ECONOMIC GUIDANCE FOR THE APPRAISAL AND PRIORITIZATION OF ADAPTATION ACTIONS

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1 Introduction

1.1 What is the context for the guidebook?

The Earth's climate is changing. The Intergovernmental Panel on Climate Change (IPCC) recently concluded that "warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level" (IPCC, 2007a). Over the last 100 years the Earth has warmed by nearly 0.75°C. The consensus of scientific studies suggests that most of the observed warming over the last 50 years is very likely a result of greenhouse gas (GHG) emissions caused by human activity -- primarily from the burning of fossil fuels.

Without drastic changes in production and consumption patterns, scenarios in which human activities continue to add GHG emissions to the atmosphere at or above current rates could cause additional warming in the likely range of 1.1 to 6.4°C over the next century, with best estimates of this additional warming between 1.8 to 4.0°C. Scientists and economists predict that there will be both positive and negative impacts on the natural environment and human society at the lower end of this range. However, if additional warming exceeds 2.0 to 3.0°C over the next century, the consequences of the negative impacts are likely to be much greater than the consequences of the positive impacts (IPCC, 2007b).

Among the anticipated impacts of global climate change for Canada are (Lemmen *et al*, 2008):

- Changes to winter snowpack, mountain glaciers and the distribution and availability of freshwater resources, reducing reliable access to water for many people and agriculture;
- Increases in incidents of extreme weather, with more frequent and severe droughts, more heat waves, fewer episodes of severe cold, and fewer, though more intense, precipitation events;
- Increases to the geographical range of climate-sensitive infectious diseases, such as tick-borne diseases;
- Diminishing air and surface water quality; and
- Increases in the risk of damage to homes and buildings from storm surges in coastal regions.

Climate change thus represents a potentially significant challenge for Canadian society and our economic prosperity.

So what can we do? There are two generic policy responses. First, globally we may be able to mitigate climate change or lessen its severity in the longer-term through activities that reduce GHG emissions or enhance carbon sinks. Mitigation is about tackling the *causes* of climate change – i.e., reducing concentrations of greenhouse gases in the atmosphere that lead to future warming. Second, at a local, regional, or national level we may be able to increase our resilience (adapt) to the consequences of climate change already in the pipeline, or that which will not be avoided by current and future global mitigation efforts. Actions such as moving to higher ground to avoid rising sea levels, or planting different crops that will thrive under new climate conditions represent adaptation actions. Adaptation is about dealing with the *effects* resulting from a given level of climate change.

Even if GHG emissions ceased completely today, changes in climate will continue for many decades and in the case of sea levels, for centuries. This is due to the historical build-up of the gases in the atmosphere and time lags in the response of climatic and oceanic systems to changes in atmospheric concentrations of the gases. According to the IPCC, emissions of GHGs as of 2000 already commit us to a likely global average temperature increase of 0.3 to 0.9°C by the end of the century (IPCC, 2007a). There is also the reality that no international policies currently on the table to curb GHG emissions look likely to restrict global warming to less than an additional 2.0 to 3.0°C.

In short, not only is the need for adaptation as a response strategy over the next few decades already pretty much set by past GHG emissions, an even greater level of adaptation further down the road looks unavoidable, as atmospheric concentrations of GHGs look unlikely to be stabilized at 'safe' levels any time soon. **A minimum level of climate adaptation in Canada is now unavoidable**.

1.2 What role does economic analysis fulfill?

Some climate adaptation is unavoidable and consequently requires urgent consideration by decision-makers responsible for safeguarding our way of life – our communities, our economy and our natural environment. To adapt efficiently to climate-related threats and opportunities, it is critical that decision-makers understand (ECA, 2009):

- ⇨ The potential losses (gains) to our communities, economy, and natural environment from existing climate patterns;
- ⇨ The extent to which future socio-economic development will increase or decrease these losses (gains);
- ⇨ The additional losses (gains) that could occur over the next several decades – through the 2050s -- under different scenarios of climate change;
- ⇨ The actions that could be taken to avoid potential losses or seize potential gains, and how much could be avoided or seized;
- ⇨ The costs of taking those actions and the resulting benefits, and the balance between costs and benefits for different levels of effort; and
- ⇨ The distribution of costs and benefits across different groups - people, assets, and sectors.

Economic analysis is a method for generating and organizing this information as an aid to decision making. It can help adaptation planners:

- ⇨ Characterize the scale of the adaptation issue and raise awareness – based on an understanding of total climate-related costs; and

- ⇨ Prioritize and select between alternative adaptation actions, including doing nothing – based on a comparison of detailed adaptation costs and adaptation benefits across options.[1]

In doing so, economic analysis can help adaptation planners unlock scarce public and private resources needed to fund an effective adaptation strategy, and ensure that these resources are allocated to the most efficient adaptation actions that achieve specified objectives, such as (UNFCCC, 2010b): avoiding (capturing) all negative (positive) climate-related impacts; returning the welfare of affected communities to pre-climate change levels; returning levels of risk to pre-climate change levels; or maximizing threat reductions (opportunity enhancements) for a given budget.

The standard analytical technique for comparing the estimated costs of adaptation actions with expected benefits is cost-benefit analysis (CBA). However, in some cases, when the goal is to achieve a given level of risk reduction at lowest cost for example, another technique, cost-effectiveness analysis (CEA), may prove more useful. In other cases still, multi-criteria analysis (MCA) may be the most appropriate appraisal technique – especially when economic performance is not the sole selection criteria, or when important aspects of the adaptation planning problem cannot be quantified or valued. While this guidebook discusses all three of these commonly used techniques, highlighting their strengths and weaknesses and providing support to help analysts choose between them, the focus of the guidebook is CBA.

CBA of climate adaptation actions – as the above discussion alludes to – is typically undertaken at the sub-national or local level to inform decisions over whether, how much, and when to invest in specific actions. It can, however, be applied at higher levels, to address different questions:

- ⇨ At the global level – analysis of adaptation costs and benefits informs the optimal balance between adaptation and mitigation efforts, the overall funding requirements for adaptation, and climate negotiations; and
- ⇨ At the national level – analysis of adaptation costs and benefits informs the prioritization of adaptation as area of public policy, adaptation planning, as well as the associated financial implications for national budgets.

The guidebook is intended to be used largely in context of sub-national and local adaptation planning, though it can still help address sector-specific policy questions at the national level through the judicious extrapolation of sub-national or local costs and benefits. Analysis at a combination of levels has proven useful in building the most comprehensive evidence base for adaptation planners (UNFCCC, 2010b).

1.3 Why develop the guidebook?

Performing CBA in any context – including selecting among adaptation actions – involves following a standard sequence of steps (HMT, 2003):

[1] The IPCC defines adaptation costs as “the costs of planning, preparing for, facilitating, and implementing adaptation measures, including transaction costs”, while adaptation benefits are defined as “the avoided [climate-related] damage costs or the accrued benefit following the adoption and implementation of adaptation measures” (IPCC, 2007b).

- ⇨ Establishing a baseline scenario – what would otherwise happen in the absence of adaptation to climate-related risks;
- ⇨ Identify, quantify, and value the costs and benefits of each adaptation action being assessed;
- ⇨ Adjust the valued costs and benefits for inflation and rising relative prices;
- ⇨ Adjust further for the timing of costs and benefits by discounting and calculating their present values;
- ⇨ Calculate the net present value of actions to determine whether they are socially worth-while;
- ⇨ Adjust for risk and uncertainty;
- ⇨ Adjust for distributional impacts (the incidence of adaptation costs and benefits on different stakeholder groups); and
- ⇨ Consider non-quantified and non-valued impacts (positive and negative) and present the results.

Given that CBA is an established and standard technique, one may reasonably ask why the need for this guidebook?

The existing literature on the costs and benefits of adaptation actions indicates a number of methodological issues. At the time of the fourth assessment report, the IPCC notes that "comprehensive estimates of adaptation costs and benefits are currently lacking," and goes on to say that "the literature on adaptation costs and benefits remains quite limited and fragmented in terms of sectoral and regional coverage" (IPCC, 2007b). Furthermore, with the exception of the UK Climate Impact Program's guidance on costing the impacts of climate change in the UK (UKCIP, 2004) and the Economics of Climate Adaptation's report on shaping climate resilient development (ECA, 2009) there are no systematic frameworks for applying CBA to climate adaptation decision problems, based on detailed 'bottom-up' estimates of costs and benefits. A number of recent literature reviews have drawn similar conclusions, identifying a number of methodological gaps, needs, and challenges, which can be grouped under three broad themes (UNFCCC, 2009; UNFCCC, 2010a and b; and UNFCCC, 2011):

1. **Valuation**:

- ⇨ The need to define a baseline scenario(s), which describes the future development of the main determinants of impacts in the absence of climate change. It is necessary to predict socio-economic developments out to the 2050s and sometimes beyond, in order to isolate climate change influences on impacts from non-climate change influences, and subsequently quantify them. Missing, incomplete or unreliable, and difficult to acquire climate-related and socio-economic data makes this task even more problematic;
- ⇨ The challenge of identifying 'prices' that are consistent with the underlying socio-economic development scenario;
- ⇨ The difficulty of quantifying, in monetary terms, climate-related benefits, in particular valuing impacts on goods and services not traded in markets (so-called 'non-market' impacts such as biodiversity losses, injuries and fatalities, new recreation opportunities, etc.);
- ⇨ The challenge of conveying the completeness of the analysis to decision-makers and stakeholders. Climate change and socio-economic development comprise numerous

different parameters, which in turn affect many individuals, communities, assets, and the natural environment in multiple ways. It is necessary to be transparent about what impacts are, and what impacts are not, covered by the CBA.

- ⇨ No consensus among economists about the discount rate to use to weight future costs and benefits in a climate change context. There is also considerable debate surrounding the consistency of the discount rate over relatively long time horizons;
- ⇨ Lack of agreement over the most appropriate time horizon for projecting impacts, costs and benefits. Extending the time horizon beyond 100 years substantially increases the present value costs of climate change (and thus the benefits of adaptation), but most planning horizons in practice are only several decades long and the need to make projections beyond the 2050s dramatically increases uncertainty; and
- ⇨ The need to account for linkages between adaptation and mitigation strategies – adaptation actions may have consequences for the mitigation of GHG emissions and actions to mitigate GHG emissions may have consequences for adaptation.

2. Uncertainty:

- ⇨ The challenge of dealing with uncertainty resulting from the need to predict future climate change impacts, future socio-economic developments and a range of adaptation actions under multiple scenarios. Even under a single scenario of socio-economic development and associated global GHG emissions, the range of possible climate–related costs is large; and
- ⇨ The difficulty of designing adaptation strategies that are ❶ flexible and can be enhanced or reversed as new climate or socio-economic information becomes available or ❷ robust to a range of plausible future scenarios.
- ⇨ The need to accommodate potential irreversible impacts. Even small changes in climate may be disruptive for some ecosystems (e.g., coral reefs). Beyond certain thresholds, natural systems may be unable to adapt at all (e.g., montane ecosystems where species have nowhere to migrate).

3. Equity:

- ⇨ The challenge of both assessing and, subsequently, conveying the distributional impacts of climate-related impacts and the costs and benefits of adaptation. Climate-related impacts are unevenly distributed across regions, sectors, communities, and individuals within those communities (disproportionately affecting the most vulnerable, poorest individuals). The uneven distributional impact of adaptation actions has to be taken into account.

