SOCIOECONOMIC IMPACTS AND ADAPTIVE RESPONSES TO CLIMATE CHANGE: A CANADIAN FOREST SECTOR PERSPECTIVE

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ABSTRACT

The purpose of social science analysis of climate change is to assist policy makers in understanding the expected flows of benefits and costs of policy options over time and to improve our understanding of the human dimensions of the climate change issue. This report deals with socioeconomic criteria for assessment and with the development of methods and approaches for obtaining a better understanding of the socioeconomic impacts and adaptive responses to climate change in Canada's forest sector. Policy makers responding to the climate change issue must deal with many complex issues and unique circumstances. These issues and circumstances also have a bearing on methodologies for undertaking analysis of the future impacts of climate change. Climate change and the effects of climate change on human society spans multiple scales, which leads to the need to consider feedback's and interactions between environmental and human systems, between political systems and between different parts or segments of economies. The implications are that dynamic general or partial equilibrium models integrated with ecosystem response models will be required in order to understand the implications of climate change for land use change, future ecosystem distributions and the supply of timber from Canada's forests. In addition to affecting future timber supply and future commercial forest areas, climate change will influence the benefits Canadians receive from non-market benefits such as outdoor recreation. Currently there is limited analysis of the effects of climate change on non-market values and this area requires more work. Another factor influencing climate change analysis is that the issue spans unusually long time frames for policy analysis and economic analysis. This raises questions about suitable discount rates and accounting for social welfare of future generations. Finally, there is significant uncertainty in long term predictions of climate change and in how the integrated human/biological system will respond over time. Decision analysis, safe minimum standards, precautionary principles and maximin criterion provide some way to incorporate uncertainty into decision making. In terms of integrated assessment models, systematic consideration for the diversity of opinions and results from scientific studies regarding future climate and ecosystems shifts is required.

RÉSUMÉ

L'analyse du changement climatique du point de vue des sciences sociales a pour but d'aider les responsables des politiques à comprendre le cheminement attendu avec le temps des avantages et des coûts des orientations adoptées et à parfaire notre compréhension des dimensions humaines du changement climatique. Le présent rapport traite des critères socio-économiques qui président à l'évaluation et de l'élaboration de méthodes et d'approches pour mieux comprendre les répercussions socio-économiques et les adaptations au changement climatique dans le secteur forestier du Canada. Les responsables des politiques qui se penchent sur la question du changement climatique doivent faire face à nombre de questions complexes et de circonstances tout à fait uniques. Ces questions et circonstances ont aussi une incidence sur les méthodologies adoptées pour l'analyse des répercussions futures du changement climatique. Le changement climatique et ses effets sur la société humaine

ont des ramifications à plusieurs échelles, ce qui implique qu'il faut étudier la rétroaction et les interactions entre les systèmes environnementaux et humains, entre les divers régimes politiques et entre diverses parties ou divers segments des économies. Il en ressort qu'il faudra que des modèles dynamiques d'équilibre général ou partiel soient intégrés aux modèles de réponse des écosystèmes si nous voulons comprendre les répercussions du changement climatique en vue d'apporter des changements à l'utilisation des terres, de saisir ce que seront la distribution future des écosystèmes et l'approvisionnement en bois d'œuvre des forêts canadiennes. En plus d'influer sur l'approvisionnement futur en bois d'œuvre et sur les zones de forêts commerciales de l'avenir, le changement climatique aura une incidence sur les avantages que retirent les Canadiens des valeurs non marchandes comme les loisirs de plein air. À l'heure actuelle, l'analyse qui se fait sur les effets du changement climatique sur les valeurs non marchandes est limitée et il faudra déployer plus d'efforts de ce côté. Un autre facteur déterminant de l'analyse du changement climatique, c'est que cette question couvre de très longues périodes dans le contexte de l'analyse des politiques et de l'analyse économique. Cet état de choses soulève des questions quant aux taux d'actualisation appropriés et à la manière de tenir compte du bien-être social des générations futures. Enfin, il y a passablement d'incertitude dans les prédictions à long terme du changement climatique et de la réaction avec le temps du système humain et biologique. L'analyse des décisions, les normes minimales à respecter, les principes de précaution et les critères du maximum de gain minimum fournissent un mécanisme d'intégration de la part d'incertitude dans le processus de prise de décisions. Sur le plan des modèles d'évaluation intégrée, il faut systématiquement considérer la diversité des opinions et des résultats découlant des recherches scientifiques relatives aux changements climatiques de l'avenir et aux répercussions sur les écosystèmes.

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INTRODUCTION

There is now agreement that future warming of the earth due to human-caused changes in the atmosphere is inevitable, even if international accords such as the Kyoto agreement are fully implemented. This situation has heightened interest in the human dimensions of climate change and, more specifically, in the long-term socioeconomic impacts of climate change and the capacity of the economy for adaptive response to various degrees of climate change. Researchers in the social and physical sciences have developed and used integrated assessment models to analyze a wide range of climate change issues. An important finding of these models is that human society and the environment are inextricably linked. Biological forecasts of future ecosystem distributions that do not consider the implications of human interventions and adaptations as climate changes over time will be unreliable. Similarly, economic forecasts of future income, consumption, industrial structure, and social welfare that do not account for the influence of a changing climate on the availability and productivity of renewable resources will be equally unreliable.

The integrated assessment models of long-range effects of climate change have been developed primarily at a global scale. This report concentrates on issues and research needs related to developing the capacity to assess the economic impacts of climate change on the Canadian forest sector and the sector's potential adaptive responses. We interpret the forest sector as encompassing the forest products industry and associated harvesting operations, the forest management industry, and nonmarket values associated with forests.

Climate change will engender adaptation within Canadian society, and these adaptations will partially offset adverse impacts. Hence, we review the adaptive responses that might lessen the magnitude of direct impacts, as well as the economic dimensions of such responses. We interpret adaptations as strategies that reduce the direct impact of climate change, such as increased disturbance levels in forests, and those that reduce the impact of mitigation measures imposed outside of but having an indirect effect on the forest sector. For example, carbon taxes or carbon permit systems would increase energy costs, and adaptation measures would thus include strategies to lessen the impacts of increased energy costs on the forest industry, such as increased use of bioenergy.

This report has three objectives. First, it identifies the potential impacts of climate change on the Canadian forest sector and assesses the strategies for adapting to those impacts. This discussion focuses on the types of impacts and adaptations that can be expected. The second objective is to identify gaps in knowledge and methodology for developing the capacity to undertake integrated assessment of the effects of climate change and to identify research questions to address these gaps. The third objective is to identify methods and approaches for analyzing the social and economic impacts of climate change and adaptation to climate change.

IMPACTS OF AND ADAPTATIONS TO CLIMATE CHANGE

This chapter outlines some physical and economic strategic dimensions of climate change, both in Canada and abroad. 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. Understanding the causes of climate change, its socioeconomic impacts, and the consequent adaptive responses of societies and sectors requires recognition of the interactions and complex feedback mechanisms between and within human systems (i.e., socioeconomic, political, and institutional systems) and environmental systems (i.e., atmospheric, climatic, ocean, and biospheric systems).

Figure 1 illustrates the complex web of interactions and feedback mechanisms between human (specifically political, economic, and social) and environmental systems at a global scale. In the figure, human systems are displayed in boxes and environmental systems, in circles. Forest ecosystems constitute a subsystem of terrestrial ecosystems, and forest products and forest sector policies are subsystems of firms and policy institutions. Terrestrial and ocean ecosystems supply environmental goods and services to human socioeconomic systems. Human socioeconomic systems in some cases consume these goods and services directly (i.e., nonmarket values) and in other cases transform them into products for consumption. These processes of production and consumption result in changes to the environmental systems (because of extraction from or introduction of industrial by-products into the environment). These changes in turn affect the stock of environmental goods and services and the ability of the environmental system to continue providing inputs to the human 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, GHG emissions are expected to cause an increase in global temperatures and other meteorological anomalies. Future climatic change will, in turn, influence household preferences, the productive capacity of renewable natural resources, and the mix of goods and services produced by firms in particular locations. In some cases, climate change may have positive social welfare impacts (i.e., by creating benefits), but in other cases, it may have negative welfare impacts. If overall social welfare after a shift in climate is lower than it would have been without the change, then mitigation policies may be warranted. However, to evaluate the existence and magnitude of changes in social welfare attributable to climate change, policymakers must have some understanding of the long-term impacts on society under various climate change scenarios. Moreover, because climate change may occur gradually and over a long time period, it is necessary to evaluate the adaptive responses of ecosystems, households, and firms, as well as the interactions between these systems over time.

Adaptation may mitigate many of the negative economic impacts of climate change. Therefore, an important consideration in economic analysis is to ensure that future assessments of impacts incorporate predictions of adaptive responses. These adaptive responses may be triggered by changes in relative prices, by changes in the physical environment, or by behavioral changes in response to policy interventions. A factor complicating the 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, which complicates the analysis.

Physical Dimensions of Climate Change

The focus of this report is on the socioeconomic dimensions of impacts, adaptation, and mitigation related to climate change. Therefore, a detailed discussion of the responses of the Canadian forest ecosystem to climate change is beyond the scope of this report. However, the assessment of impacts depends on predictions of ecosystem responses to both climate change and to human management and adaptive responses. This subsection provides a brief overview of some physical dimensions of climate change in terms of Canada's forests. More complete discussions of these aspects appear in Singh and Wheaton (1991), Houghton et al. (1996), and Saporta et al. (1998).

Predictions for increases in global temperature range from 1°C to 3.5°C by the year 2100 (Houghton et al. 1996). Other predicted changes in climatic variables include increases in growing seasons, changes in seasonal temperature means and ranges, changes in precipitation and relative humidity, and possible changes in storm frequency and intensity

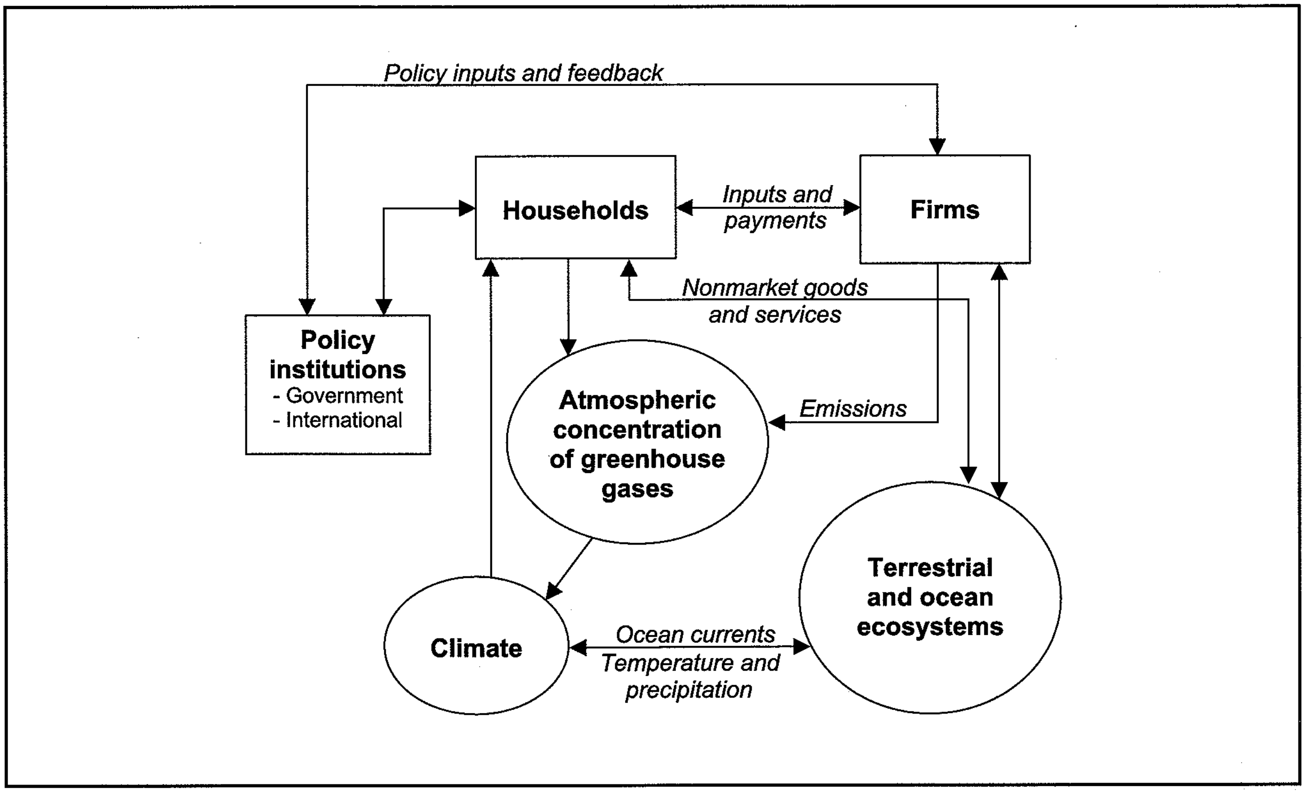

Figure 1. Interactions between the different systems involved in climate change.

(Maxwell et al. 1997; Saporta et al. 1998). Because of any number of factors (e.g., mountain ranges, large bodies of water, continental influences, and circulation patterns), these changes are expected to differ from region to region. For example, midcontinental areas are likely to become drier, while other areas may become wetter, and northern latitudes are predicted to experience greater increases in temperature than southern latitudes (Sedjo and Sohngen 1998). Thus, Canada can expect increases in mean temperature above the global mean, a dryer climate in the western boreal forest region, and changes in storm patterns.

Canada's forests are susceptible to climate change influences (Singh and Wheaton 1991). Climate change will directly influence site productivity, tree survival, and regeneration capacity (Saporta et al. 1998). The response of individual tree species will depend on the magnitude of climate change in particular locations, the rate of climate change, and the ability of each species to adapt to climate change over time. In some cases climate change could enhance site productivity because of a longer growing season, increases in precipitation or increases in heat units. In this situation, species more suited to warmer temperatures will expand their ranges. In other cases, species may suffer 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 and Flannigan 1997), insect infestations (Fleming and Volney 1995), and disease (Krauchi and Xu 1995) are predicted for some locations. Increasing disturbances may contribute to changes in species composition (Saporta et al. 1998), a decrease in mean tree size and volume, and a decrease in mean tree age (Rothman and Herbert 1997).

Because of climate change, the distribution of forest ecosystems is likely to evolve over time (Lenihan and Neilson 1995). Some species may be unable to adapt to new climate conditions in the time available (Krauchi and Xu 1995), particularly if the new conditions do not correspond to those required for flowering, pollination, seed formation, germination, and competitive success (Singh and Wheaton 1991). If climate change is beyond the limit of trees' physiological tolerance, forest dieback and ecosystem changes are inevitable, particularly at the margins of different forest ecosystems (Singh and Wheaton 1991; Hogg and Hurdle 1995).

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

Economic Dimensions of Climate Change

Since the industrial revolution, GHGs have been accumulating in the atmosphere, increasing from 300 ppm in 1900 to 320 ppm in 1965 and 345 ppm in 1985 and projected to reach 618–723 ppm by 2100 (Cline 1992). This accumulation has occurred largely as a result of human activities and more specifically as a result of human commerce. The primary sources of the increase in GHGs are carbon dioxide emissions resulting from the burning of fossil fuels; emissions of other trace gases (e.g., methane, nitrous oxide, and chlorofluorocarbons) from a variety of sources including livestock rearing, coal mining, and natural gas leakage (from pipelines, for example); and biomass reduction, largely attributable to deforestation of tropical rain forests. Climate change, therefore, is an economic phenomenon. In fact, climate change presents a classic case of market failure, where the actual current costs of producing goods and services (or the prices paid for inputs such as fossil fuel) underestimate the true societal costs to present and future generations (assuming that climate change will have negative effects on aggregate welfare). In other words, 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 now present a broader context for considering the dynamic interrelationships between climate and economic development over time. Because climatic processes are global in scale, the interrelationship between climate and the economy can be viewed at a global level (Fig. 1).

The interactions shown in Figure 1 have three main implications. First, they indicate that a comprehensive approach to impact assessment should consider the magnitude of 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, primarily because all these influences occur simultaneously and they are in many cases interlinked. Second, they indicate that any efforts to model the effects of climate change from a Canadian forest sector perspective will need to include linkages among the Canadian forest economy, other segments of the Canadian economy, and the global forest economy, because of interactions among markets. In the world economy, impacts on one sector may have higher-order effects that influence other sectors (Fankhauser 1995). Thus, the forest sector will be affected by changes in other sectors, and effects on the forest industry will in turn affect 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.

In the short run, climate is constant. In contrast, climate change occurs over long time horizons. Evaluation of the impact of such change must therefore be evaluated over similarly long time horizons. The long time scales over which the effects of climate change are realized present several challenges for any economic analysis. First, increases in the price of goods and services and increases in 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 predicting the magnitude, direction, and pace of climate change at regional levels, in predicting how natural ecosystems will respond to changing climate regimes, and in predicting how households and firms will respond to or be affected by a changing climate, changing natural resource endowments, or both. Measures of impact will at best be no more than expected values, and additional qualitative information will be necessary to take account of aspects that cannot be measured. Third, the impacts of climate change and the costs and benefits of mitigation occur over time, so for comparability all future monetary measures must be converted to a present value according to a suitable discount rate. The selection of discount rates has major effects on the magnitude of impacts, particularly over long time horizons, and therefore a suitable discount rate is imperative if estimates are to be meaningful. Fourth, the long time horizons associated with climate change raise a number of issues related to intergenerational equity and how it should be measured and reflected in the evaluation of impacts. Thus, the analysis of climate change impact embodies dynamic analysis of interacting human and environmental systems over specified time periods.

For a number of reasons, separate assessments of the impacts of climate change are needed for the forest sector. First, Canada's forests provide a broad range of both market and nonmarket 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, and 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 need to be considered in impact assessments. Various cost–benefit exercises have been undertaken to value the market and nonmarket impacts of climate change on the forest sector at global levels or in other countries, and these approaches are discussed in the section "Methodological Frameworks for Assessment," below.

Another reason for assessing the impact of climate change from a forest sector perspective is that the uncertainty associated with predicting forest ecosystem responses results in uncertainties for the forest economy and for forest management and policy (this problem is discussed further in the section "Socioeconomic Criteria and Considerations for Measuring Impacts"). The inherent sensitivities of forest ecosystems to climate and the uncertainties of ecosystem responses create unique sectoral policy and management problems (Duinker 1990). For example, long-term rotations for Canadian timber mean 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 and Wheaton 1991), but such an assumption may not be valid.

