosystem Model, BIOME-BGC, and Century) to produce a range of alternate possible ecosystem distributions and productivity scenarios which may occur with a doubling of atmospheric C02. Each of these scenarios simulates the steady state response of forested ecosystems after a 70 year adjustment period at which time C02 concentrations as well as temperature and precipitation are assumed to have stabilized. The ecosystem distribution models show shifts in land area between various forest ecosystem types. For example the DOLY model classifies the U.S. forest into boreal conifer, cool temperate northern softwood, temperate deciduous, warm temperate/subtropical mixed forests (i.e. southern pine), continental temperate conifer forest (i.e. western pine), and maritime temperate conifer forest (i.e. Pacific Northwest conifer). A non-forest category is also included to capture shifts between forest and non-forested lands. The ecosystem productivity models simulate changes in biomass accumulation with climate change within each forest type after the 70 year adjustment period.

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[16] This is a cursory summary of a complex and sophisticated analysis. The reader is encouraged to review the original article to gain a full appreciation of the framework developed by these authors.

[17] The U.S. Federal Government and various state governments also manage significant portions of forest land. The authors argue, however that the supply from these lands is not price responsive and that supply can be expected to remain constant over time.

[18] Prices adjust over time in response to both changes in demand (due to population growth and per-capital income growth) as well as due to change in supply caused by year to year changes in distributions of timber types, productivity, and landowner decisions regarding harvesting, replanting, salvage and other management activities.

Sohngen & Mendelsohn (1999) then simulate transient responses in ecosystem distribution and productivity over the adjustment period. These simulations assume the steady state responses as an end point and then simulate ecosystem change over time as the systems move toward the steady state point. In the absence of process based ecological models that estimate transient responses, the authors employ what they admit is a relatively simple approach to evaluating changes in species distribution and timber yield from period to period during transition. Generally, they assume that the ecosystem shifts from one type to another in any particular period, this occurs in direct proportion to the degree of temperature and precipitation change over the period. Thus, the total shifts predicted by the steady state models are transcribed to periodic changes in ecosystem distribution. The processes of change for these shifting areas can occur by one of two methods. The authors term the first process as "dieback." The total amount of area shifting from one type to another in a particular period is assumed to be killed, due to inability to survive under the new climatic conditions or due to losses from fire, insects, or pathogens. Once the area is killed and salvaged new species replace the old species (either by land owners planting new species suited to the new conditions or by natural processes), or the area remains unforested.

The authors term the second process "limited regeneration." Under this process of dynamic ecological change, the existing species continue to survive under the new climatic conditions but they are unable to regenerate following harvesting or disturbance. New species occupy these areas after harvesting or disturbance. Again, land owners can contribute to a more rapid rate of transition by immediately replanting the harvested area with appropriate species (assuming it is profitable to do so). In some cases, a landowner will decide not to replant, in which case a regeneration lag is introduced into the simulation.

Period to period changes in timber yield functions due to climate change are estimated by developing a periodic yield adjustment factor. This factor is based on the total change in biomass accumulation after the 70 year adjustment period, prorated over time based on the proportional change in temperature and precipitation within a period. Existing yield functions for particular timber types are adjusted to new climate conditions on a periodic basis using this adjustment factor.

Sohngen & Mendelsohn (1999) develop a dynamic partial equilibrium model which incorporates transient changes in timber type distribution and yield (resulting from climate change) as well as period to period shifts in price (attributable to shifts in demand from population growth and growth in per-capita income). The objective function for the model "defines a dynamic optimization problem which determines a time varying harvest schedule that maximizes the net present value of net surplus in the timber market." (This is the efficiency criterion discussed in subsection 3.1). Welfare estimates are made for a baseline case (i.e. no climate change) as well as under various climate change scenarios. The difference between these estimates provides a measure of the economic impact of climate change on timber markets. Model outputs include a) predicted changes in areas of various forest types and of the yield functions for various forest types over time, b) estimates of the net present value of consumer and producer surplus changes under various alternative climate change scenarios, alternative combinations of ecological models, and alternative assumptions about processes of ecological change (i.e. dieback versus limited regeneration), c) time paths of net welfare impacts under various alternate scenarios, and d) time paths of stumpage price with various combinations of ecological models.

Their model has a number of interesting features and useful capabilities. First, the model does not attempt to differentiate between types of private landowners in modeling owner behaviors, but rather considers two types of land that may reflect different management objectives. These are termed high intensity and low intensity forest lands. Harvest rates on high intensity lands assume "rational expectations" on the part of landowners. The rate of harvest on these lands is based on the decision rule that landowners will harvest up to the point where the marginal benefit and marginal costs of waiting for one period are equal. In this way, revenue streams are dynamically optimized over time. Harvest rates adjust from period to period in response to anticipated price changes and anticipated changes in yield. Once an area that is classified as high intensity forest land is harvested (or killed as may occur in the dieback scenario), it is immediately replanted with species suited to the new timber type (assuming the timber type has changed). Management and harvest decisions on low intensity forest lands does not assume rational expectations. The rate of harvesting on low intensity forest lands is determined by a "price responsive supply function." Replanting of low intensity lands after harvesting or dieback does not occur immediately but rather after a certain lag period.

Stumpage prices are both an output of the model as well as a key determining variable in the model. Stumpage prices are determined by the intersection of the "quality adjusted supply of timber in a particular period" with an inverse demand function (which is fixed in any particular period but shifts over time in response to changes in population and per-capita income). Stumpage prices feed back into the model in a number of ways. First, they determine the amount of land allocated to high versus low intensity forest land. This in turn affects harvest rates as well as rates of replanting over time. Second, stumpage prices influences land use changes. As stumpage price increases, it is assumed that some agricultural land will flow into forest land. Third, stumpage price increases result in increased yield since it is assumed that as prices increase, landowners will employ more intensive management methods (e.g. use of genetically improved stock, thinning, etc.). These influences are explicitly built into the model framework.

Sohngen & Mendelsohn (1999) find significant positive economic benefits from climate change in the U.S. timber market. They provide estimates of positive benefits that range from $3.87 billion to $32.58 billion over a 150 year adjustment period (note that ecosystems adjust over a 70 year period while markets adjust over a 150 year period). A significant portion of these positive benefits accrue to consumers. Price paths under the various climate change scenarios are lower than the baseline price path. Therefore, much of the benefits of climate change effects on timber markets occur as a result of increases in consumer surplus. The authors summarize the landowner behaviours to climate change over time as follows:

" - overall timber markets will adapt to climate change thus ameliorating some problems associated with ecological changes.

- harvest schedules will adjust from region to region and from year to year so as to use timber stocks efficiently during the transition period.
- land owners will also adjust their replanting behaviour,
- market behaviour offsets the potential damages through adaptation."

*Applicability of the results to Canada*

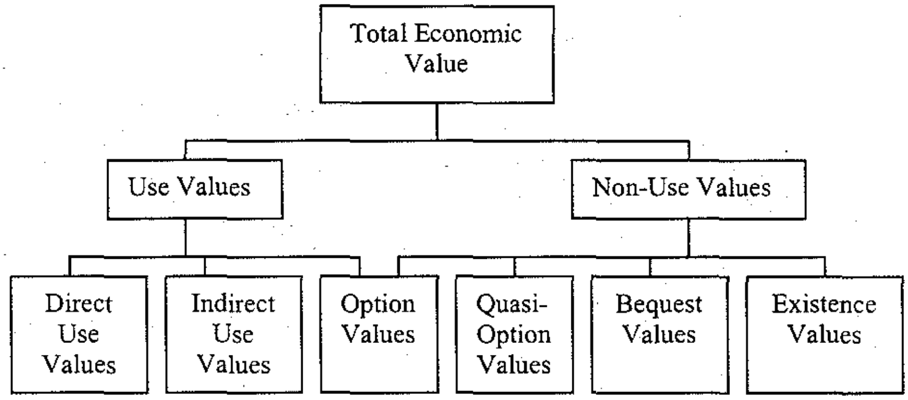
Sohngen & Mendelsohn (1999) findings of significant positive benefits from climate change can probably not be extrapolated to Canadian timber markets. There are a number of reasons for this including; (a) the possibility of more extreme climate change in Canada's more northerly latitudes; possible negative impacts on Canadian timber supply (in terms of volume and AAC) and timber quality (in terms of tree size and stand density); (b) replacement of high valued coniferous species with lower valued deciduous forest in the northern Boreal forest; inability to capture a significant portion of possible welfare benefits (i.e. consumer surplus) due to the fact that when product demand is inelastic, there is a tendency to transfer surpluses through to final product consumers and since the majority of Canadian production is exported, foreign consumers would tend to be the beneficiaries of increased timber supply (if it occurred) (Van Kooten and Arthur, 1989); (c) and the lack of market incentives to encourage adaptive responses on the part of landowners (due to the fact that most forest land in Canada is owned by governments).

The fact that the authors results of positive economic benefits and an efficiently functioning timber market mitigating economic impacts can not be extrapolated to Canada, does not mean that positive welfare benefits in timber markets will not occur in Canada. Nor is it possible to exclude the possibility of significant negative economic impacts on Canadian timber markets. There is simply no way to quantify how Canada's forest economy may adapt to climate change over time, without a dynamic-integrated ecological-economic assessment framework tailored to Canadian circumstances. Although these results may not be directly applicable to Canada because of our differing landownership and institutional arrangements, there are aspects of the methodological approach that may provide a basis for the development of an integrated assessment of adaptation and mitigation strategies in Canadian timber markets. This is discussed in subsection 5.2.

### *4.2 Non-market Impacts & Adaptations*

The discussion in the previous subsection pertained to climate change impacts on a forest value which is market based (i.e. timber markets). However, the concepts of economic efficiency and consumers surplus (discussed in subsection 2.1) are equally applicable to non-market benefits associated with forest ecosystems. Therefore it is important that these benefits be considered in assessing the socioeconomic impacts of climate change. This subsection identifies the various types of non-market benefits that could be affected and discusses how climate change will affect them. However, we do not discuss or speculate on the direction of possible value changes resulting from climate change. This is because there is limited information on the magnitude of the impact of climate change in terms of social value impacts, or on what methodological approach to employ in measuring changes in the value of non-market goods and services. This is an area that requires further research.

**Figure 4:** Use & Non-Use Values




Non-market goods include use and non-use (or passive use) values, option values and indirect use values (see figure 4) (Munasinghe, 1993). Use values are those activities where some level of utility is obtained by participation in an activity (e.g. recreation, and subsistence consumption from hunting, trapping and fishing). Passive use values include existence values and bequest values. Existence values are those associated with the value that comes from the knowledge of the continued existence of habitats and endangered species, without the need to visit them. Option and quasi-option values are considered to be a subset of passive values. These values pertain to the value that an individual places on having the knowledge that they have the option to undertake an activity at some future date if they decide to do so. Indirect use values include the value of the ecological functions of the forest, (such as water regulation, water quality improvement, erosion control, habitat provision, and carbon sequestration). The values mentioned vary in terms of their 'tangibility' to individuals (Munasinghe, 1993).

Use values and passive values need to be added together to obtain measures of the total impacts on non-market values (McConnell, 1997). Different valuation techniques that can be used to estimate economic values for non-market goods are outlined in the IPCC (1996c). However, the potential impacts of climate change are so numerous and subtle that measuring them all would be prohibitively expensive (McConnell, 1997), especially when the uncertainties involved are considered (see subsection 3.2). Therefore, there is a requirement to evaluate the feasibility and practicality of research to assess the impacts of climate change on non-market values. There is also a requirement to establish priorities for undertaking research on the impacts of climate change on non-market values.

There have been a few studies that have estimated the impacts of climate change on non-market values (e.g. see Nordhaus, 1994a, Cline, 1992, Fankhauser, 1995). In some cases these estimates have been controversial. For example, Nordhaus (1993) criticizes Cline's (1992) inclusion of the losses predicted for skiing, but the exclusion of benefits from warm-weather recreational activities such as camping. Some studies have been undertaken which focus exclusively on the impact of climate change on non-market values. Pendleton & Mendlesohn (1998) for example evaluate the impact of climate change on the U.S. freshwater sportfishery. Layton & Brown (1998) estimate the changes in passive use values associated with possible ecosystem impacts along the Colorado Front Range of the Rocky Mountains. These and other studies are discussed in more detail below.

*Non-market direct use values such as recreation*

Outdoor forest based recreation is influenced by climate, weather and their degree of variability. Some activities are more climate-sensitive than others (Wall, 1998). Sites that are primarily dependent on the attraction of natural resources are likely to be more susceptible to climate change than sites that have cultural and/or historical attractions (Wall, 1998). Therefore, outdoor recreation activities such as fishing, hunting, skiing, hiking, horse-back riding, mountain biking, snowmobiling, camping, rafting/canoeing, kayaking and bird watching (Saporta, Malcolm & Martell, 1998), may be vulnerable to the impacts of climatic change. In some cases the impacts may be positive in other cases they may be negative.

Season length is particularly important for activities such as skiing and hiking. Skiing is predicted to be adversely impacted by climate change, due to reduced quality and reliability of snowfall, increased risks of avalanches and warmer weather conditions (Wall, 1998). Possible adaptations include increased snow-making and numbers of lifts, moving sites further up mountainsides, diversification of activities to include summer attractions such as golf courses, hiking trails, swimming pools and conference facilities. However all of these adaptations come at considerable economic cost (Wall, 1998). Although winter activities may be adversely impacted by climate change, summer recreation may benefit due to an extended season (Mendelsohn, 1998).

Climatic change is likely to not only directly impact recreation locations, but also indirectly impact transportation to these sites. For example, reduced snowfall in Alberta has actually led to an increase in the number of skiers, due to mild, sunny weather (Wall, 1998). Further, if policy tools, such as carbon taxes or permits are implemented, long-haul tourists to Canada and fossil-fuel intensive tourist activities are likely to be adversely impacted. Conversely, there could be an increase in local tourists.

There are a lack of benchmarks to identify the impacts of climate change (IPCC, 1996b), and a lack of high resolution GCM outputs with which to predict local and regional non-market impacts (McConnell, 1997). This, therefore, partly explains the lack of tourism and recreation data available, in all but a few site-specific examples (Wall, 1998). However, Pendleton and Mendelsohn (1998) provide an estimation of the economic impacts of climatic change on freshwater sportsfisheries in the Northeastern U.S. They link GCMs, ecological and economic models (hedonic travel cost and random utility models). Some of their discussion and conclusions are likely to be relevant beyond their specific application. For example, they find that although the economic impact of climate change on a single species could be large, in many cases this could be offset by increases in other species. The overall net economic effect of climate change ranges from losses to benefits, depending on economic and climatic factors. Regional differences imply that while some areas are likely to benefit, others will not (Pendleton & Mendelsohn, 1998).

Recreation participants can adapt to climatic change, due to mobile recreational equipment, choices as to what, whether, when and where to participate, and the possibility of substitution of leisure activities and location, without a great deal of loss in quality (Wall, 1998). Nevertheless, as mentioned earlier, overall there are likely to be greater opportunities for summer activities and reduced opportunities for winter activities such as skiing (Mendelsohn, 1998).

Natural areas are important recreation resources due to the attraction of the species they conserve and the ecological processes they maintain (Wall, 1998). Natural areas, parks and their management and interpretation are partly chosen by their biophysical factors. Zoning, interpretive programmes and the choice of recreation activities also depend on these biophysical attributes (Wall, 1998). Climate change is likely to impact the biophysical attributes of areas, and therefore the choice of the above. For example, the long-term changes in climate are expected to cause redistribution of ecological areas (i.e. those protected in national parks), consumptive resources (i.e. game for hunters) and non-consumptive resources (i.e. birds for photographers) available in recreation sites (Wall, 1998).

*Indirect use values*

Indirect use non-market values have functional values that include the ecological functions of the forest. One example, is the ability of forests to sequester carbon, and thereby reduce the atmospheric build-up of carbon. However, if carbon permits or credit schemes are implemented, then the carbon sequestration capacity of forests may partly become a market based value (i.e. if carbon permits allow agents to trade carbon emissions for carbon sequestration, then a market price for carbon sequestration may ensue). There are, however, extenuating circumstances relative to the ability of forests to supply carbon sequestration services under new climate regimes. For example, if the predicted increases in forest fires and disturbances occur (Sedjo, 1998) they will adversely impact the forests' ability to sequester carbon. Carbon sequestration in forests is further discussed in subsection 4.5.

*Non-use values and option values*

Non-use values include existence values (the value of knowing that habitats or endangered species continues to exist) and bequest values (the value of knowing that particular natural resource features will be passed on to future generations). Option values are values associated with knowing that future options are not being foreclosed. Passive use values and option values are psychological in nature. Both option values and non-use values will be affected by climatic change, as physical and anthropogenic responses and adaptations influence the biodiversity and endangered species of Canadian forests, and the location and quality of habitats, protected areas and parks. Wildlife populations that are most at risk from climate change and variability are those already under stress (Anderson, et. al, 1998).

Biodiversity encompasses species richness, genetic diversity and landscape diversity (Anderson, et. al, 1998). Many of the passive use values held by people relative to forests are closely aligned with the issue of biodiversity. Therefore, to the extent that climate change affects biodiversity, there may be implications for passive use values and option values for forests. However, the complex web of interactions between species, ecosystems and climate mean that isolating the direct cause-and-effect relationships between climatic change and biodiversity will be difficult (Anderson, et. al, 1998).

Some suggest that there will be lag times in the establishment of new, stable biological communities after climate changes (Anderson, et. al, 1998). Genetic diversity is critical to allow adaptation by species and ecosystems to a changed climate (Anderson et. al, 1998). Species richness and biodiversity in Canada are poorly understood (Anderson, et. al, 1998). However, the preservation of ecosystem diversity and species diversity appear to be linked (Anderson, et. al, 1998). Ecosystem-level responses to climate change are possibly the hardest to predict, due to their complex dynamics, non-linearities, large temporal and spatial scales (Anderson et. al, 1998).