The aim of this guidebook is to address these methodological gaps, needs and challenges, by providing adaptation planners with a rigorous, yet pragmatic framework for assessing the costs and benefits of adaptation actions, building upon existing good practices. The guidebook starts from the premise that there is considerable scope for improving the economic analysis of adaptation actions to inform decision-making.

1.4 Who is the guidebook for?

The target audience for this guidebook is:

- Analysts required to undertake a basic CBA (or CEA) of feasible actions to adapt to climate-related threats and opportunities; and
- Anyone seeking to expand their knowledge in the area of adaptation economics.

The guidebook is intended to function as a resource document for this audience. It aims to explain concepts clearly and – in this way – does not assume the analyst has any prior knowledge of microeconomics. Nonetheless, analysts with a background or particular interest in microeconomics applied to environmental policy are likely to grasp the contents more readily than others.

1.5 When to use the guidebook?

CBA – as well as CEA and MCA – can be applied (HMT, 2003):

- At the start of the adaptation planning process – to provide prospective analysis in support of decisions to implement a new adaptation action or to renew or expand existing adaptations. In this context CBA is informing the *appraisal* part of the adaptation planning process.
- And at the finish of the adaptation planning process – to provide retrospective analysis of an adaptation action at its completion, conclusion or revision. In this context CBA is informing the *evaluation* of the adaptation planning process.

In the former context, CBA may be used to help decision-makers:

- Decide whether a proposed adaptation action should be undertaken;
- Decide whether an existing adaptation action should be continued;
- Choose between alternative adaptation actions; and/or
- Choose the appropriate scale and timing for an adaptation action.

In the latter context, CBA may be used to:

- Provide information to decision-makers and other stakeholders on whether the outcomes achieved justify the resources used, relative to alternative uses of those resources; and/or
- Clarify the focus on different components of an adaptation action, in order to see how the action, or similar future actions, could be improved, and which aspects should be cut back or expanded.

1.6 What is the scope of guidebook?

1.6.1 Economic and financial analysis

A financial CBA differs from an economic CBA in that it is conducted from the narrower perspective of the individual, firm or agency implementing the adaptation action, rather than from the perspective of society. An economic CBA addresses the question "is this adaptation action a good investment for society as a whole?" A financial CBA, in contrast, provides an answer to the question "Is this adaptation action a good investment for the individual, firm or agency?" That is, do the payments avoided or receipts generated from the adaptation action cover the necessary expenditures and provide a return on the capital invested. In financial CBA only cash-flows in and out of the individual, firm or agency are considered – cash flows to or from other affected actors are excluded, as are unpriced (or 'non-market') goods and services. Tax and subsidy payments represent real cash out or inflows for an individual, firm or agency, and are thus included in a financial CBA. However, from the perspective of society as a whole, these payments are simply a cash transfer from (to) the individual, firm or agency to (from) government. As they do not represent a net cost to society – summing to zero – they are excluded from economic CBA.

The focus of this guidebook is economic CBA, though much of the guidance is equally applicable to financial CBA. Analysts interested in discovering more about the differences between financial CBA and economic CBA should consult EC (2008), TBCS (2007) or HMT (2003).

1.6.2 Types of adaptation actions

According to the IPCC, adaptation represents any "adjustment in natural or human systems in response to actual or expected climate stimuli or their effects, which moderates harm [threats] or exploits beneficial opportunities" (IPCC, 2001). There is a great range of potential adaptation actions, which are also situation-specific. Hence, numerous typologies exist that attempt to help planners better understand and categorize actions for adaptation policy. Two categories of particular relevance to policy distinguish between the agent that initiates the action (public versus private sector adaptation) and the timing of, and reason for, the action (short-run versus long-run adaptation).

A number of definitions exist in the literature regarding the timescales of, and reasons for, adaptation. For the purpose of this guidebook, these definitions are abridged, with the aim of capturing the important distinction between:

- ⇨ Long-run, planned adaptation – proactive decisions to modify fixed inputs to the provision of goods and services, such as a commercial forester investing in new timber species given climate projections over the next several decades; and
- ⇨ Short-run, autonomous adaptation – reactive decisions to adjust variable inputs to the provision of goods and services, such as a commercial fisherman adjusting his level of fishing effort this week in response to a forecast for extreme weather conditions.

The former decisions are strategic by definition, taken before the impacts of climate change have revealed themselves, rather than autonomous or spontaneous decisions, taken after the impacts of climate change have begun to be felt.

Long-run, planned adaptation actions may be taken by the private sector or by the public sector; a partnership may even be appropriate. The aim of this guidebook nonetheless – reflecting its focus on economic CBA – is to inform the appraisal or evaluation of planned adaptations made by the public sector. Short-run, reactive adaptation actions, while generally taken by private agents acting on their own, take place within the context of existing government policies. Hence, the appraisal of publicly planned adaptation actions inevitably must also consider the extent to which private agents are incented to react accordingly to climate change.

The real issue for adaptation planners is whether individuals, communities or firms should be encouraged to view adaptation as simply a matter of responding to climate change as it happens or whether steps should be taken to anticipate and manage the eventual impacts. The guidebook informs both points of view. Efficiency criteria that underpin the application of the guidebook will dictate whether short-run or long-run adaptation is preferable, as well as whether 'hard' or 'soft' adaptations are favored.[2]

1.6.3 Direct, indirect, and induced effects

In principle, the total economic impact of climate adaptation will comprise three effects:

- **Direct effects** – primary impacts on specific individuals, communities, firms or sectors from climate-related changes in production or consumption of both market and non-market goods and services;
- **Indirect effects** – these primary impacts will generate a series of ripple effects throughout the whole economy, reflecting changes in the production and consumption of related, input goods and services and changes in their relative prices or valuations; and
- **Induced effects** – impacts that reflect changes in spending by households as their incomes (net of taxes and savings) change due to the direct and indirect effects. The changes in household spending in turn generate further changes in the production and consumption of goods and services across the economy.

Capturing the total economic impact of climate adaptation thus requires an assessment of impacts across all sectors or regions – in addition to those directly affected – as well as feedbacks between sectors and regions. Most CBAs of climate adaptation, however, only consider direct effects. Typically, whether considering impacts on market or non-market goods or services, climate-related impacts are assessed either by:

- Multiplying a change in 'quantity' by an unchanged 'price' (e.g., change in timber production times the assumed price per unit of timber; change in excess winter mortality times the value of a life year lost; etc.); or

[2] In the context of extreme weather events and water supply shortages, examples of hard adaptations include: dikes, seawalls, reinforced buildings, desalinization plants, dams, water transport systems, etc. Examples of soft adaptations in the same contexts include: insurance, early warning systems, evacuation schemes, land-use planning, demand management, changing operating regimes of water supply infrastructure, etc.

- ⇨ Multiplying a change in 'price' by an unchanged 'quantity' (e.g., the volume of water treated times the change in treatment costs per cubic meter to maintain water quality despite lower flows; the length of river dropping from 'good' water quality to 'poor' water quality times the difference in values per km of river at 'good' quality versus 'poor' quality; etc.).

This practice, while relatively simple to implement, only captures direct effects, based on the assumption that indirect and induced effects will be negligible. Assessing indirect and induced effects is considerably more complex, requiring the use of so-called 'general equilibrium' approaches to model interdependencies and feedbacks between sectors and regions. This text provides guidance on assessing the direct effects of climate adaptation. The development and application of general equilibrium approaches to climate adaptation planning problems warrants a guidebook of its own. An analysis of the direct costs and benefits of climate adaptation, even if lacking information on wider indirect and induced impacts, still provides important and useful information to decision-makers.

1.6.4 Other decision criteria

Good economic analysis based on sound science – informed by this guidebook – is a vital input to the development of an efficient adaptation strategy. It is nonetheless one component of an effective adaptation planning process, to be considered along with other key inputs, including *inter alia* technical feasibility, affordability, stakeholder views, political acceptability, the need for changes in regulations or legislation, capacity to implement, monitor and review, etc. Economic analysis does not also replace the need for sound judgment by adaptation planners.

1.7 What is in the guidebook?

The remainder of the guidebook is structured as follows:

- ⇨ **Section 2: Context for Economic Appraisal** presents a risk-based approach to adaptation planning, highlighting where in the process economic analysis is used to prioritize and select adaptation actions;
- ⇨ **Section 3: Appraisal Tools** looks at the three main methods of project appraisal (i.e., CBA, CEA, and MCA), distinguishing between their different strengths, weaknesses, and requirements;
- ⇨ **Section 4: Analytical Framework** provides a structured, step-by-step framework for conducting the appraisal of adaptation actions, explains the role of climate and socio-economic information in constructing baseline and adaptation scenarios, defines relevant cost and benefit categories, and describes how the framework is used to measure these categories;
- ⇨ **Section 5: Analyzing Costs and Benefits** examines how to value costs and benefits, with particular regard to non-market impacts (cases where market prices do not exist) using the pragmatic method of benefits-transfer;
- ⇨ **Section 6: Inflation and Rising Relative Valuations** presents a procedure to convert between nominal and real prices, to fix prices at a specific base year, and to account for rising relative valuations of non-market impacts over time;

- ⇨ **Section 7: Discounting** outlines the technique for converting costs and benefits that occur at different times to their present values and provides guidance on the choice of discount rate in a climate change context, reflecting both the 'descriptive' and 'prescriptive' camps;
- ⇨ **Section 8: Economic Evaluation Criteria** looks at the main criteria commonly used in CBA to recommend (or otherwise) adaptation actions on economic grounds and explains how each is computed and interpreted;
- ⇨ **Section 9: Uncertainty Analysis** explains how to account for uncertainty in the analysis using a range of qualitative and quantitative approaches;
- ⇨ **Section 10: Distributional Analysis** provides a three-stage hierarchical approach to assessing the distributional impacts of adaptation cost and benefits, as well as a practical approach to stakeholder analysis; and
- ⇨ **Section 11: Presenting the Analysis** concludes the guidebook with suggestions for how to present the results of the economic analysis to adaptation planners.

1.8 References and further reading

Agrawala, S. and Fankhauser, F., 2008, Economic Aspects of Adaptation to Climate Change: Costs, Benefits and Policy Instruments, OECD, Paris, France.

EC, 2008, Guide to CBA of Investment Projects: Structural Funds, Cohesion Fund and Instrument for Pre-Accession, European Commission (EC), Directorate General Regional Policy, Brussels, Belgium.

ECA, 2009, Shaping Climate resilient Development: A Framework for Decision-making, A Report of the Economics of Climate Adaptation (ECA) Working Group, Swiss Re, McKinsey, Global Environment Facility, European Commission, the Rockefeller Foundation, Climate Works, and Standard Chartered Bank, Zurich, Switzerland.

EEA, 2007, Climate Change: The Cost of Inaction and the Cost of Adaptation, EEA Technical Report, No 13/2007, European Environment Agency, Copenhagen, Denmark.

Fankhauser, S., 2010, Costs of Adaptation, *Wiley Interdisciplinary Reviews: Climate Change*, 1, p. 23–30.

Gulledge, J., Richardson, L., Adkins, L. and Seidel, S. (editors), 2010, Proceedings of Workshop on Assessing the Benefits of Avoided Climate Change, March 16–17, 2009, Pew Center on Global Climate Change: Arlington, VA, USA.

HMT, 2003, The Green Book: Appraisal and Evaluation in Central Government, HM Treasury, TSO, London, UK.