Other unique effects on the forest sector that can be expected to result from climate change include modification of fire regimes with consequent changes in forest landscapes (Weber and Flannigan 1997). Any changes in Canadian and global forest endowments are likely to have implications for international trade and prices of forest products (van Kooten and Arthur 1989). Changes in product prices and in timber supply will affect government resource revenues (Thompson et al. 1997) and the costs of management and resource development (e.g., protection costs will probably increase). Changes in Canadian forests are also likely to affect other forest-dependent sectors, such as recreation (Thompson et al. 1997). Some activities are likely to benefit (e.g., outdoor recreation opportunities in summer), while others will experience declines (e.g., winter sports) (Mendelsohn 1998). Changes in the distribution of forests may contribute to premature obsolescence of infrastructure and may change the underlying economics of recreation and the locations of forest product enterprises. These changes may, in turn, have implications for the economic performance of resource-reliant communities and for the economic welfare of residents within those communities. Finally, activities such as afforestation and intensive management of forests have the potential to sequester carbon from the atmosphere. These activities have been suggested as ways to partly offset GHG emissions (Hoen and Solberg 1994; Nilsson and Schopfhauser 1995; Sedjo et al. 1995). Essentially this means that the carbon sequestration capacity of forests has value to society. Various mechanisms for capturing this value (such as carbon credit trading) are being discussed, and some are undergoing experimentation. Incorporation of this value into forest management and decision making has the potential to change how forests are managed and to change optimal forest stock and flows.

Mitigation and Adaptation Strategies

Two types of approaches can be used to respond to and moderate the impact of climate change. Mitigation or abatement measures and adaptation or protection measures.

Mitigation measures limit the net amount of GHGs that accumulate in the atmosphere by either emission reduction or sink enhancement (Bruce et al. 1996). Examples of measures to reduce emissions include fossil fuel switching (i.e., from carbon-intensive coal to gas, which is less carbon intensive), energy conservation and improvement in energy efficiency, and use of renewable energy (i.e., bioenergy; see section entitled "Forest Sector Considerations in Assessing Impacts and Adaptation"). Sink enhancement measures include activities such as carbon sequestration in forests, soils, products, and oceans.

Adaptation encompasses activities undertaken in response to climate change itself or in response to mitigation strategies to limit the effects of climate change (Table 1). Economic systems will adapt and evolve in response to stresses, shocks, or supply shifts caused by climate change. Economic agents will respond by substituting relatively abundant resources for relatively scarce ones, by reallocating resources to relatively more profitable economic activities, and by developing and adopting new technology that saves scarce resources and increases the use of abundant resources. Market institutions and gradual changes in relative prices over time will provide the primary stimulus for these changes. The net effect will be to increase the resilience of human systems to the impacts of climate change, to reduce damages, and to increase the possible benefits (Fankhauser 1995). Adaptation measures can be classified as protection (e.g., protection against forest fires), retreat (e.g., relocation away from areas of forest dieback), and accommodation (e.g., replanting with species suitable to predicted future climate).

Adaptive responses to climate change will depend on the ability of firms, governments, and consumers to predict the impacts of climate change. If the impacts can be foreseen, anticipatory adaptive strategies can be formulated (e.g., after harvest or other disturbance, replanting with species better suited to future climate conditions) (van Kooten 1995). If events are unpredicted or unforeseen, individuals may respond to gradual changes in the patterns of events that they experience (Smith 1982).

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 et al. (1998) point out that "abrupt climatic change" may result in "unanticipated and possibly catastrophic ecosystem changes." Adaptation strategies and responses are also sensitive to the rate and consistency of change over time. Adaptation will be most effective if climatic and ecosystem changes are gradual, predictable, and relatively constant over time. Rapid or discontinuous changes may result in sudden lurches from one equilibrium to another rather than gradual convergence to a dynamically stable equilibrium.

Increased uncertainty associated with climate change will affect the behavior of firms, landowners, governments, and consumers. Each group has a unique objective function, which defines their behavior and actions over time. For example, decisions and choices made by firms are motivated by the need to maximize profits or returns on shareholder capital in order to prosper in competitive markets. Firms therefore evaluate current and future costs and product prices and will respond to actual or anticipated changes in these streams by adopting new competitive strategies. Landowners strive to maximize the stream of rents generated by their land over time. Expectations of future changes in the stream of rents 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

Table 1. Examples of impacts of and adaptations to climate change from a forest sector perspective

Physical impacts	Socioeconomic impacts	Parties affected	Adaptation policies and strategies
Changes in forest productivity	Changes in timber supply and rent value	Forest firms and landowners	Change harvest schedules (regional and annual); adjust replanting behavior, including species planted; change land use
Increase in atmospheric GHGs	Introduction of carbon credit or permit mitigation policies, which create a carbon sequestration market	Forest firms and landowners	Sequester carbon in forests (by changing rotations, manufacturing, and harvest techniques, through afforestation, through research and development); reuse or recycle wood residue and products (e.g., as a biofuel)
	Mitigation policies that increase prices for GHG-intensive energy	Firms and consumers	Substitute GHG-intensive products (e.g., steel) with wood; increase use of bioenergy and cogeneration
Increase in disturbances	Loss of forest stock and nonmarket goods	Firms, landowners, and consumers	Increase protection policies and research and development
Northward shift of ecotones	Changes in land values and land-use options	Firms, landowners, and consumers	Change competition for land (forest versus agriculture); adopt new management options
Ecosystem changes	Economic restructuring leading to social and individual stress and other social pathologies	Aboriginals and other forest-dependent consumers and firms	Improve communication, provide education, encourage participation, undertake conflict resolution, and remove institutional barriers
Changes in ecosystems and specialist species	Changes in nonmarket values, especially the passive component	Firms, landowners, and consumers	Change preferences; increase forest reserves, arboreta and seed banks
Ecosystem changes	Parks and natural areas dislocated; increasing land-use conflict	Firms, landowners, governments, and consumers	Alter park boundaries and expand into a comprehensive system
Forest ecosystem changes	Dislocation of fixed, sunk capital	Climate- and forest-dependent tourist and forest firms	Diversify (e.g., expand winter ski hills to include summer golf facilities) or relocate
Increase in atmospheric GHGs	Increased prices for GHG-intensive energy	Long-haul tourists (consumers) and their destination firms	Increase local tourism
Warmer conditions	Requirement for increased cooling of buildings	Firms and consumers	Increase planting of urban trees (which would have cobenefits)
Increase in frequency and magnitude of changes	Increase in uncertainty	Governments and firms	Increase research and development

Note: GHG = greenhouse gas.

an equitable distribution of income. Governments intervene when market failures become apparent or when there is demand for the provision of public goods that the private sector will not provide. Consumers purchase a bundle of goods and services that maximizes the utility they obtain from their fixed budget.

Climate change will create an array of new market and nonmarket signals that will lead firms, landowners, governments, and consumers to adopt various strategies to either minimize negative impacts or exploit new economic opportunities. These responses will reduce some of the social costs associated with climate change.

Forestry firms may choose from a number of adaptive strategies to respond to climate change. One option is to transfer their capital and business expertise to new industries. If the profit potential of the new investment opportunity under conditions of climate change is higher than the profit potential of the firm in the existing location under conditions of 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. For example, 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 processes that are more capital intensive but less energy intensive. The marginal costs will be higher with the new input mix but not as high as if the firm continued to use the previous input mix. Firms also have the option of developing new technology to minimize the cost impact of changes in relative input prices. Increases in the prices of timber and energy, for example, would provide incentives for development 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 for which the potential return on capital is higher but future prices are uncertain (Smith 1982). Some constraints on the ability of firms to use these strategies include technological constraints that limit the degree of input substitution, 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 price paths and land values will affect land use and 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, and hydrology. Sohngen and Mendelsohn (1999) have shown that adaptive responses by landowners to changes in prices (caused by climate change) include changes in harvesting behavior and replanting decisions. These responses contribute to an acceleration in the rate of transition from one ecosystem distribution to another.

One goal of government policy is to maximize social welfare over time by encouraging efficient allocation and by correcting market failures. Societies may also demand certain levels of income redistribution. Thus, governments may adapt to climate change by intervening to correct market failure or to redistribute income in a manner that society determines is more equitable. Also, given the high levels of uncertainty surrounding climate change and the public good characteristics of scientific information, an adaptive response by governments to climate change might be to facilitate science, technology, and knowledge regarding climate change and its impacts, adaptation and mitigation technologies, and public education.

Climate change and mitigation will lead to new prices for goods and services over time. Changes in supply will cause the prices of some goods and services to decline while the prices of other goods and services increase. These price changes will have substitution and income effects. The net effect will be a change in the "basket" of goods and services purchased by consumers, although the opportunity to substitute products dampens the impact of climate change on aggregate welfare. The degree to which climate change and mitigation reduce (or increase) aggregate welfare will depend on the elasticity of demand for 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 the adaptive capacity of consumers will be more limited and the effects of climate change on aggregate welfare more pronounced.

Mitigation and adaptation options are interlinked (Bruce et al. 1996). For example, mitigation strategies such as carbon sequestration in forests are likely to result in adaptive responses by forest managers to changes in economic incentives and prices attributable to the benefits of carbon sequestration. Furthermore, some strategies are likely to be implemented because of the benefits they yield in terms of both mitigation and adaptation. For example, afforestation and other forest management activities designed to preserve forest stock can be thought of as both mitigative and adaptive policies. Another example can be found in the forest products sector itself. Mitigation policies such as carbon taxes, carbon permit systems, or regulatory restrictions on GHG emissions will lead to higher prices for energy inputs. The forest sector will react to these mitigation policies and subsequent price stimuli with adaptive responses, including substitution away from carbon-intensive energy sources. Under this scenario, cogeneration and bioenergy options would probably be further developed and implemented.

Social policy for climate change should not consider mitigation in isolation from the impacts and social costs of adaptation. The optimal social policy should simultaneously minimize the costs of mitigation, the costs of damage due to climate change, and the costs of adaptation (Fankhauser 1995). The optimal solution occurs when the marginal net benefits per dollar spent on adaptation equal the marginal net benefits per dollar spent on mitigation. Figure 2 is 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 and the marginal net benefits of mitigation. The marginal net benefits of adaptation are usually local, in this case Canadian. This aspect is important when considering the international strategic dimensions, which are discussed in the following section.

Institutional structures can significantly influence adaptive behavior (van Kooten 1995). Because existing institutions and policies did not evolve within an environment of climate change, they are therefore not structured to accommodate the effects of climate change in a socially optimal direction (van Kooten 1995). Thus, the ability of Canadian society to adapt to climate change and to mitigate negative social consequences may entail some review and modification of existing institutional mechanisms. Assuming that mitigative and adaptive responses can be analyzed separately, the optimal combinations of mitigative and adaptative strategies are those that maximize net benefits.

Current research suggests that competitive markets constitute an important instrument for facilitating adaptations by the forest sector and other sectors in general. However, most forest land in Canada is owned and managed by government and decisions concerning harvest rates, rotation age, stumpage value, and species selected for replanting are largely determined by physical and administrative considerations. Therefore, price signals will play a limited role in determining landowner behavior. From an efficiency perspective an important question is whether government agencies will be more or less effective than private landowners in changing harvest rates, rotation ages, and species choice in response to climate change.

Strategic, Political, and Economic Dimensions of Climate Change

Various impacts of climate change at the international level may induce nations or groups of nations to behave strategically. Mitigation of the effects of climate change has characteristics of a global public good, but the inability to exclude individual nations from the benefits of mitigation may encourage what is called free-riding behavior. The possibility of noncooperative or strategic behavior by nations creates barriers to correcting global environmental market failures such as those due to climate change.

There are two types of strategic behavior. In one type, corporate, provincial, or national policy-making related to climate change is conditioned by expectations regarding the actions or policies of other corporations, provinces, or nations. Strategic behavior of this sort is important at all levels of jurisdiction, but the discussion here focuses on the international level. The second type 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 groups' objectives to the fullest extent possible.

International Strategic Dimensions

An important characteristic of mitigation of the effects of GHGs and the resultant climate change is the need for collective actions by many countries to effectively deal with the problem. No single country is in a position to resolve the problem independently. Moreover, the public-good nature of climate change means that a particular country cannot be prevented from reaping the benefits of mitigation. Therefore, individual nations that agree to a collective strategy will bear the direct costs of their efforts to reduce GHGs but must rely on other nations to fulfill their respective commitments under voluntary agreements in order to realize the collective benefits. Finally, the global nature of the problem means that there are no overriding global institutional structures to enforce agreements or ensure compliance with collective international agreements.

The inability to exclude and the lack of global institutional structures for facilitating cooperative resolutions and enforcing agreements creates incentives for individual nations to reduce their mitigation efforts, while other nations bear the costs. This is known as free-riding behavior. Such behavior may lead to collectively undesirable, inefficient, and inadequate mitigation efforts (Nordhaus and Yang 1996; Sandler 1997) (Table 2). If other countries do not fulfill their commitments, the effects of climate change on Canada will be high, regardless of what Canada does. Hence, if Canada employs costly mitigation strategies and other countries do not cooperate, Canada will experience substantial effects of climate change in addition to incurring the mitigation costs. Thus, if other countries do not cooperate in mitigation strategies, Canada's optimal strategy is to keep mitigation costs low. On the other hand, if other nations do cooperate, Canada will experience smaller climate change impacts. However, the impacts will be lower regardless of Canada's mitigation policy, which will contribute very little to the overall reduction of GHG output and 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 the perspective of pure self-interest) is to do as little mitigation as possible. The problem is that all nations face similar types of payoffs, and hence the best strategy for any country is to minimize mitigation action, in the hopes that other countries will take the lead. The result is a mutually undesirable outcome: countries do not cooperate, and GHG emissions continue to increase with economic growth.

At the international level, agreements or treaties can be constructed to try to overcome this problem. In Figure 2, this is illustrated by point O, which is the intersection of the curve for global marginal net benefit of mitigation (MB_M) and the curve for marginal net benefit of adaptation (MB_A with international cooperation). In other words, point O is the intersection between the local, Canadian marginal net benefits of adaptation (with global cooperation) and the aggregate marginal net benefits to all countries of Canadian reductions in GHGs (MB_M–Global). Policymakers should try to choose the level of obligation illustrated by point O. However, at the international level, truly binding treaties are difficult to construct and enforce, so maintenance of cooperation at the international level is extremely difficult.

It is important to understand this aspect of international policy on climate change from an adaptation perspective, because under its influence the best mixes of mitigation and adaptation strategies at the national level depend on the mitigation policies of other nations. Both Figure 2 and Table 2 illustrate this point. In Figure 2 the optimal mix of mitigation and adaptation from a global perspective is at point O. At this point all countries cooperate, and all countries take the benefits to other countries into account when formulating their own mitigation policy. If other countries do not cooperate, however, the optimal

Table 2. Alternative scenarios for evaluation of impacts of climate change on the forest sector in Canada

Scenarios	Other countries fail to fulfill Kyoto commitments	Other countries fulfill Kyoto commitments
Canada fails to fulfill Kyoto commitments	Mitigation cost low Impacts of climate change may be large Significant adaptation required	Mitigation cost low Impacts of climate change lower Less adaptation required
Canada fulfills Kyoto commitments through a mix of interventions[a]	Mitigation cost high Impacts of climate change may be large Significant adaptation required	Mitigation cost high Impacts of climate change lower Less adaptation required

[a] Improved energy efficiency, fuel substitution or switching, increased use of renewable energy, clean development credits, and carbon sequestration.

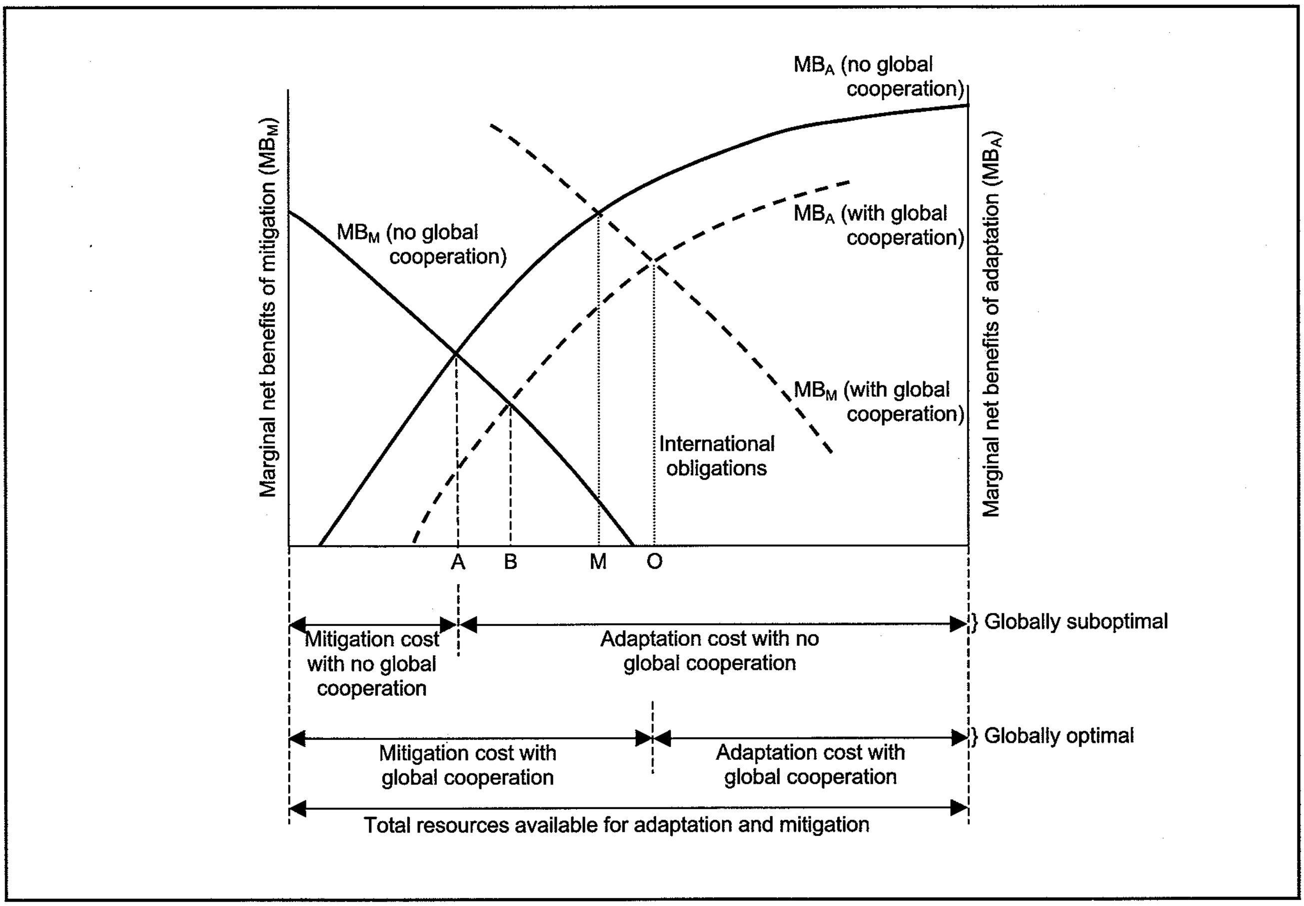

Figure 2. Relationships between marginal net benefits of mitigation and adaptation to help determine the optimal mix of mitigation and adaptation strategies. Single letters on horizontal axis label points of intersection of curves, as follows: A = optimal Canadian mix of mitigation and adaptation if other countries do not cooperate and Canada does not consider other countries in developing its mitigation strategies, O = optimal mix of mitigation and adaptation from a global perspective (all countries cooperate and take other countries into account in formulating their own mitigation strategies).

mix for Canada is at point M, where Canada still considers the benefits to other countries of its own mitigation efforts. However, from Canada's own perspective, if no other country cooperates to reduce emissions, the optimal mix of Canadian mitigation and adaptation strategies is at point A.