Layton & Brown (1998) is one of the few studies which discuss the impacts of climate change on passive use values. Their estimate the value of ecosystem impacts along the Colorado Front Range of the Rocky Mountains. They use a stated preference approach to find substantial heterogeneity in respondent preferences. Interestingly, the respondents had the same preferences over two different time horizons. The mean willingness to pay to mitigate the ecosystem impact associated with climate change was found to be significant. Moreover, the amount people were willing to pay for mitigation increased with the level of the impact (Layton & Brown, 1998).

The Intergovernmental Panel on Climate Change (IPCC, 1996b) identifies a number of adaptation strategies to reduce the negative non-market impacts resulting from climate change. They include the following: First, mixed species planting to increase diversity and flexibility. Second, selection and planting of appropriate species and varieties suited to future conditions. Third, the identification and management of a system of protected areas which anticipates future ecosystem changes in response to climate change. Fourth, species at risk (which may be restricted in geographic range), should be conserved in forest reserves, arboreta, and conventional seed banks and cryogenic storage, to ensure their survival (IPCC, 1996b). Finally, it will be important to preserve those ecological features that contribute to the adaptability and resiliency of ecosystems (Anderson, et. al 1998).

Passive use values are an important class of values relative to social welfare and public policy and these values will be affected by climate change. They are difficult and expensive to quantify and there are high levels of uncertainty relative to how the specific environmental attributes that determine passive use values will respond to climate change. However, given that there is some potential for irreversible losses of certain environmental attributes without intervention there is a need for some consideration of these values in policy. These considerations will probably have to be developed in the absence of explicit measures of the impact of climate change on passive use values. Although economics will likely not be able to fully quantify climate change effects on non-market values, economics can still contribute to developing policy responses. There are two aspects where economics can make a contribution: 1) identifying the conditions and circumstances when the application of the "Safe Minimum Standard" approach[19] for protecting ecological attributes would be appropriate, and 2) identifying social preferences and rankings for selected and geographically explicit passive use values.

Finally, climate change implies the need for pro-active policies relative to future protection of key passive use values. Natural resource management in Canada has recently evolved in the direction of sustainable ecosystem management. This philosophy applies to the management of parks, wildlife management and management of Canada's forest resources. However, climate changes injects a new variable into the mix of traditional factors which impact ecosystems. Existing policies may reflect the traditional mix of factors but in many cases they do not take climate change into account. Thus there is a growing need for reviewing natural resource management policies at various levels. For example, one of the main instruments for protecting non-market values and for protecting ecosystems is protected areas and parks. There may be a need for reconsideration of existing park policy in the context of climate change. However, since climate change is a new type of variable, new and creative policy solutions will likely be required. For example, rotating reserves would be a way of protecting certain critical pieces of natural capital such as old growth in a dynamic environment of changing climate. Nevertheless, land use conflicts between the provision of non-market and market values are likely to increase (Wall, 1998).

### *4.3 Forest Sector/Agricultural Sector Interactions*

Having outlined the market and non-market values within Canadian forests, the next two subsections examine the interactions between the forest sector, and other sectors. Namely, agriculture in this subsection, and the energy sector, in the following subsection.

Agriculture and forestry interact in a number of different ways. First, agricultural products and forest products can be substitutes for each other. For example, organic material for biofuels can originate from either agricultural lands or forest lands. Second, products from one industry can provide inputs for the other industry, as is the case when wood residue products are used as livestock bedding materials. Third, since agriculture and forestry (particularly winter timber harvesting) are seasonal in some respects, there is some seasonal movement of the labour force between them (particularly in geographic

[19] See Berrens (1996) and subsection 3.2.

locations situated close to the agriculture-forestry margin). Fourth, in addition to producing agricultural products, many farmers also manage small woodlots on their land that provides an alternative source of revenue for the landowner. Fifth, and perhaps most important, agriculture and forestry compete for inputs, the most obvious of which is land. Therefore changes in biophysical conditions and in economic circumstances in one sector will lead to changes and responses in the other sector. This subsection discusses how the interactions between the agricultural and forest sector may be affected by climate change. The principal issue in this regard is how climate change may affect the relative value of land in forestry production versus agriculture production. Changes in land values should lead to changes in land use. This will be an adaptive response to climate change and it is one of the reasons why the assessment of impacts from a forest sector perspective should consider responses in the agriculture sector and vice versa. For example, reductions in timber values at a particular location may be offset by increased agriculture rents. Thus the net social impact may be positive. Alternatively, if marginal agricultural land is converted to forest land (on which the net present value of costs and revenues is positive) then net social impacts may be positive. The remainder of this subsection provides a brief overview of climate change effects on the agriculture sector and discusses possible land use shifts which may occur as a result of climate change.

*Lessons from Mendelsohn, Nordhaus and Shaw, 1994: The Impact of Global Warming on Agriculture: A Ricardian Analysis*

While the Mendelsohn, et. al (1994) paper is specific to agriculture there are important lessons in this analysis for forest management. The paper also holds lessons for linkages between forest land use and agricultural land use. The major lesson from this analysis is that the negative impact of global warming can be overestimated if one does not account for adaptive responses of those affected by global warming. The authors point out that farmers in the U.S. will not be as negatively affected as some damage analyses suggest because farmers will adapt by switching crops toward those that are more suitable to a changing climate. As a result the margin at which land suitability changes from one crop to another will change as climate changes. This holds an important lesson for optimal land use along the current forest-agriculture land boundary.

This can be illustrated in the above figure 5 that shows how the value of land changes for different types of agricultural crops with climate variables. This is a type of site specific decision rule for determining what type of land use can be expected on a particular area subject to climate variables. As the climate variable increases (i.e. temperature), the type of land use that occupies the particular site may also change. When changes in land use for individual sites are aggregated over a larger area, the distribution of total area in each land type and the margin between forest land and agricultural land also changes. Changes over time in spatial distribution of land types and in the agriculture forestry margin in response to climate change for a hypothetical area are illustrated in figure 5.

This means that farmers will change crop types or change from crops to rangeland. If left to natural migration processes, changes in forest types on forest land will take place more slowly. However, if forest managers intervene they may accelerate the natural process introducing species or possibly genetically bred hybrids to land that would otherwise have taken longer periods of time to migrate to appropriate locations.

This suggests that the process of ecosystem transition is important to track and relates directly to suggested policies to afforest marginal agricultural land. Will marginal agricultural land still be marginal in 20 or 30 years? In light of this, how much investment should be made to afforest currently marginal agricultural lands? Answering these questions requires knowledge about the rate of ecosystem migration.

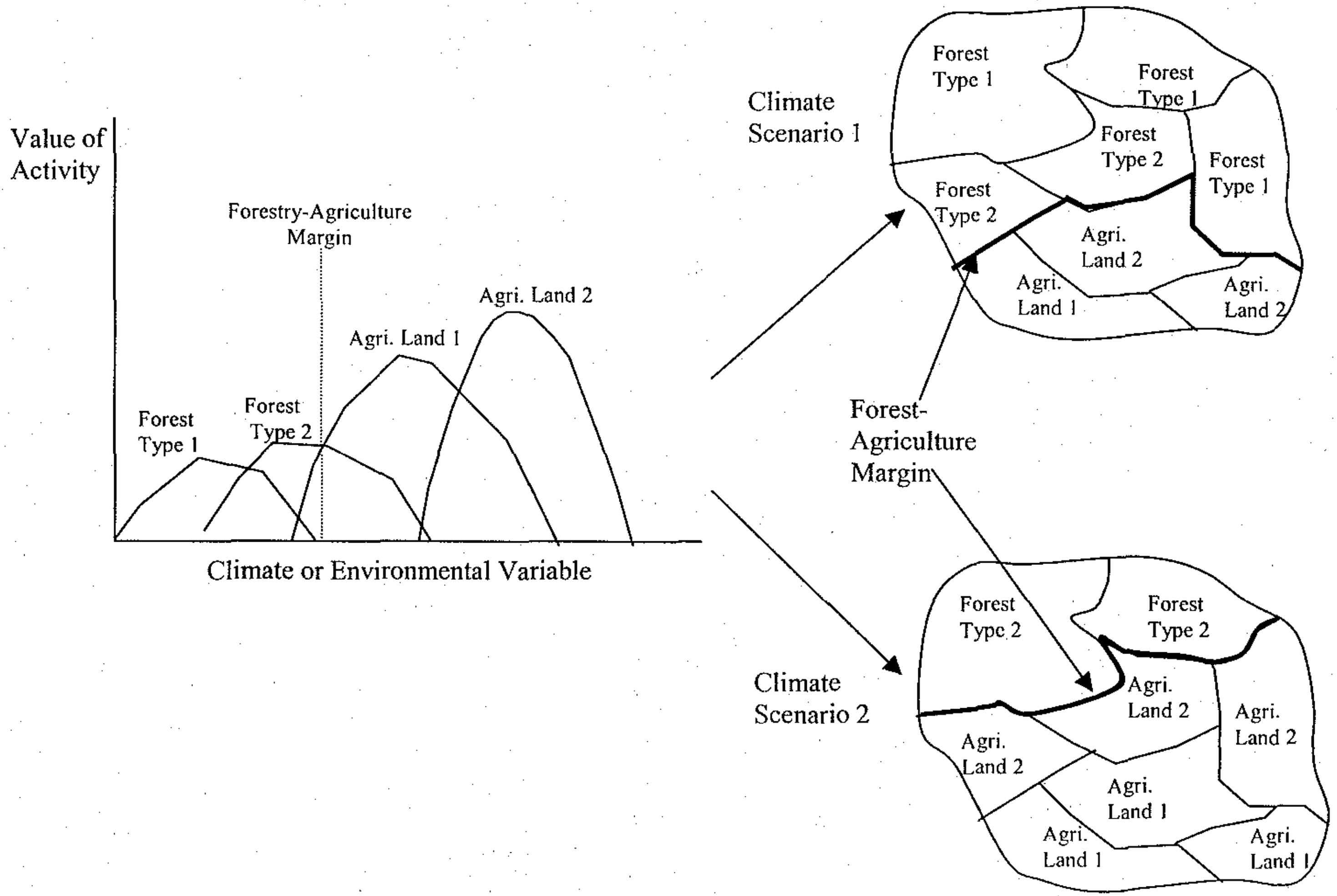
*Impacts of climate change on agriculture*

Future long-term changes in precipitation, storm frequency and intensity, temperature, and so on will affect agricultural productivity and profitability. As is the case with the forest sector, these impacts will vary from location to location. Moreover, climate change will have a positive impact in some locations and a negative impact in other locations (IPCC, 1996c, and Brklacich, et. al 1998). However, due to short crop cycles and the stronger influence of market incentives in the Canadian agriculture sector (compared to the forest sector), adaptation will occur more rapidly in the agricultural sector.

Agricultural responses to climate change include changes in crop yields and shifts in production and relative productivity (IPCC, 1996c). The predicted northward movement of Canadian ecoclimatic zones is likely to impact land use. However, as the boreal forest shifts northward, agriculture may be unable to expand northward, if winter conditions are not conducive to agriculture (Brklacich, et. al, 1998), and/or if northern soils can not support agriculture.

Possible negative impacts of climatic change on agriculture include heat stress, decreased soil moisture, and increases in the incidence of pests and diseases (IPCC, 1996c). Also, warmer temperatures could accelerate the growing cycle of some plants, reducing the time available for plant development before maturity is reached (IPCC, 1996c). Increased precipitation is likely to increase soil erosion. Conversely, decreased rainfall in mid-continental regions, including the Prairies, could increase the frequency and intensity of droughts, and associated increases in winds and storms, could increase wind erosion. As with forestry, the agricultural areas most likely to be threatened by climate change are regions that are relatively poor and lack either the financial resources or knowledge with which to adapt (Helms, Mendelsohn & Neumann, 1996).

**Figure 5:** Model of the Relationship Between Climate Variables, Land Use, and Land Values and the Spatial Location of Land Use Under Different Climate Change Scenarios. The diagram represents how the forestry-agriculture margin along the climate dimension may be mapped over space.



Beneficial impacts of climatic change could include longer growing seasons, in certain areas, associated with increases in the frost free season and decreases in frost-induced crop injuries (Brklacich, et. al, 1998). There is also a possibility of increased carbon fertilisation, leading to increased photosynthesis, which could have beneficial effects on crop yields, when competition, water and nutrient limitations allow. The potentially limiting factors to carbon fertilisation can be more easily addressed in an agricultural setting, rather than in a forestry environment (Helms, Mendelsohn & Neumann, 1996).

*Effects of climate change on land use patterns*

The few Canadian studies that have focused on changes in agricultural distribution are regional and have been summarised by Brklacich, et. al (1998). The general findings of these studies are that the Peace River Region and northern agricultural areas of Quebec and Ontario are predicted to expand. Impacts and land use changes North of 60° (i.e. the Mackenzie Basin) are not expected to be significant (Brklacich, et. al, 1997). Overall, a northward shift in agriculture is predicted, although this could be partly offset by losses in agricultural land in the south (to grasslands). Expansion north may be restricted by environmental limitations.

Market forces may be an important determinant of changes in land use patterns in response to climate change. Although Mendelsohn, Nordhaus & Shaw (1994) do not explicitly model the actual competition between forestry and agriculture for land, their Ricardian analysis of the impact of climate change on agriculture does allow for changes in land use, as well as for farmer adaptation, via the inclusion of farmland values. They suggest that the literature does not consider changes in land use from farming to forestry, although some work has focused on this since their paper was written; their observation is still largely true. Nevertheless, if land use changes and other adaptations are not included in models the damages from climate change are likely to be overestimated (Mendelsohn, et. al, 1994).

The importance of change in relative land values between agricultural and forestry is generally considered in papers that analyse the possibility of carbon sequestration via afforestation (Sedjo & Solomon, 1989, Nilsson & Schopfhauser, 1995, Van Kooten, et. al, 1999)[20]. Subsection 4.5 discusses some economic dimensions of afforestation in more detail, however, a few comments will be made here. Krcmar-Nozic et. al (1999) suggest that the uncertainty associated with carbon sequestration via afforestation on marginal Canadian agricultural lands and reforestation is difficult to model, especially when different strategic options (base case, optimistic and pessimistic scenarios, and lax and strict management policy regimes) are included. Forage and pasture lands that are considered suitable for afforestation in Alberta and the Peace River region of British Columbia are analysed by Van Kooten, et. al (1999). They find that as much as 7 million ha of agricultural land could be afforested. However, the cost of sequestering carbon by this option would limit afforestation to less than 2 million ha, which would sequester an average of 7Mt of C per year, for 50 years. In the whole of Canada no more than 6 million

[20] Carbon sequestration on agricultural land, via reduced tillage has also been suggested.

ha of agricultural land are likely to be available for afforestation. Nevertheless, this area could provide over 25% of Canada's Kyoto commitment (Van Kooten, et. al, 1999).

### *4.4 Forest Sector/Energy Sector Interaction*

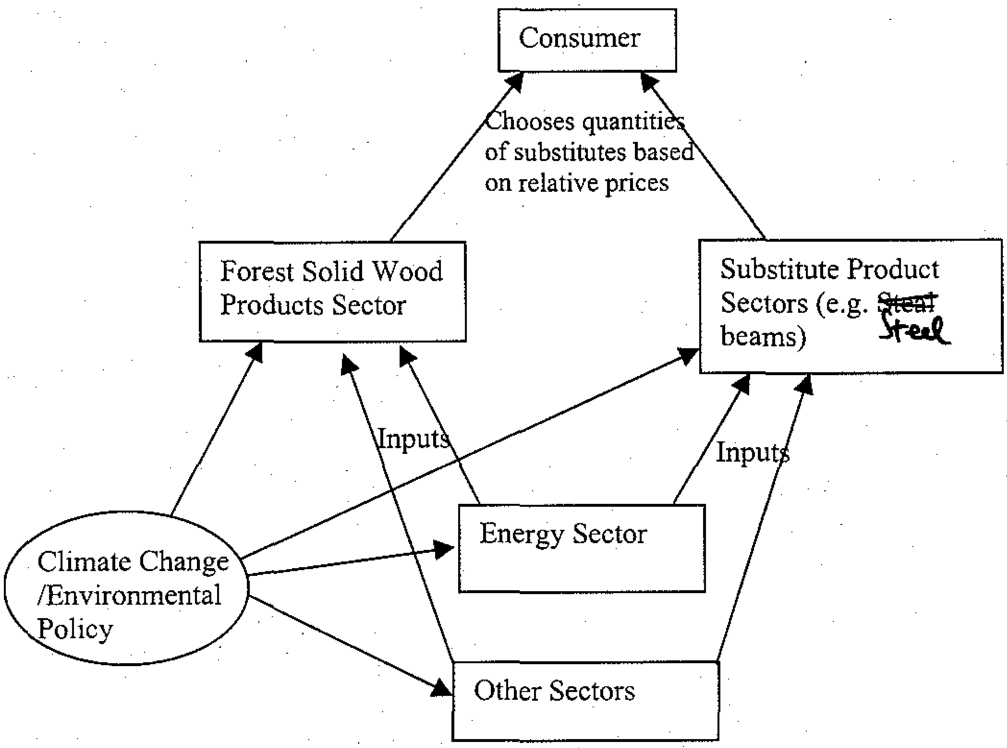
The forest sector and energy sector interact in a number of ways. However, these linkages differ from those in the agriculture sector in terms of their implications relative to impact assessment and mitigation policy. Whereas the nature of the interactions between agriculture and forestry is important in the context of climate trends over long time periods (i.e. possible changes in patterns of land use), the interactions between the forest sector and energy sector are more important in the context of carbon emission abatement/mitigation policies. Thus, the nature of these interactions has more immediate implications relative to the design of socially optimal mitigation policies and the magnitude, nature and distribution of the social costs of mitigation.

The purpose of mitigation is 1) to reduce emissions of greenhouse gases into the atmosphere, 2) to increase carbon stocks through the permanent sequestration of atmospheric carbon into organic materials (i.e. soil organic matter, wetlands and above ground biomass) above a baseline, and 3) to limit the reduction of existing carbon stocks (and their consequent release to the atmosphere) by discouraging deforestation (this is primarily a tropical rainforest issue). Various instruments have been proposed to facilitate mitigation including increasing the price of fossil fuel energy (e.g. through the imposition of carbon taxes), imposing regulations to ensure minimum levels of energy efficiency, investment in afforestation projects, substitution of renewable energy for fossil based fuels, and the use of market based systems (e.g. emission allowance trading and/or carbon allowance trading) as a possible way to minimize the total cost of mitigation.