IPCC, 2001, Summary for Policymakers, Climate Change 2001: Impacts, Adaptation and Vulnerability, Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) [J. McCarthy, O. Canziani, N. Leary, D. Dokken and K. White (eds.)], Cambridge University Press, Cambridge, UK and New York, NY, US.

IPCC, 2007a, Summary for Policymakers, Climate Change 2007: The Physical Science Basis, Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)], Cambridge University Press, Cambridge, UK and New York, NY, US.

IPCC, 2007b, Summary for Policymakers, Climate Change 2007: Impacts, Adaptation and Vulnerability, Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) [M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson (eds.)], Cambridge University Press, Cambridge, UK and New York, NY, US.

Lemmen, D., Warren, F., Lacroix, J. and Bush, E. (editors), 2008, From Impacts to Adaptation: Canada in a Changing Climate 2007, Government of Canada, Ottawa, Canada.

NRTEE (Canada), 2011, Paying the Price: Impacts of Climate Change for Canada, Climate Prosperity Report 4, National Round Table on the Environment and Economy, Ottawa, Canada.

Parry, M., *et al*, 2009, Assessing the Cost of Adaptation to Climate Change, A Review of the UNFCCC and Other Recent Estimates, International Institute for Environment and Development and the Grantham Institute for Climate Change, Imperial College, London, UK.

TBCS, 2007, Canadian Cost-benefit Analysis Guide: Regulatory Proposals, Treasury Board of Canada Secretariat (TBCS), Ottawa, Canada.

UNFCCC, 2009, Potential Costs and Benefits of Adaptation Options: A Review of Existing Literature: Technical Paper, FCCC/TP/2009/2, UN Framework Convention on Climate Change Secretariat, Bonn, Germany.

UNFCCC, 2010a, Report on the Technical Workshop on Costs and Benefits of Adaptation Options, FCCC/SBSTA/2010/9, UN Framework Convention on Climate Change Secretariat, Bonn, Germany.

UNFCCC, 2010b, Synthesis Report on Efforts Undertaken to Assess the Costs and Benefits of Adaptation Options, and Views on Lessons Learned, Good Practices, Gaps and Needs, FCCC/SBSTA/2010/3, UN Framework Convention on Climate Change Secretariat, Bonn, Germany.

UNFCCC, 2011, Assessing the Costs and Benefits of Adaptation Options: An Overview of Approaches, UN Framework Convention on Climate Change Secretariat, Bonn, Germany.

Yohe, G., 2010, Addressing Climate Change through a Risk Management Lens, Assessing the Benefits of Avoided Climate Change: Cost-Benefit Analysis and Beyond, Gulledge, J., Richardson, L., Adkins, L. and Seidel, S. (editors), Proceedings of Workshop on Assessing the Benefits of Avoided Climate Change, March 16–17, 2009, Pew Center on Global Climate Change: Arlington, VA, USA.

2 Context for Economic Appraisal and Evaluation

2.1 Purpose

The purpose of this section is to:

- Provide a synopsis of the overall adaptation planning process to establish the context for performing economic appraisal and evaluation;
- Review the initial administrative process to set the 'terms of reference' for developing an adaptation strategy;
- Outline an approach to identify, analyze, and prioritize climate-related risks, to ensure resources are focused on the most significant threats and opportunities;
- Outline a process to set adaptation goals and to identify, screen, and appraise candidate adaptation actions, with a view to determining priorities for the emerging adaptation strategy;
- Highlight where in this process assessing the costs and benefits of adaptation actions can be used to identify a preferred action or package of actions; and
- Outline a process to make the adaptation strategy operational, to keep it relevant, and to continue the adaptation planning process generally.

2.2 Risk-based approach to climate change adaptation

Weather and climate already affect economic activity and everyday life in many ways. Extreme weather events (e.g., windstorms, droughts, floods, heat waves, etc.) over the last few years have alerted us to the relative sensitivity of ecosystems; human health; and man-made systems, such as buildings, industrial processes, energy demand and infrastructure to current climate conditions. These events also signal the threat posed by projected climate change. Climate change is anticipated to result in a variety of effects, including changes in the frequency, intensity or distribution of extreme weather, as well as changes in average conditions and increased seasonal variability in temperature and precipitation. Our current social and economic structures and supporting systems all developed under relatively stable climate conditions. And those organizations that currently take account of weather when making decisions will have formulated business plans with a view to existing climate conditions. These plans may, however not be resilient to, or able to take advantage of, projected changes in future climate conditions.

Understanding how climate conditions are projected to change, and what the implications are for an organization, is critical to determining:

- Whether, and to what extent, the organization's business plans and longer-term vision are vulnerable to climate change; and in turn
- Whether, when, and how much action is needed to increase the organization's resilience to projected changes in climate, and enhance its ability to take advantage of any opportunities that may arise.

The answers to these two questions, and the process of deriving them, can be formalized in an adaptation strategy.

2.2.1 Developing an adaptation strategy

Generally speaking, adaptation is most effective when it is integrated ('mainstreamed') into existing strategies, plans, policies, and decision-making processes, and not undertaken as stand-alone activities solely to address climate-related risks.

Most organizations will have some form of strategic planning process. In broad terms, strategic planning involves identifying business objectives, setting goals, understanding trends and issues, identifying and prioritizing activities, allocating resources, and undertaking the most appropriate tactical actions to achieve the overall objectives. It is this process that gives rise to the 'decision problem', which is the focus of adaptation planning (see Section 2.2.2.1 below). Fewer organizations will have some form of risk management framework in place, whether fully integrated or less formal. A risk management framework identifies, analyzes and evaluates risks and potential mitigating responses to ensure the overall objectives can be achieved.

Effective adaptation requires the adaptation planning process, resulting adaptation strategy, and associated implementation plan to be fully integrated into an organization's everyday decision-making processes. The adaptation strategy and implementation plan will thereby serve as inputs to the organization's strategic planning processes and can be evaluated against other organizational priorities, due to the use of a standardized, consistent approach to evaluating all risks and determining preferred responses, regardless of the nature of the risk under consideration.

Figure 2-1 below illustrates one way of integrating an organization's existing strategic planning process and risk management framework with an (new) adaptation planning process. In this case, the adaptation planning process is considered a component of the risk management framework, focusing on climate-related risks.

2.2.2 The adaptation planning process

Several frameworks or processes have been developed to assist with a structured approach to the development of an adaptation strategy; some key frameworks can be found in the documents listed at the end of this section. In general, these are not new frameworks or processes, but are, rather, variations of existing approaches to generic risk and disaster management. For example, the Australian Government's guide for business on Climate

Change Impacts & Risk Management is based on the Australian and New Zealand Standard for Risk Management, AS/NZS 4360:2004, which is widely used in the public and private sectors to guide strategic, operational, and other forms of risk management.

While no two frameworks or processes are identical, they do share a number of key generic stages, including (consider the bottom diagram in Figure 2-1):

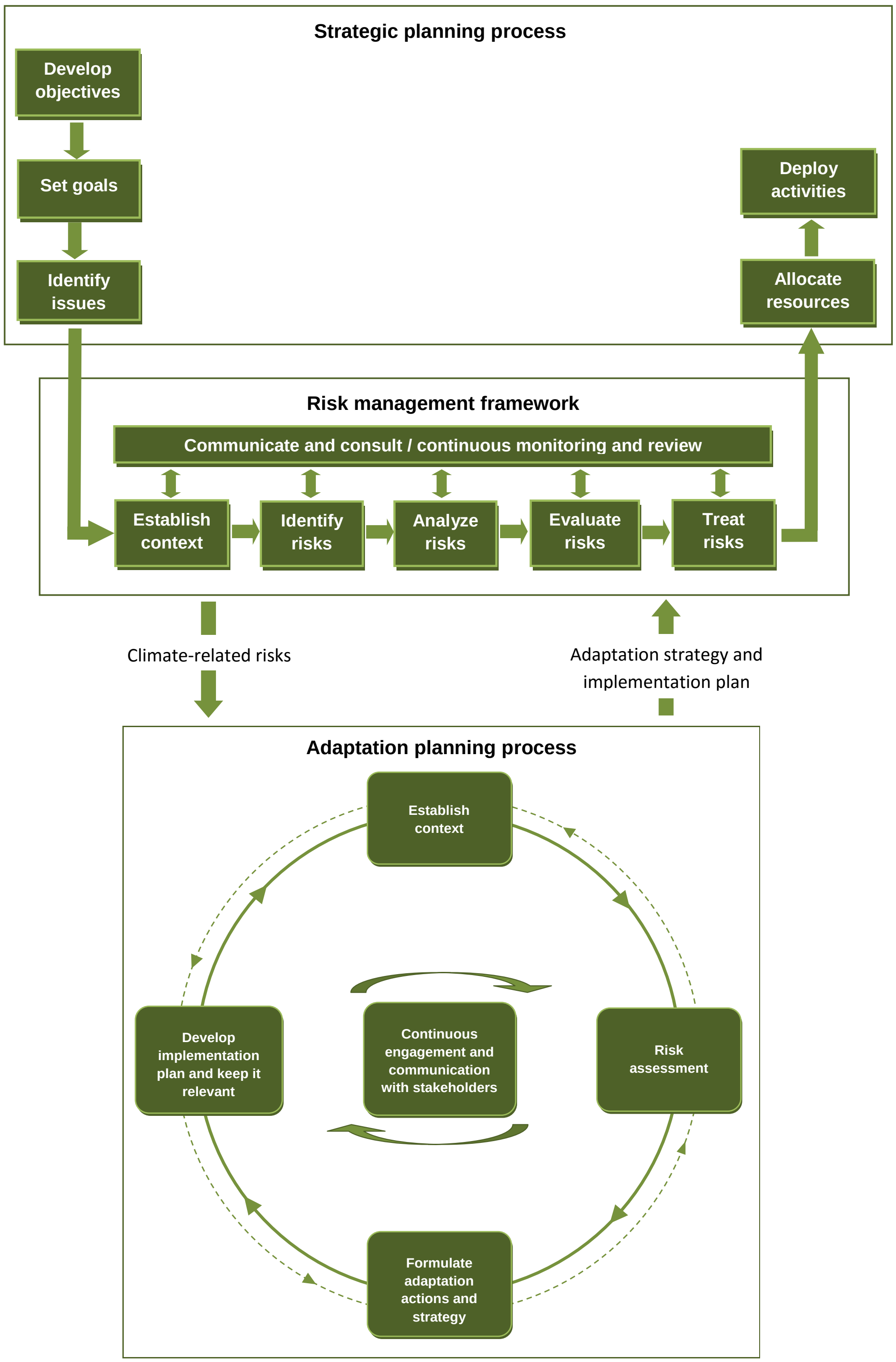
- ⇨ Establishing the context for adaptation planning;
- ⇨ Undertaking a climate change risk assessment (i.e., analysis of the organization's ability to cope with the current climate and future climate change);
- ⇨ Developing a set of preferred adaptation actions and formulating an implementation plan for the preferred actions;
- ⇨ Monitoring and reviewing to evaluate the impact of selected adaptations and to keep the plan relevant; and
- ⇨ Continuous engagement and communication with stakeholders.