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

National Strategic Dimensions

Individuals, environmental groups, and industrial and manufacturing groups will attempt to influence government and the policy-making process so that the resulting policies leave them as well off as possible. In formulating policy, governments must be careful not to be unduly influenced by special interest groups acting strategically.

This type of strategic behavior 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 (Table 3, in a later section, provides an overview of permit-trading systems). The two main categories of distribution systems are auctions and grandfathering (Cramton and Kerr 1998; Cramton, P.; Kerr, S. 1998. The distributional effects of carbon regulation: why auctioned carbon permits are attractive and feasible. Unpublished paper.). These two systems have different implications for the distribution of scarcity rents[1] that are generated when a cap and a carbon-allowance trading system are implemented. These differences, in turn, create incentives for rent seeking[2]. 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 would limit the transfer of income from their shareholders to the government or the general public. Environmental groups might lobby for an auction system so that rents can be captured by the government and possibly be redirected toward energy-saving or new clean-energy technologies. Second, if the decision is to implement a grandfathering system for permits, the government would expose itself to further rent seeking as various companies and industries argued for the largest possible share of the total number of permits. In addition, any policy would have to be carefully crafted to avoid possible perverse incentives that might encourage corporations to emit as much GHGs as possible before the allocation of permits was decided, as in the situation where permit allocations to firms are determined by historical emission levels.

Credit-trading systems, which are particularly relevant to options for carbon sequestration in forests, may also encourage rent-seeking behavior. In credit-trading systems, credits are given for reductions of emissions from a projected baseline (Rolfe, C. 1998. Selling clean air: market instruments for climate protection. A discussion paper prepared for West Coast Environmental Law Research Foundation workshop, Selling Clean Air: Market Instruments for Climate Protection, 15–16 October 1998, Vancouver, BC.). There are several potential difficulties with this type of system. The first is in predicting the baseline. Any predictions are likely to

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[1] Scarcity rent or economic rent can be defined as "a payment for the services of an economic resource which is not necessary as an incentive for its productioon. Unimproved land, which is valuable purely on account of its location, commands a rent based on its value to the user" (Black 1997).

[2] Rent seeking can be defined as "spending time and money not on the production of real goods and services, but rather on trying to get the government to change the rules so as to make one's business more profitable" (Black 1997).

be highly variable because of regular supply and demand cycles and uncertainties in the market. For example, policymakers would have to decide whether they wish to give credit for reductions in emissions that are simply the result of market downturns. Another example of the difficulty in determining a baseline relates specifically to forest management. Suppose 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 would be particularly difficult for several reasons. First, forest disturbance regimes such as forest fire and insect and disease attacks are highly erratic (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. Hence, the baseline depends 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.

Table 3. Market-based instruments for reducing emissions of greenhouse gases (GHGs)

Instrument	Entity traded	Cause of reductions in emissions	Determinants of distribution of costs
Cap and emission allowance trading	GHG emission allowances, which represent a license to emit a tonne of CO_2 (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[a]
Cap and carbon allowance trading	Carbon allowances, which represent the right to import or produce a tonne of fossil fuel carbon; may be tradeable 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 a reduction in emissions from a projected baseline	Stringency of emission reduction standards, 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	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

[a] See Cramton and Kerr (1988 and unpublished paper, The distributional effects of carbon regulation: why auctioned carbon permits are attractive and fusible), for a comparison of auctioning and grandfathering tradeable carbon permits (auctions are found to be preferable).

Note: CO_2 = carbon dioxide.

SOCIOECONOMIC CRITERIA AND CONSIDERATIONS FOR MEASURING IMPACTS OF CLIMATE CHANGE

From an economics perspective, the objective of impact assessment, policy evaluation, or project analysis is to determine whether an action or policy leaves people better or worse off. In the case of adaptations, the aim is to determine whether adaptive strategies reduce the negative impacts on welfare caused directly by climate change. This requires two things: a way of measuring change in welfare and a means of aggregating the changes in welfare experienced by those affected. This section presents a variety of criteria, approaches, and considerations for assessing the impacts of climate change and related adaptation strategies, specifically efficiency, equity, uncertainty, and competitiveness criteria, as well as social considerations.

Efficiency and 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 or to prevent climate change. The first part of this discussion is a review of the basic economic criteria used in cost–benefit analysis and other forms of economic analysis, namely the efficiency or Pareto criterion and the compensation principle. The second part examines equity in both intra- and inter-generational contexts and the implications of discounting methods.

The Efficiency Criterion and the Compensation Principle

A practical issue related to measuring impacts and evaluating policies is the unit of measure that should be used 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 benefits that the good or service provides to a consumer minus the cost of supplying the good or service, usually measured in dollars (Sinden and Worrell 1979). When aggregated over all consumers of a good, the measure of total benefit is the sum of the area under the consumer demand curve, the measure of cost is the area under the supply curve, and the measure of social value is the difference between these two areas. This area is referred to as the net social benefit. Net social benefit includes two types of values: consumer surplus and producer surplus. (Consumer surplus and producer surplus are relatively straightforward, regularly used critera for measuring social benefits; however, microeconomists argue that they are not the theoretically correct measures. The more theoretically correct criteria for assessing the welfare effects of policy are compensating variation and equivalent variation [see Layard and Walters 1978].)

Cost–benefit analysis is an extension of these principles to situations where the costs and benefits occur at different points in time and where some costs and benefits may not be supplied or demanded in markets. 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 related policies. The difference (which may be either negative or positive) is then a measure of the impact of the event. However, because the net benefits occur over different periods, they must be discounted to a present value if they are to be compared. In cost–benefit analysis, policies (or projects) should be accepted only if the discounted benefits are greater than the discounted costs (i.e., the net present value of the investment is positive).

The efficiency or Pareto criterion is the basis for assessing change in welfare in a cost–benefit analysis, as well as in more sophisticated economic models. A new policy satisfies the efficiency criterion if it leaves all parties involved at least as well off as they were before the policy was implemented and at least some parties better off. According to the efficiency principle, if a new policy leaves some better off and others worse off, it cannot be considered more efficient than an existing policy. In these situations, it is traditional to invoke the compensation principle. According to the compensation principle, a new policy or project is acceptable only if the "winners" in a new policy environment can compensate the "losers," at least hypothetically (Boadway and Bruce 1989). The compensation must be such that under the new policy the losers are just as well off as they were before the policy was implemented. In addition, the winners must be better off even after they compensate the losers. The compensation principle clearly invokes a distributive principle that prevents some from losing in a new policy environment while others benefit. The distributional information needed to assess efficiency cannot be determined simply by looking at the net present value of a project or policy. The way in which the costs and benefits are distributed among those affected by changes in policy must also be examined.

Efficiency, however, is not the only legitimate economic criterion. In some situations members of a group in society feel that a redistributive policy is warranted. Even if the explicit objective of a policy change is redistribution, there is still a good reason for accepting such a policy only if the benefits exceed the costs (which implies that hypothetical compensation is possible): if the benefits of a new policy are less than its costs, then those whom the policy was meant to benefit can be made just as well off by means of a cash payment that is less than the cost of the policy (Lind and Schuler 1998).

There are two aspects to a decision to undertake a redistributive policy (Lind and Schuler 1998). The first is an ethical decision to transfer wealth from society in general to those that will benefit from the new policy. This decision must be based on values outside the scope of cost–benefit analysis, which simply does not indicate whether or how redistributive policies should be enacted. The second aspect concerns the question of how best to make the transfer: through the policy or through a cash transfer. Clearly, implementing a redistributive policy or project is more efficient if the benefits of the project are greater than the costs, and a straight cash transfer is more efficient otherwise. Hence, cost–benefit analysis is useful even if deliberately redistributive polices are being considered.

Intergenerational Equity and Discounting

Climate change policies related to forests are likely to result in transfers of wealth from one sector of society to another. Such transfers will raise fundamental equity issues pertaining to the allocation of welfare across the regions of Canada, across interest groups, and across generations. Hence, just as in many other policy environments, net present value or efficiency is not the only or even the most important consideration. Although members of the current generation who are negatively affected by a new policy can voice their opposition, members of future generations cannot, which may place a strong moral obligation on current generations to protect the interests of future generations.

Economists have traditionally been uncomfortable speaking about equity. However, this situation appears to be changing (see Pezzey 1997; Chichilnisky 1997), and some economists have suggested that, at least under climate change, equity considerations are more important than any concerns about efficiency (Lind and Schuler 1998). Moreover, economists are often in the best position to point out to policymakers the equity and redistribution consequences of policies or policy changes. It is our view that economists and other policy proponents should consider the equity aspects of the policies they prescribe. In this section we concentrate on the intergenerational aspects of equity.

When the 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. Discounting costs and benefits at each point in time allows costs and benefits that occur at different times to be compared in common units and thus added and subtracted. For an individual policy (or project), the result of this procedure, is a single number called the net present value (NPV), which can be compared with the NPV of other policies to determine which policies are most efficient. 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, in both 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. Although 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 and Schuler 1998). Climate change is just one such long-term issue. Here, we do not try to determine which discount rate, in numerical terms, should be used. Instead, we provide an overview of the various technical issues related to discounting.

Arrow et al. (1996) and Lind and Schuler (1998) discussed two general approaches to discounting: prescriptive and descriptive. These approaches differ in their philosophical underpinnings, using different questions as their points of departure. The prescriptive approach starts from an ethnical premise, asking "How should society value impacts on future generations that are generated by its current actions?" In contrast, the descriptive approach starts with an empirical question, asking what trade-offs across generations and over time people actually make.

Prescriptive approaches usually generate lower discount rates than descriptive approaches. The following expression is helpful in understanding the difference in these approaches:

$$d = r + qg$$

Both approaches are interested in *d*, which in the prescriptive approach is often called the social rate of time preference (or social discount rate). The term *r* is known as the pure rate of time preference and reflects how society discounts the welfare of future generations. This is the equity component of the discount rate. The term *q* is a measure of the marginal utility of additional income and the term *g* is a measure of the rate of growth of income. The expression can be derived from a basic optimal growth model of the economy, the objective of which is to maximize the sum of weighted or discounted welfare, where the basic choices that society faces are current consumption and saving.

Most economists agree that this is a useful framework from which to begin discussions about the appropriate discount rate. However, they disagree about what values should be used on the right side of the equation in evaluating these benefits. In particular, they disagree about the appropriate value of *r*. The prescriptive approach suggests that, on ethical grounds, the value of *r* should be zero. For example, Cline (1998) argued that there is no justifiable reason for choosing any value other than zero because the zero value reflects an equal weight placed on each generation. Hence, in the prescriptive approach, all that remains to be determined is the value of the last term. This value can be determined empirically, because it requires a forecast of growth in welfare. Long-run rates of growth are usually estimated at between 0.5% and 3%, depending on the rates of technological progress. Hence, given that the prescriptive approach sets *r* to zero, the social rate of discount calculated by the prescriptive approach is also between 0.5% and 3%. If estimates suggested that welfare would decrease over time, then *g* would be negative, which would justify a negative discount rate.

There are two criticisms of the prescriptive approach (Bruce et al. 1996). First, the opportunity costs of capital are often greater than the social rate of time preference calculated by the prescriptive approach. Hence, if an investment was made in mitigative activity that yields a return that exceeds the social rate of time preference but is below the market rate (for example, 5%), then other capital investments yielding returns of 5% or above might be displaced. This means that the value of capital stock transferred to future generations would be lower than what could be transferred by investing only in projects with yields greater than 5%. The higher-valued capital accumulated by investing in the highest-yielding projects could presumably be used to offset losses due to climate change or lower volumes of forest stocks. This would tend to make future generations better off, instead of worse off. The second criticism is that the behavior of society is not consistent with the assumption of *r* equal to zero. The fact that market rates of return on capital are greater than the social rate of time preference is one such inconsistency. Others include low savings rates and low levels of spending on education, which represent investments in physical and human capital.

The counterargument is that there can be no guarantee that investments set aside for compensation purposes will be available to future generations. For example, it has been argued that one way of compensating future generations for damage created by current activities would be to set up a trust fund from which those incurring damage would be compensated. However, setting up such a fund is difficult, if not impossible, for several reasons. First, there is no way of guaranteeing that the intervening generations will not consume the capital that has been set aside. Second, identification of individuals harmed by current actions or choices will be difficult, because climate change is likely to benefit some and harm others. Third, even if it were possible to set up such a fund, requirements to not consume the compensation fund may be overly restrictive and may prevent later generations from using the fund to adapt to new circumstances that might arise for a variety of reasons, such as technological change and the acquisition of new information. To summarize the argument, using cost–benefit analysis and the compensation principle in evaluating the long-term effects of climate change must incorporate an intergenerational resource-transfer mechanism. However, it is impossible to have confidence in such a mechanism because the commitment of intervening generations cannot be guaranteed. Finally, if there is no way of making the transfer or guaranteeing that the capital will be passed on to future generations, then using the market rate of return on capital in a cost–benefit analysis may be invalid (Lind and Schuler 1998).

Lind and Schuler (1998) also argue that no discount rate based on the market rate of interest can indicate how resources should be allocated across generations, or, more specifically, how the current generation, either collectively or individually, should make trade-offs between consumption by the current generation and that by some future generation. This is purely a question of intergenerational distribution and is a choice variable that cannot be inferred from behavior within existing institutional structures, including markets. The issue of intergenerational distribution is analogous to decisions to transfer income to communities in northern Canada for the purpose of development, education, or some other reason. Both situations involve purely distributional choices, and cost–benefit analysis cannot help in the decision making.

So there is no consensus within economics as to the appropriate discount rates for economic analysis of long-term impacts of climate change. However, several recommendations can be made concerning the use of discounting in economic analysis. First, cost–benefit analyses or other modeling approaches used to evaluate policy should be repeated with various discount rates so that policymakers will have information about how discount rates affect the present values of alternatives. Second, because the question of intergenerational equity relates directly to how resources are allocated over time, the time path of important climate change variables, such as the size of the forest sector, production and consumption levels, forest growing stocks, and carbon sinks, should constitute part of the analysis. This will give information to policymakers about intergenerational impacts that would be lost if only NPV results were presented (Lind and Schuler 1998).

Uncertainty

In this section, we consider choice criteria under conditions of uncertainty. Uncertainty, according to Arrow (1971), is characterized by incomplete knowledge of the world. Without complete knowledge, the nature of the impacts of climate change and the precise consequences of human reactions to climate change are unknown. Examples of uncertainties related to climate change are discussed in the preceding section, "Impacts of and Adaptations to Climate Change," and occur in the stocks, flows, and systems illustrated in Figure 1. (The later section "Methodological Frameworks for Assessment" provides a complementary discussion of uncertainty within cost–benefit, decision analysis, and multicriteria analysis.) Arrow et al. (1996) divide the uncertainties about the impacts of climate change into three main areas: scientific uncertainties (i.e., those related to physical and biological systems such as the atmosphere, oceans, and ecosystems, as well as dynamic feedback between systems), socioecological uncertainties (i.e., those concerning the relationship between humans and forests), and socioeconomic uncertainties (i.e., the economic and social welfare effects of climatic change and associated strategies and policies for adaptation and mitigation). These uncertainties ought to be considered when decisions and policies related to climate change are formulated.

Clearly, the uncertainties associated with the physical sciences have a bearing on the uncertainties in socioeconomic systems. If the physical impacts occur gradually and continuously, human and ecological systems are more likely to adapt smoothly, easily, and at relatively low cost. However, the more extreme and sudden the physical impacts, the more likely that high-cost, catastrophic, and irreversible damage will occur to human welfare and human institutions. Therefore, the probability of these extremes occurring is vital to decision making and policy choice.

The long-term nature of climate change is associated with many uncertainties, which further complicate analysis of long-term impacts. The complications arise, in part, because technological innovation and adoption are difficult, if not impossible, to predict accurately centuries or even decades into the future. Long time horizons also force analysts to deal with difficult intergenerational issues and make assumptions about the preferences of future generations (Portney 1998), which are likely to change.

Analysis Tools and Evaluation Criteria for Uncertainty

An important tool for tackling uncertainties in formal quantitative studies is decision analysis. In decision analysis, the uncertainties associated with outcomes from alternative choices are assigned probabilities. The choice of probabilities can be based on either objective scientific knowledge or subjective personal judgment (Arrow et al. 1996). Decision analysis, like cost–benefit analysis, requires a uniform measure of the value of outcomes (the costs and benefits), which may be in terms of dollars or in terms of consumer utility. Either of these measures may include attitudes toward risks and uncertainties. The choice criterion is either expected value (if outcomes are measured in dollars), expected utility, or certainty equivalents. Certainty equivalents account for attitudes toward risk and measure what a decision maker is willing to accept to exchange a riskless proposition for a risky proposition. Generally, risk-averse individuals prefer guaranteed payoffs to investments with slightly higher expected payoffs but with higher risk. Risk takers, on the other hand, prefer alternatives that may have lower expected returns than an alternative with a guaranteed payoff but which have a chance of generating higher payoffs. In other words, risk-averse individuals prefer evaluation criteria that minimize the chance of the worst possible outcome, whereas risk takers prefer criteria that maximize the chance of the best possible outcome (Arrow et al. 1996).