Increased energy costs and energy efficiency regulations have the potential to increase production costs and transportation costs for the forest products sector. Various aspects of the implications of increased energy costs on the forest sector are discussed in this subsection. Related aspects such as afforestation and reforestation, bioenergy, and carbon trading systems, are discussed in the following section, which focuses on the role of the forest sector in achieving greenhouse gas emission targets. We should note at this stage that these issues are discussed at some length in the recently released "Foundation Papers" prepared by the Forest Sector Table (1998) and the National Sinks Table (1998) under the National Climate Change Process.

Figure 6 illustrates the relationship between the forest products sector, substitute products sector, the energy sector, and other sectors and consumers. Consumers will choose between products based on the relative prices of these products. If products are substitutes, increases in the price of one product will result in increased demand for the other product. If products are complements, increased prices in one product will result in a decrease in demand for the other product. The following two paragraphs describe how changes in fossil fuel input costs will have varying effects on supply and on relative changes in the quantity demanded of different products.

**Figure 6:** Interactions Between the Forestry & Energy Sectors




The impact of changes in the price of energy and/or regulation varies from industry to industry. The response of a particular industry to changes in the price of fossil fuels will be a function of the energy intensity of the particular industry and its capacity to substitute other inputs (i.e. capital, labour, or alternative energy sources such as biofuels) for fossil fuel energy. Because energy price responses vary from industry to industry, the relative price effects of fossil fuel price increases also vary from industry to industry. Thus, changes in relative production costs can be expected with increased prices for fossil fuels and/or increased costs of production resulting from regulation. Energy intensive industries (i.e. the pulp and paper industry) tend to be more influenced by changes in energy prices than less energy intensive industries. However, industries with greater ability to substitute alternate inputs for fossil fuels (i.e. increasing bioenergy use in the pulp and paper industry) will be less affected. Changes in costs will lead to changes in the supply function and changes in the equilibrium price for a particular good.

The previous paragraph describes how changes in the price of an input will vary between industries in response to supply curve changes. What effect will price changes have on the relative mix of quantities demanded? Again, this varies from product to product depending on the elasticity of demand for the particular product. Products with inelastic demand tend to be products a) that are essential commodities, b) that do not have numerous substitutes in the market, and/or c) where their demand is derived from the demand for other products (i.e. the product is an input in the production of a final product) and d) where the input product accounts for a relatively low proportion of the cost of production of a final product. For example, lumber accounts for a low percentage of the total cost of house purchase and therefore the derived demand for lumber is considered to be inelastic. When a particular product has inelastic demand, the quantity demand is relatively insensitive to price changes[21].

The above concepts can be illustrated with an example using two products: forest products and steel. Both of these industries are relatively energy intensive, however, the forest industry has demonstrated a capacity to substitute biofuels for other energy sources over the last number of years (Forest Sector Table, 1998). Thus, assuming that energy costs, as a proportion of total costs, are similar in both industries (which they may not be) a given increase in fossil fuel costs would tend to shift the supply curve for steel to a larger degree than the supply curve for forest products. This is because the forest products sector would be able to substitute biofuels for fossil fuels. The effect of a shift in supply on total quantity demanded for the two products will depend on their relative elasticities of demand. If the demand for forest products is more inelastic than the demand for steel, then the effects of an increase in the price of forest products will have less of a pronounced impact on demand than an increase in the price of steel. A final question of interest is: what is the effect of a change in the relative price of forest products and steel? This depends on the extent to which steel and forest products are substitutes or compliments. If they are substitutes and if the relative price of steel to forest products increases as a result of mitigation policy, then consumers will substitute forest products for steel and the demand for forest products will increase. If these products are compliments, then increases in the relative price of steel to forest products will cause a decline in demand for forest products. The impacts of a change in price for one product on the demand for another product is provided by measures called cross price elasticity of demand.

### *4.5 Role of the forest sector in mitigation*

The Canadian forest sector can contribute to mitigation in a variety of ways including carbon sequestration, using wood products as a replacement for more GHG-intensive products, reducing fossil fuel energy use, and increasing the use of bioenergy as an energy source. These mitigation options are reviewed in the following subsection[22]. Associated adaptation strategies are included, and a final discussion concerning related domestic policy issues is given.

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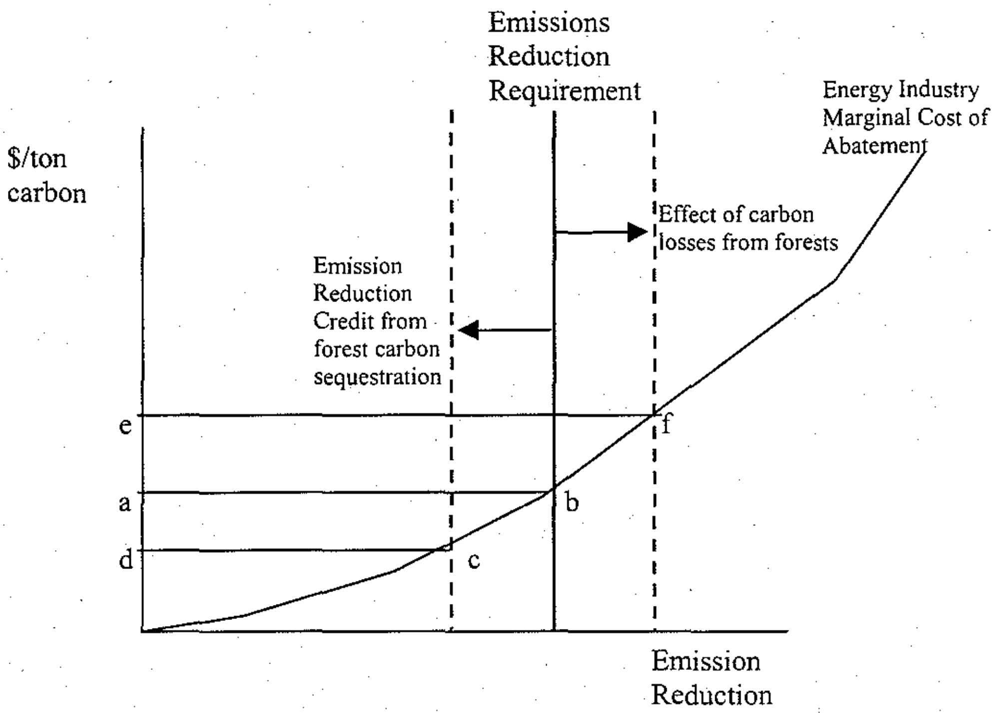
[21] An interesting side note is that fossil fuels have many features of a product characterized by inelastic demand. The demand for energy by industry is derived from the demand for final products. With respect to household consumption, there are few substitutes for fossil fuels for home heating and for gasoline for private vehicles. The implication of inelastic energy demand is that price increases (such as from a carbon tax) will need to be substantial to have significant effects on the quantity of fossil fuels consumed.

[22] For further details of the role of the forest sector in mitigation see the Forest Sector Table (1998) and the National Sinks Table (1998).

**Figure 7:** Forests Mitigation Potential for Offsetting Fossil Fuel GHG Emissions




One of the indirect, non-market use values identified in subsection 4.2 was the ability of forests and forest soils to sequester and store carbon. This is an issue of increasing importance in forest management because the inclusion of carbon sequestration as a management objective has significant implications for how forests are managed. For example, species selection, rotation age, reforestation strategies, preferred harvesting systems, forest protection strategies, and intensive management strategies may be influenced when carbon sequestration is included as a management objective. In fact, the possibility that forests may have some role in carbon sequestration means that adaptation strategies and actions leading to mitigation are closely linked. These close linkages make it difficult to classify and/or differentiate actions that are adaptive from actions who's purpose is mitigation. For example, it has been suggested that climate change will increase the rate of fire disturbance. An adaptive response by fire management agencies to increasing fire disturbance would likely be increased protection effort. However, an increased protection effort may also have implications for carbon accounting for the purpose of monitoring Canada's efforts to mitigate GHG emissions.

Forests and forest management have the potential to contribute to mitigation goals by offsetting emissions produced as a result of fossil fuel production and use. These tradeoffs are illustrated in figure 7 which is a simple model that assumes that the energy sector has some fixed target for emission reduction that is tied to the rate of carbon sequestration or carbon loss from forests. Carbon sequestration from forests (or agriculture) could shift the emission reduction requirements of the energy sector to the left. This would result in a savings equal to the area *abcd* in the energy sector (i.e. from a social welfare perspective, it would be worthwhile for the energy sector to invest an amount up to the area *abcd* to sequester forest carbon through changes in forest management or land use, such as afforestation). Alternatively, increases in carbon emissions over and above natural rates of loss may result in a shift to the right in energy sector emission reduction requirements. The resulting increase in energy sector costs is the area *abef*. Thus, it would be worthwhile for the energy sector to invest the area *abef* to prevent carbon losses from forests attributable to anthropogenic effects. However, key questions relative to the practicality of a system with tradeoffs between emissions and sequestration are: To what extent are forests a sink or source and does sink/source status change over time? What kinds of human interventions can enhance carbon sequestration capacity? What are the costs and benefits of human interventions to enhance carbon sequestration capacity? What are the most effective mechanisms for enhancing carbon sequestration capacity? What are the measurement issues relative to accounting for dynamic changes in carbon stocks and flows (which themselves are extremely sensitive to future climate changes) with and without intervention?

A number of authors have examined the issue of forest carbon sequestration (Sedjo, 1998, Harmon, et. al, 1990, Price & Apps, 1995, Englin & Callaway, 1993; Van Kooten et. al, 1995). Carbon sequestration is the process whereby atmospheric carbon is sequestered into living biomass and dead organic material. At any given point in time a particular defined area (such as a forest management unit) will contain a stock of carbon. This carbon will be contained in living biomass, dead and decaying organic matter, and soil organic matter. In each future time period, the stock from the previous period is adjusted by inflows and outflows of carbon. A certain amount of carbon is sequestered - due to growth, and a certain amount returns to the atmosphere - due to decay, natural events such as forest fire[23] and/or human activities such as harvesting or deforestation. If the amount of carbon sequestered in an area between two time periods exceeds the amount of carbon emitted then the area is a carbon sink. Alternatively, if the amount of carbon emitted is greater than the amount sequestered then the area is a carbon source (Sedjo, 1998). Forest sinks are particularly important, as they are the only sinks explicitly recognised as eligible for emissions reduction credits by the Kyoto protocol (Sedjo, 1998).

The above discussion of forest carbon dynamics is a simplistic representation of a dynamic carbon budget from forests. What is the actual situation with respect to Canada's forests? The National Sinks Table (1998, pp. 2, executive summary) states the following:

> "Analyses indicates that the net effect of the observed changes in natural disturbance patterns (fire, insect) has been a shift in the role of total Canadian forests from a carbon sink to a carbon source between 1970 and 1989. Analyses

[23] Binkley et. al (1997) note that suppression of such disturbances is usually just delaying their inevitable occurrence.

> also indicates that they will likely revert to a carbon sink over time, but that the timing of this change is highly dependent on the assumptions about future natural disturbance rates (including responses to global warming)."

When considering whether Canada's forests are a sink or source in the context of what is considered under the Kyoto forest, the National Sinks Table (1998) notes that there is considerable uncertainty and that Canada's forest could be either a sink or source depending on the final definitions for reforestation, afforestation and deforestation. The National Sinks Table (1998) explains the following:

> "It is critical to appreciate that, depending on the final decision on many outstanding issues, the net contribution of sources and sinks from reforestation, afforestation, and deforestation activities since 1990 during the commitment period 2008 - 2012 could be either a substantial source or sink. For example, in a "worst case" scenario, Canada's ongoing reforestation after harvest could be excluded from the Kyoto Forest or could be a net source term, while deforestation resulting from expansion of agricultural land and urban growth was fully accounted as a reduction in C stocks."

An important question relative to the consideration of forests as a possible sink for the sequestration of atmospheric GHG is the issue of short versus long term capacity for forest lands to store carbon. The conclusions of the National Sinks Table (1998) suggest that forests have fluctuated from being a sink to a source and that they may, in the future, become a sink again. Thus forest carbon stocks were increasing, then started decreasing in the last 20 years, but are expected to increase in the future. This leads to some important questions such as: 1) Should we be considering the carbon sink/storage issue on a longer term basis and look at long term trend lines (with short term fluctuations) instead of relatively short term fluctuations? 2) If such a temporally stable long term trend line does in fact exist, is there a potential to shift the long term trend upward with human intervention? 3) How will climate change affect future long term trends? These questions are important because they provide alternate ways of looking at the issue of sequestration credits. For example, if human interventions result in a change in forest carbon sequestration, but the change only affects the forests short term storage ability and has no effect on storage ability in the long term then storing carbon in trees is really only a mechanism to buy time so that new technologies may be discovered to reduce use of fossil fuels or reduce the GHG output from the use of fossil fuel. Also, if forest carbon is not permanently stored and if gains in the present will be emitted in the future, then presumably future increases in forest GHG output would need to be offset by further GHG emission reductions from fossil fuels.

The previous discussion leads to questions about what can be done to improve forest carbon storage. The timing of harvesting affects carbon sequestration capacity. Generally speaking, prolonging rotations in natural forests will increase carbon sequestration (Binkley, et. al, 1997). Englin & Callaway (1993) integrate a carbon sequestration life cycle into the Faustmann model. They determine an optimal timber rotation for the joint maximization of timber and carbon sequestration, which is sensitive to the discount rate chosen.

Carbon sequestration can also be enhanced by silvicultural practices and techniques, such as thinning, fertilization, and modified harvesting. However, carbon sequestration by reforestation may be more biologically and economically efficient than changes in silvicultural practices and techniques (Dixon, 1997). Hoen & Solberg (1994) suggest that fertilization has the most potential and is the most economically efficient type of silvicultural treatment for increasing carbon sequestration in a managed boreal forest in Norway. However, Sedjo (1998) notes that mature and "overmature" forests in high-latitude climates are likely to experience little net growth if fertilizer is applied. He also argues that silvicultural treatment, although effective in initial forest establishment, has little to offer to mature forests. And that more intensive forest management and lengthened industrial timber rotations would have only a very modest impact on reducing atmospheric carbon buildup.

*Substitution of wood based products for non-wood products*

Another way to reduce atmospheric carbon emissions is to encourage the use of products where the rate of carbon emission associated with their production and use is relatively low (Forest Sector Table, 1998). However, understanding the implications of the production and consumption of particular products relative to carbon emission rates requires an analysis of the rate of emission of GHG at each stage of the product lifecycle (i.e. extraction, production, consumption, recycling and disposal). Such analysis is termed "lifecycle analysis". Some suggest that wood products require less fossil fuel energy in their production than competing products, such as steel, concrete, glass and vinyls. These conclusions are, however, somewhat speculative at this time. More thorough analysis of the lifecycle impacts of various products using similar methodologies would provide a better basis for a comparison of the implications of consumption of these products on carbon emissions and the possibilities of controlling carbon emissions by encouraging alternative product mixes. Moreover, decisions should not be made strictly on the basis of life cycle impacts. It would be more beneficial to link lifecycle impacts with general equilibrium analysis so that a comprehensive view of the economic consequences of changing product mixes could be compared to whatever economic costs and benefits may be associated with the promotion of new product mixes.

Some analysis suggests that wood products release less carbon than other building materials for certain uses. Marcea & Lau (1991) compare the energy consumption and $CO_2$ emissions of wood, brick, aluminum, concrete and steel materials in the construction of buildings, and find that wood uses the least energy and creates the least $CO_2$ emissions.

The recycling of materials extends the products' lifecycle and this may have positive effects on the reduction of GHG emissions. However, this is a complex issue. For example, the recycling of paper can reduce the pressure to utilize forest stocks and thereby increase the amount of stored carbon, in the short-term (Sedjo, et. al, 1995).

However, in the long-term a decrease in the demand for virgin wood fiber will reduce the investments in pulpwood tree plantations, and could result in alternative uses of the wood and the land (Sedjo, et. al, 1995).

*Reducing forest sector consumption of fossil fuels*

Increases in energy costs and prices may occur as a result of the implementation of GHG or carbon reducing policies. Such cost increases would lead to adaptive strategies to minimize the impact. These responses would include reductions in total energy requirements and/or changes in the mix of energy sources used to satisfy energy requirements (e.g. through more significant use of biofuels). In the absence of climate mitigation policies, both of these adaptations are already occurring in the pulp and paper industry (Forest Sector Table, 1998, and Wellisch, 1998). This discussion below briefly mentions issues pertaining to reducing energy consumption, and especially fossil fuel consumption. This is followed by a discussion of bioenergy, which is also a strategy to decrease fossil fuel use.

Adaptive strategies by forestry firms to decrease total energy requirements include changing the product mix to less energy-intensive products, retrofitting forestry buildings and equipment, staff education, environmental audits, research into more energy efficient production processes, and innovation of more energy efficient technology.

Retrofitting forestry buildings and plants could increase energy-efficiency and reduce fuel costs (Hornung, 1998; Forest Sector Table, 1998). The location of new forest products mills could be chosen to minimize transportation distances from the resources and the market (Forest Sector Table, 1998). These options could be combined with education, awareness raising and incentive schemes to encourage staff to decrease their energy use. Environmental audits, focusing on GHG-intensive energy, could also help in locating sources of energy inefficiencies, and possible improvements. For example, improvements in in-house repairs and maintenance to restore equipment (i.e. boilers) to their design capacity, on-line energy use monitoring and management systems, and a systems approach to optimize energy use, may be possible options (Forest Sector Table, 1998).