The most successful frameworks provide both a systematic and flexible approach to the adaptation planning process, where completion of one stage leads logically to the next, until a decision to adapt to a particular 'material' risk or set of risks is taken. The circular nature of the process enables the context, the risk assessment, and the formulation of a strategy, all to be refined as a result of analysis undertaken in previous stages, prior to any decisions being implemented. In addition, it permits decisions to be monitored and revisited over time, as new information becomes available or when it is realized that an adaptation strategy is unlikely to meet the organization's goals. For adaptation to be successful, it should be viewed as a dynamic process that evolves with changing information and circumstances over time. In effect, previous iterations of the framework act as inputs to the current version of the adaptation strategy. Monitoring and review procedures must therefore be in place to provide the necessary feedback.

In practice, it may be necessary to return to a previous stage, in light of analysis undertaken in subsequent stages. For example, the problem definition established at the outset may need to be modified, due to the nature of threats defined during the risk assessment or to accommodate a wider set of practical adaptation actions that fell outside the originally defined scope. Revisiting previous stages is indicated by the dotted lines within the adaptation planning process in Figure 2-1.

Although not shown in Figure 2-1, certain stages in the adaptation planning process are tiered. This facilitates the screening and prioritization of risks and potential adaptation actions, enabling organizations to focus resources and effort on material threats and opportunities. Simply put, it would be wasteful to subject every identified climate-related risk to detailed, quantitative analysis.

Figure 2-1: Mainstreaming adaptation planning process



Each of the broad stages shown in Figure 2-1 is outlined briefly below; detailed descriptions of each stage can be found in the readings listed at the end of this section.

2.2.2.1 Getting started – establishing the context for adaptation planning

Objective of stage: To develop the terms of reference for a specific application of the adaptation planning process.

This stage comprises the initial administrative process; in effect, it sets the terms of reference for developing the adaptation strategy. It is intended to create a common view of the process for all participants and to allow for the activities to be completed efficiently, to be replicable, and for the outputs to be communicated clearly to stakeholders. It also ensures that the outcomes of the process can be integrated ('mainstreamed') into existing decision-making processes within the investigating organization.

Establishing the context for adaptation planning typically consists of, but is not restricted to:

- ⇨ Defining the 'decision problem' of interest to the investigating organization;
- ⇨ Clarifying the objectives and expectations of working through the process;
- ⇨ Setting the scope and scale of the exercise;
- ⇨ Determining who should participate and how to communicate with them. Deciding who's views need to be taken into account; who can contribute to the analysis; and who needs to be informed of the outcomes and how;
- ⇨ Formulating an adaptation team and assigning roles and responsibilities to each member of the team; and
- ⇨ Synthesizing available information on present vulnerabilities, projected climate change impacts, and existing adaptation activities (the adaptation baseline) relevant to the decision problem at hand.

A decision problem could refer to a strategic vision or (single or multi-year) plan; a program; or individual projects, such as long-term investments in infrastructure or equipment. Different factors – drivers – may have led to a decision problem being formulated. For example, strategic plans are typically reviewed as part of a regular, fixed-year planning cycle. Other drivers behind the need to formulate a decision problem include:

- ⇨ The development of a new investment project;
- ⇨ Changes in legislation or government policy;
- ⇨ Public opinion or pressure from interest groups (e.g., as a result of an abrupt or unexpected change in an ecosystem or impact on human settlements); or
- ⇨ New scientific information on projected climate change and possible impacts.

Two broad objectives of adaptation planning may include:

- ⇨ Making the business case to senior management of the need to adapt to climate variability and climate change in order to gain their support (and resources) for developing an adaptation strategy; and
- ⇨ Making a decision problem more resilient to, or better able to take advantage of, climate-related impacts.

2.2.2.2 Risk assessment

Objective of stage: To identify, analyze and prioritize climate-related risks.

Box 2-1: Key questions addressed during Stage 2

- ⇨ What are the current climate-related threats and opportunities (from past and present day weather and climate conditions)?
- ⇨ What are the impacts and related consequences of these threats and opportunities?
- ⇨ What are the main non-climate stressors – e.g., population growth, economic development, pollution levels, infrastructure decay, etc.?
- ⇨ What the main climate stressors – e.g., too little snowfall, too much rainfall, high temperatures, storms, etc.?
- ⇨ How will the magnitude, frequency, geographical extent and timing of impacts and consequences be affected by projected climate change? Are they likely to get worse, stay the same, or improve?
- ⇨ What trends in the main non-climate stressors will influence future impacts and consequences?
- ⇨ Which of the predicted future impacts and consequences are acceptable (can be tolerated)? Which are not acceptable (cannot be tolerated)?

Efficient adaptation requires awareness of pertinent climate-related risks and, importantly, an understanding of the relative significance of those risks. It is unlikely that development of an adaptation strategy that attempts to deal with the full array of climate-related risks facing an organization will be practical or cost-efficient. Rather, priorities need to be established so that actions taken are reasonable and commensurate with the anticipated threats and opportunities. In short, efficient adaptation planning requires an understanding of those organizational aspects that are most at risk – and why.

An incremental or tiered risk-based approach to identifying, analyzing, and prioritizing risks can be used to set priorities, thus avoiding certain resource intensive downstream stages in the adaptation strategy development process (UNFCCC, 2009). Specifically, a screening assessment of climate-related risks can be used to identify and distinguish between material (high priority) risks that require action now and those (low priority) risks that may only need to be monitored during the current iteration of the adaptation planning process.

Conventional risk assessment frameworks comprise three broad steps:

1. Risk identification	Identify impacts (or hazards)	Identify consequences of impacts
2. Risk analysis	Estimate magnitude of consequences	Estimate likelihood of consequences
3. Risk evaluation	Evaluate significance of the risk	

Step 1 Risk identification

The purpose of risk identification is to list and describe all (current and anticipated future) climate-related impacts and possible consequences for 'key elements' of the decision problem at hand. It is advisable to break down the decision problem into discrete topics (known as key elements or priority systems). Each key element is somewhat narrower than the whole scope being considered, allowing analysts to focus their thoughts and probe deeper than if they tried to deal with all aspects of the decision problem at once.[3] Impacts can represent either threats to, or opportunities for, each key element.

Risk identification is conducted with respect to each of the climate scenarios being considered.

Step 2 Risk analysis

The purpose of risk analysis is to help determine the materiality of each of the identified climate-related risks. This information is used to prioritize each risk during risk evaluation. Risk analysis involves two activities:

- ⇨ Characterizing the magnitude of the various consequences arising from each identified climate-related risk, if that risk was to arise.
- ⇨ Characterizing the frequency or likelihood of suffering that particular level of consequence, given that a particular climate scenario is realized.

Again, these activities are performed for each of the climate scenarios being considered.

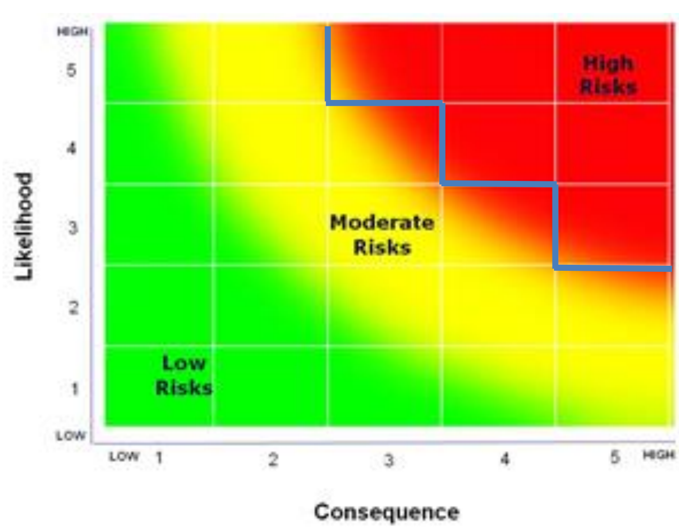
[3] This is especially true if workshops involving a range of stakeholders are the primary vehicle for the risk assessment.

Step 3 Risk evaluation

The purpose of the final step in the risk assessment, risk evaluation, is to assign a priority rating to each climate-related risk, based on the combination of consequence and likelihood 'scores'. This, again, is undertaken for each of the climate change scenarios being used.

A risk (rating) matrix, similar to that shown in Figure 2-2, can be used to define the level of priority associated with each combination of consequence and likelihood. To create such a matrix, the likelihood and consequence scores assigned to each climate-related risk developed during risk analysis are combined, and each risk is placed accordingly in the matrix. Given that risk is an increasing function of both likelihood and consequence, higher priority – in terms of an immediate need for action or further assessment – should be given to climate-related risks where there are both the potential for relatively severe consequences and a relatively high likelihood of realizing those consequences. For these risks, which are found in the upper right-hand corner of the risk matrix, climate change represents a material concern (i.e., an unacceptable risk). In contrast, climate-related risks found in the lower left-hand corner of the risk matrix exhibit neither the potential for relatively severe consequences nor a relatively high likelihood of realizing those consequences; the risk posed by climate change is negligible or acceptable. Thus, the priority for immediate further action is low or very low. In between these two extremes are risks which may be considered as medium priorities for further action or consideration, either because some aspect of the organization is at risk to severe consequences with a low likelihood of occurrence or milder consequences with a higher likelihood of occurrence.

Figure 2-2: Example of risk (rating) matrix



Color (traffic lights) can be used to clarify the significance of risks. The example matrix shown in Figure 2-2 employs three qualitative measures of significance: low priority risks (green light); moderate priority risks (amber light); and high priority risks (red light). In practice, the priority levels need to apply to specific cells in the matrix, as opposed to blurring across boundaries.

The location of the boundaries between the priority level regions in the matrix will depend on the 'risk appetite' of the organization. Risk appetite describes what climate-related risks the decision-maker(s) of an organization are prepared to accept for now, and which risks need to be reduced. It is not the absolute score assigned to a climate-related risk that is important but rather, whether or not the risk is regarded as tolerable (i.e., acceptable), or how far the risk is away from tolerability, which is important. For example, the thick blue line in the matrix shown in Figure 2-2 may distinguish tolerable risks from intolerable risks for a particular organization. Climate-related risks falling northwest of this line will therefore be judged unacceptable, and must be reduced – i.e., shifted southwest of the thick blue line. It is these climate-related risks that are the focus of Stage 3 in the adaptation planning process, and thus potentially subject to economic appraisal.

This is not to suggest, however, that climate-related risks initially falling southwest of the line be ignored; as shown in Figure 2-1 the adaptation planning process is iterative over time. An organization may have established the following rules, for example, governing the treatment of moderate and low priority risks:

- ⇨ Moderate priority risks – At this point in time the priority for further attention is moderate, and some adaptation issues are foreseen. Thought should be given to including these risks in the monitoring plan (Stage 4) to ensure that due consideration is given to their management; and
- ⇨ Low priority risks – At this point in time the priority for further attention is low. No further action is needed at present, apart from routine review to ensure that there has been no change that would make them more severe (re-evaluate these risks as the adaptation planning process enters a new cycle).

2.2.2.3 Formulating and prioritizing adaptation actions

Objective of stage: To identify, screen and appraise adaptation actions with a view to determining priorities, and putting together a (draft) adaptation strategy.

Box 2-2: Key questions addressed during Stage 3

- ⇨ What are the existing plans, policies, regulations or practices for managing impacts and consequences from current climate-related risks?
- ⇨ How adequate are these actions today at reducing threats, enhancing opportunities, or improving resilience?
- ⇨ Are they viable in the future? How do these actions need to be improved or extended to deal with projected climate change? What other adaptations can be used to reduce threats, enhance opportunities, or improve resilience?
- ⇨ What are the strengths (benefits) and weaknesses (costs) of each candidate adaptation action?
- ⇨ What is the preferred adaptation action(s) in the view of decision-makers?
- ⇨ Which portfolio of preferred actions constitutes a robust adaptation strategy?