Decision analysis can be difficult to apply in cases such as climate change where there is limited historical experience or data (either actual or experimental) that can be used to make objective estimates of uncertainty. This type of analysis usually requires that a component of the uncertainties be based on subjective probabilities, for which estimates can be obtained from experts (Morgan and Keith 1995; Morgan 1998). In many contexts, such as climate change, the experts are not likely to agree on such probabilities. An alternative approach may be sensitivity analysis. Standard techniques are available for sensitivity analysis on probabilities, with the aim of determining the importance of variations in the probabilities to optimal policies or decisions. Another way of modeling uncertainty is the "fuzzy number" approach. This approach was applied by van Kooten et al. (1999) in forest land management contexts. This approach may be especially useful in situations where it is difficult to model the multiple uncertainties prevelant in forest land management situations, such as harvest yields, future land productivity, and future prices, and where targets and constraints are uncertain.

Although decision analysis might be difficult to apply, the exercise of decision analysis is itself a useful process. For example, identifying the important decision and system variables and the linkages between system processes and quantifying the uncertainties in system variables forces a formality and rigor on the decision-making process. Quantifying uncertainty can also assist decision makers in selecting the directions of future research.

Woodward and Bishop (1997) described another approach, which treats climate change as "a case of choice under pure uncertainty". Pure uncertainty occurs when outcomes are well-defined, but the decision maker is unable to assign probabilities to the different outcomes (Woodward and Bishop 1997). (In contrast, in the case of risk, probabilities can be assigned to different outcomes. Some authors therefore distinguish between risk and uncertainty in this way.). One such example is found in Nordhaus (1994a), where the widely diverse opinions of different scientific and economic experts in the field of climate change very aptly indicate that a consensus of opinion on likely impacts of climate change would be impossible to reach. This approach takes the view that the applicability of probabilistic analysis and, by association, expected values in decision making related to climate change may be limited. The principle of insufficient reason, whereby each expert's probability estimates are assigned the same weight, may also be limited because there is no objective way of assigning weights to differing opinions (Woodward and Bishop 1997).

Nevertheless, decisions concerning climate change are needed, and therefore an appropriate way to include uncertainty is required. Woodward and Bishop (1997) presented axioms derived from Arrow and Hurwicz (1972), which represent rational criteria for decision making for problems with great uncertainties. The critical axiom is the irrelevance of repetitive states, which says that the number of experts supporting a possible outcome is irrelevant. In other words, if a particular opinion about the possible outcomes of climate change is already represented on a committee of experts, there is no need to duplicate the opinion by including another expert with the same opinion. In this kind of decision-making environment, which is similar to that suggested by Nordhaus (1994a), rational choice criteria are severely limited. The only such criteria available are the maximin and the maximax criteria. In both cases, decisions are based on extreme outcomes (Arrow and Hurwicz 1972; Woodward and Bishop 1997), which supports Schelling's (1992) suggestion that research should focus on the extreme possibilities of climate change.

Figure 3 illustrates the maximin criterion. The current generation may choose between a pre-emptive policy or a wait-and-see policy. The payoffs of these policies to future generations depend on the size of the uncertain climate change outcome. If the impacts are large, the benefits to future generations of the preemptive policy are also large. However, if the impacts are small, the preemptive policy will yield small or possibly negative benefits (i.e., costs) to future generations. On the other hand, if the impacts are large, a wait-and-see approach entails very high costs to future generations. Finally, if the impacts are small, a wait-and-see policywill yield negligible costs or benefits. The maximin criterion identifies the worst possible outcome for each policy choice and then chooses the policy that gives the maximum of the worst possible outcomes. For the situation illustrated in Figure 3, this is the pre-emptive policy. It should be noted that this example is for illustrative purposes only. We are not suggesting that in the case of climate change the maximin strategy is necessarily a preemptive mitigation strategy. If the condition that decision makers are "uncertainty averse" (which is related to extreme risk aversion) is added to the set of axioms suggested by Arrow and Hurwicz (1972), satisfying the maximin criterion is the only rational decision rule. Woodward and Bishop (1997) applied this theoretical finding to a climate change example using the Dynamic Integrated Model of Climate and the Economy (DICE; Nordhaus 1994b) model and found that a rational, risk-averse policymaker should pursue an aggressive abatement policy, with the option of switching to a more moderate policy if future knowledge indicates that catastrophic climate impacts are very unlikely.

Choice criteria under conditions of pure uncertainty are related to the safe minimum standard and the precautionary principle (Woodward and Bishop 1997). The SMS suggests that critical resource levels, below which degradation of the resource is economically irreversible, should be avoided by policymakers, unless the costs of achieving this are immoderate. Woodward and Bishops's (1997) findings for the maximin criterion findings under conditions of pure uncertainty suggest that the safe minimum standard and the precautionary principle are rational choices under such conditions. Therefore, these two approaches should be considered as tools for formulating policies related to climate change.

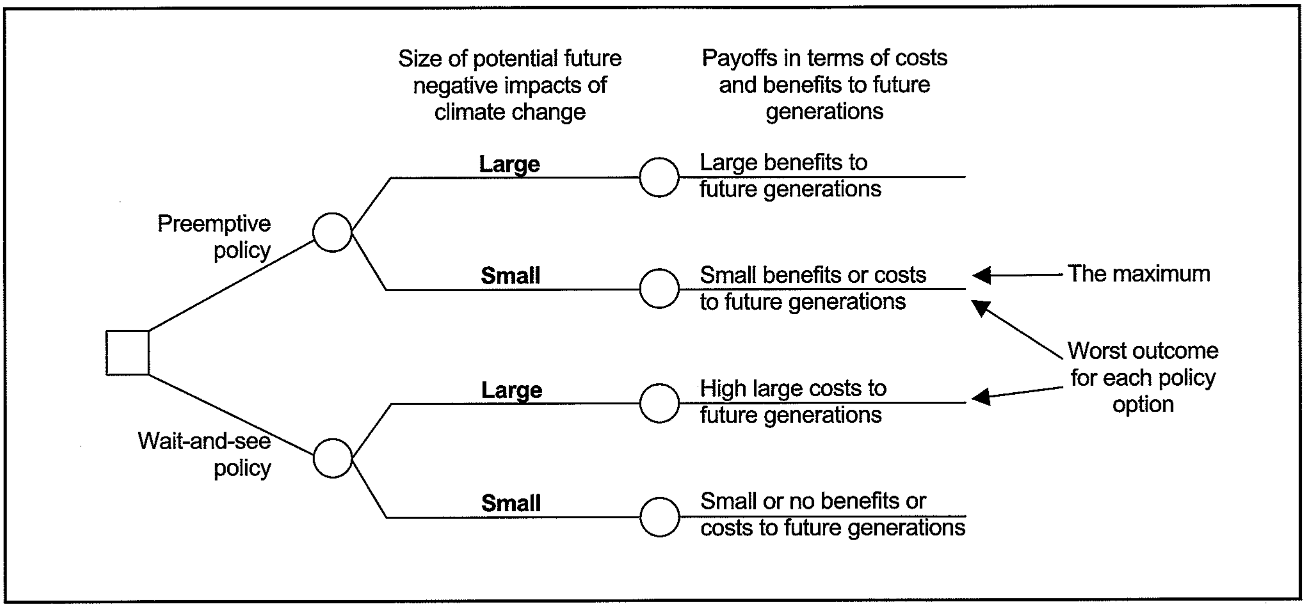

Figure 3. Illustration of the maximin criterion.

Competitiveness

An area of concern to policymakers 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. Such changes may be attributable to market forces, changes in regulation and policy, and other factors.

The main reason that policymakers 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 underemployment of certain factors of production (including labor), 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 the 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 might result in inefficient use of society's resources.

The impacts of climate change on the competitiveness of the forest industry are a function of many factors, including the magnitude of 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 that they provide for adaptation and mitigation through input substitution (e.g., if the relative price of energy or timber increases over time, then firms will strive to substitute relatively lower- priced inputs, such as capital, labor, and bioenergy, for the 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 of and the adaptive responses to climate change and climate change policy. Thus, competitiveness analysis is a useful and possibly necessary complement to large economy–climate modeling exercises, because the models must be properly specified if they are to yield accurate representations of industry responses. Also, competitiveness analysis can provide supporting information for accurate interpretation and analysis of model results.

A related idea is the concept of comparative advantage. The theory of comparative advantage was introduced by David Ricardo as an improvement on the theory of absolute advantage developed by Adam Smith (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 for which it has an absolute advantage in terms of cost or efficiency. Total output increases when a country specializes in producing and trading those products for which its efficiency is higher, allowing other countries to produce and trade products for which its efficiency is relatively lower (even though the costs of production are lower in the country in question). The country can then export the products it produces and import the products 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. (By necessity, the preceding is a very cursory and incomplete description of the theory of comparative advantage. The reader should refer textbooks on international economics and the gains from trade for a more complete discussion of this theory.)

The theory of comparative advantage was extended by the development of the Hecksher–Ohlin–Vanek theorem. Prestemon and Buongiorno (1997) note that because of a range of limiting assumptions embedded in this theorem, alternative models for describing trade flows have been developed. However, according to Prestemon and Buongiorno (1997), the theorem does seem to have explanatory power in explaining trade in forest products. Prestemon and Buongiorno (1997) describe the theorem 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 that resource. This concept can be quantified by means of a revealed comparative advantage index. This index has been applied by Bonnefoi and Buongiorno (1990), Jacques (1995), and Prestemon and Buongiorno (1997) to evaluate trends in the comparative advantage of regions in forest trade.

Effects of Change in the Forest Ecosystem

Climate change will affect the distribution of ecosystem types, as well as productivity within those ecosystems types. As noted above, changes in the relative endowment of forest resources in a country can be expected to have an affect on the comparative advantage of that country in the production and export of forest products (all other factors being equal). Some industries in which forest resources are an important input include forest products industries, tourism, trapping, outfitting, and recreation and vacation camps and lodges. The remainder of this discussion focuses on one particular forest resource, 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 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).

Effects of Global Market Responses to Climate Change on Canadian Competitiveness

Canada is the world's leading exporter of forest products, accounting for about 20% of global trade in this market, with a total value of exports of about $32 billion in 1994 (Natural Resources Canada 1996). Thus, changes in supply, demand, and prices attributable to climate change will affect the competitiveness of suppliers, particularly high-cost marginal producers. However, the interrelationships are complex, and the economic impacts depend on elasticities of supply and demand.

Perez-Garcia et al. (1997) linked various response scenarios (based on a doubling of carbon dioxide concentration) to a process-based biogeochemical model and a global trade model, to simulate the impacts of climate change on the global market in forest products. Their findings suggest that climate change will increase the productivity of the global forest which will in turn result in significant welfare gains for producers and some welfare losses to timber owners. Their findings for the USA indicate that welfare gains will be large for consumers and somewhat smaller for mill owners, and will more than offset losses experienced by timber owners (US timber owners will incur a net loss because the decreases in price will outweigh any effects on output).

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 an estimation of linear supply and demand curves in the USA and Canada. They concluded that welfare losses to Canadian producers would exceed welfare gains to Canadian consumers and that market responses to climate change would lead to a net welfare loss to Canada. This analysis is dated and oversimplified, and therefore its specific findings have limited applicability in the context of current policy needs. However, the approach illustrates that climate change impacts are transmitted through international markets and such markets should thus be taken into account and also illustrates the significance of market structure and elasticity in supply and demand in evaluating domestic impacts of climate change transmitted through global markets.

Social and Cultural Considerations

Most of this report focuses on the economic dimensions of the impact of and adaptation to climate change. However, economics constitutes only one branch of the social sciences. Other areas such as sociology and political science can provide insights into the impacts and implications of climate change for society and for decision-making and policy-making processes. Castle (1996) argued that economists need to recognize the requirement for a pluralistic approach to evaluate complex social problems that are subject to uncertainty. According to Castle (1996), pluralism "refers to the use of multiple viewpoints or intellectual approaches." An important component of evaluating the impacts of climate change will be understanding the social impacts on Canadian society. Social impact analysis falls within the discipline of sociology. There are equity-oriented, pragmatic, and technical reasons for broadening the scope of social science analysis related to climate change. First, there are ethical questions about inequity tolerance related to the distribution of costs of mitigation and adaptation that should be considered in the development of policy responses. In some cases these costs are not 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 that of other groups, and therefore the burden may be asymmetrically distributed because of 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 policy must be generally acceptable to society if it is to be effective (Bruce et al. 1996). Therefore, in addition to considering the technical dimensions of climate change from biological and economic viewpoints, the public policy process must also account for public perceptions regarding climate change and acceptable policy responses. Moreover, it should ensure that social institutions are designed so that the public is satisfied with policies and is involved in the decision-making process. Also, new approaches may be required to resolve social conflicts precipitated by climate change or to anticipate the occurrence of conflict and to take preventive steps. Sociologists can provide some insight into "attachment-to-place" issues. Sociological research can also contribute to improved understanding of public perceptions and the development of social institutions for involving the public in decision making and for resolving conflict.

A third reason for broadening the scope of social science analysis related to climate change is technical. Economics as a consequentialist doctrinaire, wherein "the worth of an action is judged in terms of its consequences" (Castle 1996), has certain limitations in accounting for some people's views about the value of nature's attributes (Castle 1996). That is to say, economics is particularly anthropocentric about the value or worth of natural resources. In this context the value or worth of a natural resource is a consequence of the value that individuals obtain from 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). Yet some people in society believe that nature's attributes have "intrinsic merit" (Castle 1996), that they are important for what they are and not in terms of the value they contribute to humans. This situation reflects differences in beliefs and value systems within society. Failure to account for differences in beliefs and value systems related to changes in nature's attributes resulting from climate change could lead to social conflict and policy failure. Economics has other limitations. Economic models of human behavior generally assume some level of consistent and rational behavior on the part of individual consumers and producers (e.g., Sohngen and 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 the impacts of climate change are based on measures of welfare impacts. For Nordhaus (1994b) the objective function is maximization of the "discounted sum of the utilities of consumption . . . summed over the relevant time horizon." Sohngen and Mendelsohn (1999) adopted an objective function of maximized present value of net consumer and producer surplus. There has been a history of discussion in the economics literature of the relevance of adding individual utility to determine aggregate social preferences. Bruce et al. (1996) noted the following:

> [A previous author] 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.

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

Climate change can affect social interaction and quality of life in various ways. First, changes in precipitation and temperature regimes can affect human behavior. For example, changes in average temperature, cloudiness, amount of snowfall, season length, severity of seasons, and frequency of extreme weather events can cause higher levels of stress and other social pathologies (Farhar-Pilgram 1985). Second, changes in climate have implications for human health (e.g., in terms of heat stress, disease, and 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 or social dysfunction (especially for human settlements that are relatively immobile 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). (If climate change increases agricultural productivity, there will be downward pressure on food prices [Darwin et al. 1995]. 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, and transportation accounts for a higher proportion of the cost of food in rural locations.) The demand for energy and food (when considered as aggregate commodity groups) is inelastic, which means that these goods have relatively few substitutes. Thus, increased costs, for 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, but rural residents may face relatively higher costs because of 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, and mining communities). These influences may be aggravated by climate change.

The types of social impacts that may result 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 mitigation efforts depends on many factors including the magnitude, rate, and continuity or discontinuity of climate changes; the types of ecological responses that occur; the relative sensitivity or exposure of particular communities to climate change, its impacts, and mitigation policy; the economic circumstances of affected social groups; and the ability or capacity of these groups to adapt or respond. Human communities at risk from a forest sector perspective include Aboriginal settlements, residents of economically undiversified rural communities reliant on forests for their economic livelihood, and social groups for whom forest access contributes to "sense of place" (Farhar-Pilgram 1985).

The ability of communities or social groups to respond and adapt to climate change will depend on the capacity of local institutions and community leaders. Adaptive capacity will be enhanced if the affected parties are satisfied with their level of involvement in decision making and if they are well informed about what to expect and what their options are. Some social groups face significant barriers in terms of their ability to respond, in the form of institutional rigidities that reduce their mobility. For example, Aboriginal peoples living on reserves may find themselves facing unstable ecosystems on the reserves but will have limited opportunity to relocate or search for alternative opportunities. Thus, the existence of institutional rigidities can reduce the adaptive capacity of some forest-based social groups. This issue requires further exploration.

In their final report to Congress, the Sierra Nevada Ecosystem Project Science Team and Special Consultants (1996) noted 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.

FOREST SECTOR CONSIDERATIONS IN ASSESSING IMPACTS OF AND ADAPTATION TO CLIMATE CHANGE

In the previous two sections, we have provided a general description of the physical, economic, and strategic dimensions of climate change and an overview of various criteria that can be used to assess the socioeconomic impacts and implications of climate change and related policies. However, these general discussions have not identified many of the specific considerations needed to apply the concepts to the special problem of climate change as it relates to the forest sector. This section considers the forest sector by looking at which forest values are affected by climate change, how climate change affects these values over time, the effects that adaptive responses by forestry firms, forest landowners, governments, and consumers may have on the flow of forest values over time, and how interactions with closely tied sectors affected by climate change (primarily agriculture and energy) might influence the future time paths of production and the prices of forest products, as well as social welfare measures. Some earlier Canadian papers on the topics in this section include van Kooten and Arther (1989) and Binkley and van Kooten (1994).

Timber Market Impacts and Adaptations

The ability to forecast the impact on timber markets of climate change and related adaptive responses requires dynamic models that integrate forecasts of future climatic conditions with physical models of ecosystem distribution and productivity and economic models of markets and interactions in renewable resource sectors (i.e., agriculture and timber). In such analyses, the effects of climate change are measured by comparing the stream of benefits occurring with climate change with the stream of benefits expected to occur without climate change (i.e., the baseline).

For market-based goods and services, prices and quantities are determined by the interaction between supply and demand. Market impacts (or changes in price and quantity) occur when some exogenous change results in a shift in supply or demand, or both. The magnitude of market impacts depends on the degree of the shift and the relative elasticities of supply and demand. The main influence of climate change on timber markets is expected to occur through changes in the underlying production function for timber, with consequent changes in timber supply (Sohngen and Mendelsohn 1999). There are, however, a number of ways of viewing and defining timber supply. Also, several factors that simultaneously influence timber supply, including biophysical factors, economic factors, and social values (Williams 1994). Climate change will likely have some influence on the physical productivity of the land base; however, to understand how changes in physical productivity might affect timber supply and consequently timber markets, it is necessary to understand the full set of interactions that determine timber supply at any particular point in time and, if possible, to incorporate these influences into empirical models.