Research and development into new technologies and practices that are more energy-efficient is another option. Some emerging technologies which could reduce GHG emissions in the pulp and paper industry are outlined by the Forest Sector Table (1998, p 62). An important consideration relative to the research and development option, however, is that the technological capacity of firms has not kept pace with industrial requirements over the last number of years (Globerman, et. al, 1999). Moreover, because of increasingly stringent environmental regulations on emissions (i.e. dioxins, waste solids, etc.), much of the research and development capacity of the industry has focused on the development of environmental technologies, in some cases at the expense of the development of more energy efficient production processes and new products. Thus, the opportunity cost of requiring the industry to invest in developing technological solutions to energy consumption may lead to a further decline in competitiveness in the long term (see subsection 3.3). An alternative option, however, may be to engage the forest products research cooperatives (Paprican, Feric, Forintek) to expand their research programs in the areas of developing generic technologies for cost effective improvement in energy efficiency in the forest industry. The possibility of exporting energy efficiency technologies to developing countries and obtaining development credits for this activity, provides some basis for consideration of increased public support for this area of research.

*Bioenergy*

Bioenergy can be used as a fossil fuel substitute, and can therefore also be used to decrease the fossil fuel consumption within the forest sector (and the rest of the economy). Bioenergy is already the largest source of renewable energy in Canada[24], providing about 6% of total primary energy supply and 7% of primary residential heating (Mercier, 1998). The pulp and paper industry is the main producer and consumer of bioenergy. Research into improvement in forest management for biomass, tree plantations and bioenergy technologies are already underway, partly due to an anticipation of increased demand and reliance on biomass in the future. The total demand for GHG-intensive fuels by the forestry industry is predicted to decrease from 15.7 Petajoules in 1990 to 13.3 Petajoules in 2020. This reduction will occur despite the fact that gross output by the industry is expected to increase (Natural Resources Canada, 1998). The reason for diminished use of GHG fuels is the increased use of biofuels by the forest products industry. This trend is forecast to continue in the future. The use of wood waste, pulp and spent pulping liquor (bioenergy sources) are predicted to double for the pulp and paper industry, between 1990 and 2020 (Natural Resources Canada, 1998). Municipal solid waters, crop residues and cereal products are other sources of biofuels (Mercier, 1998).

Fuel switching, from GHG-intensive fuel sources, to less GHG-intensive energy sources, will be an adaptive option for the forest sector (Forest Sector Table, 1998) particularly if firms see tangible benefits to them of undertaking these changes. There are 7 million bdt of surplus wood residue in British Columbia, Alberta, Quebec and Ontario (Wellisch, 1998). Annually 450 petajoules of bioenergy from hog fuel and logging residues is either burnt without energy recovery, or diverted to landfills (Logie, 1998). This figure does not include waste paper and other forest products that are often transported to landfills. Landfills not only store potential bioenergy, they also emit methane. If these potential sources of bioenergy were either utilized before they reached the landfill, or if the methane emitted during their decomposition was collected and burnt to generate energy (Hornung, 1998), this would be environmentally beneficial. Pearce (1997) goes as far as arguing that it may be environmentally preferable to burn waste paper, rather than recycling it.

Bioenergy is thought to be an effective way to reduce carbon emissions (Kurz, Apps, Webb & McNamee, 1992), as long as the wood biofuel is harvested sustainably.

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[24] At present, wind and solar energy are more costly than conventional energy sources, and therefore they currently play a marginal role (Mercier, 1998).

Although, the use of biomass energy results in GHG emission, it is usually considered to be 'CO2 neutral' because the carbon contained in the biomass material was sequestered from the atmosphere (Mercier, 1998). Thus, the use of bioenergy leads to a dynamic carbon cycle between biomass and atmospheric GHG. The burning of fossil fuels, alternatively, leads to constant accumulation of GHG into the atmosphere (Swisher, 1997).

*Domestic policy instruments*

Encouraging actions such as fuel switching to bioenergy, enhanced forest carbon sequestration, product substitution, and improving energy efficiency, are alternative ways in which the forest sector and forest products can contribute to a reduction of GHG emissions in Canada. These actions, however, may in some cases (though not necessarily all) require policy and/or program interventions. The purpose of these interventions may be to either provide funds for programs that deliver certain outcomes (e.g. planting programs for afforestation) or change incentive structures so that firms and consumers adjust their behaviour in order to reduce emission rates. Domestic policy options include regulation (e.g. the establishment of energy efficiency standards), program development (e.g. government funding support for afforestation, research and development), and market-based instruments. Market-based instruments include, carbon taxes, and various carbon trading systems (see table 3). Although market policy instruments are important, few economists believe that they are the complete solution (Rolfe, 1998a).

The attraction of market based instruments is that decisions regarding how to achieve an environmental goal are transferred into the market place. It is suggested that market instruments provide a mechanism to achieve an objective at minimum social cost. This is because producers will tend to seek technologies and cooperative strategies that minimize costs. It is in the best interests of both industry and society to apply market based instruments in all circumstances where such mechanisms are feasible to apply. The example provided in figure 7 demonstrates the potential advantages of having the ability to trade carbon credits between the forest sector and the energy sector. The choice and mix of policy instruments must consider various factors. These include the least cost approach, economic efficiency (i.e. maximization of the stream of net benefits over time discounted to present value), transaction costs, the level of burden placed on producers and consumers, equity considerations, political and social acceptance and feasibility, crowding out, environmental effectiveness, technical feasibility, flexibility, and ease of implementation, measurement, verification and enforcement. Many of these considerations are complex and some are based on value judgements. The uncertainty associated with climate change makes policy choice and implementation even more difficult (see subsection 3.2), as appropriate levels of taxes, quotas, permits and/or caps are unclear[25]. Another key consideration for policy choice are the limitations and constraints relative to international recognition of what actions can be used for carbon

[25] For more detailed information on policy instrument options and choices related to climate change and the Kyoto protocol see, Chapter 11 in the IPCCc (1996), Commission for Environmental Cooperation (1997), and Rolfe (1998b).

credits towards Canada's contribution to GHG emissions reduction under international agreements (e.g. the Kyoto protocol).

Comprehensive and clear identification and definitions of actions and activities that will permit Canada to claim a credit against emission reduction targets under the Kyoto protocol (or other future international accords) are a fundamental consideration for policy interventions to encourage sequestration. Unfortunately, it appears that the Kyoto protocol is neither clear nor comprehensive. Again we extract from the National Sinks Table (1998) to describe the issue:

> "By limiting the actions humans can take to enhance sinks to afforestation and reforestation undertaken after 1990, the Protocol has fundamentally changed the accounting system and the way in which we look at forests and land-use changes. It has produced a new forest, the so called "Kyoto Forest", which for many Parties represents a small fraction of their existing managed forests and is a radical departure from an historical perspective on the management of forests for commercial timber production."
>
> "Article 3.3 of the Protocol specifies that GHG emissions and removals that result from three specific direct human-induced land-use changes and forestry activities are to be used in meeting the emission reduction commitments of Annex 1 countries in 2008 - 2012. These activities are reforestation, afforestation, and deforestation activities since 1990. The impact of these activities is to be measured as the verifiable change in carbon stock between 2008 and 2012. It is this amount that may help meet the emission reduction commitment in 2008-2012, by offsetting some fraction of the gross emissions in the commitment period."

A number of issues around the treatment of reforestation, afforestation and deforestation (RAD) remain unresolved and are discussed in the National Sinks Table (1998). These are;

1. definitions of each RAD activity;
2. the total area included in the Kyoto forest;
3. carbon pools that are included (above ground biomass, below ground biomass, soil C, litter and harvested forest products);
4. the baseline to be used for measuring carbon stock changes when an area becomes Kyoto Forest after January 1st, 2008 (the carbon commitment period); and
5. methodology for carbon stock change accounting.

A final important point made by the National Sinks Table (1998) is:

> "The reporting requirements of the Kyoto Protocol cannot be fulfilled with the inventory information and models currently available in Canada. Considerable

investments into research and information technology will be required to be able to provide internationally credible estimates of the verifiable change in C stocks."

The above suggests that any discussion of possible explicit policy instruments to enhance carbon sequestration is probably mute until clearer and more acceptable definitions of forest land, carbon stock, afforestation, reforestation and deforestation have been adopted within Kyoto or other international accords. Moreover, it is clear that significant enhancement of carbon stock accounting capacity will be required before it is possible to provide verification.

It has been suggested that terrestrial carbon should be included in a full carbon, long term accounting system, of which the Kyoto Protocol partial accounting system could be a subset (IGBP Terrestrial Carbon Working Group, 1998). All components of the ecosystem must be considered, including soil, peat, above and below ground vegetation, products, fossil fuel consumption and substitution (Price & Apps, 1996). Changes in the carbon budget must be compared to an established and defined, "business as usual" baseline which will enable substantiation that carbon sequestration is real and additional (Sedjo, 1998). The Canadian Boreal Forest Transect Case Study can be used to help validate these findings (Price & Apps, 1995).

Credible measures of carbon values can provide a useful benchmark for assessing programs and policies. However, the value of carbon can be interpreted in a number of different ways. For example, the value of carbon could be derived from a marginal damage curve that plots economic damages against atmospheric GHG concentrations. The value of carbon from this perspective is the amount of damage averted by reducing atmospheric concentrations by 1%. (Note that this measures the value of carbon emission reduction only. The value should also be compared to the cost of reducing the carbon). Another way of placing a value on carbon is to develop a marginal cost curve for carbon abatement (see figure 7). In this case, the value of a unit of carbon sequestered is equal to the cost reduction of moving down the marginal emissions abatement curve. This variety of interpretations leads to some variation in carbon values in the literature. Carbon values range from $5 and $300 per tonne (Thompson et. al, 1997). These estimates are, however, highly speculative, imprecise and probably do not apply to Canada. Research into the value of tradable carbon (i.e. carbon credits and debits which can be measured, monitored and verified) is therefore required.

| **Table 3.** Market Based Instruments | | | |
|---|---|---|---|
| | **What is traded?** | **Cause of emissions reductions** | **What determines the distribution of costs?** |
| **Cap and Emission Allowance Trading** | GHG emission allowances, which represent a license to emit a tonne of CO2 (or equivalent). | A cap on total allowable emissions. | If allowances are auctioned the distribution of costs is determined by the manner in which the revenue is used by the government. If allowances are allocated free of charge, the distribution of costs is determined by who does not receive a free allocation[26]. |
| **Cap and Carbon Allowance Trading** | Carbon allowances, which represent the right to import or produce a tonne of fossil fuel carbon. They may be tradable with emission allowances. | A cap on total fossil carbon used. | The manner in which tax revenue is used by the government. |
| **Credit Trading** | Credits for an emission reduction from a projected baseline. | The stringency of emission reduction standards, the threat of regulation and corporate voluntary commitments. More stringent regulations are needed to maintain the cap. | The stringency of emission reduction standards. |
| **Carbon or Emission Tax** | The tax represents the price of the right to emit carbon or GHGs. | Increased price of fossil carbon based fuels. Increases in the tax may be necessary to maintain the cap. | The manner in which tax revenue is used by the government. |
| Adapted from: Rolfe, 1998a, p 5. | | | |

[26] See Cramton & Kerr, 1998a and 1998b, for a comparison of auctioning and grandfathering tradable carbon permits. (Auctions are found to be preferable.)

### *4.6 Summary*

This section has provided different case studies to illustrate impacts, adaptation options and mitigation strategies that are likely to be of relevance to the Canadian forest sector under climate change. For example, changes in timber supply will effect international and Canadian timber markets, as shown in subsection 4.1. Non-market values of the forest will be impacted and possible options to adapt to these changes were suggested in subsection 4.2. The interactions between the forest sector and both the agriculture sector (especially in terms of land use, see subsection 4.3), and the energy sector (see subsection 4.4) were discussed. Finally, mitigation strategies for the forest sector (including carbon sequestration, wood products replacing more GHG intensive products, reducing fossil fuel use and increasing bioenergy use) were outlined. Adaptive options and policy issues related to these mitigation strategies were also examined. Throughout this section, the need for greater understanding of the complex issues covered was apparent. Therefore, the next section provides methodological approaches that can be used to aid in the assessment of these issues.

## 5. Methodological Frameworks for Assessment

This section provides a review of methodological frameworks for supporting policy decisions related to the assessment of climate change impacts, adaptations, and mitigation strategies. Given the importance of integrated assessment in analysing climate change policy options, the section provides a brief review of physical models and more detailed information on economic frameworks for assessment.

### *5.1 Physical models*

Physical models that either directly model climate change and ecosystem responses, or have been applied to climate change issues, are discussed in this section. These models vary in many different ways. For example, they vary in terms of their spatial extent, whether they provide steady state or dynamic predictions of ecosystem change, whether they include disturbance regimes, the choice of forest types, the treatment of uncertainty. Due to the economic, rather than physical backgrounds of the authors, this section will be limited to the provision of a basic background discussion of physical models. Namely, climate models, biome/ecosystem/vegetation response models, as well as a brief discussion of paleo data.

*Global and regional climate models*

Global general circulation models[27] (GCMs) are the main modeling tool used to simulate how future climate will respond to changes in atmospheric concentrations of GHG. They use mathematical equations to describe the fundamental physical principles of behavior and interactions between such components of the earth as the atmosphere, snow, ice, vegetation, land surfaces and oceans (Kacholia & Reck, 1997). There are a number of different models in existence. These models vary in their choice of parameters, complexity, comprehensiveness and feedback mechanisms. They also vary, to some extent, in their predictions of future climate change.

The results from general circulation models include expected changes and variability in temperature (annual and seasonal), precipitation (annual and seasonal), cloud cover, and so on. However, major uncertainties revolve around the different parameters, especially clouds, aerosols and ocean (Kacholia & Reck, 1997). Further, differences in the modeling of dynamics and feedback mechanisms associated with the different parameters result in varying future predictions. Although the results from different GCMs vary, these variations can (and have been) used to develop ranges of possible future climate scenarios rather than relying on the result from any single model (Williams, et. al, 1998).

[27] For further information, see Shackley, et. al (1998) which provides a detailed critique of GCMs, focusing on their complexity, the uncertainties involved, and a comparison with other models.

Most GCMs assume that vegetation distribution will remain static under climate change. However anthropogenic land use changes and climatically induced changes in natural vegetation distribution will occur within the time frames of GCMs. Therefore the inclusion of the static vegetation distribution has important ramifications for the accuracy of GCMs. This is because vegetation types have differing effects on surface albedo, evapotranspiration, moisture convergence and precipitation, and therefore on climate (IPCC, 1996a). Biogeophysical feedbacks are also important and have been excluded from GCMs, except in the cases where GCM models have been coupled with vegetation models.

The analytical sophistication and spatial nature of GCMs, coupled with the enormous size of data bases required to run them and limitations in the capacity of most computers to handle the required database sizes and computational requirements (GCMs runs are conducted with supercomputers) means that most general circulation model outputs are conducted at a course scale of resolution (Caya, et. al, 1995). As a result of these constraints various approaches that simulate regional climate by limited-area models coupled with global low-resolution models have been developed, including the Canadian Regional Climate Model (Caya, et. al, 1995). Regional climate models provide more accurate predictions of future climate at a local level because they incorporate land form effects such as mountain ranges and large water bodies.

*Biogeographical/biogeochemical ecosystem models*

Biogeographical and biogeochemical ecosystem models are two classes of ecosystem models that have been used in integrated assessments of climate change (e.g. Mendelsohn & Neuman, 1999). Biogeographical models predict the future steady state distribution of ecosystem types based on various climate scenarios. Biogeochemical models provide steady-state predictions of future productivity for particular ecosystem types. The combination of the two types provides the capability to simultaneously evaluate future changes in ecosystem distribution and ecosystem productivity (measured in terms of biomass) with climate change. A limitation of these models is that they only provide predictions of some future steady state. They do not describe transient responses of ecosystems over time. Nor do they take account of the processes that cause an ecosystem to change from one type to another (Sohngen & Mendelsohn, 1999).

BIOME2 (Haxeltine, et. al, 1996), MAPSS (Neilson & Marks, 1994) and DOLY (Woodward et. al, 1995) are three examples of biogeographical models. Although each of the models are distinct, they have some common features. The biogeographical models are based on "mechanistic relationships" between various types of factors determining species and plant growth (Sohngen & Mendelsohn, 1999). When tied to GCM outputs, the models predict future ecosystem distributions by assessing future combinations of plant growth factors (including new climate regimes) and defining a set of boundaries which match species combinations (called biomes) to future conditions.

BIOME-BGC (Running and Gower, 1991), and Century (Parton, et. al 1988) are two examples of biogeochemical models. As was the case with biogeographic models, biogeochemical models are distinct in terms of the underlying ecological processes modeled and they provide varying estimates of ecosystem productivity. They are, however, similar in terms of output variables. These models quantify net primary productivity (a flow variable which measures periodic biomass accumulation) and total biomass (the total stock of biomass measured in grams of carbon per square meter) for particular ecosystem types. When tied to GCM outputs, the models predict future biomass accumulation. Comparisons of biomass accumulation with and without climate change, therefore, can be used to provide an indication of the effects of climate change on ecosystem productivity (Sohngen and Mendelsohn, 1999).

*Vegetation models*

Whereas biogeographic and biogeochemical models provide steady state predictions of future ecosystem conditions, vegetation models describe changes in ecosystems over time. Vegetation-dynamics models, (which include forest succession models), can model Type A vegetation responses. Type A vegetation responses are those primarily caused by the differential effects of climate on the regeneration and growth of different plant and taxa types. Problems with these models include unrealistic assumptions of stylised climatic responses, unrealistic growth equations, and so on (IPCC, 1996a). Type B vegetation responses include those resulting from changes in ecosystem structure and composition resulting from, for example, changes in disturbances such as forest fire (IPCC, 1966a).