In the previous stage, climate-related risks were identified, analyzed, and ranked in terms of whether they represented a material threat to (or opportunity for) the anticipated objectives of the decision problem at hand. This involved separating out relatively low priority risks that could be set aside for now from relatively high priority risks that require further, immediate attention. Stage 3 of the adaptation planning process involves:

- Setting adaptation goals for high priority risks;
- Identifying potential adaptation actions;
- Gathering relevant information on these actions;
- Screening, appraising, and prioritizing actions; and
- Incorporating priority actions into a strategy for implementation.

Screening may involve identifying risks for which more detailed analysis is recommended prior to making any further decisions, as well as selecting appropriate appraisal methods, including cost-benefit analysis (CBA), cost-effectiveness analysis (CEA) or multi-criteria analysis (MCA).

Step 1 Setting adaptation goals

The process of selecting adaptation actions begins by defining a goal (or set of goals) regarding each risk that was deemed to be of sufficient priority to warrant immediate attention. An adaptation action then effectively becomes a policy or project undertaken to achieve a stated adaptation goal(s). For example, assume a risk assessment conducted by the governing council of a major metropolitan area identified climate-induced deteriorations in local air quality and associated human health impacts as a high priority risk. Two possible adaptation goals are: ❶ inform residents about air quality in a timely manner so they may act appropriately; and ❷ maintain good air quality ambient standards (98 per cent of the time) across the metropolitan area.

At least one adaptation goal should be defined for each high priority risk, as well as the time frame over which the organization expects to accomplish these goals. The time frame chosen should be consistent with the organization’s (longer-term) planning goals, or based on the projected impacts of climate change and the risks those impacts give rise to.

The stated goals also must be consistent with the overall objective for the adaptation planning process.

Step 2 Identify candidate adaptation actions

The next step is to identify appropriate actions to achieve the defined adaptation goals. For example, if the adaptation goal is to inform residents about climate-induced changes in air quality in a timely manner so they may act appropriately, candidate adaptation actions may include:

- Developing and implementing a public air quality index with improved health messages;
- Designing and implementing an effective (forest fire) smoke forecasting and alert system;
- Implementing a public information campaign on air quality and human health; and

- ⇨ Research and development (R&D) of methods on how best to inform and target ‘at risk’ individuals.

The identification exercise should start with existing actions and their effectiveness before moving on to look at the need to formulate new actions that could be introduced. Do existing actions adequately deal with today’s climate or do they need to be improved? Even if they perform well today, will they need to be enhanced to deal with projected climate change? Initially, the net should be cast widely in order to develop a comprehensive long-list of different candidate adaptation actions; an opportunity to screen the actions to generate a workable short-list follows. To this end, it is helpful to attempt to identify candidate actions across each of the following broad categories of adaptation actions (UKCIP, 2008):

- ⇨ Soft actions (building adaptive capacity) – developing the institutional capacity to respond effectively to climate variability and climate change, which involves compiling the information needed, and creating the necessary regulatory and non-regulatory, institutional and managerial conditions for specific hard actions to be undertaken (e.g., undertaking research, collecting and monitoring data, and raising awareness / increasing understanding through environmental education and extension / training initiatives).
- ⇨ Hard actions – putting in place physical or managerial arrangements to: ❶ reduce exposure or sensitivity to risks; or ❷ offset losses by spreading or sharing risks or losses; or ❸ accept impacts and bear losses.

Step 3 Gather information on candidate adaptation actions

To help qualitatively screen candidate adaptation actions prior to taking any decisions on the way forward, it is necessary to collate some basic information. For example:

- ⇨ The geographical scale to which the action would be predominantly applied – e.g., national, provincial, regional, or site-specific;
- ⇨ The time it would likely take to have the action fully operational – e.g., less than 1 year from now, 1-3 years from now, more than 3 years from now, or it is currently ongoing;
- ⇨ The relevant community of interest (i.e., internal and external stakeholders) key to the successful implementation and operation of the action;
- ⇨ Implementation barriers or constraints – e.g., scientific, technological, financial, governance, in-house expertise, high-level buy-in, public acceptability; and
- ⇨ A qualitative understanding of the required investment and annual recurring costs, where relevant – e.g., are they likely to be high, medium or low compared with other planned expenditures by the organization?

Step 4 Screen, appraise and prioritize actions

Given the reality of scarce financial and human resources, it is nearly always necessary to refine or prioritize the long-list of candidate actions, and identify a preferred adaptation action or package of actions. So, how does an analyst evaluate the long-list of candidate actions and know which action(s) is ‘best’? Addressing this question is the focus of these guidelines, beginning in Section 3.

Step 5 Formulate the adaptation strategy

The final step during Stage 3 is to consolidate the evidence generated over all previous tasks, along with the package of preferred adaptation actions, into a draft adaptation strategy. The strategy should be transparent to enable stakeholders to review it and assure themselves that it is robust. At a minimum, all individuals or groups that have participated in the planning process thus far should be given the chance to comment on the emerging strategy. Depending on the scope and scale of the decision problem at hand, a wider audience of relevant (internal and external) stakeholders also may need to be given the opportunity to take stock of what has emerged from the adaptation planning process. This is necessary to validate, across the wider stakeholder community, the evidence base and the prioritized set of adaptation actions contained within the draft strategy. Among other things, it is vital to know – in the views of all key stakeholders – whether risks will be reduced to tolerable levels at reasonable cost and effort.

Once the draft adaptation strategy has been validated by all relevant stakeholders, more than likely it will need to be presented to a key decision-maker, committee or board, to get final approval to go ahead. An accompanying implementation plan and monitoring and review plan then can be prepared for the approved adaptation strategy.

A transparent strategy document provides a vital audit trail. This will help ensure the strategy itself is resilient to personnel and structural changes within the implementing organization. Given that an adaptation strategy is a living document, evolving over time, such continuity is extremely important.

2.2.2.4 Implement the adaptation strategy and keep it relevant

Objective of stage: To develop a plan to implement the approved adaptation strategy and a protocol to monitor, evaluate, and review the cost-effectiveness and other impacts of the strategy and continue the adaptation planning process generally.

The final two steps in the adaptation planning process involve:

Step 1 Develop an implementation plan

The adaptation strategy will contain a package of different actions of varying priority addressing a range of adaptation goals and related risks, each with specific timeframes, governance, staffing requirements, budgets, communication needs, etc. The strategy is put into action via an implementation plan, which outlines:

- How the prioritized adaptation actions are to be integrated (mainstreamed) with existing, relevant business programs, projects, practices, etc.;
- How the prioritized adaptation actions are to be integrated with existing decision-making processes at an appropriate level within the organization. This requires that the level of decision-making most relevant to each individual action be identified;
- Potential constraints and barriers to integration, including supporting governance, internal capacity, public acceptability, available budgets and technologies. Understanding these constraints and barriers, and devising strategies to overcome them, will greatly improve the likelihood of successful implementation;

- ⇨ Operational modalities, including: budgets, resource inputs and flows, management and administrative issues, institutional arrangements, staffing, etc. This should also include the mechanism by which the results of monitoring and evaluation are incorporated into the relevant management and decision-making processes;
- ⇨ When implementation should start, distinguishing between urgent and less urgent adaptation actions. For those actions whose implementation is delayed, either because the risk is not judged to be immediate, because additional resources or approvals are required, or because more detailed analysis is recommended, it is important that a review date is established and documented;
- ⇨ Timelines for the achievement of key milestones, including monitoring and evaluation.
- ⇨ A communication strategy for key stakeholders at all levels. It is clearly desirable that an action(s) that affects the public has their support. To this end, various outreach and news media fora can be used to, for example, address common misconceptions over climate change and variability, associated risks and uncertainties, and subsequently the need for the adaptation action(s).

Step 2 Monitor, evaluate and review

As with any strategic planning process, it is important to periodically look back and determine the effectiveness of the adaptation strategy (and implementation plan) in meeting stated goals.

The purpose of monitoring is to provide the necessary information to enable the achievements of the adaptation strategy to be systematically evaluated. This requires that the analyst identify a number of 'performance indicators' to be monitored, as well as specify how, when and by whom the information is to be collected, processed, and archived. Performance indicators can be described along the following broad dimensions of an adaptation strategy:

- ⇨ Implementation;
- ⇨ Institutional change;
- ⇨ Environmental impacts; and
- ⇨ Socio-economic impacts.

On the basis of the information gathered during monitoring, evaluation is the process by which the efficiency and effectiveness of the adaptation strategy is assessed with respect to the individual adaptation goals – and by extension – with respect to the expected outcomes of the decision problem at hand. Evaluation, like monitoring, is an on-going process.

At the outset it was emphasized that the adaptation planning process was circular and iterative. This allows the strategy itself, and all decisions taken, to be reviewed in light of the monitoring and evaluation procedure; new information on climate change; other organizational sensitivities, exposures and impacts; and changes in organizational goals. In effect, the adaptation strategy formulated during the current iteration of the planning process serves as an input to the next iteration, with the future strategies building upon past strategies. In this way, current adaptation practices are improved, because an organization is provided with an opportunity to learn from past experiences.

2.3 References and further reading

Arctic North Consulting, 2009, Climate Change and Canadian Mining: Opportunities for Adaptation, report prepared for the David Suzuki Foundation, Vancouver, Canada.

Broadleaf Capital International & Marsden Jacob Associates, 2006, Climate Change Impacts and Risk Management: A Guide for Business and Government, Prepared for the Australian Greenhouse Office, Department of Environment and Heritage, Canberra, Australia.

Canadian Council of Professional Engineers, 2008, Adapting to Climate Change: Canada's First National Engineering Vulnerability Assessment of Public Infrastructure, Canadian Council of Professional Engineers, Ottawa, Canada.

Caribbean Community Secretariat, 2003, Caribbean Risk Management Guidelines for Climate Change Adaptation Decision Making, Adapting to Climate Change in the Caribbean (ACCC) Project, (available online at http://www.caribbeanclimate.org).

DEFRA, 2010, Method for Undertaking the CCRA Part II – Detailed Method for Stage 3: Assess Risk, UK 2012 Climate Change Risk Assessment, Department for Environment, Food and Rural Affairs, London, UK.

Ebi, K., 2010, Social Vulnerability and Risk, Assessing the Benefits of Avoided Climate Change: Cost-Benefit Analysis and Beyond, Gulledge, J., Richardson, L., Adkins, L. and Seidel, S. (editors), Proceedings of Workshop on Assessing the Benefits of Avoided Climate Change, March 16–17, 2009, Pew Center on Global Climate Change: Arlington, VA, USA.

Ford, J. and Smit, B., 2004, A Framework for Assessing the Vulnerability of Communities in the Canadian Arctic to Risks Associated with Climate Change, *Arctic*, 57, p. 389-400.

Fussel, H. and Klein, R. , 2006, Climate Change Vulnerability Assessments: An Evolution of Conceptual Thinking, *Global Environmental Change*, 75, p. 301-329.

HM Treasury, 2006, Thinking About Your Risk: Setting and Communicating Your Risk Appetite, HM Treasury, London, UK.