There are two perspectives from which to view timber supply. Forest scientists view timber supply as a physical flow, whereas economists view it in terms of price–quantity relationships. In this section we begin with a review of timber supply from a physical flow perspective and then discuss other socioeconomic considerations that determine timber supply from a policy or political economy perspective. The discussion then proceeds to a general overview of particular considerations in assessing the impacts of and adaptation to climate change within Canadian timber markets. Finally, a short review of a study of US timber markets is used to illustrate one approach to assessing the impacts of climate change on timber markets.

As mentioned above, timber supply is sometimes viewed as a physical flow reflecting forest land area, the productive capacity of the land base, the existing forest inventory, and regulatory constraints. Concepts such as allowable annual cut and long-run sustained yield provide empirical measures of timber supply from this perspective. These measures depend primarily on the existing inventory, the land base, growth and natural mortality factors, management inputs, utilization standards, operability, environmental constraints, and other policy considerations that may constrain availability. Moreover, the measures tend to change over time with new information on stocks and productivity and with changes in land use, regulations, accessibility (e.g., due to the development of new road systems), policies, and relative social values.

In Canada, most forest land is publicly owned. The implication of this pattern of ownership is that timber supply is only indirectly a function of economic variables such as prices, income, costs, and technology and does not directly respond to changes in these variables. In the main, timber supply and prices are determined administratively by a combination of policy considerations, social values, and biophysical characteristics (Williams 1994). Thus, it may be difficult to directly model or forecast the impacts of climate change on Canadian timber supply and timber markets as an economic process. A similar line of reasoning applies to forecasting trends in adaptation, because adaptive responses to climate change in Canada will be decided by public-forest land managers responding to changes in policy and management objectives, and it is difficult to model these responses. Some combination of heuristic decision rules, expert opinion, and optimization methods may be required to account for and incorporate the mix of policy, economic, and social factors that will likely determine the future path of timber supply in response to climate change. This is not to say that economic analysis does not have a role in anticipating impacts on and adaptations of timber markets. Economic analysis can provide assessments of optimal changes in land use in response to climate change. It will also play a role in elucidating how changes in global markets in response to climate change might affect product prices for Canadian producers and consumers. Finally, economic analysis will play a role in translating climate-induced changes in physical timber supply over time into social welfare impacts such as gains or losses in consumer and producer surplus.

Timber supply can also be viewed as an economic resource responding to price signals and the profit-maximization objectives of landowners. Where forest lands are privately owned and owners are price takers in timber markets, timber production, consumption, and prices are determined endogenously. The behaviors of landowners can therefore be modeled, and future time paths of price, consumption, and net social benefits can be forecasted. Changes in land productivity due to climate change will affect timber prices and relative land prices, which in turn will affect decisions by landowners regarding land use and management. For example, it is possible to estimate when landowners might convert their land to alternative uses, when they might change the cover type by planting new species, the rate of harvest or rotation age they will select, and the economically optimal levels of investment they will make in forest management. Each of these areas must be considered in assessing the impacts of climate change on the timber markets and their adaptive responses in an environment where markets are the dominant mechanism for determining land use and management.

In contrast to the situation in Canada, most forested land in the USA is held by private landowners (either large corporations or smaller individual landowners). Therefore, it is possible to model the responses of US timber markets to climate change as an economic process. Sohngen and Mendelsohn (1999) have illustrated an approach to integrated assessment modeling of climate change impacts on timber markets. They developed a dynamic partial equilibrium model of the US timber market and linked this model to dynamic models that simulate the effects of climate change on ecosystem distribution and productivity. The authors argued that landowners in particular locations will adjust their harvest schedules and replanting decisions in response to expected changes in future prices and yield. These decisions will in turn affect regional timber supply, as well as the price path for timber over time. Prices adjust over time in response to both changes in demand (due to population growth and per-capita income growth) and changes 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. Thus, price and harvest levels would be determined endogenously. Timber supply, management intensity, and land use (i.e., forestry or agriculture on lands suited to both) are responsive to price and risk, and it is relative changes in current and expected future prices as well as risk of future loss that will trigger adaptive responses to climate change on the part of landowners. These dynamic adaptive responses will 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 and Mendelsohn (1999) projected that climate change would have significant positive economic benefits in the US timber market. They estimated that these positive benefits would range from US$3.87 billion to US$32.58 billion over a 150-year adjustment period (note that ecosystems adjust over a 70-year period, whereas markets adjust over a 150-year period), and a significant portion of these positive benefits would accrue to consumers. Price paths under the various climate change scenarios were lower than the baseline price path. Therefore, much of the benefit of climate change on timber markets would occur as a result of increases in consumer surplus. The reason that price paths are lower is that landowners would respond to climate change by adjusting harvest schedules and silviculture investments to take advantage of the more favorable growing conditions that are expected for US forests. Thus, climate change will result in increased supply and lower prices for forest products. Significantly, these benefits occur as a result of adaptations that are motivated by market signals and the responses of economic agents.

For a number of reasons Sohngen and Mendelsohn's (1999) projections of significant positive benefits from climate change can probably not be extrapolated to Canadian timber markets. First, it is possible that climate change will be more extreme in Canada's more northerly latitudes, and this may have negative impacts on Canadian timber supply (in terms of volume and allowable annual cut) and timber quality (in terms of tree size and stand density). Second, highly valued coniferous species may be replaced with lower- valued deciduous forest in the northern boreal forest. Furthermore, it may be impossible to capture a significant portion of the possible welfare benefits (i.e., consumer surplus) because when product demand is inelastic, there is a tendency to transfer surpluses through to the consumers of the final product; given that most Canadian production is exported, foreign consumers would tend to be the beneficiaries of increased timber supply, if it occurred (van Kooten and Arthur 1989). Finally, there is a lack of market incentives to encourage adaptive responses on the part of landowners (because most forest land in Canada is owned by governments).

The fact that the projection of positive economic benefits and an efficiently functioning timber market mitigating economic impacts cannot be extrapolated to Canada does not mean that positive welfare benefits will not occur in Canadian in timber markets, nor is it possible to exclude the possibility of significant negative economic impacts. There is simply no way to speculate on the economic impacts of climate change on Canada's forest economy without an assessment framework tailored to Canadian circumstances.

Nonmarket Impacts and Adaptations

The preceding discussion pertained to the impacts of climate change on a forest value that is market based (i.e., timber markets). However, the concepts of economic efficiency and consumer surplus are equally applicable to nonmarket 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 various types of nonmarket benefits and discusses how climate change might affect them. However, we do not speculate on the direction of possible value changes because there is limited information on the magnitude of the impact of climate change on social values and because the appropriate methodological approach for measuring changes in the value of nonmarket goods and services is not known. These areas require further research.

Nonmarket goods include some use values and non-use (or passive-use) values (Fig. 4) (Munasinghe 1993). Use values are those activities for which some level of utility is obtained by participation (e.g., recreation or subsistence consumption from hunting, trapping, and fishing). Non-use values include existence values and bequest values. Existence values are those associated with the knowledge of the continued existence of habitats and endangered species, without the need to visit them. Bequest values are those associated with the knowledge that particular natural resource features will be passed on to future generations. Option and quasi-option values are also considered subsets of non- use values. These values pertain to an individual's knowledge that he or she has the option to undertake an activity at some future date. 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.

Use and non-use values must be summed to obtain measures of the total impacts on nonmarket values (McConnell 1997). Bruce et al. (1996) outline different valuation techniques that can be used to estimate economic values for nonmarket goods. However, the potential impacts of climate change are so numerous and subtle that measuring them all would be prohibitively expensive (McConnell 1997), especially given the uncertainties involved. Therefore, the feasibility and practicality of research to assess the impacts of climate change on nonmarket values must be evaluated. Priorities for undertaking research on the impacts of climate change on nonmarket values must also be established.

A few studies have estimated the impacts of climate change on nonmarket values (e.g., Cline 1992; Nordhaus 1994b; Fankhauser 1995). In some cases these estimates have been controversial. For example, Nordhaus (1993) criticized Cline (1992) for including losses predicted for skiing but excluding benefits from warm-weather recreational activities such as camping. Some studies have focused exclusively on the impact of climate change on nonmarket values. Pendleton and Mendlesohn (1998), for example, evaluated the impact of climate change on the US freshwater sportfishery. D.F. Layton and G. Brown (1998 "Heterogeneous preferences regarding global climate change" unpublished paper) estimated the changes in non-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.

Outdoor forest-based recreation is influenced by climate, weather, and their degree of variability; however, some activities are more sensitive to climate than others (Wall 1998). Sites preferred because of their natural resource features are likely to be more susceptible to climate change than sites with cultural or historical significance (Wall 1998). Therefore, outdoor recreation activities (such as fishing, hunting, skiing, hiking, horseback riding, mountain biking, snowmobiling, camping, rafting, canoeing, kayaking, and bird-watching) may be vulnerable to the impacts of climatic change, either positive or negative.

Season length is particularly important for activities such as skiing and hiking. Skiing is predicted to be adversely impacted by climate change, because of 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, relocation of sites further up mountainsides, and diversification of activities to include summer attractions such as golf courses, hiking trails, swimming pools, and conference facilities. Although winter activities may be adversely affected by climate change, summer recreation may benefit from extension of the season (Mendelsohn 1998).

There is a lack of benchmarks to identify the impacts of climate change (Watson et al. 1996) and a lack of high-resolution general circulation model outputs with which to predict local and regional nonmarket impacts (McConnell 1997). These gaps partly explain the paucity of tourism and recreation data for all but a few site-specific examples (Wall 1998). However, Pendleton and Mendelsohn (1998) estimated the economic impacts of climate change on freshwater sportsfisheries in the northeastern USA. They linked general circulation models and ecological and economic models (specifically, models for hedonic travel cost and random utility). Some of their discussion and conclusions are probably relevant beyond their specific subject of study. For example, they found that although the negative economic impact of climate change on a single species could be significant, in many cases it could be offset by increases in other species.

According to their analysis, the overall net economic effect of climate change ranged from losses to benefits, depending on economic and climatic factors. Differences between regions meant that although some areas would likely benefit, others would not (Pendleton and Mendelsohn 1998).

Participants in recreational activities can adapt to climatic change through use of mobile recreational equipment, choices as to whether, when, and where to participate and in what activities, and the possibility of substituting leisure activities and location, without a substantial loss in the quality of their experience (Wall 1998). Nevertheless, as mentioned earlier, overall there are likely to be greater opportunities for summer activities and reduced opportunities for winter activities (Mendelsohn 1998).

Indirect-use values include the value of the ecological functions of the forest. One example is the ability of forests to sequester carbon and thereby reduce the atmospheric buildup of carbon. However, if carbon permits or credit schemes are implemented, then the carbon-sequestration capacity of forests may become in part 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 arise). There are, however, extenuating circumstances in terms of forest's ability to sequester carbon under new climate regimes. For example, if the predicted increases in forest fires and disturbances occur (Sedjo 1998), they will adversely affect forests' ability to sequester carbon.

As mentioned earlier, non-use values include existence values, bequest values, and option values. All of these types of values are psychological in nature and will be affected by climatic change. For example, climate change will influence biodiversity, the viability of particular endangered species, and the location and quality of habitats. Ecosystem shifts will mean that existing protected areas and parks may no longer protect the environmental attributes that they were established to protect in the first place. Wildlife populations that may be at the greatest risk of decline from changes in habitat due to climate change will be, in many cases, those that are already at risk (Anderson et al. 1998).

Biodiversity incorporates species richness, genetic diversity, and the ecological diversity of landscapes (Anderson et al. 1998). Many of the non-use values of forests are closely aligned with the concept of biodiversity. Therefore, to the extent that climate change affects biodiversity, there may be implications for non-use values, including option values. However, the complexity of the web of interactions between species, ecosystems, and climate will make it difficult to isolate the direct cause-and-effect relationships between climatic change and biodiversity (Anderson et al. 1998).

The study by D.F. Layton and G. Brown (1998 "Heterogeneous preferences regarding global climate change" unpublished paper) is one of the

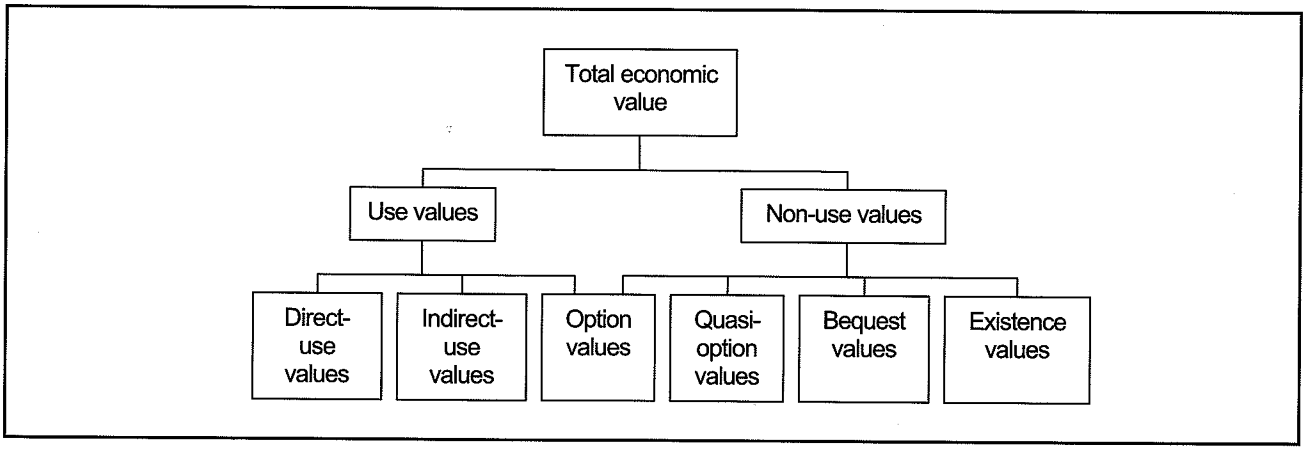

Figure 4. Use and non-use values of nonmarket goods.

few to discuss the impacts of climate change on non-use values. They estimated the value of ecosystem impacts along the Colorado Front Range of the Rocky Mountains. Using a stated-preference approach, they found substantial heterogeneity in respondents' preferences. Interestingly, individual respondents had the same preferences over two different time horizons. The mean willingness to pay for mitigation was significant. Moreover, the amount that people were willing to pay for mitigation increased with the level of the impact (D.F. Layton and G. Brown 1998 "Heterogeneous preferences regarding global climate change" unpublished paper).

The Intergovernmental Panel on Climate Change (Watson et al. 1996) identified several adaptation strategies to reduce the negative nonmarket impacts of climate change, including mixed species planting to increase diversity and flexibility, selection and planting of species and varieties suited to future conditions, and identification and management of a system of protected areas that anticipates future ecosystem changes in response to climate change. In addition, it was recommended that species at risk (which may be restricted in geographic range) be conserved in forest reserves, arboreta, and conventional seed banks and cryogenic storage to ensure their survival (Watson et al. 1996). Finally, it will be important to preserve those features that contribute to the adaptability and resiliency of ecosystems (Anderson et al. 1998).

Non-use values are difficult and expensive to quantify, and there are high levels of uncertainty as to how the specific environmental attributes that determine non-use values will respond to climate change. However, given that, without intervention, there is some potential for irreversible losses of certain environmental attributes, these values must be considered in policy development. Such considerations will probably have to be developed in the absence of explicit measures of the impact of climate change on non-use values. Although economics will likely not be able to quantify the effects of climate change on aggregated nonmarket values, it can still contribute to developing policy responses, by identifying the conditions and circumstances when applying the safe minimum standard approach (Berrens 1996) for protecting ecological attributes would be appropriate and by identifying social preferences, rankings and values for selected and geographically explicit non-use values.

Finally, climate change will create the need for proactive policies for the future protection of key non-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, and Canada's forest resources. In general, current policies do not take climate change into account. However, climate change represents a new variable in the mix of factors that affect ecosystems. Thus, there is a growing need to review natural resource management policies at various levels. For example, one of the main instruments for protecting nonmarket values and ecosystems is the establishment of protected areas and parks. There may be a need to reconsider 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 or parks would be a way of protecting certain critical pieces of natural capital such as old growth in a dynamic environment of changing climate.