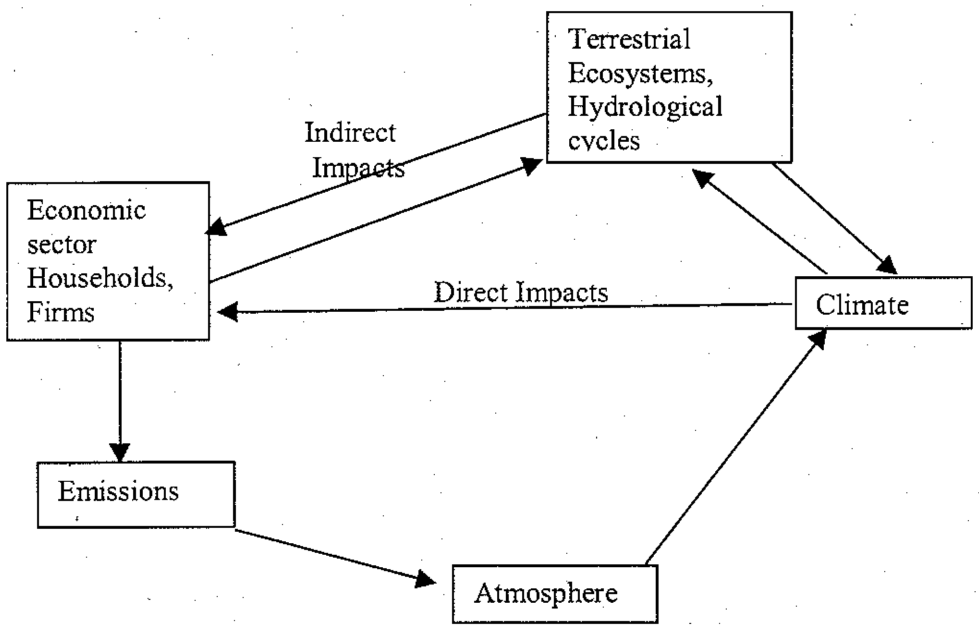
*Paleo models*

Paleo approaches can be used to provide estimates of future ecosystem conditions and distributions (under climate change) based on historical relationships between climate and ecosystems. Historical relationships are developed by examining fossil pollen data (which shows historical ecosystem distributions) and through the analysis of charcoal in lake sediments (which provides an indication of fire history in an area). Paleo approaches to estimating future conditions and the various models described above are complementary.

### *5.2 Evaluation of Existing Economic Impact Analysis & Integrated Assessment Tools*

Because of the long-term nature of climate change and the extreme complexity of atmospheric, ecosystem, and economic systems and their interactions (see subsections 2.1 and 2.2), quantitative estimates of long term impacts and adaptations will be subject to high levels of estimation error. The possible sources of such error are numerous and include model mis-specification, data errors, incorrect assumptions, low resolution of biophysical models, lack of complete knowledge, irrational behaviour, etc. Two strategies for dealing with this issue are a) to undertake sensitivity analysis by changing the underlying assumptions, and b) to use multiple combinations of climate, ecosystem response models, and economic models to evaluate orders of magnitudes of impacts and ranges of impacts. The use and interpretation of integrated assessment models will, however, need to be used with caution and with a complete awareness that these results are speculative.

**Figure 8:** The Interactions Between Human Actions & Climate Change




Economic impact assessment is difficult because human actions create climate change impacts through a complex process that includes feedbacks from the climate system back to human behaviour both on the adaptation and on the mitigation side. This can be illustrated using the simple flow diagram in figure 8. Human activities create GHG emissions, which are diffused into the atmosphere. These emissions change the climate. The climate may have a direct impact on human beings via the weather or it may have an indirect effect through impacts on terrestrial systems, hydrological cycles or other important terrestrial and oceanic processes. The last linkage in this system finally connects human activities back to terrestrial ecosystems. Human actions both affect and are affected by changes in terrestrial ecosystems. For example, changes in ecosystems occurring as a result of climate change will affect human activities. Humans will respond through various types of adaptations. These adaptations will in turn feedback to and result in further changes to terrestrial ecosystems. Each link in the system is complex. The degree of complexity is multiplied as one moves from one system to another, through intermediate system/s. The level of complexity will be the greatest at the point of making the economic valuation.

The purpose of this subsection is twofold. First, we outline several methods of analysis that have been used in climate change research. Second, we review some of the strengths and weaknesses of these different methods. By no means is this a comprehensive survey.

Our intention here is to give an idea of what types of analysis have been applied and some of their strengths and weaknesses.

*Integrated assessment*

Integrated assessments combine knowledge (sometimes in the form of models) from a variety of disciplines. Integrated assessment models (IAMs) generally include some combination of general circulation models, ecological models and economic models. The motivation for developing IAMs is to provide input into policy making for mitigation and adaptation and to allocate scarce resources for climate change research (Dowlatabadi, 1995). The IPCC (1996c) suggests that integrated assessments provide a number of benefits including coordination of assumptions from different disciplines and introduction of feedbacks among disciplines. Economic analysis and climate change impact assessments clearly require integration of disciplines at various levels. A wide variety of integrated assessment models have been developed. A review of these is provided in Dowlatabadi (1995) and IPCC (1996c). We do not attempt a similar review here but rather attempt to give some flavour for selected models and analytical frameworks that we feel have particular relevance to the forest sector. They include a) cost-benefit/decisions analysis/multi-criteria analysis, b) optimal rotation and carbon sequestration models, c) optimization models, d) partial equilibrium models and e) general equilibrium models.

*Cost-benefit/decision analysis/multi-criteria analysis*

Cost-benefit analysis is a widely used tool in economic analysis. The following discussion examines the suitability of cost-benefit analysis as a tool for the analysis of climate change policies. In one sense, this is a difficult task because economic tools are not rigid. If one tool is not suited to a particular task because some assumption is violated, then there are usually methods for extending the method to account for the violated assumption. Certainly traditional cost benefit analysis, which is suited to marginal changes or small changes in an overall economy, are not appropriate for many climate change policy analyses. Cost benefit analysis relies on partial equilibrium analysis where only one relevant sector of the economy is considered. A major assumption is that feedbacks due to policy change in the sector create small responding changes in the rest of the economy. Since many climate change policies affect large segments of the economy or have widespread impacts it is difficult to justify cost-benefit analysis as it is traditionally applied. This is why general equilibrium analysis has been extensively applied in the analysis of climate change options (i.e. Jorgenson & Wilcoxen 1992, Nordhaus 1994a, Norhaus & Yang 1996, etc.). However, we believe that cost-benefit analysis does have its place, particularly if it is appropriately extended to account for its shortcomings, and may have some advantages over general equilibrium analysis for some types of analysis. However, it is important to realise that cost benefit analysis even if extended to account for some of its problems is certainly stretched in climate change research, but perhaps not more than in other areas where it is applied (Portney, 1998).

The basic framework of cost benefit analysis is to compare the costs and benefits of two or more policy or management options. To justify a new policy action the benefits that the policy generates must exceed the costs of putting that policy into action. If there is more than one alternative, then one should choose the alternative whose benefits exceed costs the most. This kind of criteria clearly requires converting all costs and benefits into monetary units. This is what distinguishes cost-benefit analysis from other forms of analysis such as multi-criteria analysis, which does not require conversion of all costs and benefits into monetary units.

There are several major challenges in applying this method. First among these is the valuation exercise itself. Valuation of costs and benefits should be based on total economic values. In the case of climate change, this should include all impacts on human values including health and human made physical, cultural and ecological capital. For example, in an analysis of forest management options in British Columbia (Thompson, van Kooten & Vertinsky, 1997) values were estimated in four categories: (1) timber production values, (2) carbon uptake values, (3) preservation or non-use values, and (4) recreation values. (Note that this study is described later in the part on general equilibrium models). Because of the difficulty of estimating all values associated with a particular policy change, most economic analysis simply cannot hope to account for all costs and benefits.

For this reason other techniques such as multicriteria analysis and cost effectiveness analysis have been developed for cases where not all benefits and costs can be quantified in monetary terms (IPCC, 1996c). Cost effectiveness analysis requires that benefits be held constant across all alternatives. Hence, in evaluating reaching a target level of GHG emissions one could conceive of a set of alternatives that would achieve this target level of GHG emissions. Cost effectiveness analysis attempts to find the least cost alternative. Multicriteria analysis is a technique developed to address situations with multiple objectives – objectives that may go beyond pure economic efficiency concerns. While valuation techniques have been developed to capture benefits that were formerly not estimable, some of these techniques are still controversial. Multi-criteria analysis was developed to address situations with multiple objectives – objectives that may go beyond efficiency concerns. It is a tool that can be used to identify tradeoffs between conflicting objectives.

Another major challenge to the application of cost-benefit analysis to climate change issues is that costs and benefits of climate change and the policies to either adapt to or mitigate are uncertain. This uncertainty falls on many levels. For example, there is uncertainty about the extent of physical impacts, how quickly these impacts will occur, valuing costs and benefits of impacts, the costs of mitigations, and about how various policies will be implemented. Decision analysis is a technique that extends cost-benefit analysis and other forms of economic analysis to determining optimal decisions under uncertainty. Decision analysis denies the argument that uncertain outcomes are a reason for inaction but rather a reason for developing rational strategies that directly account for uncertainties in the costs and benefits of alternatives courses of action. Decision analysis is also a useful framework for analysis of the value of information. Decision analysis begins with an explicit definition of a structural model that identifies the linkages between various components of a system. For example, in the case of forest carbon sequestration it is likely that a forest growth model would have to link to a carbon accounting system. The carbon accounting system should track carbon in above ground biomass and soils over the life of the forest stands, and then through the forest products processing system, consumer sector and into waste streams. In addition, the model might need to be linked to a forest disturbance module. Each linkage will have degrees of uncertainty associated with it, and decision analysis techniques would require the definition of relevant probability distributions. Decisions are then evaluated based on the highest expected value of decision or the conversion of expected values into certainty equivalents (certain returns which would be accepted instead of risky investments which yield higher expected returns). Decision analysis can be used to place a value on a research program that would eliminate or reduce some of the uncertainties. This may be an extremely valuable approach given the large uncertainties present in climate change science.

Another issue related to that of uncertainty is that of irreversibilities. One example of this arises because greenhouse gases are stock pollutants, and these gases are reabsorbed by the biosphere at a rate much lower than the rate of GHG emissions. Hence, reductions in emissions do not diminish the stock of gases in the atmosphere very quickly or at all. For reductions in the stock to occur we depend on slow natural processes which effectively make decisions concerning greenhouse gases reductions irreversible. That is failure to reduce now makes it impossible to respond later in response to direct climate change damage because of the long life of gases in the atmosphere (IPCC, 1996c). This is one of the reason that Nordhaus et. al (1996) find that mitigation policies have a minimal impact in the short term. Irreversibilities can be built into cost benefit analysis by accounting for them in terms of the costs of decreased future flexibility. This extra cost is called quasi-option value and it requires that decision-makers need to recognise potential irreversabilities and reduction in potential future options, and then respond by planning for future flexibility.

Another source of uncertainty is the complexity of the earth's climate systems, which may make it inherently nonlinear. Hence, effects may be relatively minor for a long time and then a critical point is reached where part of the climate system makes a sudden change that may have catastrophic consequences.

Another major challenge with the application of cost-benefit analysis for mitigation options is that mitigation efforts in any one country create benefits that are diffused over all other countries of the world. This is the global public goods characteristic of climate change mitigation efforts (Schelling, 1992). Hence, if cost-benefit analysis only accounts for the benefits that accrue within the borders of the country, then benefits may be vastly underestimated. However, attempts to do valuation outside of national borders can be extremely difficult. Valuation of impacts within one's own country is difficult enough. One practical solution to this problem is to essentially ignore the valuation problem and simply look for least cost options for meeting reductions specified in international agreements.

Despite these problems and limitations, cost benefit analysis techniques have an important advantage. They force policy analysts and policy makers into a formal analytical process that can often illuminate the critical issues that bear on the decisions that need to be made. It has been said that this rigorous process is often more beneficial than the actual results of the analysis (IPCC, 1996c)

Perhaps the most comprehensive cost benefit analysis was carried out by Cline (1992). This cost benefit analysis is carried out on a world level. The policy choice is to pursue aggressively the cutback of carbon emissions to 4 billion tons annually and then to freeze at this level. The analysis attempts to estimate the benefits of reduction as well as the costs of reduction. The benefits of reduction are in terms of reduced damage. Agricultural losses were estimated at about $18 billion US (using a benchmark warming of 2.5C). Other potential losses from climate change were: losses from seal level rise at about $7 billion, increased electricity requirements for air conditioning (an adaptive response to increased climate) at $11 billion, lower runoff into water basins at $7 billion, increased urban pollution associated with warmer weather at $4 billion, increased mortality from heat stress at $6 billion with value of life conservatively estimated at lifetime earnings, lumber value of forest loss at $3 billion, ski industry loss at $1.5 billion. The total annual overall loss was estimated to be $60 billion annually or 1 percent of GDP. These do not include certain intangible, losses such as species loss. With higher warming levels Cline estimates these losses to be 2 –4 percent of GDP. A unique feature of Cline's analysis is that it bases estimates costs on synthesis of costs estimated with general equilibrium models. The final benefit costs synthesis suggested that cutbacks on carbon emissions to 4 billion tons annually yields a C/B ratio at point estimates of ¾ - suggesting that this level of mitigation is not warranted. However, if cost benefit analysis is adjusted to account for risk aversion the cost benefit ratio is 1.3. Furthermore, potential for catastrophe boosts these cost/benefit ratios further. Hence, climate change mitigation efforts at this level are justified once risk aversion and the potential for catastrophe is introduced to the analysis.

Many factors affect the choice of the optimal mix of mitigation and adaptation strategies. These include the fact that greenhouse gases are stock pollutants (meaning they persist in the atmosphere for long periods of time), there are asymmetrical distribution of costs and benefits, and uncertainties concerning climatic change impacts, due to a lack of data and the risk of nonlinearities within the climate system. These different issues are outlined in the remainder of this section.

Stock characteristics occur in climate change because the GHG emission levels in a given year are small when compared to the stock of GHGs. The climate system will therefore not respond much to short-term, current actions (i.e. those proposed under the Kyoto protocol), but will only significantly respond to long-term and sustained actions to reduce atmospheric GHGs. Hence, once the damages from sustained GHG output become evident it will probably be too late to change the GHG stock levels quickly enough to have an immediate impact on reducing the damages, in other words the climate change problem may have become irreversible.

Asymmetrical distribution of costs and benefits are likely to occur under climate change. For example, some countries are likely to have higher costs of mitigation than others. However, this issue is arguably being addressed within joint implementation, where high mitigation costs in an Annex 1 country (i.e. Canada) can be exchanged for lower mitigation costs in a non-Annex country (i.e. Argentina) within the Kyoto protocol. The costs and benefits of climate change are also likely to vary between different countries, regions and locales. Therefore equity issues concerning the asymmetrical distribution of climate change related costs and benefits need to be addressed. Especially as some poorer countries, who could have few resources with which to adapt to climatic change, and high levels of net costs relative to their GHG emissions, may need international assistance and compensation for the climate change damages they experience.

*Novel approaches to the application of cost-benefit analysis*

Application of the traditional approach of cost-benefit analysis to problems with long time horizons requires making assumptions about the values of future generations as well as projection and estimation of costs and benefits over long time frames. Even present costs and benefits are difficult to determine. Portney (1998) suggests another way to formulate the problem calling it "the climate change referendum". Portney (1998) suggests that the problem of determining how many resources to divert to adaptation and mitigation strategies for climate change may be viewed as a problem of social insurance. This approach is useful because it avoids the problem of estimating all future costs and benefits of adaptation and mitigation. The assumption with this approach is that these future costs and benefits will never be precisely estimated. This view also tries to avoid the problem of selecting a discount rate, which is very difficult and should be avoided (see subsection 3.1).

Instead the referendum approach says lets ask the following question: "How much are members of the present generation willing to pay to reduce the likelihood of a stream of adverse effects (and some positive effects) happening in the future to an entirely different group of people, most of whom are not now alive and when they are will be living in different countries?" With the referendum approach, if aggregate willingness to pay over all individuals living today is greater than the cost of the corresponding reduction policy, then based on efficiency grounds alone the policy should be implemented. On the other hand, if aggregate willingness to pay is less than the cost of the policy, then the policy should not be implemented unless there are other compelling reasons for doing so (i.e. the equity reasons discussed in subsection 3.1).

There are several advantages to this approach. First, the current generation will decide what and how many resources to pass on to the next generation. They will also decide the state of the biosphere that will be passed on to the next generation. The referendum approach will do this with regard to ethical debates that are made about intergenerational allocations of resources. Hence, this approach closely approximates the political decisions that will be made regarding reduction of GHG emissions. The referendum approach also eliminates the need to guess or make assumptions about how future generations will value perceived costs and benefits.

Implementation of this approach involves giving members of the present generation a description of likely impacts and the likely changes in these impacts under various climate scenarios and mitigation and adaptation policies. This will allow each individual to choose their own discount rate for assessing the time paths of outcomes of both no-response and mitigation and adaptive policies. Hence, the problem of choosing a single social rate of discount is avoided.

This approach does not avoid all problems. For example, there is still a need to describe the series of possible outcomes and the likely impacts of new policies as accurately as possible. The referendum approach also requires ascertaining willingness to pay for a stream of alternative outcomes as compared to some baseline.

*The optimal rotation and carbon sequestration*

In subsection 4.5, forest carbon sequestration options are discussed. But how does carbon sequestration affect harvest rotations or roughly translated, the rate at which forests should be harvested? The optimal economic rotation rule may be an important tool for analysis of existing forest stock resource management and rotation decisions on afforested land, especially when combined with wider more comprehensive forest management models.

Important pieces of information required for rotation decisions with sequestration go beyond the normal pieces of information required (van Kooten et. al 1995, Martin 1998, Englin & Callaway, 1993). This information includes the price of carbon, the amount of carbon per unit volume of tree biomass, the amount of carbon lost during and after harvest and the amount tied up in long term forest products such as lumber and panelling, the amount in landfills, etc. In other words the rotation decision is affected much more by things that go on in the product market and in long term capital stocks of buildings and houses. This implies the need for a more comprehensive lifecycle analysis of forest products.