ICLEI, 2007, Preparing for Climate Change: A Guidebook for Local, Regional and State Governments, Climate Impacts Group, Centre for Science in the Earth System (in association with ICLEI – Local Governments for Sustainability), Joint Institute for the Study of the Atmosphere and Ocean, University of Washington, Washington State, USA.

IEMA, 2009, Adapting to Climate Change: A Guide to its Management in Organizations, Best Practice Series, Volume 13, prepared by UKCIP on behalf of Institute of Environmental Management and Assessment, Lincoln, UK.

IoMosaic Corporation, 2002, Designing an Effective Risk Matrix, Salem, New Hampshire, USA.

Jones, R. and Boer, R., 2004, Assessing Current Climate Risks, Section II, Chapter 4, Adaptation Policy Framework [Burton, I., B. Lim and S. Huq (editors)], United Nations Development Program, New York, USA.

Jones, R. and Mearns, L., 2004, Assessing Future Climate Risks, Section II, Chapter 5, Adaptation Policy Framework [Burton, I., B. Lim and S. Huq (editors)], United Nations Development Program, New York, USA.

Mehdi, B. (editor), 2006, Adapting to Climate Change: An Introduction for Canadian Municipalities, Canadian Climate Impacts and Adaptation Research Network (C-CIARN), Ottawa, Canada.

Ministry for the Environment, 2008, Climate Change Effects and Impacts Assessment: A Guidance Manual for Local Government in New Zealand, 2nd Edition, Mullan, B., Pratt, D., Dean, S., Hollis, M., Allan, S., Williams, T. and Kenny, G., Ministry for the Environment, Wellington, NZ.

Perez, R. and Yohe, G., 2004, Continuing the Adaptation Process, Section II, Chapter 9, Adaptation Policy Framework [Burton, I., B. Lim and S. Huq (editors)], United Nations Development Program, New York, USA.

Smit, B. and Wandel, J., 2006, Adaptation, Adaptive Capacity, and Vulnerability, *Global Environmental Change*, 16, p. 282-292.

Spanger-Siegfried, E. and Dougherty, B., 2004, User's Guidebook, Section I, Adaptation Policy Framework, [Burton, I., B. Lim and S. Huq (editors)], United Nations Development Program, New York, USA.

Sussman, F. and Freed, J. , 2008, Adapting to Climate Change: A Business Approach, Sections 1-3, prepared for the PEW Centre on Global Climate Change, Arlington, Virginia, USA.

UKCIP, 2008, Identifying Adaptation Options, UK Climate Impacts Programme, Oxford, UK.

UKCIP, 2010, UKCIP Adaptation Wizard, UK Climate Impacts Programme, Oxford, UK.

Willows, R. and Connell, R. (eds.), 2003, Climate Adaptation: Risk, Uncertainty and Decision-making, Part 1, UKCIP Technical Report, UK Climate Impacts Programme, Oxford, UK.

3 Approaches to Appraise and Evaluate Candidate Adaptation Actions

3.1 Purpose

The purpose of this section is to:

- Outline a procedure to qualitatively screen and categorize candidate adaptation actions in terms of whether further, more detailed analysis is needed;
- Identify the three most commonly used approaches to appraise and evaluate adaptation actions;
- Summarize the main steps of each approach;
- Outline the key relative strengths and weaknesses of each approach; and
- Help analysts select the most appropriate approach for the adaptation decision problem at hand.

3.2 Prioritizing adaptation actions

During Stage 3 of the adaptation planning process (recall Figure 2-1), the analyst may have identified a range of both soft and hard actions to meet each of the stated adaptation goals. Given the reality of scarce financial and human resources, it is nearly always necessary to refine or prioritize candidate adaptation actions and identify a single preferred action or package of actions. This is true even if only one adaptation action was identified, since there is always the option of persisting with business-as-usual – i.e., doing nothing. The analyst is, therefore, confronted with the questions of how to evaluate candidate adaptation actions and how to know which action(s), including doing nothing, is best?

In Section 2 an incremental or tiered approach was recommended for the climate risk assessment. A similar approach is recommended for the appraisal of candidate adaptation actions. Appraisal should start with some form of qualitative screening assessment. The screening assessment is used to reduce a long-list of candidate actions down to a workable short-list to take forward. More detailed, quantitative analysis can then be employed to appraise the smaller sub-set of actions, as warranted.

3.2.1 Qualitative screening of candidate adaptation actions

During screening, emphasis should be placed on ranking the candidate adaptation actions, with the aim of sorting them into groups that define a course of action to be followed.

In rare cases, the screening assessment may show that a single candidate action performs better than all others against the screening criteria. The action required to meet a specific adaptation goal is thus obvious and could be considered for immediate implementation without further analysis or justification. The screening assessment may also indicate those actions that are obviously not suitable candidates at this time and can be dropped from further consideration. In other cases still, attempting to screen actions may reveal that additional information is needed before passing any judgment on a candidate action(s). Furthermore, depending on the importance of the decision problem at hand and an organization's existing project or investment appraisal protocols, it may be concluded that more structured decision-support tools need to be employed before a decision can be reached (see Section 3.2.2).

The screening assessment may be undertaken by the adaptation team (see Section 2.2.2.3), or by holding interviews, focus groups, or workshops with relevant stakeholders. Regardless of the approach to screening, as with elsewhere in the adaptation planning process, it is important to document why certain candidate actions were, or were not, selected to take forward, and to validate this with stakeholders.

Candidate adaptation actions can be screened qualitatively at two levels:

1. Relative to standard project selection criteria; and
2. Relative to the likelihood of them being economically efficient, given the inherent uncertainties.

3.2.1.1 Standard project selection criteria

Candidate actions can be screened first against a set of standard criteria typically considered by decision-makers during project appraisal, including:

- ⇨ **Effectiveness –** to what extent is the candidate action, if successfully implemented, expected to contribute to the relevant adaptation goal?
- ⇨ **Equity –** if successfully implemented, is the action expected to have unintended or undesirable distributional effects?
- ⇨ **Windows of opportunity –** are there windows of opportunity for implementing the action – e.g., annual reviews, regulatory processes, asset or equipment replacement cycles?
- ⇨ **Urgency –** how soon does the candidate option need to be implemented, and how quickly can it practically be implemented?
- ⇨ **Acceptability –** is the action likely to be supported by the general public, decision-makers, and politicians, if relevant?
- ⇨ **Policy coherence –** is the action, if successfully implemented, likely to create perverse (antagonistic) effects for other organizational goals? Or is it likely to offer co-benefits (synergistic) effects for other organizational goals?

3.2.1.2 Likely economic performance of actions

Candidate actions can be screened next to determine whether they are likely to be economically efficient given the inherent uncertainty in making decisions in a climate change context.

When considering the relative merits of the candidate adaptation actions, decision-makers will often have concerns related to uncertainty associated with the selection and implementation of preferred action(s). In effect, they will be concerned about making a poor decision in retrospect. For example, is the preferred action(s) necessary or too much (over-adaptation), less than ideal or not enough (under-adaptation), restrictive or simply wrong or unjustified (maladaptation)?

There are several ways to effectively address concerns about making poor, uneconomic adaptation decisions in the face of uncertainty (UKCIP, 2008):

- ⇨ Adopt a flexible or adaptive management approach, which involves implementing the required adaptation action(s) in a phased or incremental manner;
- ⇨ Look for the most robust adaptation action(s) – i.e., the one that is the most insensitive to a range of future climate conditions, instead of looking for the 'best' choice under a single, plausible climate scenario;
- ⇨ Recognize the value of no-regret, low-regret, and win-win adaptations (see Box 3-1 and Section 4.3.4.1);and
- ⇨ Avoid (maladaptation) actions that constrain future adaptations or limit the adaptive responses of others.

Box 3-1: Candidate adaptation actions likely to be economically efficient under uncertainty

Win-win adaptation actions: Actions that have the desired result in terms of minimizing the climate threats or exploiting potential opportunities, but also have other social, environmental or economic benefits. These types of actions include those that are introduced primarily for reasons other than addressing climate risks (e.g., managing non-climate risks or meeting social, environmental or economic objectives), but also deliver some desired adaptation benefits.

No-regret adaptation actions: Actions that are worthwhile (i.e., they deliver obvious and immediate net socio-economic benefits) whatever the extent of projected climate change. These types of actions include those justified (cost-efficient) under current climatic conditions and those that are further justified when their introduction is consistent (in terms of the projected direction of change in climate) with addressing risks associated with projected climate changes.

Low-regret adaptation actions: Actions for which the associated costs are relatively low and for which the benefits, although primarily realized under projected future climate change and thus deemed to be uncertain, may be relatively large. These types of actions seek to maximize the return on investment when certainty (uncertainty) of the associated risks is low (high).

Source: UKCIP (2008)

These specific types of actions also can serve as criteria to help screen candidate adaptation actions. For example, which of the candidate actions facilitates phased implementation? Which of the candidate actions is effective under a range of climate futures? Are any candidate actions no-regret adaptations?

Following the screening assessment, the analyst should have shifted the long-list of candidate adaptation actions into one of several broad groups that define what happens next. For example:

- ⇨ Those actions that could be implemented immediately (e.g., during this iteration of the planning process) without the need to collect further information or conduct quantitative analysis;
- ⇨ Those actions that could be implemented now, but require additional resources or approvals prior to proceeding with implementation; or
- ⇨ Those actions that could be implemented in future but for which it is first necessary to gather additional information or undertake more detailed analysis to be sure that the candidate action is indeed the best form of response.

In addition, some of the identified adaptation actions may not be suitable candidates at this time because, for example, they are not cost-effective or politically acceptable and this is obvious without collating further information or performing quantitative analysis. In this case, if no alternative actions have been identified, the risk may simply be borne for now, despite being labeled high priority.

3.2.2 Structured decision-support tools

Depending on, among other things, the importance of the decision problem at hand (primarily in economic terms) and the perceived difference in performance between the candidate actions vis-à-vis the relevant adaptation goal, qualitative estimates of performance may be sufficient to identify the preferred adaptation action(s). However, it may be necessary to defend the choice of a preferred action(s) through the use of well-structured decision-support tools, which entail more detailed, quantitative analysis. The three decision-support tools, or techniques, traditionally used to appraise public policies or projects are: ❶ cost-effectiveness analysis (CEA); ❷ cost-benefit analysis (CBA); and ❸ multi-criteria analysis (MCA). The main strength of these techniques is that they provide a framework for thinking rationally about the use of resources through a systematic examination of the advantages and disadvantages of each alternative way of achieving an adaptation goal. The first two are economic appraisal or monetary-based techniques.

3.2.2.1 Economic appraisal techniques

Two features characterize economic appraisal, in general:

- ⇨ First, economic appraisal deals with both the inputs and outputs, or the costs and consequences, of policies or projects (such as adaptation actions). It is a comparison of costs and consequences that enables a decision to be reached.

- Second, economic appraisal is concerned with choices. The fact that resources are scarce means society cannot produce all desired outputs (every efficacious adaptation action); choices must be made across all areas of human activity. These choices are made on the basis of many, sometimes explicit, but often implicit, criteria. Economic appraisal attempts to identify and make explicit one set of criteria – namely, efficiency – that may be useful in making choices about different uses of scarce resources.

Given these two features, in the context of adaptation planning, economic appraisal can be defined as the *comparative* analysis of alternative actions for achieving the same adaptation goal (including business-as-usual or the ‘do minimum’ options) in terms of both their *costs* and *consequences*. The consequences may or may not be measured in money terms.