Interactions between the Forest Sector and the Agricultural Sector

This section discusses interactions between the agricultural and forest sectors. The question of interest is how climate change may affect the relative value of land in forestry and agriculture production. Changes in land values should lead to changes in land use (van Kooten 1995). This will be an adaptive response to climate change and 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 the present value of timber incomes of amount $X at a particular location may be offset by an increase in the present value of net agriculture net returns of amount $Y. If $Y is greater than $X, the net social impact may be positive. The opposite situation is also possible, whereby positive increases in the present value of timber production exceed declines in agriculture at a particular site. Figure 5 shows how the value of land for different types of agricultural crops changes 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 (e.g., temperature) increases, the type of land use that

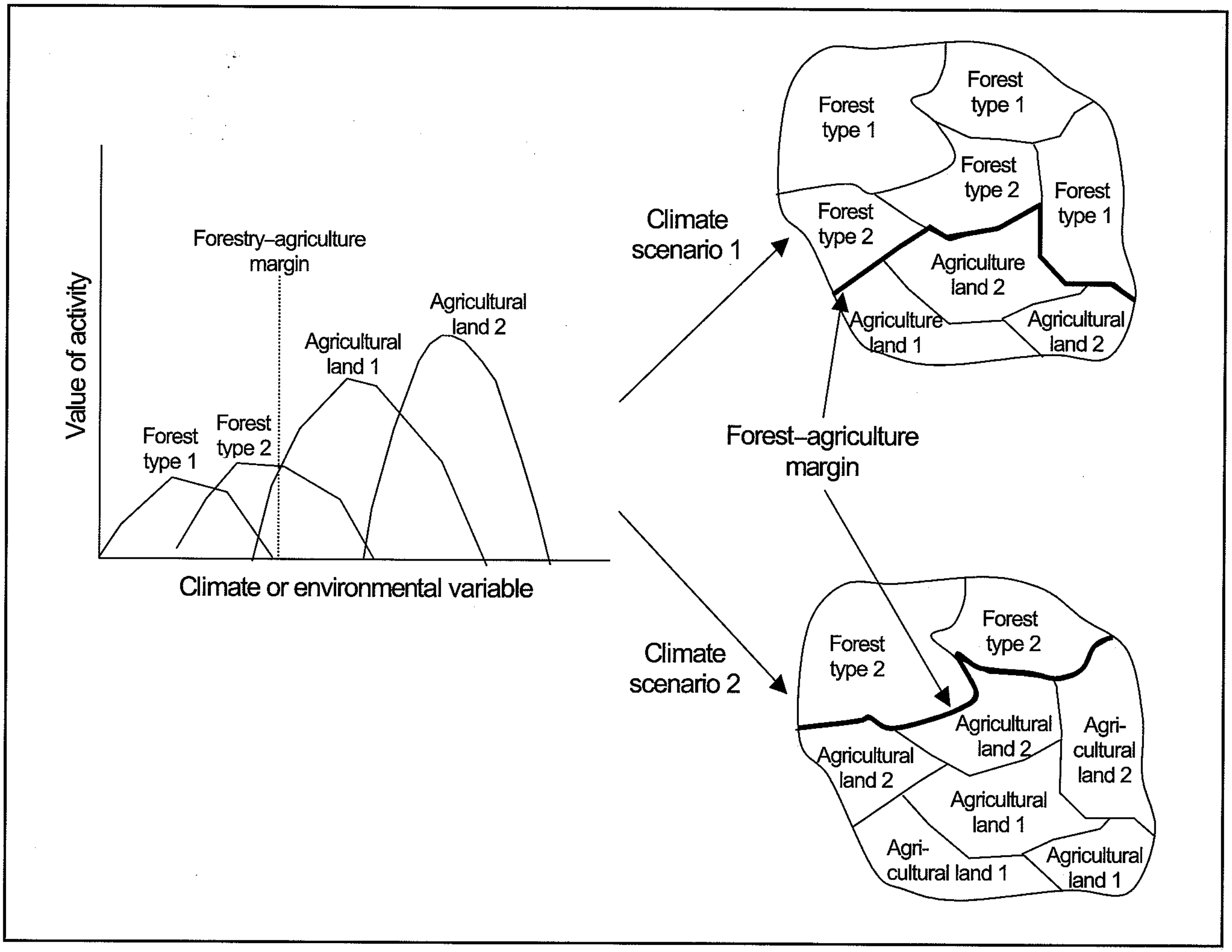

Figure 5. Model of the relationship between climate variables, land use, and land values, and the spatial location of land use under different climate scenarios.

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 change. Changes over time in the spatial distribution of land types and in the agriculture–forestry margin in response to climate change for a hypothetical area are also illustrated in Figure 5.

Changes in land use because of climate change at a local or national level will be the result of two influences. First, at a local level, climate change will affect the length of the growing season, moisture availability, rates of variance in weather patterns, and other factors that affect plant growth and species suitability for particular sites. Also, increased atmospheric concentrations of carbon dioxide may have positive effects on plant productivity (Darwin et al. 1995). This change has implications for production possibilities at particular sites (e.g., grains, fruits and vegetables, forage, rangeland, intensive forest management, extensive forest management, particular tree species). The second influence occurs as a result of changes in markets. The relative price paths for these goods will influence land use and, because climate change is global, structural changes in global markets and world prices can be expected. Because forestry and agriculture compete for the same land, forecasts of future land-use trends in one sector or the other require simultaneous consideration of the effects of climate change on productive possibilities and on global market prices for both sectors (Darwin et al. 1995). Also, adaptation or adaptation capacity in each sector will affect final land-use patterns. The implications are twofold. First, losses due to climate change in one sector may be offset by economic gains in the other sector. Second, impacts and adaptation in one sector are functionally dependent and closely interrelated to impacts and adaptation in the other sector, both at local levels and in terms of global market trends. The remainder of this section summarizes some studies of the effects of climate change on agriculture, both in Canada and globally. This discussion does not constitute an exhaustive review of the literature, but these studies illustrate some general findings regarding interactions and trends. Lewandrowski and Schimmelpfennig (1999) have reviewed the recent literature and studies assessing the impact of climate change on the US agriculture sector.

Darwin et al. (1995) modeled the effects on world agriculture of a doubling of atmospheric carbon dioxide concentrations. Their analysis considered the joint effects of productivity changes and market factors and found that grain production and livestock would increase, while nongrain crops and forest land use would decline at the global level. The overall implication was that the production of processed foods would be slightly higher than current levels. The authors also noted that these results would not apply to all regions. For example, "in Canada, output of agricultural and processed food commodities increases, while in Southeast Asia, output of these commodities generally decreases" (Darwin et al. 1995).

The impacts of climate change on agriculture will vary from location to location, having a positive impact (e.g., longer growing seasons, increased moisture availability, and increased carbon fertilization effects) in some locations and a negative impact (e.g., heat stress, moisture deficits, and increases in the incidence of pests and diseases) in other locations (Darwin et al. 1995; Bruce et al. 1996; Brklacich et al. 1998). Agricultural responses to climate change include changes in crop types and yields (Bruce et al. 1996) and changes in the regional distribution of production (Darwin et al. 1995; Brklacich et al. 1998). Canadian studies that address changes in agricultural potential have been summarized by Brklacich et al. (1998). The main finding of these studies is that crop potential in the Peace River region and the northern agricultural areas of Quebec and Ontario will expand (although expansion in the Peace River region will be moderated by increased moisture stress). Some expansion of fruit and vegetable production capacity is probable in British Columbia and in southern Ontario and Quebec. Changes in agricultural potential in the Northwest Territories are not expected to be significant (Brklacich et al. 1997). However, these studies are based purely on growing season, moisture availability, and other physical factors, with limited comprehensive analysis of how landowner adaptation and market trends might influence cover types and land uses. This is an area that requires additional research.

Change in relative land values between agriculture and forestry might also occur as a result of carbon-sequestration policies (Sedjo and Solomon 1989; Nilsson and Schopfhauser 1995; van Kooten et al. 1999). In addition to sequestration of carbon in forests, it has been suggested that carbon could be sequestered on agricultural land, via reduced tillage. Krcmar-Nozic et al. (1999) suggested that the uncertainty associated with carbon sequestration through afforestation on marginal Canadian agricultural lands and reforestation is difficult to model, especially when different strategic options (e.g., base case, optimistic and pessimistic scenarios, and lax and strict management policy regimes) are included. Forage and pasture lands considered suitable for afforestation in Alberta and the Peace River region of British Columbia were analyzed by van Kooten et al. (1999), who found that as much as 7 million ha of agricultural land could be afforested. However, the cost of sequestering carbon by this means would limit afforestation to less than 2 million ha, which would sequester an average of 7 Mt of carbon per year for 50 years. In the whole of Canada no more than 6 million ha of agricultural land is likely to be available for afforestation. Nevertheless, this area could provide over 25% of Canada's Kyoto commitment (van Kooten et al. 1999). However, in most cases these scenarios do not consider what will happen to the economics of sequestration if climate change actually occurs. Van Kooten (1995) suggested that if climate change is inevitable, the optimal strategy might not be to convert marginal agricultural land to forestry but rather to convert forest land to agricultural production.

Carbon Sequestration

The Canadian forest sector can contribute to mitigation in a variety of ways, including carbon sequestration, use of wood products as a replacement for more GHG-intensive products, and increased use of bioenergy. For further details of the role of the forest sector in mitigation see the Forest Sector Table (1998) and the National Sinks Table (1998).

Carbon Sequestration in Forests

Forests and forest soils have the capacity 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 in terms of species selection, rotation age, reforestation strategies, preferred harvesting systems, forest protection strategies, and intensive management strategies. In fact, the possibility that forests may have a role in carbon sequestration means that adaptation strategies and actions leading to mitigation are closely linked, which makes it difficult to differentiate adaptive from mitigative actions. For example, it has been suggested that climate change will increase the rate of fire disturbance. A likely adaptive response to this increase by fire management agencies would be increased protection effort. However, increasing 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 can contribute to mitigation goals by offsetting emissions produced as a result of the production and use of fossil fuels. These tradeoffs are illustrated in Figure 6. This simple model assumes that the energy sector has some fixed target for emission reduction that is tied to the rate of carbon sequestration in or carbon loss from forests. Carbon sequestration by forests (or agricultural lands) could shift the requirements for emission reduction of the energy sector to the left. This would result in a saving equal to the area defined by the points a, b, c, and d. In this situation, it would be worthwhile for the energy sector to invest an amount up to this area 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 might result in a shift to the right in requirements for emission reduction in the energy sector. The resulting increase in energy sector costs is the area defined by points a, b, e, and f. In this case, it would be worthwhile for the energy sector to invest an amount equal to this area to prevent carbon losses from forests attributable to anthropogenic effects.

The following are some important questions about the practicality of carbon sequestration as a substitute for reductions in GHG emissions: What is the baseline time path of carbon storage from natural forests? 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 promoting efficient trades between GHG emitters and those that own the property rights to carbon-sequestration capacity? What are the measurement issues related to accounting for dynamic changes in carbon stocks and flows, with and without intervention? How will future climate change affect carbon-sequestration capacity and the pool or stock of carbon that has already been stored or sequestered? Several authors have examined these and other issues pertaining to the economic dimensions of carbon sequestration in forests (e.g., Harmon et al. 1990; Englin and Callaway 1993; van Kooten 1995; Price et al. 1996; Price et al. 1997; Sedjo 1998; van Kooten et al. 1999).

In considering forests as a possible sink for the sequestration of atmospheric GHGs, the short- and long-term capacity for forest lands to store carbon must be examined. The conclusions of the National Sinks Table (1998) suggest that forests have changed from being a sink to being a source and that they may, in the future, become a sink again. Thus, forest carbon stocks were increasing until about 1980, have been decreasing in the last 20 years, and are expected to increase again in the future. This fluctuation leads to some important questions: Should the carbon sink–storage issue be considered on a longer-term basis, by looking at long-term trend lines (with short-term fluctuations) instead of relatively short-term fluctuations? If such a temporally stable long-term trend line does exist,

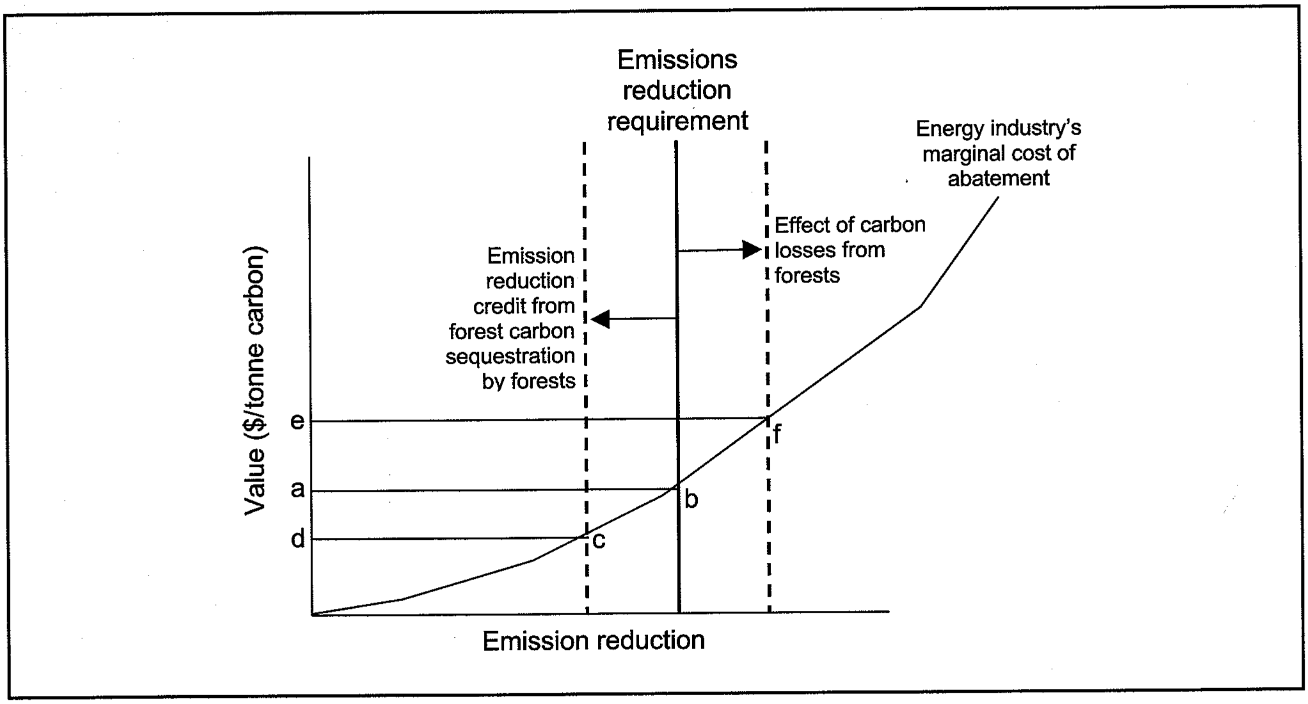

Figure 6. Mitigation potential of forests for offsetting greenhouse gas emissions from fossil fuels.

could the long-term trend be shifted upward with human intervention? How will climate change affect future long-term trends? These questions provide alternative ways of looking at the issue of sequestration credits. For example, if human interventions result in a change in carbon sequestration in forests, but the change effects only short-term, not long-term, storage ability, then storing carbon in trees is only a mechanism to buy time for discovering new technologies to reduce use of fossil fuels or to reduce the GHG output from the use of fossil fuels. Also, if forest carbon is not permanently stored and if carbon sequestered in the present will be emitted in the future, then presumably future increases in forest GHG output would need to be offset by further reductions in GHG emissions from fossil fuels.

The preceding discussion leads to questions about what can be done to improve carbon storage in forests. The timing of harvesting affects carbon-sequestration capacity (van Kooten et al. 1995). Generally speaking, prolonging rotations in natural forests will increase carbon sequestration (Binkley et al. 1997). Englin and Callaway (1993) integrated a carbon sequestration life cycle into the Faustmann model. They determined an optimal timber rotation for the joint maximization of timber and carbon sequestration; this optimal rotation was sensitive to the discount rate chosen.

Carbon Sequestration in Forest Products

Another way to reduce carbon emissions is to encourage the use of products for which the rate of carbon emission associated with production and use is relatively low (Forest Sector Table 1998). However, understanding the implications of the production and consumption of a particular product for carbon emission rates requires an analysis of the rate of emission of GHGs at each stage of the product's life cycle (i.e., extraction, production, consumption, recycling, and disposal). Some have suggested that wood products require less fossil fuel energy in their production than do competing products, such as steel, concrete, glass, and vinyls. However, these conclusions are somewhat speculative at this time. A more thorough analysis of the life-cycle impacts of various products would provide a better basis for determining the implications of consumption of these products and the possibilities of controlling carbon emissions by encouraging alternative product mixes. Moreover, decisions should not be based solely on life-cycle impacts. It would be more beneficial to link life-cycle impacts with general equilibrium analysis, so that the economic consequences or costs and benefits of alternative product mixes could be assessed.

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

Recycling extends a product's life cycle, which may help in reducing GHG emissions. However, this is a complex issue. For example, the recycling of paper can reduce the pressure to use 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 investments in pulpwood tree plantations and could result in alternative uses of the wood and the land (Sedjo et al. 1995).

Bioenergy

Bioenergy can be used as a substitute for fossil fuel and can therefore also be used to decrease consumption of fossil fuels within the forest sector (and the rest of the economy). Bioenergy is already the largest source of renewable energy in Canada, providing about 6% of total primary energy supply and 7% of primary residential heating (at present, wind and solar energy are more costly than conventional energy sources, and therefore they play a marginal role) (Mercier 1998). The pulp and paper industry is the main producer and consumer of bioenergy. Research into improving forest management for biomass, tree plantations, and bioenergy technologies is already under way, partly because an increase in demand for and reliance on biomass is anticipated in the future. An increase in the use of biofuels will lead to a predicted decrease in the total demand for GHG-intensive fuels by the forestry industry, from 15.7 PJ in 1990 to 13.3 PJ in 2020, despite the fact that gross output by the industry is expected to increase (Natural Resources Canada 1998). This trend is forecasted to continue beyond 2020, for example, the use of wood waste, pulp, and spent pulping liquor (bioenergy sources) by the pulp and paper industry is predicted to double between 1990 and 2020 (Natural Resources Canada 1998). Municipal wastes, 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 of undertaking these changes. There are 7 million board feet of surplus wood residue in British Columbia, Alberta, Quebec, and Ontario (Wellisch 1998). Each year, 450 PJ of bioenergy from hog fuel and logging residues is either burned 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. Not only do landfills store potential bioenergy, they also emit methane. If these potential sources of bioenergy were used before they reach landfill or if the methane emitted during their decomposition was collected and burned to generate energy (Hornung 1998), environmental benefits would accrue. Pearce (1997) went so far as to argue that it might be environmentally preferable to burn waste paper rather than recycling it.

Using bioenergy is thought to be an effective way to reduce carbon emissions (Kurz et al. 1992), as long as the wood biofuel is harvested sustainably. Although the use of biomass energy results in GHG emission, it is usually considered "carbon dioxide neutral" because the carbon in the biomass material was originally sequestered from the atmosphere (Mercier 1998). Thus, the use of bioenergy leads to a dynamic carbon cycle between biomass and atmospheric GHGs. Alternatively, the burning of fossil fuels leads to constant accumulation of carbon in the atmosphere and biosphere (since some of the carbon is taken up by plants) (Swisher 1997).

Domestic Policy Instruments

Actions such as switching to bioenergy, enhancing carbon sequestration in forests, substituting products, and improving energy efficiency are alternative ways in which the forest sector and forest products can contribute to reducing GHG emissions in Canada. However, these actions may require policy or program interventions by government agencies. The purpose of these interventions may be to either provide funds for programs that deliver certain socially desired outcomes (e.g., planting programs for afforestation) or change incentive structures or regulations so that firms and consumers adjust their behavior to reduce emission rates. Domestic policy options include regulation (e.g., the establishment of standards for energy efficiency), 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-based instruments are important, few economists believe that they are the complete solution (Rolfe, C. 1998. Selling clean air: market instruments for climate protection. A discussion paper prepared for West Coast Environmental Law Research Foundation workshop, Selling Clean Air: Market Instruments for Climate Protection, 15–16 October 1998, Vancouver, BC.).