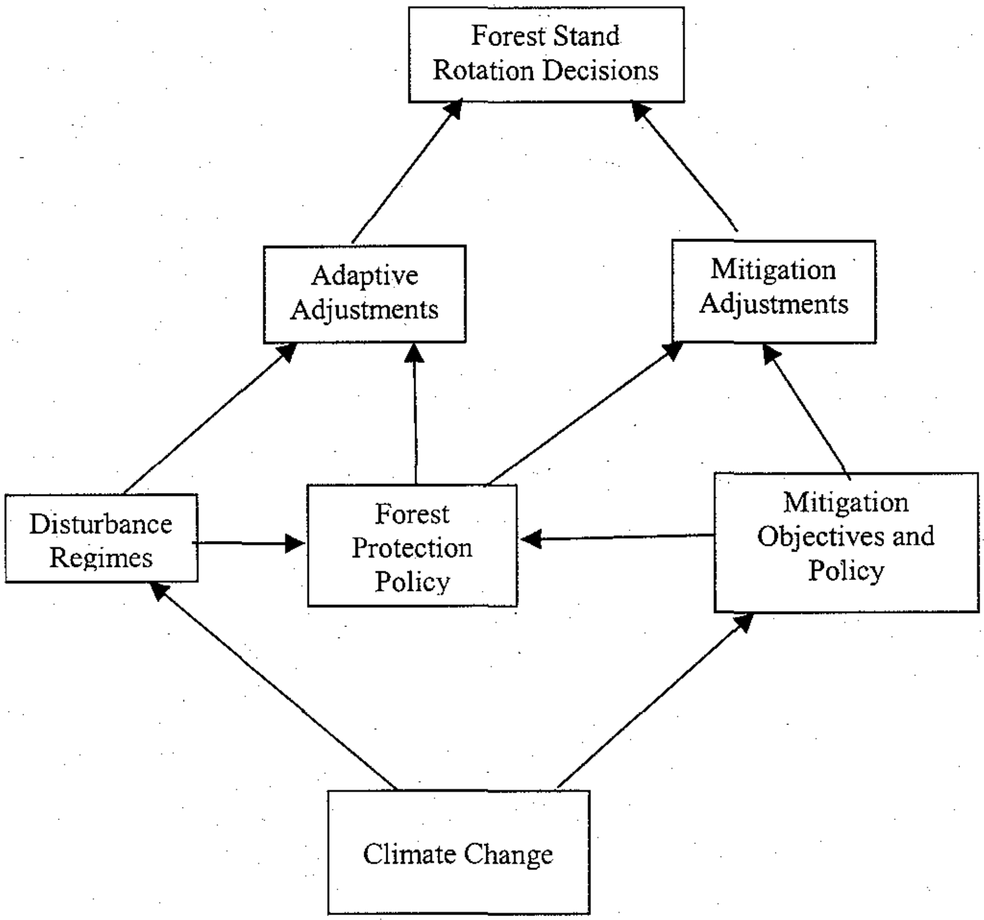
Another important factor is that both underground and above ground biomass changes as a stand grows. Thus, rotation choices will affect the amount of carbon stored in stands as well as soil carbon content. Many optimal rotation studies have considered above ground biomass only. Therefore, there is a need for studies to investigate the optimal rotation of stands with consideration for changes in both above and below ground carbon stocks.

Most studies tend to treat the price of carbon as a constant over time. However, the price of carbon should be tied to the marginal cost of abatement that ultimately is tied to the cost of abatement in other sectors of the economy such as the energy sector. Studies by Nordhaus (1994a) and others suggest that marginal abatement costs are likely to change over time. Hence, the assumption of constant price in optimal forest rotation studies is limiting.

Nevertheless useful insights have been derived. The most important conclusion that can be derived from the forest rotation studies is that the effect that carbon sequestration has on harvest rotation age appears to be to lengthen it (i.e. Martin, 1998, Englin & Callaway, 1993, etc.). A further weakness of these studies, however, is that the forest rotation analyses do not include potential for increased disturbance such as fire, disease and insect attacks, which may lead to increased rates of carbon losses and ultimately to changes in forest types and their distribution. In addition, the agriculture forestry margin may move northward by a significant extent. This points to another potential weakness of forest rotation studies which tend to treat the forest rotation decisions as part of a mitigative strategy. Forest rotation policy will also have to be adaptive in the sense that it will have to respond to these potentially increased disturbances. Figure 9 illustrates why adaptation policy is not separable from mitigation policy. Climate change leads to mitigation policy and a desire to use forests as a potential sink for carbon dioxide (i.e. a desire to increase the amount of forest carbon). This is the side that has been discussed in forest rotation papers thus far. However, little attention has been given to the other side of the diagram that has to do with the direct impacts of climate change on the forest disturbance regimes. Disturbance regimes are expected to increase in intensity. The forest industry will be required to respond to these as an adaptation simply for sake of timber supply management. These adaptive responses may lead to a decrease in rotation ages or increased rotation ages depending on the regulatory environment. Adaptive responses will be on two levels – adjustment of rotations and adjustments of forest protection policy. Forest protection policy is another example of the difficulty in separating adaptation and mitigation policy. Forest protection may be thought of as both adaptive, in the sense of protecting timber supply for forest products production, and as mitigative in the sense of stopping or delaying carbon emissions to the atmosphere that occur as a result of disturbance.

Forest rotation analysis tends to treat forest stands in isolation. That is the analysis is centred on the harvest decision of a single forest stand or hectare of forest land. These analyses can yield important insights into the management of forests. However, the analysis also suggests that a more integrated analysis is needed. This needs to occur on two levels. (1) The forest stands need to be integrated into a whole forest level analysis, and (2) the forest level analysis needs to be integrated into an economy wide analysis that includes a lifecycle analysis that is integrated with an economic model that accounts for behavioural adjustments of households and firms in response to new price and regulatory signals created by forest, and other, policies.

**Figure 9:** Linkages Between Adaptation & Mitigation Strategies




Another area that requires more analysis is the appropriate incentive mechanisms for corporations to make the optimal decisions for carbon uptake and storage in biomass. Increasing rotation age is in some sense a decision to increase the size of the current forest standing biomass. While increasing biomass may generate credits in the form of reduced requirements for mitigation elsewhere in the economy it also creates increased risk of debits created by forest disturbances. An integrated forest level analysis will allow analysis of the ability of existing regulatory structures and public land management institutions to respond to carbon storage and sequestration objectives under different policy configurations. This will also allow analysis of forest protection regimes that will have an impact on forest rotation decisions.

*Optimisation models*

Optimization models have many different forms including optimization models with single or multiple choice variables and single or multiple objectives, constrained optimization (which can be linear or non-linear in terms of their objective functions and constraints) and dynamic optimization models. Economic relationships are often presented in the form of functional relationships between variables (which can be referred to as models). Optimization involves a process of applying a series of first and second order conditions to some functional relationship to determine local and/or global maximums and minimums for the endogenous variable(s). Constrained optimization models attempt to optimize (i.e. to find the maximum or minimum value) an objective function subject to a series of constraints. Dynamic optimization models optimize functions over time (e.g. to find the value of the choice variables that maximizes the flow of net benefits over time subject to constraints).

An example of the application of a constrained optimization model to climate change is the Dynamic Integrated model of Climate and the Economy (DICE) (Nordhaus, 1994a). The model is based on optimal growth theory models. It is global in scale and it provides direct linkages between the global economy and global climate. The DICE model maximizes the "discounted sum of utilities of consumption over time" subject to a number of equality constraints that determine growth and describe the relationships between the global economy and climate. It has had much influence primarily because of the way the climate model is linked to the economic model. The model allows climate to be endogenously determined through the incorporation of various economic output/emissions, emissions/climate relationships, and policy variables (e.g. the optimal rate of emissions reduction).

*Partial equilibrium models: static and dynamic*

Partial equilibrium models determine market clearing equilibrium prices and outputs for a specific sector. Some partial equilibrium models solve equilibrium price and output on the basis of predetermined supply and demand relationships (Percy, et. al, 1989). In other cases the model is designed to solve for the set of market clearing prices and outputs that will maximize an objective function (i.e. maximization of net benefits). Static partial equilibrium models generally treat time as a discrete variable. An iterative process determines time paths for price and output. Dynamic partial equilibrium models determine price and output for all time periods simultaneously (Percy, et. al, 1989). Partial equilibrium models have three distinguishing features. First, they do not consider inter-sectoral linkages in their determination of input prices, output prices and quantity produced. Second, shifts in demand are determined exogenously. Third, they assume that the sector being modeled is small relative to the rest of the economy and that changes in output and price will have insignificant effects on broader economy measures such as investment, unemployment, wage rates, etc. (Percy, et. al, 1989).

Subsection 4.1 provided a summary of the results of an analysis by Sohngen & Mendelsohn (1999)[28] of the effects of climate change on the US timber market. The authors employed a dynamic partial equilibrium model integrated with dynamic ecosystem models. The study provides a good illustration of the application of partial

[28] The Sohngen & Mendelsohn (1999) study integrates an economic dynamic optimization model or partial equilibrium model with a climate change scenario and subsequent effects on ecosystem productivity and distribution of forest ecosystems. A separate study by Sohngen & Mendelsohn (1997) concentrates on the change in carbon storage in US forests over time.

equilibrium model to evaluate climate change impacts and adaptation. The following discussion provides a brief overview of their methodology.

We will not repeat the description of the model here, but will highlight some of its main assumptions. First, the model is an integrated assessment model. It incorporates both ecological and economic models. The ecological change models are called biogeographic models (geographic models) and biogeochemical cycle models (ecosystem production models) (these models were discussed in subsection 5.1)[29]. These models are linked to GCM climate change predictions. The ecosystem models estimate steady state changes in the distribution of ecosystems and changes in their biological productivity from climate change. The authors then translate the steady state results to dynamic responses by assuming that ecological change occurs proportionally to expected changes in temperature and precipitation. Changes from ecosystem type to ecosystem type (when they occur) are the result of two processes (the model assumes either one process or the other for all forest types). The first process is species dieback (i.e. mortality of existing species followed by regeneration with new species). The second process is called regeneration. Under this second process, existing species survive climate change but are replaced by new species through regeneration as they are harvested or lost to other disturbances. These processes incorporate lags to account for limitations in species migration speed.

The economic model is a dynamic partial equilibrium model. The key assumption of the dynamic timber optimization model is that timber markets are dynamically efficiently. This means that forest landowners will anticipate and react to changes in forest composition, location and productivity in an economically efficient manner. The assumption is that independent landowners will adjust and adapt to changing ecological conditions in anticipation of future conditions (Sohngen & Mendelsohn, 1999).

While these may be suitable first approximation assumptions for U.S. timber markets it is doubtful that these assumptions are appropriate in Canada, where most land is public rather than private and where forest tenure holders are subject to a wide variety of regulatory regimes. One of the challenges is to arrange tenure systems on public lands in such a way that management responds to external incentives created by climate change and to policy changes external to the forest sector. At present the incentives are created via direct regulation rather than economic incentives. It is not clear whether further regulation can create the right environment for optimal responses to ecosystem changes.

The model developed by Sohngen & Mendelsohn (1999) shows that it is possible to link a dynamic timber market model to ecosystem models. However, it is likely that some of the underlying behavioural assumptions would have to change if such a model was to be applied in Canada. For example, the model assumes that land managers adapt in an efficient manner to changing conditions. The adaptive responses include changes in harvesting and regeneration decisions in a way that minimizes economic losses and accelerates the transition to new forest types suitable to new climatic conditions.

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[29] The models are BIOME2 geographic model and TEM ecosystem production, the MAPSS geographic and BIOME-BGC ecosystem production models).

Without some credible understanding of future changes in timber type boundaries and timber type yield over time, it is not possible to evaluate the impacts of climate change on timber markets. Moreover, since economic agents will adapt gradually to gradual changes in ecosystems and timber types, dynamic models of ecosystem change that predict transient responses from period to period are needed. This is an aspect of the Sohngen & Mendelsohn (1999) framework that has the greatest potential for application in a Canadian context.

Sohngen & Mendelsohn (1999) develop a creative (although simplified) approach to translating steady state estimates of shifts in ecosystem boundaries and biomass accumulation to dynamic shifts in the boundaries of timber types and dynamic shifts in the yield function of these timber types. Moreover, they do not subscribe to any particular model or model combinations but adopt the approach of employing multiple combinations of ecosystem models to develop ranges of forecasted impacts. Canadian climate and forests scientists are currently actively engaged in improving climate forecasts and in developing methods to predict the transient responses of forest ecosystems in Canada. However, it will be some time before these efforts will lead to reliable national forecasts of the transient responses of Canadian forest ecosystems. The Sohngen and Mendelsohn (1999) approach (which relies on existing course scale climate and ecosystem models) may have some possible applicability in a Canadian context. However, such an approach would only be an interim measure until reliable Canadian approaches for predicting transient ecosystem changes were available.

The results are also of interest because they suggest that the distinction between adaptation and mitigation (or carbon stock protection and enhancement) may be closely tied. Effective mitigation strategies must be considered in light of long-term dynamic ecosystem responses to climate change (e.g. shifts from one forest type to another forest type or land use shifts between forest and agriculture). Sohngen & Mendelsohn (1999) show that climate change impacts will be reduced by adaptive behavior by landowners. They will consider expected future changes in the economic value of their timber holdings and make economically sensible decisions regarding harvesting and species selection for regeneration. However, the models used in their study suggest large shifts in vegetation patterns. Hence, it is important that carbon stock enhancement strategies take account of future climate change by ensuring appropriate species and site selection for afforestation/regeneration and that harvesting strategies account for the increased possibility of future dieback in some areas. Sohngen & Mendelsohn (1999) argue that because mitigation options generally consider marginal lands, mitigation and adaptation become blurred because both may lead to the same choice of land use.

*General equilibrium models: static and dynamic*

This section briefly describes general equilibrium models and provides a few examples. General equilibrium models contain representations of the whole economy either at regional, country or international levels. These models contain various levels of detail in their sectoral and household representations. In general, however, they do not model the interactions between economic sectors and resource stocks.

General equilibrium models are important because they link all sectors of the economy together allowing one to analyse how policy changes filter from one sector to another and from sectors to households. This is one of the major advantages of general equilibrium models over partial equilibrium approaches. Consideration of inter-sectoral linkages results in greater precision relative to quantifying economic effects. It also permits assessment of how changes in one sector affect other sectors. This is clearly of interest in the energy and forest sectors, because energy price increases will result in substitution toward other fuels or other inputs. This may affect the relative costs of production and prices of forest products and other substitute products. Changes in the price of Canadian forest products relative to other products (and relative to prices offered by firms in other countries) will directly affect the relative demand for forest products and other products. In addition, energy price changes will have differential effects on sectors depending on differences in the elasticity of substitution between energy and other inputs in various sectors. General equilibrium models can be used to assess the total cost (in terms of reduced economic output) of policy change. This is important relative to mitigation policy because they provide the capability of measuring the marginal cost to society of increases in energy input costs. General equilibrium models have provided some of the first estimates of the marginal cost of carbon abatement.

As was the case with partial equilibrium models, general equilibrium models can be static (where markets clear in a single time period) or dynamic (in which case market clearing equilibrium price and output paths are defined over time).

Below are three examples of previous applications of general equilibrium models to climate change analysis.

*Assessing timber and non-timber values in forestry using a general equilibrium framework – Thompson, van Kooten & Vertinsky, 1997.*

An important feature of this model is that it directly incorporates a representation of the forest sector into a general equilibrium model framework. This structure permits analysis of the impact of forest product markets on timber production. The model links a forest simulation model to a general equilibrium model of the British Columbia economy. The forest simulation model is a comprehensive forest system model describing the dynamics of the biological system and the direct effects of forest harvesting. The general equilibrium model models the province as an open economy. The simulation model shows costs and benefits of harvesting, recreation, carbon uptake and existence values. The model considers four types of values simultaneously, including timber, carbon sequestration, preservation or existence values, and recreation values.

*A regional dynamic general-equilibrium model of alternative climate-change strategies: Nordhaus & Yang, 1996.*

The Regional Integrated model of Climate and the Economy (RICE) divides the global economy into ten regions. The model determines equilibrium outputs over time of three different scenarios: "do nothing (the market solution). finding an efficient solution given the existing distribution of income (the cooperative solution), and finding the solution in which nations select policies to maximize national preferences alone (the non-cooperative or nationalistic solution)" (Nordhaus & Yang, 1996, pp. 745). Thus, the RICE model can be used to examine the difference between non-cooperative and cooperative outcomes at a global scale. Under cooperative equilibrium carbon taxes range from approximately $6 per ton (US) in 2000 to $10 per ton in 2020 and increase to about $18 per ton in 2050 and over 25$/ton by 2080. However, if the world does not cooperate then taxes remain below $2/ton for all countries. The rate of emissions control in the U.S. under the cooperative scenario increases from 9% (from a baseline) in the year 2000 to 10% in 2010, and to 14% in 2100. These cost impacts are higher than the costs that would be incurred under the Kyoto accord.

### *5.3 Summary*

This section has briefly described the key physical models of climate change of relevance to forestry, which include general circulation models, biogeographical/biogeochemical ecosystem models, vegetation models and paleo models (subsection 5.1). Many of these physical model types have been linked to economic models using integrated assessment techniques, which are discussed in subsection 5.2. Specially, cost-benefit/decision analysis/multi-criteria analysis, optimal rotation and carbon sequestration, static and dynamic partial equilibrium models, and static and dynamic general equilibrium models are examined, including examples and critiques of these approaches. The follow subsection encourages the application of some of these approaches, as part of our suggestions of future research priorities.

## 6. Research Needs

### *6.1 Synthesis & Problem Analysis*

Canada has committed itself to reduce $CO_2$ emissions by 6% below a 1990 baseline by the period 2008-2012. Achieving this target will be costly and will impact the productive capacity of Canadian industry and consumer welfare. However, irrespective of the success or failure of the Kyoto protocol, climate change will occur and the resulting ecosystem changes will also impact the Canadian economy and society. Thus a comprehensive approach that accounts for climate change impacts and adaptation, guides mitigation and adaptation policy, reflects the linkages and feedbacks between mitigation impacts, environmental impacts and possible policy responses is necessary. The purpose of this section is to provide a guide to the systematic development of a research program that develops models and frameworks that can be used to inform policy. This is important because the government wants to create a policy environment that will provide incentives to guide or steer the forest industry, forest land owners, forest managers and forest users toward optimal responses.