The two main economic appraisal techniques are CEA and CBA. Both these techniques can be applied (HMT, 2004):

- At the start – to provide prospective analysis in support of decisions to implement a new adaptation action or to renew or expand existing adaptations. In this context they are informing the *appraisal* part of the adaptation planning process.
- And at the finish – to provide retrospective analysis of an adaptation action at its completion, conclusion or revision. In this context they are informing the *evaluation* of the adaptation planning process.

Cost-effectiveness analysis

Where there are alternative actions to achieve a specific adaptation goal of interest, but where the *main* consequence of each action is not readily measurable in monetary terms, CEA can be used to determine:

- The action or set of actions that minimizes the cost of achieving the defined adaptation goal; or
- The action or set of actions that yields the greatest benefit (e.g., delivers the maximum reduction in climate-related risk) subject to a budget constraint (or other resource constraint).

The mechanics of pursuing both agendas are the same. The main steps in conducting a CEA in the context of adaptation planning are outlined in Box 3-2. These steps are outlined thoroughly in Metroeconomica (2004) and are therefore not repeated in detail in this guidebook. Case Studies 5-6 in UNFCCC (2011) illustrate the application of CEA in an adaptation planning context.

Box 3-2: Steps in CEA

1. Establish the decision context (equivalent to Stage 1 of the adaptation planning process).

2. Agree on a well-defined adaptation goal and identify a candidate action(s) that can be expected to reasonably achieve the set goal.

3. Establish a baseline scenario(s) – the situation(s) projected to occur in the absence of the candidate adaptation action(s):

    a) Define a non-monetary indicator for evaluating the effectiveness of the candidate action(s) vis-à-vis the goal (e.g., m^3 of water supplied, cases prevented, number of lives saved);
    b) Predict (quantify) the level or magnitude of the indicator over time; and
    c) If relevant, estimate the total (life-cycle) costs of any baseline level of adaptation.

4. Establish an extended adaptation scenario – the situation projected to occur with the successful addition of the candidate adaptation action(s):

    a) Predict (quantify) the level or magnitude of the indicator over time; and
    b) Estimate the total (life-cycle) costs of the candidate action(s).

5. Discount all life-cycle costs and aggregate over time to obtain present values.

6. Discount the predicted value of the non-monetary indicator and aggregate over time to obtain present values.

7. Calculate relevant measures of cost-effectiveness – e.g.,

    a) Average cost-effectiveness ratio (ACER) – deals with a single candidate adaptation action and evaluates that action against the baseline level of adaptation, which may be nothing.
    b) Marginal cost-effectiveness ratio (MCER) – assesses the specific changes in total life-cycle costs and outcomes when baseline adaptation is expanded.
    c) Incremental cost-effectiveness ratio (ICER) – compares the differences between the total life-cycle costs and outcomes of two or more candidate adaptation actions that compete for the same resources and is generally described as the change in cost per change in non-monetary indicator. When comparing multiple competing candidate actions incrementally, one action should be compared with the next-less-effective alternative.

8. Compare the cost-effectiveness ratio(s) of the candidate adaptation action(s) bearing in mind the following rules:

   a) When assessing independent candidate adaptation actions:

      - Order the actions from least to most effective;
      - Eliminate the strongly dominated actions[4];
      - Calculate ACERs; and
      - Include in your strategy actions in order of increasing ACER until either resources are exhausted or the ACER is equal in value to one unit of effectiveness.

   b) When assessing a mix of independent and mutually exclusive candidate adaptation actions:

      - Form groups of mutually exclusive actions;
      - Order actions within each group from least to most effective; and within each group
      - Calculate the ICER;
      - Eliminate both strongly and weakly dominated actions;
      - Calculate the ACER of each independent action;
      - Rank all actions in order of increasing ACER;
      - Include in your strategy actions in order of increasing ACER until either resources are exhausted or the ACER is equal in value to one unit of effectiveness.

9. Assess risk and uncertainty – e.g., conduct a sensitivity analysis, develop cost-effectiveness acceptability curves.

10. Inform decision-maker.

Cost-benefit analysis

CBA seeks to value all the major expected inputs (costs) and consequences (benefits) of an adaptation action in monetary terms. These valuations are based on the well-developed economic theory of the willingness-to-pay of potential gainers for the benefits they will receive as a result of the action, and the willingness of potential losers to accept compensation for the costs they will incur (see Section 5.1.1.2). In principle, a candidate adaptation action is desirable if the monetized benefits exceed the costs, appropriately discounted for time.

CBA, in an attempt to value all impacts in monetary terms, draws upon an array of specialist valuation methods. An adaptation action may, for example, have impacts on so-called non-market goods or services, such as human health, water quality, biodiversity, visual amenity, or ecosystem health. There is an extensive, although by no means always conclusive, literature on the valuation of impacts of this general kind. Two widely used methods are, for example, hedonic pricing and contingent valuation surveys. Hedonic pricing techniques use market valuations, such as house prices, which may contain information about individuals' values for

[4] A strongly dominated candidate adaptation action is one for which an alternative action exists that is both more effective and less costly. A weakly dominated action generates effectiveness at a higher marginal cost than an alternative action. Any candidate adaptation action that is dominated by another should be removed from the list of competing alternatives so that the most efficient allocation of resources can be achieved.

other housing attributes, such as visual amenity, and try to separate out the amenity component using statistical techniques. The use of observed prices to reveal individuals' preference for impacts on non-market goods or services contrasts with the contingent valuation method. Contingent valuation seeks more direct valuations of such impacts by directly asking individuals about their willingness-to-pay, or willingness-to-accept compensation, for specific changes in the provision of the non-market good or service.

CBA as conventionally implemented does not address equity considerations related to the distribution of benefits and costs across stakeholder groups. As noted in Section 10 it may be desirable to draw attention to the distributional impacts of adaptation actions – to identify who wins and who loses, and by how much. Furthermore, since willingness-to-pay and willingness-to-accept compensation are partially dependent on incomes, some commentators argue for explicit weighting of gains and losses within a CBA to take account of the existing income distribution. That is, we should attach higher (lower) weight to costs and benefits that accrue to relatively poorer (richer) individuals? These forms of distributional analysis are seldom done in practice because of: ❶ the lack of consensus on what, if any, weighting system is appropriate in particular circumstances for individuals or groups having different incomes; and ❷ the additional measurement difficulty of tracing out who ultimately receives benefits and pays costs once their initial value has been determined.

The key attractions of CBA as an economic appraisal technique are that:

- ⇨ It considers the gains and losses to all members of the society on whose behalf the CBA is being undertaken;
- ⇨ It values impacts in terms of a single, familiar metric – money – and in principle therefore can show that implementing an adaptation action (or put another way, achieving a specific adaptation goal) is worthwhile relative to persisting with business-as-usual; and
- ⇨ The money values used to weight the relative importance of the different impacts are based on individuals' preferences, using established methods of measurement.

The main steps in conducting a CBA in the context of adaptation planning are outlined in Box 3-3; these steps are the focus of this guidebook. Note that several of the steps in Box 3-3 are also relevant to conducting CEA (recall Box 3-2). Hence, this guidebook also will help analysts performing CEA to inform adaptation planning. Case Studies 1-4 in UNFCCC (2011) illustrate the application of CBA in an adaptation planning context.

Box 3-3: Steps in CBA

1. Establish the decision context (equivalent to Stage 1 of the adaptation planning process).
2. Agree on a well-defined adaptation goal(s) and identify candidate actions that reasonably can be expected to achieve the set goal(s).
3. Decide whose gains and losses count –i.e., define who has ‘standing’.
4. Establish a baseline scenario(s) – the situation(s) projected to occur in the absence of the candidate adaptation action(s):
   a) Identify impacts on those with standing;
   b) Predict (quantify) these impacts over time; and
   c) Monetize the predicted impacts.
5. Establish an extended adaptation scenario – the situation projected to occur with the successful addition of the candidate adaptation action(s):
   a) Identify impacts on those with standing;
   b) Predict (quantify) these impacts over time; and
   c) Monetize the predicted impacts.
6. Discount all costs and benefits and aggregate over time to obtain present values.
7. Compare the present value costs and benefits predicted under the baseline scenario(s) and extended adaptation scenario(s), and apply evaluation criteria.
8. Assess risk and uncertainty –– e.g., conduct a sensitivity analysis, use cost-utility or portfolio analysis, or calculate real option value.
9. Identify who gains and who loses and by how much.
10. Inform decision-maker.

CBA versus CEA

It will be rare to find candidate adaptation actions where either all the benefits or none of the benefits can be expressed in monetary terms. It is also hard to say what is actually meant by "can be valued" in practice; most benefits can be valued if sufficient resources are devoted to the task and there is no urgency for making a decision, although there may still be no real consensus about the valuations produced.

CBA is most appropriate where the major benefits of a candidate adaptation action (as well as the costs) can be valued. This permits the decision–maker to compare actions of different kinds using a single metric, dollars. CBA is ideal in cases where there is sound information on which to base the analysis and where the scale (dollar value) of the investment justifies the work entailed.

CEA, on the other hand, is used where the major benefits cannot be valued in money terms. Instead, the costs involved in achieving a specific adaptation goal are compared. CEA therefore only permits a decision-maker to compare actions that address the same adaptation goal. Of course, not needing to value benefits in monetary terms enables CEA to be more readily applied.

To apply CEA, the adaptation goal needs to be clearly defined and accepted by decision-makers as being worth achieving, so that the only tasked faced by the analyst is to identify the least-cost way of meeting it. A clearly defined adaptation goal ideally should make some reference to the level of adaptation desired by decision-makers, for example:

- ⇨ To avoid all, or only part of, the expected consequences;
- ⇨ To return social welfare to levels estimated prior to overlaying the impacts of climate change;
- ⇨ To maintain expected consequences at current levels; or
- ⇨ To reduce expected consequences as much as budgets allow.

CEA cannot be used to evaluate whether the defined goal and level of adaptation is justified. CBA, in contrast, can be used to justify a goal and level according to the single criteria of efficiency.

In summary, whether CBA or CEA is the most appropriate form of economic appraisal is dependent on:

- ⇨ The overall size or importance of both the candidate adaptation action as a whole and the difficult to quantify or value benefits;
- ⇨ The effort required to value the difficult to quantify or value benefits and the likely accuracy of the resulting valuations; and
- ⇨ Whether the adaptation goal is well defined and already accepted by decision-makers.

It is worth noting that neither conventional CBA nor CEA address equity considerations, though a supplemental distributional analysis can be overlain by the analyst.

3.2.2.2 Multi-criteria analysis

Multi-criteria analysis (MCA) differs from CBA and CEA in three main areas:

- ⇨ While the economic appraisal tools focus on efficiency, MCA is not limited to a single objective, allowing for consideration of a wide range of objectives and criteria (e.g., social, environmental, ethical, as well as economic).
- ⇨ Secondly, economic appraisal tools require that consequences be measured in quantitative terms to allow for the application of prices (to estimate costs in CEA and to estimate both costs and benefits in CBA). MCA can be broken down into three groups of techniques: one that requires quantitative data, a second that uses only qualitative data, and a third that simultaneously handles a mixture of both.

- ⇨ Finally, MCA does not require the use of prices, although they might be employed to arrive at a score for an efficiency criterion. It is worth noting that whenever some impacts can be valued in monetary terms, these data should be used within an MCA.