The attraction of market-based instruments is that decisions about how to achieve an environmental goal are transferred to the marketplace. It is suggested that market-based instruments can be relatively more efficient than direct government intervention because competitive market forces ensure that the objective is achieved at minimal social cost, because producers 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. The example in Figure 6 demonstrates the potential advantages of 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, including 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 (i.e., the possibility that investments with high returns are displaced by investments with lower returns), 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 judgments. The uncertainty associated with climate change makes policy choice and implementation even more difficult, as appropriate levels of taxes, quotas, permits, and caps are unclear. For more detailed information on policy instrument options and choices related to climate change and the Kyoto protocol see Fisher, B.S.; Barret, S.; Bohm, P.; Kuroda, J.K.; Mubozi, A.S.; Shah, A.; Stavins, R.N. 1996. Pages 397–439 *in* Bruce et al. (1996), Commission for Environmental Cooperation (1997. Analysis of the potential from a greenhouse gas trading system—phase 1: Institutional analysis and design considerations. Unpublished report prepared for Secretariat of the Commission for Environmental Cooperation through its Climate Change and Energy Efficiency Program. Montreal, QC.), and Rolfe (1998). Another key consideration for policy choice is the limitations and constraints imposed by international recognition of the actions that can be used for credit toward Canada's contribution to reductions in GHG emissions under international agreements (e.g., the Kyoto protocol).

METHODOLOGICAL FRAMEWORKS FOR ASSESSMENT

This section considers methodological frameworks for assessing the impacts of and adaptations to climate change, by reviewing a variety of physical models and examining economic frameworks for assessment in more detail.

Physical Models

Global and Regional Climate Models

Global general circulation models (GCMs) are the main modeling tool for simulating how future climate will respond to changes in atmospheric concentrations of GHGs. They use mathematical equations to model interactions among atmospheric systems, the biosphere, land surfaces, and oceans (Kacholia and Reck 1997) for the purpose of forecasting trends in future climatic variables. A number of models have been developed, for example, by the United Kingdom Meteorological Office, Oregon State University, the Geophysical Fluid Dynamic Laboratory, affiliated with the National Ocean and Atmospheric Administration, US Department of Commerce, and the Canadian Climate Centre. Because these models have different specifications, they also vary in their predictions of future climate change.

The results from GCMs include expected changes and variability in climatic variables such as temperature (annual and seasonal), precipitation (annual and seasonal), and cloud cover. However, some aspects, especially clouds, aerosols, and oceans, are associated with major uncertainties (Kacholia and Reck 1997). Differences in the modeling of dynamics and feedback mechanisms associated with the different parameters result in differences in predictions. These variations can be and have been used to develop ranges of possible future climate scenarios, so that researchers do not have to rely on the result from any single model (Williams et al. 1998).

Most GCMs assume that the distribution of vegetation will remain static under conditions of climate change. However, anthropogenic changes in land use and climatically induced changes in the distribution of natural vegetation will occur within the time frames of most GCM simulations. Therefore, the status of vegetation distribution in most GCMs has important ramifications for their accuracy, because vegetation types have different effects on surface albedo, evapotranspiration, moisture convergence, and precipitation, and hence on climate (Houghton et al. 1996). The coupling of GCMs with dynamic vegetation models (see below) will address this limitation (Foley et al. 1996).

The analytical sophistication, short time-step requirements, long time frames, and spatial nature of GCMs, combined with the enormous size of the data bases required to run them and the limitations in the capacity of most computers to handle such data bases and their computational requirements (GCMs are run on supercomputers), mean that most GCM outputs have a course scale of resolution (Caya et al. 1995). To address these constraints, various approaches have been developed to simulate regional climate by means of limited-area models coupled with global low-resolution models, including the Canadian Regional Climate Model (Caya et al. 1995). Regional climate models are expected to more accurately predict future climate at a local level because they incorporate landform effects such as mountain ranges and large bodies of water with more detail than global GCMs. Shackley et al. (1998) have provided a detailed critique of GCMs, focusing on their complexity, the uncertainties involved, and a comparison with other types of models.

Biogeographical and Biogeochemical Equilibrium Models

Biogeographical and biogeochemical models are two classes of models that have been used in integrated assessments of climate change. Biogeographical equilibrium models predict the future equilibrium distribution of ecosystem types on the basis of particular climate scenarios. Biogeochemical models predict future productivity for particular ecosystems. Combining the two types allows evaluation of future equilibrium changes in ecosystem distribution and productivity (measured in terms of biomass) with climate change.

BIOME2 (Haxeltine et al. 1996) and MAPSS, Mapped Atmosphere-Plant-Soil System, (Neilson and Marks 1994) are two examples of biogeographical models. Although distinct, they have some common features. In general, biogeographical models are based on "mechanistic relationships" between various types of factors determining species distributions (Sohngen and Mendelsohn 1999). When tied to GCM outputs, these models predict future ecosystem distributions by assessing future combinations of plant growth factors (including new climate regimes) and defining a set of boundaries that match species combinations (called biomes) to future conditions.

FOREST-BGC (Running and Gower 1991) and Century (Parton et al. 1988) are two examples of biogeochemical models. Individual biogeochemical models are distinct in terms of the underlying ecological processes modeled, and they yield various estimates of ecosystem productivity. These models quantify net primary productivity (a flow variable that 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, these models predict future biomass accumulation. Comparisons of biomass accumulation with and without climate change can be used to obtain an indication of the effects of climate change on ecosystem productivity (Sohngen and Mendelsohn 1999).

A limitation of many of the initial biosphere models is that they generally focused on future steady states (Foley et al. 1996). They did not describe transient responses of ecosystems over time, nor did they necessarily take account of the processes that cause an ecosystem to change from one type to another (Sohngen and Mendelsohn 1999). However, more recent biosphere models do consider ecosystem processes and ecosystem change over time (Foley et al. 1996). Called dynamic vegetation models (DVMs), these models are described in the next section.

Dynamic Vegetation Models

The responses of plants to climate change are precipitated by differential effects of climate on the regeneration and growth of different plant and taxa types or by changes in patterns of disturbances such as forest fire (Houghton et al. 1966). Dynamic vegetation models model these processes (to various degrees) to simulate changes in vegetation cover over time (i.e., transient responses).

The Integrated BIosphere Simulator (IBIS) (Foley et al. 1996) is one example of a DVM. The IBIS integrates biophysical, physiological, and ecological processes and simulates transient changes in vegetation patterns over time. Moreover, the model is designed for direct linkage and integration with climate models, a feature that improves the capability for more directly incorporating feedback between the biosphere and the atmosphere in global climate models.

Paleontological Models

Paleontological approaches can be used to estimate future ecosystem conditions and distributions (under climate change) on the basis of historical relationships between climate and ecosystems. These relationships are determined by examining fossil pollen data (which show historical ecosystem distributions) and analyzing charcoal in lake sediments (which provides an indication of fire history in an area). Paleontological approaches to estimating future conditions are complementary to the other physical models described earlier.

Economic Analysis and Integrated Assessment Approaches

Because of the long-term nature of climate change and the complexity of atmospheric, biospheric, and economic systems and their interactions (see "Impacts of and Adaptations to Climate Change," above), quantitative estimates of long-term impacts and adaptations are subject to high levels of estimation error. The possible sources of such error are numerous and include model mis-specification, errors in the data, incorrect assumptions, low resolution of biophysical models, lack of complete knowledge, and irrational behavior. Three strategies for dealing with error are to perform sensitivity analysis by changing the underlying assumptions; to use multiple combinations of climate, ecosystem response, and economic models to evaluate the orders of magnitude and ranges of impacts; and to explicitly model uncertainty with either probabilistic or nonprobabilistic models (Krcmar-Nozic et al. 1999).

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, and humans will respond through various adaptations. These will in turn feed back to and result in further changes in the terrestrial ecosystems. Each component of the integrated environmental–economic system is complex, and the level of complexity increases when the individual components are linked for integrated assessment. There are two important implications of this situation. First, assessment models should explicitly recognize uncertainty as well as the stochastic nature of climate change (Smith 1982). Second, because future responses will be the result of action and feedback loops between atmospheric, terrestrial, and human socioeconomic and political systems, the ability to forecast the impacts of climate change will require the integration of dynamic models of atmospheric, biospheric, and economic systems, with full recognition of the complexity of the integrated system and the generality of the results of these types of models.

Integrated assessment models (IAMs) generally include some combination of general circulation, ecological, 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). Bruce et al. (1996) suggested that integrated assessments offer a number of benefits, including coordination of assumptions from different disciplines and introduction of feedbacks among disciplines. Economic analysis and assessments of the impacts of climate change clearly require integration of disciplines at various levels. The wide variety of IAMs that have been developed were reviewed by Dowlatabadi (1995) and Bruce et al. (1996). We do not attempt a similar review here but instead attempt to give a flavor for selected models and analytical frameworks that we feel have particular relevance to the forest sector, including cost–benefit analysis, cost-effectiveness analysis, referendum approaches, optimal rotation and carbon sequestration models, optimization models, partial equilibrium models, general equilibrium models, spatial equilibrium models, and Ricardian analysis.

Cost–Benefit Analysis

Cost–benefit analysis is widely used in economic analysis. However, there is some question regarding its suitability for analyzing climate change policies (Smith 1982). Cost–benefit analysis generally concentrates on evaluating the effects of policy on one or a few main sectors. A major assumption is that feedbacks due to the effects of the policy change on the target sector result in relatively small changes in the rest of the macroeconomy. Given that many climate change policies affect large segments of the economy or have widespread impacts, such as assumption may not be valid. General equilibrium models (discussed below) do not have this limitation and hence have been extensively applied in the analysis of climate change options (e.g., Jorgenson and Wilcoxen 1992; Nordhaus 1994b; Nordhaus and Yang 1996).

Uncertainty may also have a bearing on the applicaton of cost–benefit analysis to climate change. Uncertainty occurs at many levels. For example, there is uncertainty about the extent of physical impacts and how quickly these impacts will occur, there is uncertainty in valuing the costs and benefits of impacts and the costs of mitigation, and there is uncertainty about how various policies will be implemented. Uncertainty can be incorporated into cost–benefit analysis and other forms of economic analysis by means of a technique called decision analysis. This technique begins with the explicit definition of a structural model that identifies the linkages between various components of a system. Each linkage is associated with degrees of uncertainty, and decision analysis techniques require the definition of the relevant probability distributions. Potential decisions are then evaluated on the basis of their highest expected value or the conversion of expected values into certainty equivalents (certain returns that would be accepted in lieu of risky investments with higher expected returns). For example, 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 in climate change science.

Another challenge associated with the application of national-level cost–benefit analysis of options for mitigation of climate change is that efforts in any one country create benefits that are diffused over all other countries of the world. Thus mitigation efforts have characteristics of a global public good (Schelling 1992). If cost–benefit analysis accounts only for the benefits that accrue within the borders of the country undertaking the mitigation, benefits may be vastly underestimated. However, attempts at valuation beyond national borders can be extremely difficult.

Cost–benefit analysis does, however, have some favorable features in relation to climate change. The basic framework of cost–benefit analysis is a comparison of the costs and benefits of two or more policy or management options. This exercise forces policy analysts and policymakers to undertake a formal analytical process that can often illuminate the critical issues bearing on the necessary decisions. This process of rigorously defining costs, benefits, time scales, spatial scales, and underlying assumptions regarding time preferences can be more beneficial than the actual results of the analysis (Bruce et al. 1996).

Cline (1992) illustrated a cost–benefit analysis of climate change, by estimating the costs and benefits GHG mitigation. The policy objective was to reduce global carbon emissions to 4 billion tons annually and then to freeze emissions at this level. A unique feature of Cline's analysis is that costs were estimated with general equilibrium models. Cline's analysis indicated that reductions in global carbon emissions to this level would yield a benefit:cost ratio of 3:4, which suggested that this level of mitigation would not be warranted. However, when the analysis was extended to account for risk aversion and possible unforeseen catastrophic events, the benefit:cost ratio was higher than 1:1. Cline concluded that efforts to limit emissions to 4 billion tons annually at the global level would be justified if the analysis included risk aversion and the potential for catastrophe.

Cost-Effectiveness Analysis

Cost-effectiveness analysis is used when there is a range of alternative approaches for achieving a specific policy goal. Its purpose is to measure the overall costs of each alternative and propose the one that achieves the objective at the least social cost. The principal advantage is that this approach circumvents the need to quantify or value the stream of benefits associated with some level of mitigation or intervention. The main disadvantage is that the analysis does not indicate if benefits exceed costs, and therefore it yields no information regarding the extent to which the policy is justified in terms of economic efficiency.

Referendum Approaches

The application of cost–benefit analysis to issues such as climate change requires assumptions about the preferences of future generations, as well as estimation of costs and benefits over long time frames. It also requires the adoption of suitable discount rates. Portney (1998) suggested another way to formulate the problem, calling it "the climate change referendum." He observed that the problem of determining how many resources to divert to adaptation and mitigation strategies for climate change could be viewed as a problem of social insurance. This approach is useful because it avoids the need to estimate all future costs and benefits of adaptation and mitigation.

The referendum approach asks the following question: How much are members of the present generation in a given country 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 many of whom will be living in other countries? If the aggregate willingness to pay among all individuals living today is greater than the cost of the corresponding reduction policy, then, on efficiency grounds alone, the policy should be implemented. On the other hand, if the aggregate willingness to pay is less than the cost of the policy, the policy should not be implemented unless there are other compelling reasons for doing so, such as redistribution of income or wealth (see "Socioeconomic Criteria and Considerations for Measuring Impacts," above).

Implementation of this approach involves giving members of the present generation a description of the likely impacts of various climate change scenarios and the likely changes in these impacts with different mitigation and adaptation policies. Each person can then choose his or her own discount rate for assessing the time paths of outcomes for the various policies. Hence, the problem of choosing a single social rate of discount is avoided.

The referendum 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. Thus, although the problem of estimating future costs and benefits is avoided, it is still necessary to estimate how climate change and mitigation policies will affect the time path of prices, so that adaptation can be incorporated into the assessment of outcomes. The referendum approach also requires determining willingness to pay for a stream of alternative outcomes compared with some baseline. Finally, this approach leads to decisions that are based exclusively on the values, beliefs, and preferences of the current generation.

Optimal Rotation and Carbon Sequestration

An important question related to using forests to sequester carbon is how such sequestration affects harvest rotations or, roughly translated, the rate at which forests should be harvested. The rule of optimal economic rotation may be an important tool for analyzing the management of and rotation decisions for existing forest stock on afforested land, especially when combined with more comprehensive forest management models.

The determination of optimal rotations for timber production objectives requires information on yield, price trends, management costs, risk of loss, and discount rates. Consideration and incorporation of carbon sequestration in determining rotation requires additional information (Englin and Callaway 1993; van Kooten et al. 1995; Martin 1998), such as the price of carbon, the amount of carbon per unit volume of tree biomass, the amount of carbon lost during and after harvest, the amount tied up in long-term forest products such as lumber and paneling, and the amount in landfills. In other words, the rotation decision is affected by long-term carbon storage and carbon cycles in wood products (e.g., building materials and paper products). This means that life-cycle analysis of forest products should be incorporated into the analysis of optimal rotations.

The most important conclusion that can be derived from forest rotation studies is that carbon sequestration appears to lengthen harvest rotation age (Englin and Callaway 1993; Martin, P. 1998. Carbon sequestration and the timber rotation period. Univ. Guelph, Dep. Econ., Guelph, ON. Can. Resour. Environ. Econ. Stud. Group. Annu. Meet. 1998, Ottawa, ON. Unpublished preliminary draft.). A limitation of these studies is that they do not include the potential for increased disturbance such as fire, disease, and insect attacks, which may lead to increased rates of carbon loss and ultimately to changes in forest types and their distribution.

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

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

Modifying the length of forest rotation can be a way of sequestering carbon and therefore has some potential to contribute to mitigation. However, optimal forest rotations will also be sensitive to productivity changes and changes in disturbance patterns due to climate change. Determining rotation requires simultaneous consideration of carbon sequestration (mitigation) and the risks of holding timber stock in an environment in which the frequency of disturbance is increasing (adaptive strategy). Thus, there is a link between mitigation and adaptation. Figure 7 illustrates why certain aspects of adaptation and mitigation policy must be considered simultaneously. Forest protection policy provides another example of the need for simultaneous consideration of adaptation and mitigation policy. Forest protection may be thought of as both adaptive, in the sense of protecting timber supply for production of forest products, and as mitigative, in the sense of stopping or delaying carbon emissions to the atmosphere that occur as a result of disturbance.

Another area that requires more analysis is the development of efficient incentive mechanisms for carbon uptake and storage. Increasing rotation age is, in one sense, a decision to increase the size of the current standing biomass of the forest. Although increasing biomass may generate credits in the form of reduced requirements for mitigation elsewhere in the economy, it also increases the risk of debits created by forest disturbances. An integrated forest-level analysis allows 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 the forest protection regimes that will have an impact on forest rotation decisions.

Optimization Models

Optimization models have many different forms, including models with single- or multiple-choice variables and single or multiple objectives, constrained optimization models (which may be linear or nonlinear in terms of their objective functions and constraints), and dynamic optimization models. Optimization involves applying a series of first- and second-order conditions to some functional relationship to determine local and global maximums and minimums for the endogenous variable or variables. Constrained optimization models attempt to optimize (i.e., to find the maximum or minimum value of) an objective function, subject to a series of constraints. Dynamic optimization models optimize functions over time (e.g., to find the values of the choice variables that maximize the flow of net benefits over time, subject to certain 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 1994b). The model is based on optimal growth theory models. It is global in scale and 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 relationships between economic output and emissions and between emissions and climate, as well as policy variables (e.g., the optimal rate of reduction in emissions).

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 intersectoral 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 economic measures such as investment, unemployment, and wage rates (Percy et al. 1989).