The review of models and methods in section 5 provides a brief summary of the many types of policy analysis tools that may be selected. These include cost–benefit analyses, cost effectiveness studies, timber supply models, partial equilibrium models, general equilibrium models and dynamic models. Each of these has advantages and disadvantages. While all of these approaches will be useful, we would like to stress the need for integrated analytical frameworks. This integration can occur on two levels. First, forest sector models can be integrated in the sense that they contain linkages to climate change via connections to vegetation and ecosystem transition models, forest resource inventories and carbon budget models. Moreover, impact and adaptation assessments should be dynamic and sensitive to regional effects so that the long term and spatial impacts of climate change can be assessed. Second, given the multiple linkages that the forest sector has with other sectors (e.g. the energy sector and agriculture) and with other countries via international forest products trade, and given that direct climate change impacts and climate change mitigation policy impacts are likely to be widespread in the economy, it is important for models to link the forest sector to other key sectors of the economy. It is not necessary, feasible or even desirable to attempt to incorporate these linkages all at once. However, it is important to have an array of analysis tools, some of which contain one or more of these linkages.

### *6.2 Knowledge Gaps for Policy Evaluation and Analysis*

In this subsection, we suggest key socio-economic policy analysis areas that require further research and evaluation using socio-economic methods. The overall goal of research in this area should be to contribute to the following broad research questions:

i. What is the overall impact of climate change on the Canadian forest economy in terms of decreases in the welfare of Canadian citizens directly involved in the forest sector, those that are indirectly involved, and those that use Canadian forests for recreational use or simply derive benefits from the existence of Canadian forests?

ii. How will Canadian citizens, forest products firms, environmental groups, and governments adapt to climate change impacts on Canadian forests and to what extent will these adaptations lessen the direct impacts of climate change?

iii. How will the forest sector adapt to changes in the economy brought about by mitigation policies in other sectors such as the energy sector?

Of course these fit into an even broader research agenda that concerns the overall impact of climate change on the Canadian economy, not just the forest sector. However, even when isolated to the forest sector alone these questions are too broad for any one research program to focus on in the immediate future. Hence, we have suggested a number of more specific research themes together with some research questions that as a whole would contribute to an integrated assessment of forest sector impact, adaptation and mitigation responses to climate change. Each research question can be interpreted as a relatively self-contained research project. The research themes, questions and methods are summarised in table 4. We would like to point out that the research themes and questions outlined below contain definite cross linkages and are very much related. Finally, it is important to note that table 4 is meant to identify research gaps that need further exploration and research. We have not attempted to suggest priorities. Therefore, the order of projects in the table should not be interpreted as an ordering of priorities.

*Research Themes*

<u>Analysis of impacts, adaptation, adaptive land use and forest land use change</u>.

In subsection 4.1 and 4.4 we discussed the possibility that under climate change optimal land use may change resulting in a shift in land use patterns over the landscape. For example, marginal agricultural land may become more suitable for more intensive agriculture and forest land may become more suitable for rangeland. More generally, climate change may alter land use suitability over a wide range of land types, including forest, cropland agriculture, rangeland, and grassland. Afforestation should also be compared to other land uses that have carbon sink implications such as agricultural options, and bio-energy. Optimal forest land use may shift across the landscape for a variety of reasons. First, forests may migrate causing the forest/agriculture margin to shift northward. Second, sequestration of carbon in forests will increase the value of land in forests on the margin provided that suitable credit is given for sequestration. Third, appropriately managed agricultural land, rangeland and grassland may also sequester additional carbon (National Sinks Table, 1998) which will partially offset the effect of changes in the value of land under forest. These land value changes will have an effect on the quantity of land available for afforestation and on what land ought to be used for afforestation.

Another important question concerns the rate at which adaptive measures are developed and adopted by landowners and users. It is important to mention at this point, that people and firms will adapt regardless of what government policies are developed. The role of government in adaptation should be to facilitate adaptation to climate change by providing information and by adapting itself by changing its institutions, rules and policies as appropriate. For example, an important consideration in research into the rate of adoption of adaptive measures by landowners and forest users is the effect of current land ownership patterns, such as the predominance of public land ownership in the forest sector, and regulatory regimes on adoption rates. More specifically, does the current configuration of mostly public forest land create rigidities or is it flexible enough to permit the required adaptations within land use types (tree species or crop selection) or the changes in land use (forest, range or agriculture) that may be required?

Shifts in land use patterns and adaptive responses to climate change by consumers, firms, landowners, and governments are components of the broader and significantly more challenging question : What is the impact of climate change on social welfare ? This is an important question because it is the basis for fundamental decisions regarding whether some kind of collective social intervention is warranted and what level of social costs are justified in solving the problem. Socioeconomic dimensions of these difficult questions are touched on throughout the report. In section 3.1 we note that there are important economic efficiency and equity dimensions that must be incorporated into policy. Integrated assessment models are the usual framework for measuring the economic efficiency implications of climate change impacts. These models evaluate the stream of net benefits under various climate change scenarios and compare this stream to a baseline simulation (i.e. the forecast stream of net benefits without climate change). The difference between the baseline and climate change streams provides an estimate of social welfare impacts attributable to climate change. A number of integrated assessment models have been developed at the global level and in the U.S. In some cases, these models focus on a specific sector of the economy and in other cases they look at multiple sectors or regions and consider the effect of inter-sectoral linkages on net-benefit streams. There is currently no integrated assessment capability in Canada. The development of a model to assess the long-term impacts of climate change in Canada is feasible, but it would require a significant resource commitment, the creation of an environment conducive to multidisiplinary research and time.

<u>Economic assessment of afforestation and forest management strategies for combined adaptation and carbon sequestration values.</u>

In subsection 4.5 we discussed carbon sequestration strategies. Van Kooten et. al (1999) have done some preliminary work in this area on the use of afforestation for sequestration of carbon on marginal agricultural land. However, there are still many issues that require examination. The Kyoto agreement currently includes only afforestation and deforestation in its carbon accounting framework (National Sinks Table, 1998). However, there appears to be some interest in expanding this to include reforestation and management of the entire existing forest carbon stock. Hence, there is a need for a more comprehensive analysis to determine how afforestation and future storage and/or harvest of newly afforested land area should fit into an overall forest carbon sequestration and storage management program. In addition, there is a need to examine the impacts of different configurations of treaty specified carbon accounting frameworks, which may not be complete, on actual net changes in carbon storage in forest biomass. In other words, incomplete carbon accounting frameworks set up by international treaties (i.e. the Kyoto protocol) for the purpose of determining Canada's, or any other countries net contribution to carbon sequestration, may create incentives to ignore other important parts of the overall carbon sink. This highlights the need for a comprehensive carbon accounting framework, regardless of what carbon accounting frameworks are implemented through international treaties.

In the context of forest and carbon management, the fundamental question is how limited resources should be allocated among investments in afforestation, reforestation, and protection of existing forest stocks from forest disturbances so as to optimise net additions or net reductions to the carbon stored in forest bio-mass, together with other non-market benefits and timber benefits. In addition, there is a need to determine how forest harvest rotations and forest management schedules should be altered to account for both the fact that carbon sequestration and storage will have value, and for the direct impacts of climate change. The direct impacts of climate change will most probably be an increase in the rates of fire, insect and disease disturbance regimes. This leads to further questions about how (i) forest rotations and management schedules, and (ii) forest protection should be altered under the joint influence of carbon sequestration values and increases in forest disturbance regimes (i.e. direct impact). Moreover, there are also feedbacks between forest rotation and management regimes and forest protection regimes. Hence, one could ask how forest protection regimes alter optimal forest rotation and management schedules? Finally, previous research on optimal forest rotation with carbon sequestration benefits points out the need to model the fate and eventual release of carbon from forest products. The implication is that the rate of decay of forest products, or more generally the fate of forest products, actually affects what forest rotations and management schedules should be chosen in the forest. Hence, there is a need to evaluate how assumptions about the mix of forest products produced, how quickly these forest products release carbon, and how recycling policy and management of forest products waste streams affect forest management strategy. In other words lifecycle analysis of forest products must be integrated into forest management policy analysis. This clearly suggests that one should also look at the possibility of managing the forest products carbon pool. These questions are further elaborated in "Assessment of forest product pool management strategies".

The preceding analysis may be carried out at various scales. Perhaps the preceding analysis is most appropriate at the management unit scale. However, on provincial and national scales changes in ecosystem disturbance regimes leads to changes in the spatial location of ecosystem types. Hence a relevant question at the provincial and national scales is: What are the optimal comprehensive carbon sequestration and storage strategies given potential forest migration scenarios? As suggested previously forest migration scenarios coupled with carbon sequestration values will affect optimal land use and hence what land will be available for afforestation and what land is optimally managed for various forest tree species.

A related area of research concerns the effect of various configurations of credit/debit systems for carbon sequestration, storage and release affect economic incentives and thus behaviour of forest products firms and therefore the net amount of carbon sequestered. For example, a clear research question in this area would be: Are perverse incentives created if afforestation is given credit (as under the current Kyoto provisions) while current forest management is not considered? In other words, if credit is only given for afforestation, what does this imply for how existing forest stocks should be managed from the forest industry's viewpoint versus how they should be managed if credit/debit systems are expanded to include sequestration and storage in existing forests? Presumably, if afforestation is given credit but management for carbon sequestration in existing forest is not there is an incentive to shift forest management expenditures toward afforestation. Hence, investments in large afforestation projects may represent a diversion of investment dollars away from other investment alternatives, investments which may include reforestation and management of existing forests, or other adaptation or mitigation strategies. Thus afforestation projects should be analysed in the context of a limited supply of capital and the potential to crowd out other beneficial investments.

The value of carbon storage in forest biomass can be thought of as being derived from offsetting potentially expensive fossil fuel emission reduction policies. Hence, forest carbon storage policies must be tied to carbon price paths derived from mitigation cost studies that focus on the rest of the Canadian economy. Various price paths have been derived for carbon for the world and various regional and country markets (see IPCC, 1996c). These price paths tend to vary depending on the underlying assumptions used in the models. Hence, there is a need to perform sensitivity analysis by determining optimal forest carbon storage policies for alternative price paths to determine if there are wide differences in optimal policies across the range of uncertainty.

Finally, Canada's forest land is relatively unproductive compared to many parts of the world. This suggests that Canada should look for potential offsets in other parts of the world. However, many of afforestation options outside of Canada are likely to be in developing countries. In these settings the stability of investments in afforestation may be in question. Hence, a complete analysis requires an assessment of the relative risks of offshore afforestation versus domestic afforestation.

Some of the preceding research questions may seem oriented to mitigation policy. However, as we have previously argued, adaptation and mitigation policy are not always easily separated. For example, forest protection provides both mitigation and adaptive benefits. However, given that adaptation and mitigation are often discussed as separate types of policy responses an appropriate research question becomes: What is the optimal mix of adaptation, mitigation and joint adaptation/mitigation strategies? How much out of the limited climate change budget should be allocated to various mitigation, adaptation, and joint mitigation/adaptation initiatives to assure the largest net flow of benefits?

Analysis of incentive mechanisms for carbon storage and management in forests

It is not enough to simply determine that carbon sequestration in forests is worthwhile as compared to other mitigation or sequestration options. Implementation is an important consideration that must be addressed, given that carbon values are inherently non-market values. When developing policies to encourage forest products firms and landowners to manage for carbon storage in forests, it is important that the correct economic signals are sent, so that firms and landowners are steered in the direction of optimal strategies.

The first issue concerns appropriate incentive mechanisms for private and public land. What kinds of incentive mechanisms are suited to private land and what kinds of mechanisms are suited to forest products companies operating on public land via long term tenures. Several sources have suggested credit systems as a means of sequestering carbon in forests via afforestation of marginal agricultural farmland (subsection 4.3). However, the theoretical literature on forest rotations suggests that while credits are required for landowners and public land tenure holders to sequester additional carbon, there is a need to tax or debit for lost carbon that occurs as a result of forest harvesting (Martin, 1998, Van Kooten et. al., 1995, Englin & Callaway, 1993). This provides incentives to hold onto carbon in forests longer than forest products companies or private landowners might otherwise. The dichotomy between what the theoretical literature says and the absence of discussion about taxes suggests a need to do research on the efficiency characteristics of various configurations of a credit/debit system for carbon gains and losses from Canada's forests.

Other related questions concern how this system would be linked to an energy carbon permit or carbon tax system and how a carbon credit/debit system might operate in an environment of uncertainty regarding the extent of future natural disturbances in forests and thus the extent of future carbon storage or loss. Another question concerns the best mix of private land and public land incentives. Finally, implementation of credit systems requires the estimation of baseline scenarios. Firms operating in such an environment will have an incentive to understate their baseline carbon sequestration or overstate carbon losses to claim as much credit as possible. Hence, there is need to understand the strategic incentives and political economy created by such a system, so that actual proposed systems minimise these strategic behaviours.

There are several types of analysis that could be attempted for this work. These include (i) applied analysis of the effect of carbon storage incentives on optimal forest management at the management unit level, (ii) theoretical analysis of the efficiency characteristics of credit/debit systems and linkages to the energy sector, and (iii) provincial and national scale integrated assessments of these policies and their effects on Canadian forests and the forest products sector.

Long term timber supply and forest products supply analysis.

This research project is related to several of the preceding projects. However, rather than focusing on land use change, forest migration, forest rotations, management schedules or resource allocation, problems this project should focus on timber supply at the national and provincial levels. The analysis should use the same modelling frameworks suggested for these preceding projects and should attempt to incorporate as many of the important factors suggested that will ultimately affect timber supply. This type of project would prove useful if it could provide projections of marginal costs of supply for comparison purposes with similar outputs from world timber supply and other regional timber supply models.

Assessment of forest product pool management strategies

As suggested earlier, management of forest products carbon pools will have an effect on the overall carbon flux of the Canadian economy but also the best management options for Canada's forests. Hence, there is a need to answer such questions as: What is the optimal production of solid wood and paper products given market demand and supply constraints? In addition, since carbon emissions must be seen in the context of market failure there is a need to examine what types of government policy interventions would be required to steer the private market in the direction of the optimal production mix. The analysis should also be a complete lifecycle analysis of forest products from harvest through to the management of waste streams via recycling and landfill management policies. There is also a need to compare the characteristics of forest based products lifecycle with that of possible substitutes, such as steel. However, lifecycle analysis must be connected to behavioural models because current product mixes, input mixes and waste streams are likely to change with changes in relative prices brought about by climate change mitigation policies.

Assessment of energy cost impacts and adaptation strategies

Carbon taxes or carbon permit systems imposed either on the sale of fossil fuels or on carbon dioxide emissions will increase the cost of fossil fuel consumption. While all manufacturing industries will have to adjust to this change, energy intensive industries, such as the forest products industry, will have to adapt the most. One advantage that the forest products industry has over others is a competitive advantage in the use of bioenergy from waste wood generated during the production process. This advantage gives the forest products industry the potential for substitution away from fossil fuels to biofuels more readily than other industries. Hence, a series of needed empirical studies arise. These include an analysis of the impacts of carbon taxes or permits on the forest products mill energy management. More specific studies might include an analysis of the costs and benefits of increasing co-generation capacity under increased fossil fuel energy costs as well as an analysis of the impediments to co-generation in the forest sector. Finally, an assessment of the economics of biomass plantations for energy in a high cost fossil fuel energy economy are warranted.

Analysis of inter-relationships between the forest sector, other Canadian sectors and trade responses

There are many reasons for linking forest sector models with other key sectors of the economy, such as energy and agriculture. For example, afforestation and carbon storage policies for Canadian forests will ultimately have to be assessed in the context of the larger economy. As suggested in the preceding discussion on incentive mechanisms, there is a need to examine the linkage between forest carbon sequestration/release and carbon permit or tax systems. In addition, there is a need to analyse forest sector, energy sector and agricultural sector linkages through energy cost impacts and linkages to greenhouse gas emission reduction policies. How does energy cost increase impact the forest sector and agricultural sectors and how can these sectors reduce cost of achieving greenhouse gas reduction targets? These energy cost impacts are essentially direct impacts. However, energy cost increases are also likely to have indirect impacts on the forest industry. For example, energy cost increases are likely to change relative prices between forest products and forest product substitutes such as steel beams. Hence, an analysis of substitution possibilities among various forest industry inputs and the technological capacity of the forest sector to adapt to new relative prices created by climate change mitigation policy is warranted.

Given that the Canadian forest industry makes up a large part of Canada's export economy, another important question concerns the relative impact of climate change and climate change mitigation policies on the Canadian forest sector. Will climate change impacts increase or decrease the contribution of the forest sector to Canada's surplus balance of payments? This will also depend on climate change impacts and policy responses in the United States and other jurisdictions. This will require explicit trade linkages in models, preferably in a dynamic context. An important input to this type of analysis would be a comparative assessment of technological structure and performance in the forest products industry versus other Canadian sectors, and the forest products industry in other exporting countries. Another important question that has received little or no attention is how credit/debit systems for carbon storage in forests and in subsequent forest products would work when forest products are traded across international borders. Presumably the importing country should take on the burden for carbon losses from forest products, however, no analysis has been performed on this issue and the details of how a such a system would function have not been worked out.

Another important question concerns how the forest sector relates to the capital equipment sector and to research and development of technologies that reduce greenhouse gas emissions. The main question here is at what rate should the forest sector replace existing capital stocks which were developed before the climate change issue became important, and especially capital stocks that would be difficult and expensive to retrofit to generate immediate greenhouse gas emission reductions. This will require specialised dynamic models that explicitly account for differences in the age of physical capital.

<u>Analysis of non-market benefit impacts on forests.</u>

As suggested in section 4.2, there are likely to be many impacts on non-market goods and services provided by forests. Climate change adds a new element to an already long list of variables that must be considered in developing and protecting non-market values and unique ecosystems. As pointed out in section 4.2 one of the key tools used to accomplish this goal is a national and provincial system of protected areas and parks. Given that climate change is likely to occur there is a need to adapt parks and protected areas policies just as in other areas of resource management. This points to a need to reconsider existing parks and protected area policy in the context of climate change. Given that ecosystems might move as a result of climate change there is a need for research into the development of new and creative policy solutions. For example, rotating reserves may one way that certain pieces of critical natural capital such as old growth can be protected, given dynamic ecosystem responses to climate change. The fundamental research question is then: How should Canada's network of protected areas be modified in an environment of accelerated dynamic ecosystem response to climate change?

One of the preceding research projects suggested was to investigate how forest harvest rotations and forest management schedules should be altered because of direct impacts of climate change and because of changes in mitigation, sequestration and carbon storage policy. This research should also be extended to determine (i) how these altered forest management schedules impact non-market benefits such as wildlife habitat and (ii) how these management schedules should be further modified to maintain or enhance wildlife habitat.

Given that Canada is still developing endangered species legislation another question that arises is about how or should policy account for climate change. Under climate change ecosystems will change so that the most adaptable species migrate to the climates for which they are most suited. Hence, the following question arises: how should endangered species policy be formulated in an environment of accelerated dynamic ecosystem response to climate change?

Another non-market aspect of climate change is related to the intergenerational equity aspect of climate change, which was discussed in section 3.1. In that section, we discussed the difficulties in choosing discount rates for evaluation of climate change policies. It also pointed out that the choice of discount rate is important because the discount rate will have a profound effect on the optimal management and policy choices. In section 5.2, a novel approach to cost-benefit analysis was suggested, that in part avoids some of these issues. This approach inspires the following research question: What are current generations of Canadians willing to pay to assure that future generations of Canadian's can (i) have less severe climate change impacts, and (ii) can more readily adapt to climate change impacts?

<u>Analysis of social and cultural impacts</u>

Social and cultural impacts are discussed in section 3.4. In that section we suggested that analysis of climate change impacts should be expanded to include the full breadth of social science. The authors of this paper are economists and thus most of the research ideas presented here are economics oriented. This should not be taken as an indication that the economic contributions are more important than other social science contributions, but a reflection of the fact that we are more qualified to point out the major economic questions. Nevertheless, we include three major questions that we feel could be major contributions from the field of sociology.

These questions are:

- What are the public perceptions of climate change and how should they influence climate change policy?
- How should existing social institutions be designed or adapted to address climate change issue? The aim of these institutions is to ensure that the public is satisfied with climate change policy, that the pubic is involved in climate change decision making, and to resolve conflicts precipitated by climate change.
- Determination and identification of vulnerable social groups and analysis of institutional capacity for adaptation.

*Methods of Analysis*

We have suggested some of the methods of analysis that might be used to explore these questions in table 4. These are approaches that we feel are either appropriate or could be extended to answer the research questions discussed above and listed in the table. However, this is not an exhaustive list and other researchers may have other creative approaches. Some of these approaches are discussed in more detail below.

Appropriate analysis of impacts and adaptations to ecosystem migration and change should preferably be dynamic and will require integration of ecosystem models with economic models. Sohngen & Mendelsohn (1999, 1997) use a dynamic partial equilibrium model to analyse the effect of forest ecosystem change on timber markets (see section 4.1 and 5.2). This modelling approach could conceivably be expanded to incorporate land use changes that will occur because of ecosystem change. The dynamic aspect of this analysis would be critical because of forest migration, and because the optimal land use is likely to change over time. Moreover, the forest rotation and stock management problem is also inherently dynamic and the value of carbon credits are likely to change over time. Another type of analysis that may be useful to analyse land use change is the Ricardian land value approach used by Mendelsohn et. al (1994) to link agricultural land values to climate variables. This approach was discussed in subsection 5.2.

The study of rates of adaptation will require creative research methods. Some of this research may simply be qualitative or descriptive where the purpose is to identify the potential barriers to land use change in the current institutional structures. One of the difficulties in doing quantitative analysis is the lack of historical data available on adaptation rates. However, there is research that has looked at adoption rates of new agricultural farming techniques and of technological change in agriculture (Hayami & Ruttan, 1986) that may be useful. One approach to this is to perform a pure optimality analysis – and determine the optimal land use given rational expectations of future changes in ecosytems and markets. This gives an upper bound on the rate of adaptation because it assumes that individuals and firms will adapt optimally to changing conditions.

In a sense this is similar to the Mendelsohn et. al (1994) analysis which assumes that farmers will adapt rapidly to land value price signals. Other approaches may include econometric or statistical approaches that might be used to estimate the rate of adaptation of new technologies in the forest industry or in other parts of the country. Extrapolation to the climate change scenarios will be difficult, however.

Analysis of afforestation, deforestation, and forest management strategies for combined adaptation and carbon sequestration values could be carried out at different scales: forest management unit level, provincial and national. At the forest management unit level dynamic timber supply models or dynamic optimisation models with linkages to carbon budget models, forest disturbance models, ecosystem and vegetation dynamics models, and wildlife habitat models is one way of assessing the combined impact of carbon values and changes in climate on forest management. At the provincial or national levels dynamic partial equilibrium models such as that employed by Sohngen & Mendelsohn (1999, 1997) is a more useful approach, although the approach could be significantly extended to account for forest carbon budgets, forest products lifecycles, and carbon values. This approach might be extended to a dynamic sector model or general equilibrium model to include linkages to the energy sector so that impacts of fossil fuel price increases and interactions of carbon credit/debit systems with energy sector carbon offsets can be modelled. Dynamic sector or general equilibrium models linked to lifecycles of forest products and potential substitute products will be necessary for analysis of the product substitution issue.

These analyses should eventually also account for various levels of cooperation on climate change at the international level. Given the multiple possible outcomes of cooperation and the uncertainties in climate change a number of decision analysis techniques that should be applied. At a minimum sensitivity analysis should be applied to see how optimal policy might vary over a range of possible climate change outcomes. Sensitivity analysis could also be useful for identifying the variables in the economic, biological and climate systems for which optimal policy responses are most responsive. This might be used to set priorities for future research. Other decision analysis techniques that will be useful for determining policy under uncertainty are probabilistic analysis, Monte Carlo simulations and value of information studies.

In incorporating uncertainty directly into analyses, there are some tradeoffs to be made with model size. Generally, models with more details will be larger, more computationally intensive and thus more difficult to run over multiple scenarios required for sensitivity analysis and probabilistic analysis. Hence, a mix of projects with larger models that capture many interactions between sectors of the economy and with biological systems and smaller models that ignore some interactions but allow more model runs to be made is probably desirable.

An analytical modelling approach will be useful for determining the efficiency characteristics of credit/debit systems for forest carbon sequestration and storage and interactions of these systems to the energy industry. This type of modelling does not necessarily involve empirical work, but involves theoretical analysis that can help clarify the advantages and disadvantages of various configurations of these systems in terms of maximising societal welfare and distribution of gains and losses to various segments of society. This type of analysis involves rigorous specification of a model with various actors in the economy, their incentives, resources traded in the economy and specification of the carbon credit/debit incentive systems. Analysis then proceeds with purely mathematical and graphical techniques. This type of analysis will be extremely important for understanding the social welfare characteristics of some of credit/debit systems proposed because to the authors' knowledge this type of extensive analysis has only been performed on cap and allowance trading systems and carbon tax systems.

### *6.3 Summary*

This section has identified and outlined a series of possible research areas and projects as well as possible modelling approaches and analytical frameworks. The list is long but by no means exhaustive, which serves to illustrate what we do not know about the economic and social impacts of climate change.

It is important to point out that there are many interrelationships between these projects. For example, the dynamic partial equilibrium and sector models we suggest as modelling approaches for the Analysis of impacts, adaptation, adaptive land use and forest land use change section could easily be adopted or used in an Assessment of carbon sequestration and storage strategies (Research area 2) or in the Long term timber and forest products supply analyses (Research area 4). Research into forest product pool management strategies or into energy cost impacts and adaptation strategies could serve as inputs into assessment of carbon sequestration, long term timber and product supply, and into analysis of impacts and adaptation. It is difficult to place clear cut lines around these research areas and projects.

One of the areas that we did not explicitly list as a research area was the international strategic dimension, which was felt to lie somewhat outside the scope of this nationally oriented study. Nevertheless we have included some research questions and modelling strategies that take this into account. The main points are that impact, adaptation, and mitigation studies and sensitivity analysis in these studies should account for a range of possible cooperative outcomes on the international mitigation side. However, national mitigation and adaptation policies will not be made in isolation of international negotiations on climate change mitigation policy. It is important that Canadian negotiators have an understanding of not only the costs and informational requirements of negotiated polices but also the underlying global common pool resource and public goods games that are being played out in the climate change context. These games underscore the need for Canada to examine its obligations at the international level and a need for Canada to decide whether it wants to play a leadership role in ensuring that the Kyoto treaty and potential future treaties are successful. A research project that examines Canada's negotiating alternatives at the international level would be a worthwhile endeavour.

**Table 4.** Research Programs, Questions & Projects

| Research Themes | Specific Research Questions | Modelling Strategies/Analytical Frameworks and Analysis Requirements |
|---|---|---|
| 1. Analysis of Impacts, Adaptation, Adaptive Land Use and Forest Land Use Change. | 1. Analysis of impacts on benefits of current land use and analysis of optimal land use under various climate change scenarios.<br>2. What are the implications of optimal land use change to afforestation strategies?<br>3. How do current land ownership patterns affect ability of forest products sector, forest users and other land users to adapt to climate change?<br>4. How should species selection and forest harvesting and management schedules adapt to climate change to reduce negative impacts to a minimum and to protect genetic diversity?<br>5. How should forest protection policy change with increased disturbance regimes and various forest migration scenarios?<br>6. Analysis of rate of adoption of adaptive technologies and techniques.<br>7. Analysis of adaptation under uncertainty for climate change impacts.<br>8. Evaluation of the value of information about ecosystem and vegetation migration scenarios under climate change. | 1. Econometric analyses of land use values with linkage to climate variables.<br>2. Dynamic partial equilibrium and sector models with<br>- Linkages to vegetation and ecosystem dynamics models with linkages to GCM climate scenarios.<br>- Linkage to forest inventory, forest land use and agricultural land use.<br>- Linkage to models of adaptive behaviour and foresight of changing conditions.<br>3. Analysis should account for various possible co-operative and non co-operative international mitigation outcomes.<br>4. Decision analysis techniques<br>- Sensitivity analysis as a minimum requirement to account for uncertainty<br>- Probabilistic analysis to account for uncertainties<br>- Value of information studies |
| 2. Assessment of combined afforestation, deforestation, and forest management strategies for carbon sequestration and storage. | 1. How does afforestation fit into a comprehensive forest carbon storage management program? How would a budget for carbon storage in forests be optimally spent: afforestation, forest renewal, protection of forest growing stocks, etc?<br>2. How should forest rotation and allowable cut policies be altered to account for carbon sequestration and storage?<br>3. How are forest harvest rotations and forest management schedules affected by changes in fire, insect and disease disturbance regimes. | 1. Dynamic partial equilibrium and sector models<br>- Explicit representation of existing forest stocks and marginal farmland.<br>- Linkage to forest carbon budget models.<br>- Linkage to forest products lifecycle models.<br>- Linkage to vegetation and ecosystem dynamics models<br>- Linkages to vegetation and ecosystem dynamics models with linkages to GCM climate scenarios. |

**Table 4**. Research Programs, Questions & Projects, continued.

| Research Themes | Specific Research Questions | Modelling Strategies/Analytical Frameworks and Analysis Requirements |
|---|---|---|
| 2. Assessment of combined afforestation, deforestation, and forest management strategies for carbon sequestration and storage, continued. | 4. How are forest management schedules connected/influenced by disturbance protection regimes (e.g. fire)?<br>5. What are the implications of different carbon price paths to overall carbon storage in Canada's forests?<br>6. Optimal afforestation, forest renewal, and forest protection programs under different configurations of carbon credit/debit systems. Do current Kyoto provisions create perverse incentives?<br>7. How do optimal comprehensive strategies at national and provincial scales vary under different forest/agricultural land migration scenarios?<br>8. How does management of the forest products carbon pool (product lifecycle) affect forest management strategy?<br>9. What are the relative merits of onshore versus offshore carbon sequestration strategies?<br>10. What co-benefits or co-damages are created by carbon sequestration and storage policies?<br>11. Analysis of carbon storage/sequestration strategies under uncertainty of climate change impacts.<br>12. What is the optimal mix of mitigation and adaptation strategies?<br>13. What should Canada's negotiation strategy be for expanding sinks to include existing forest growing stocks? Should Canada negotiate to expand sinks and sources beyond current Kyoto provisions? If Canada negotiates to expand the current provisions, what is the best set of accounting rules for carbon accounting? | 2. Dynamic timber supply model<br>- Linkage to forest disturbance models.<br>- Linkage to wildlife habitat models.<br>3. Analysis should account for various possible co-operative and non co-operative international mitigation outcomes.<br>4. Decision analysis techniques<br>- Sensitivity analysis as a minimum requirement to account for uncertainty<br>- Probabilistic analysis to account for uncertainties<br>- Value of information studies |
| 3. Analysis of incentive mechanisms for carbon storage and management in forests. | 1. What incentive mechanisms are appropriate for private land and public land with long term tenures?<br>2. Identification and analysis of the impacts of different configurations of carbon credit/debit and other carbon storage incentive systems on forest management and the | 1. Theoretical/analytical models<br>2. Dynamic partial equilibrium and sector models (see modelling strategy 1 under Research Area 2)<br>3. Dynamic timber supply model<br>- Linkage to forest disturbance models. |

**Table 4**. Research Programs, Questions & Projects, continued.

| Research Themes | Specific Research Questions | Modelling Strategies/Analytical Frameworks and Analysis Requirements |
|---|---|---|
| 3. Analysis of incentive mechanisms for carbon storage and management in forests, continued. | forest products sector.<br>4. Analysis of efficiency characteristics of various configurations of carbon credit/debit and carbon storage incentive systems.<br>5. How should forest carbon system be linked to a tax or carbon cap and permit trading systems?<br>6. Understanding the political economy of determining baseline scenarios for carbon credit/debit systems?<br>7. How should incentive schemes be developed in an environment of uncertainty concerning natural disturbance regimes and the extent of change in disturbance regimes due to climate change? | |
| 4. Long term timber and forest products supply analysis | 1. Analysis of direct impacts of climate change on Canadian timber supply.<br>2. Analysis of regional impacts of climate change on timber supply.<br>3. What are the impacts of climate change mitigation policies on national timber supply? | See modelling strategies for research area 2: <u>Economic Assessment of afforestation and forest management strategies for combined adaptation and carbon sequestration values.</u> |
| 5. Assessment of forest product pool management strategies? | 1. What is the optimal production mix of solid wood and paper products when carbon storage is valued for climate change mitigation?<br>2. What are the best options for management of forest product carbon pools inclusive of recycling and waste pools?<br>3. How does optimal management of forest products pools alter optimal management of forest biomass pools? (e.g. forest rotations, forest protection, etc). | 1. Integrated optimization or behavioural model with life cycle analysis.<br>2. Integrated dynamic forest products sector, waste sector and forest management model. |

**Table 4**. Research Programs, Questions & Projects, continued.

| Research Themes | Specific Research Questions | Modelling Strategies/Analytical Frameworks and Analysis Requirements |
|---|---|---|
| 6. Assessment of energy cost impacts and adaptation strategies? | 1. What are impacts of carbon taxes or permits on the forest product mill energy management?<br>2. Analysis of co-generation and biomass energy, and biomass energy plantation costs and benefits under increased fossil fuel energy costs<br>3. Analysis of impediments to co-generation and bioenergy in the forest sector.<br>4. Analyses of tax versus subsidy approaches to encourage lower carbon fuel. | 1. Cost benefit analyses<br>2. Forest products mill modelling |
| 7. Analysis of inter-relationships between the forest sector, other Canadian sectors and trade responses | 1. Analysis of forest sector, energy sector, agricultural sector linkages through energy cost impacts and linkages to greenhouse gas emission reduction policies. How does energy cost increase impact the forest sector and agricultural sectors and how can these sectors reduce cost of achieving greenhouse gas reduction targets?<br>2. Comparative assessment of technological structure and performance in the forest products industry versus other Canadian sectors and industry in other exporting countries. Implications for impact assessment, adaptive response capacity and mitigation policy.<br>3. Analysis of substitution possibilities among various forest industry inputs and technological capacity of for forest sector to adapt to new relative prices created by climate change mitigation policy.<br>4. What is the optimal rate at which the forest sector should replace existing climate change unfriendly technologies with climate change friendly technology?<br>5. What is the impact of differences in other national jurisdictional responses to climate change on Canadian forest products trade?<br>6. Analysis of debit/credit when forest products are traded across international boundaries. | 1. Dynamic sector or general equilibrium modelling with<br>- trade linkages to other nations<br>- linkages to forest inventory and carbon budget models.<br>2. Technological efficiency/productivity studies<br>3. Econometric estimation of production functions |

**Table 4.** Research Programs, Questions & Projects, continued.

| Research Themes | Specific Research Questions | Modelling Strategies/Analytical Frameworks and Analysis Requirements |
|---|---|---|
| 8. Analysis of non-market benefit impacts on forests. | 1. How should Canada's network of protected areas be modified in an environment of accelerated dynamic ecosystem response to climate change?<br>2. How would changes in forest management schedules designed to sequester and store carbon affect non-market benefits of forests such as wildlife habitat?<br>3. What are the costs and benefits of endangered species policy in an environment of accelerated dynamic ecosystem response to climate change?<br>4. How should non-market values of citizens in other countries be incorporated or added to the valuations of critical natural capital of Canadian citizens? | 1. Identification of critical natural capital, safe minimum standards approaches, and risk assessments.<br>2. Dynamic timber supply models, with<br>- Linkage to wildlife habitat models<br>- Linkage to ecosystem and vegetation dynamics models<br>3. Theoretical/analytical models |
| 9. Intergenerational equity and discounting issues | 1. What are current generations of Canadians willing to pay to assure that future generations of Canadian's can (i) have less severe climate change impacts, & (ii) can more readily adapt to climate change impacts?<br>2. How do current generations discount the future on climate change issues as compared to how they discount the future on private consumption allocation decisions? | 1. Contingent valuation surveys<br>2. Stated preference surveys<br>3. Willingness to pay questions as suggested by Portney (1998). |
| 10. Analysis of Social and Cultural Impacts | 1. What are the public perceptions of climate change and how should they influence climate change policy?<br>2. How should existing social institutions be designed or adapted to address climate change issues.<br>- To ensure that the public is satisfied with climate change policy.<br>- To ensure public involvement in climate change policy making.<br>- To resolve conflicts that are precipitated by climate change.<br>3. Determination and identification of vulnerable social groups and analysis of institutional capacity for adaptation. | 1. Sociological survey methods. |

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