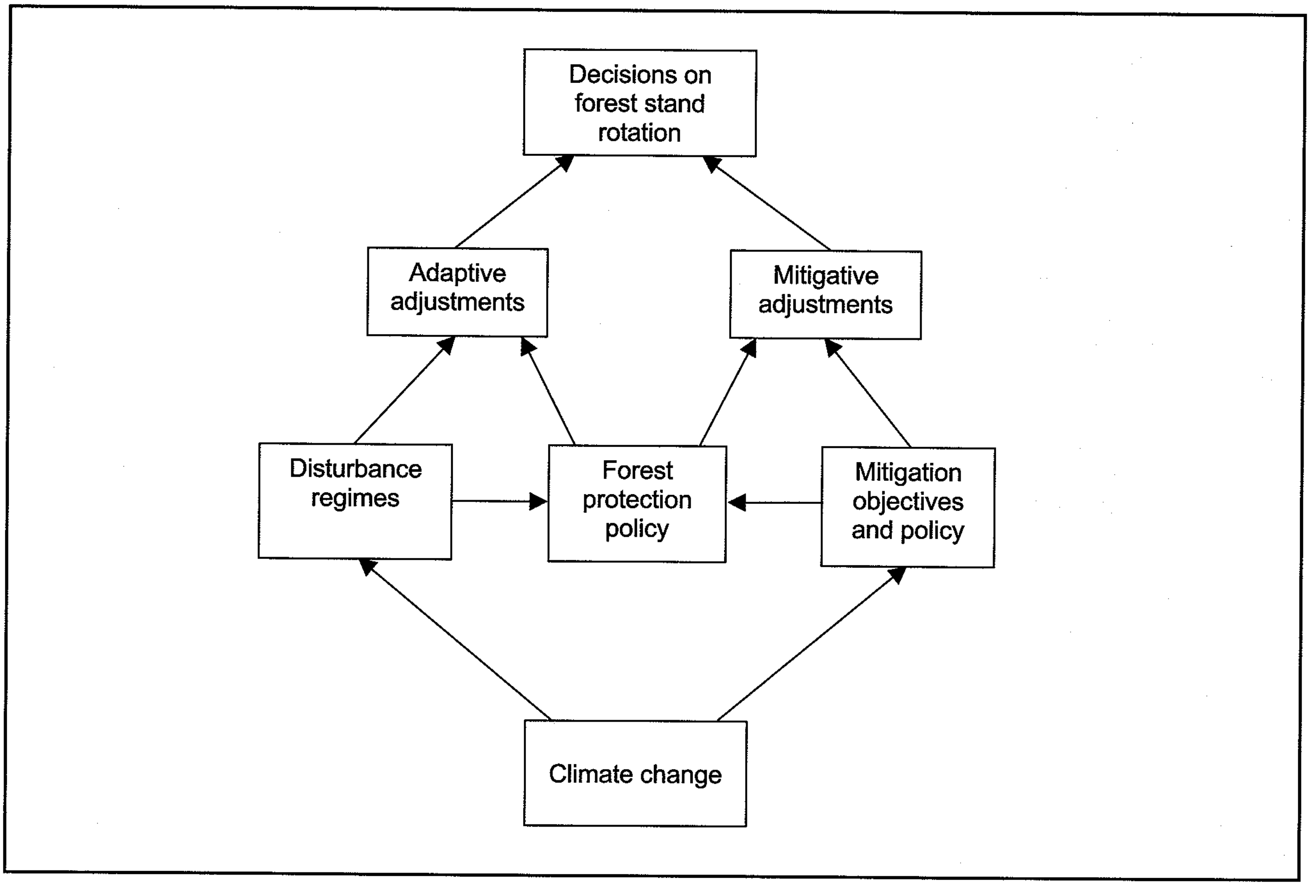

Figure 7. Linkages between adaptaion and mitigation strategies.

The earlier section "Forest Sector Considerations in Assessing Impacts and Adaptation" summarized the results of an analysis by Sohngen and Mendelsohn (1999) of the effects of climate change on the US timber market. The authors integrated a dynamic partial equilibrium model with dynamic ecosystem models and developed an approach for coupling climate models, biosphere models, and partial equilibrium models of timber markets. They employed different combinations of ecosystem models to develop ranges of forecasted impacts.

General Equilibrium Models: Static and Dynamic

This section briefly describes general equilibrium models, which incorporate representations of the whole economy at a regional, national, or international level. 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 an analysis of 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 intersectoral linkages results in greater precision when economic effects are quantified. It also permits assessment of how changes in one sector affect other sectors. This is clearly of interest in the energy and forestry sectors, because increases in energy prices will result in substitution of other fuels or other inputs. This may affect the relative costs of production and the prices of forest products and substitute products. Changes in the prices of Canadian forest products relative to those of 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, changes in energy prices 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 for mitigation policy because these models provide the capability to measure the marginal cost to society of increases in the costs of energy inputs. In fact, general equilibrium models 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).

Thompson et al. (1997) described a model for assessing timber and nontimber values that 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 treats the province as an open economy. The simulation model shows the costs and benefits of harvesting, recreation, carbon uptake, and existence values, and considers four types of values simultaneously: timber, carbon sequestration, preservation or existence values, and recreation values.

Nordhaus and Yang (1996) developed a dynamic general equilibrium model. The Regional Integrated model of Climate and the Economy (RICE) divides the global economy into 10 regions. The model determines equilibrium outputs over time of three different scenarios: "[doing] 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 and Yang 1996). Thus, the RICE model can be used to examine the difference between noncooperative and cooperative outcomes at a global scale. Under cooperative equilibrium, carbon taxes would range from approximately US$6 per ton in 2000 to US$10 per ton in 2020 and would increase to about US$18 per ton in 2050 and to over US$25 per ton by 2080. However, if countries do not cooperate, then taxes would remain below US$2 per ton for all countries (conversion factor: 1 ton = 907.2 kg). The rate of emissions control in the USA under the cooperative scenario would increase 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.

Darwin et al. (1995) developed a model linking a geographic information system to a computable general equilibrium model of world agricultural production. The framework evaluates the response of 13 commodities (wheat; other grains; nongrain crops; livestock; forestry; energy; other minerals; fish, meat, and milk; other processed foods; textiles and clothing; other nonmetallic manufactured goods; other manufactured goods; and services) in eight regions (USA, Australia and New Zealand, Canada, Japan, other east Asian countries, Southeast Asia, European community, rest of the world) to a doubling of atmospheric carbon dioxide concentrations. Climate change enters the model through changes in production possibilities derived within the geographic information system component. The computable general equilibrium component evaluates the abilities of sectors to compete for land resources under changing climatic conditions and then determines changes in land use over time.

Interregional and Spatial Models

Spatial equilibrium models evolved in response to the growing importance of international trade. These models evaluate regional supply- and demand-relationships, shipments balance relations, and profit conditions to endogenously determine equilibrium quantities and prices for individual spatial units and interregional trade (Adams and

Haynes 1987). These models take transportation costs, exchange rates, and shipment modes into account. The models are solved by optimization methods or by recursive–iterative methods.

Perez-Garcia et al. (1997) analyzed the impacts of climate change on the global forest sector by linking four general circulation models to the Terrestrial Ecosystem Model and a spatial equilibrium model called the Cintrafor Global Trade Model (developed at the Center for International Trade in Forest Products at the University of Washington). The spatial equilibrium model characterizes the global forest sector according to 43 log- producing regions and 33 consuming regions. Overall, the study found that climate change would lead to increased productivity, higher harvest rates, and lower prices for forest products. As a result, consumers (and consuming regions) would gain, while landowners would lose because of price reductions. One limitation of this study (as identified by the authors) is that the analysis provides information on terminal equilibrium conditions only. There is no information on price or harvest paths during the transition from the business-as-usual condition to the new equilibrium conditions. Also, the models do not explicitly model or incorporate adaptation.

Adams et al. (1999) used a spatial equilibrium framework to assess the economic effects of climate change on US agriculture using the Agriculture Sector Model.

Ricardian and Duality-Based Approaches

The essence of Ricardian and duality-based approaches is an analysis of cross-sectional data to assess the adaptation of landowners to existing differences in climate between regions. Mathematical relationships are then derived that relate economic variables to particular sets of climatic conditions. These relationships are then used to evaluate how exogenous changes in future climate might affect production and land use. Two studies with this general approach are Segerson and Dixon (1999), which considered farmers' adaptation to climate change, and Mendelsohn et al. (1994), which also considered the impact of climate change on agriculture.

RESEARCH NEEDS

Under the Kyoto agreement, Canada has committed to reduce carbon dioxide emissions to 6% below 1990 emission levels by the period 2008–2012. Achieving this target will be costly, and it will affect 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 affect the Canadian economy and society. Thus, a comprehensive approach—one that accounts for the impacts of and adaptations to climte change and guides adaptation and mitigation policy—is required. The purpose of this chapter is to provide a general outline for the systematic development of a research program to create models and frameworks that can be used to inform policy.

The review of models and methods in the preceding section briefly summarizes the many types of study suitable for climate change analysis. These include cost–benefit analyses, cost-effectiveness studies, timber supply models, optimization analysis, partial and general equilibrium models, and dynamic models. Each has advantages and disadvantages for particular types of policy analysis. Although all of these approaches will be useful, it is important 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 through international trade in forest products, and given that the direct effects of climate change as well as the effects of mitigation policy are likely to be widespread in the economy, it is important that models 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 analytical tools, some of which contain one or more of these linkages.

This section of our report matches socioeconomic research needs to broad policy questions or research themes. It identifies several research themes, together with some research questions, which as a whole would contribute to an integrated assessment of forest sector impacts and adaptative responses. It is important to note that the research themes and questions outlined below are interrelated and are, therefore, in many cases complementary. Also, no attempt has been made to assess the relative priorities of these research areas.

Analysis of Impacts, Adaptation, Adaptive Land Use, and Change in Forest Land Use

The section "Forest Sector Considerations in Assessing Impacts and Adaptations," above, discussed the possibility of changes in land use in response to climate change. Climate change may alter the suitability of land for a wide range of uses, including timber production, agricultural crops, rangeland, and grassland. Patterns of use of forest lands may shift across the landscape for four main reasons. First, climate change will affect species viability at particular locations. Second, climate change will affect the relative productive capacity of particular uses at sites. Third, climate change will affect disturbance regimes (which is related to the first two points). Fourth, credits for sequestration of carbon in forests will increase the relative value of land and land uses with relatively high carbon-sequestration capacity.

An important consideration in assessing adaptive responses and the rate and direction of change in land use is the effect of current landownership patterns (van Kooten 1995). For example, what are the implications of the predominance of public landownership in the forest sector and of regulatory regimes on adaptation? 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 patterns of land use and adaptive responses to climate change are components of a broader question: What is the impact of climate change on social welfare? This question is important because it is the basis for decisions regarding whether some kind of collective social intervention is warranted and what level of social costs is justified in solving the problem. The socioeconomic dimensions of these questions have been identified throughout this report. In the section "Socioeconomic Critera and Considerations for Measuring Impacts" we noted important economic efficiency and equity dimensions that should be incorporated into policy. Integrated assessment models are the usual means of measuring the implications for economic efficiency 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 the impacts on social welfare attributable to climate change. A number of IAMs have been developed at the global level and in the USA. 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 intersectoral 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 would require a significant commitment of resources and the creation of an environment conducive to multidisciplinary research.

Economic Assessment of Approaches, Strategies, and Incentive Mechanisms for Carbon Sequestration from a Forest Sector Perspective

Comprehensive analysis is needed to determine how forest policy can contribute to and fit into an overall management program for emission reduction, carbon sequestration, and carbon storage. In addition, there is a need to examine the implications of different configurations of treaty-specified carbon accounting frameworks. In other words, partial carbon accounting frameworks set up by international treaties (e.g., the Kyoto protocol) may fail to create welfare-maximizing incentives for carbon storage in other important parts of the overall carbon sink. This highlights the need for a comprehensive carbon accounting framework, regardless of the frameworks 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 optimize net additions to or net reductions in the carbon stored in forest biomass, together with other nonmarket 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 the fact that carbon sequestration and storage will have value and for the direct impacts of climate change. These direct impacts will probably take the form of increases in the rates of fire, insect, and disease disturbance regimes. This leads to further questions about how forest rotations, management schedules, and forest protection should be altered under the joint influence of carbon sequestration values and increases in forest disturbance regimes (i.e., direct impacts). Moreover, there are feedback mechanisms between forest rotation and management regimes and forest protection regimes. Hence, it is of interest to know how forest protection regimes alter optimal forest rotation and management schedules. Finally, previous research on optimal forest rotation with carbon-sequestration benefits points to 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. Hence, there is a need to evaluate how assumptions about the mix of forest products produced, how the speed with which these products release carbon, and how recycling policy and the management of waste streams affect forest management strategy. In other words, life-cycle analysis of forest products must be integrated into the analysis of forest management policy. Such integration suggests the possibility of managing the forest products carbon pool and the need to evaluate the extent to which carbon cycles in forest products pools affect the socially optimal mix of forest products and industrial products (for example, what are the trade-offs between concrete, steel, wood products, pulp and paper products, and other materials with respect to long-term storage of carbon in industrial products?).

A related area of research concerns how various configurations of credit–debit systems for carbon sequestration, storage, and release affect economic incentives and the net amount of carbon sequestered. For example, one question in this area would be the following: 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, what are the implications, from the forest industry's viewpoint, for how existing forest stocks should be managed if credit is given only for afforestation or 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 alternatives, investments that might include reforestation and management of existing forests, or other adaptation or mitigation strategies. Thus, afforestation projects should be analyzed in the context of a limited supply of capital and the potential to crowd out other beneficial investments.

Finally, Canada's forest land is relatively unproductive compared with forest lands in many other parts of the world. Thus, Canada should look for potential offsets in other parts of the world. However, many of the 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 and domestic afforestation.

Some of these 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 adaptive and mitigative benefits. However, given that adaptation and mitigation are often discussed as separate types of policy responses, an appropriate research question arises: What is the optimal mix of adaptation, mitigation, and joint adaptation–mitigation strategies? How much of the limited climate change budget should be allocated to various adaptation, mitigation, and joint adaptation–mitigation initiatives to assure the largest net flow of benefits?

It is not enough to simply determine that carbon sequestration in forests is worthwhile compared with other mitigation or sequestration options. Implementation is an important consideration that must be addressed, given that carbon values are inherently nonmarket 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 be sent, so that firms and landowners are steered in the direction of optimal strategies.

Analysis of Long-Term Timber Supply and Forest Products Supply

As mentioned in the section "Forest Sector Considerations in Assessing Impact of and Adaptation to Climate Change" timber supply can be measured and assessed in terms of physical flows and qualitative characteristics or in terms of price-quantity relationships. In fact these alternative perspectives are complementary. For example, the production function for timber is implicit in timber supply functions that relate price and quantity. Understanding how climate change results in shifts in timber supply functions is fundamental to integrated assessments methods that evaluate the long-term economic costs and benefits of climate change. However, in some cases policymakers are interested in information on the future long-term supply of timber measured in terms of physical flows. Thus some important research questions in this context are: What will be the effect of climate change on expected long-term timber supply at various levels? What influence will climate change have on the sustainability of forest resources? What are the implications of climate change relative to silviculture and protection inputs?

The main influence of climate change on timber markets is expected to occur through changes in lands allocated to forests and changes in the underlying biological productivity of forest lands. However, several factors simultaneously influence timber supply, including biophysical factors, economic factors, and social values (Williams 1994). Climate change will likely have some influence on the physical productivity of the land base; however, to understand how this might affect timber supply and consequently timber markets, it is necessary to understand the full set of interactions that determine timber supply at any particular point in time and, if possible, to incorporate these influences in empirical models.

Assessment of Impacts on Energy Costs

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. All manufacturing industries will have to adjust to this change, but energy-intensive industries, such as the forest products industry, may have to adapt to the greatest extent. One advantage that the forest products industry has over others is the option of using bioenergy from waste wood generated during the production process. The forest products industry can thus substitute away from fossil fuels to biofuels more readily than other industries. Increases in energy costs in the forest products sector point to a number of possible study areas. These include analysis of the impacts of changes in energy prices on competitiveness and analysis of the costs and benefits of increasing cogeneration capacity under conditions of higher costs for fossil fuel, as well as analysis of the impediments to cogeneration in the forest sector. Finally, the economics of biomass plantations for energy (in an economy where the cost of fossil fuel is high) should be assessed.

There are many reasons for linking forest sector models with models of 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 carbon sequestration and release in forests and carbon permit or tax systems. In addition, there is a need to analyze linkages among the forest, energy, and agricultural sectors through energy costs and policies to reduce GHG emissions. How does an increase in the cost of energy affect the forest and agricultural sectors, and how can these sectors reduce the cost of achieving targets for GHG reduction? These energy cost impacts are essentially direct impacts. However, increases in energy costs are also likely to have indirect impacts on the forest industry. For example, they will probably change relative prices between forest products and substitutes such as steel beams. Hence, it would be appropriate to analyze substitution possibilities among various inputs to the forest industry and the technological capacity of the forest sector to adapt to new relative prices created by policies to mitigate climate change.

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 mitigation policies on the Canadian forest sector. Will the impacts of climate change increase or decrease the contribution of the forest sector to Canada's balance of payments? The answer to this question will also depend on the impacts of and policy responses to climate change in the USA and other jurisdictions. Determining these aspects 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 Canadian forest products industry, 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 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, this issue has not been analyzed, and the details of how 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 GHG emissions. The main issue here is the rate at which the forest sector should replace existing capital stocks, which were developed before climate change became important, especially capital stocks that would be difficult and expensive to retrofit to generate immediate reductions in GHG emissions. This will require specialized dynamic models that explicitly account for differences in the age of physical capital.

Analysis of Impacts on the Nonmarket Benefits of Forests

Climate change can be expected to have significant impacts on the nonmarket goods and services provided by forests. The supply of nonmarket goods is ensured by public ownership of forest lands, wildlife and recreation management policies, environmental regulations, and a system of protected areas and parks under federal and provincial jurisdiction. Given the inevitability of climate change, there is a need to reconsider how environmental benefits can be maintained and unique environmental attributes protected in stationary parks and protected areas. The fundamental research question is then, How should Canada's network of protected areas be modified in an environment of accelerated ecosystem change occurring in response to climate change?

One of the research projects suggested earlier was an investigation of how forest harvest rotations and forest management schedules should be altered because of the direct impacts of climate change and because of changes in mitigation, sequestration, and carbon storage policy. This research should be extended to determine how these altered forest management schedules affect nonmarket benefits such as wildlife habitat and how these schedules should be further modified to maintain or enhance wildlife habitat.

Another question that arises is whether and how endangered species policy should 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.

Analysis of Social and Cultural Impacts

Some important questions under this research theme are the following: What are the public's 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? Which groups in society are most vulnerable to climate change? Does climate change require a unique approach in terms of public involvement in decision making?

International Strategic Dimensions

The international strategic dimensions of this issue lie outside the scope of this national- and sectoral-oriented study. Nevertheless, this is an important area where economic analysis can make a contribution. 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 developed in isolation from international negotiations on 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 in the context of climate change. These games underscore the need for Canada to examine its obligations at the international level and 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 worthwhile.

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