CBA is preferable to MCA: if ❶ efficiency is the only criterion; if ❷ major impacts readily can be quantified in a way that facilitates monetization; and if ❸ relevant prices are available. However, in cases where there is a range of non-quantifiable, quantifiable and monetized impacts and where there is the need to trade-off disparate criteria, MCA may offer a more practical and realistic alternative. MCA provides a set of structured techniques that enable decision-makers to overcome difficulties in handling large amounts of diverse information in a more consistent and open way, compared with simply relying on the implicit judgments that may otherwise be made.

MCA establishes preferences among candidate adaptation actions by reference to an explicit set of objectives that a group has identified and for which it has established measurable criteria to appraise the extent to which the objectives have been achieved. The extent to which each action meets the established criteria is scored, and an explicit weight is assigned to each of the criteria to reflect its relative importance. The data pertaining to individual criteria are aggregated to provide an indicator of the overall performance of candidate actions. The estimated performance indicators can, in turn, be used to:

- ⇨ Identify a single, most-preferred action;
- ⇨ Rank actions;
- ⇨ Distinguish acceptable actions from unacceptable actions;
- ⇨ Highlight the strengths and weaknesses of the attributes (scores on individual criteria) of each of the candidate actions; and
- ⇨ Combine different actions based on relative strengths (e.g., actions that maximize performance across criteria).

A key question with MCA concerns which group gets a say when: ❶ establishing objectives and criteria, ❷ estimating relative importance weights and ❸ assessing the contribution of each candidate action to each decision criterion. Possible groups include all members of the decision-making body, a panel of experts asked to make judgments, or the wider stakeholder community. The potential for direct stakeholder engagement in this is considered an advantage of MCA, since it enables those who benefit from adaptation actions to be involved in choosing them. This is important for creating acceptance and ownership of the actions. With MCA, the choices that any group may make are also open to scrutiny, analysis and change if they are considered to be inappropriate.

A limitation of MCA is that it cannot show that a candidate adaptation action makes a net contribution to the welfare of those with standing. Unlike CBA, there is no explicit decision rule that benefits should exceed costs. Thus, similar to CEA, with MCA the best action can be inconsistent with improving social welfare. Maintaining baseline levels of adaptation could, in principle, be the preferred option. Another key disadvantage is that, if carried out to its fullest extent, with quantitative scoring and weighting, MCA can be a very time-consuming and resource-intensive process. Among other things, it is not always easy to reach agreement among stakeholders on relevant criteria, how each candidate action performs (scores) vis-à-vis a criterion, and the importance given to each criteria (their relative weights). It is advisable to perform sensitivity analysis to check the robustness of the results to changes in scores and weights. Sensitivity analysis also should be applied when conducting CBA and CEA for the same reason – to see if the results are sufficiently robust to withstand scrutiny.

The main steps in conducting a MCA in the context of adaptation planning are outlined in Box 3-4. Providing guidance on the practical application of MCA is beyond the scope of this document. An analyst interested in employing MCA or related techniques could start by looking at the guidance manual produced by the UK government (DCLG, 2009). Case Studies 7-8 in UNFCCC (2011) illustrate the application of MCA in an adaptation planning context.

Box 3-4: Steps in MCA

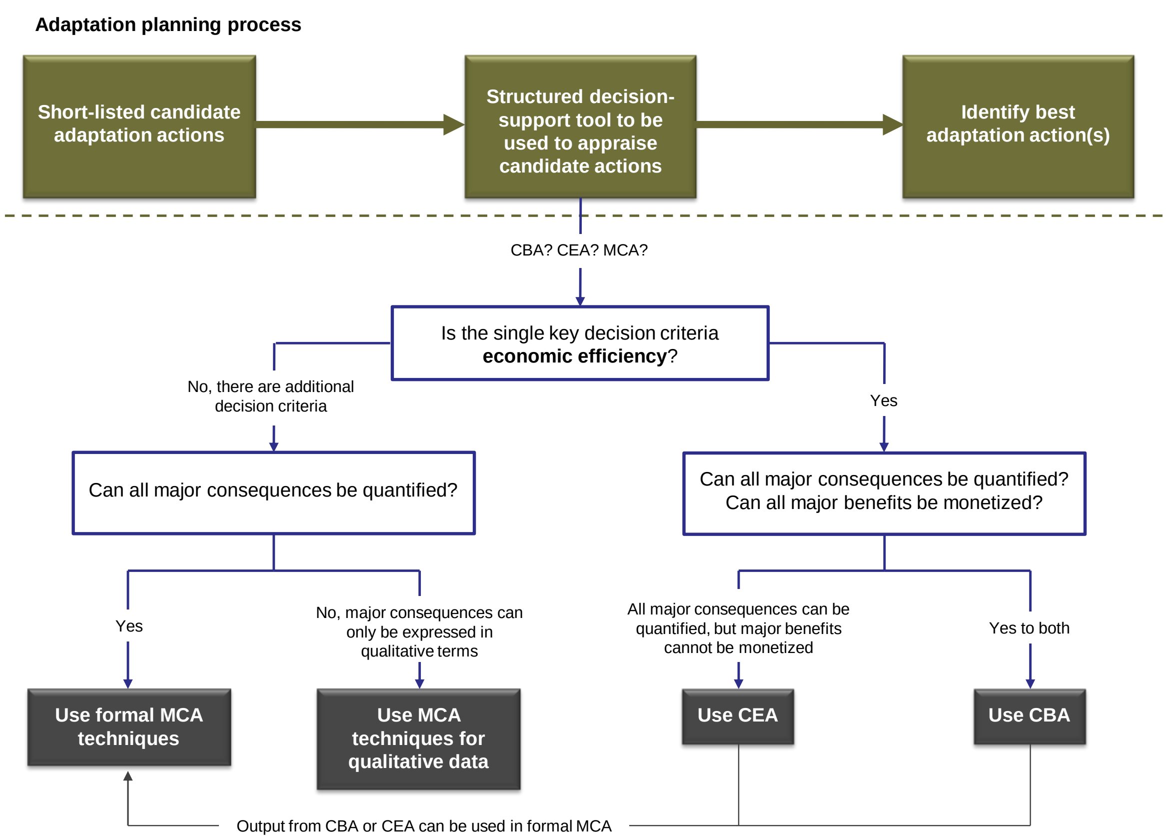
1. Establish the decision context (equivalent to Stage 1 of the adaptation planning process).
2. Identify the candidate adaptation actions to be appraised.
3. Identify criteria for assessing the consequences of each candidate action.
4. Scoring. Assess the expected performance of each candidate action against all the criteria. Next, assess the value (score) associated with the consequences of each candidate action for each criterion. Check the consistency of the scores on each criterion.
5. Weighting. Assign weights to each of the criterion to reflect their relative importance to the decision problem at hand.
6. Combine the weights and scores for each candidate action to derive an overall value. Calculate overall weighted scores.
7. Examine the results.
8. Conduct a sensitivity analysis. Do other assumptions, preferences, or weights affect the overall ordering of the candidate actions?

Source: Adapted from DCLG (2009)

3.2.2.3 Which structured decision-support tool to use?

In cases where the use of one of the above three structured decision-support tools – CBA, CEA or MCA -– is deemed necessary, the decision tree provided in Figure 3-1 can be used to help analysts select the most appropriate technique for the problem at hand. The choice depends on whether a range of criteria – social and environmental, in addition to economic – needs to be considered, and on data and information availability in relation to the economic criteria.

Figure 3-1: Decision tree to help choose between CEA, CBA, and MCA when it is necessary to use a structured decision-support tool



3.3 References and further reading

Ackerman, F., DeCanio, S., Howarth, R. and Sheeran, K., 2010, The Need for a Fresh Approach to Climate Change Economics, Assessing the Benefits of Avoided Climate Change: Cost-Benefit Analysis and Beyond, Gulledge, J., Richardson, L., Adkins, L. and Seidel, S. (editors), Proceedings of Workshop on Assessing the Benefits of Avoided Climate Change, March 16–17, 2009, Pew Center on Global Climate Change: Arlington, VA, USA.

DCLG, 2009, Multi-criteria Analysis: A Manual, Department for Communities and Local Government (DCLG), London, UK.

HMT, 2004, The Green Book: Evaluation and Appraisal in Central Government, HM Treasury Guidance, The Stationary Office, London, UK

IEMA, 2009, Adapting to Climate Change: A Guide to its Management in Organizations, Best Practice Series, Volume 13, prepared by UKCIP on behalf of Institute of Environmental Management and Assessment, Lincoln, UK.

IIED, 2010, Beyond Cost-benefit: Developing a Complete Toolkit for Adaptation Decisions, Briefing, International Institute for Environment and Development (IIED), London, UK.

Niang-Diop, I. and Bosch, H., 2004, Formulating an Adaptation Strategy, Section II, Chapter 8, Adaptation Policy Framework [Burton, I., Lim, B. and Huq, S., (editors)], United Nations Development Program, New York, USA.

NSW Government, 2010, Economic Appraisal Guidelines – Guidance on Climate Change for Asset and Infrastructure Assessments, NSW Government, Treasury Circular, NSW TC 10/12, Sydney, Australia.

UKCIP, 2008, Identifying Adaptation Options, UK Climate Impacts Programme, Oxford, UK.

UNFCCC, 2009, Potential Costs and Benefits of Adaptation Options: A Review of Existing Literature: Technical Paper, FCCC/TP/2009/2, UN Framework Convention on Climate Change Secretariat, Bonn, Germany.

UNFCCC, 2011, Assessing the Costs and Benefits of Adaptation Options: An Overview of Approaches, UN Framework Convention on Climate Change Secretariat, Bonn, Germany.

Willows, R. and Connell, R., (editors), 2003, Climate Adaptation: Risk, Uncertainty and Decision-making, Part 1, UKCIP Technical Report, UK Climate Impacts Programme, Oxford, UK.

4 Framework for Estimating the Costs and Benefits of Adapting to Climate Change

4.1 Purpose

The purpose of this section is to:

- Place adaptation decision-making in the wider economic context of international and national policy responses to climate change, to highlight the relationship between mitigation and adaptation;
- Provide a conceptual framework for the economic appraisal and evaluation of adaptation actions;
- Identify broad categories of costs to be considered within the framework;
- Show how the framework uses estimates of these costs to measure the total costs of climate change, the net benefits of adaptation, and residual damage costs;
- Outline a practical process (series of steps) for implementing the framework;
- Explain the role of climate and socio-economic scenarios in this process;
- Highlight where other sections in the guidebook should be consulted; and
- Link the economic appraisal and evaluation of adaptation actions back to the overall adaptation planning process.

4.2 The economics of climate change

There are two generic policy responses to climate change. The first response is mitigation. Mitigation seeks to tackle the *causes* of climate change by reducing concentrations of greenhouse gases in the atmosphere that lead to future warming. Decisions on the level of mitigation are made globally as part of international negotiations and later implemented through national policies. The second response is adaptation. Adaptation seeks to increase our resilience to the *consequences* of climate change already in the pipeline, or warming that cannot be avoided by current and future mitigation efforts. Decisions on the level of adaptation are frequently made at the local or regional scale (municipal or provincial governments) and by private actors (households, farmers, businesses). Sometimes adaptation actions taken by these groups are supported by national policy initiatives.

Decision-makers at the global and local-regional level face slightly different, but connected, decision problems. Since the suggested framework for appraising and evaluating adaptation actions is grounded in these two decision problems, they are briefly described below.

4.2.1 The decision problem facing global decision-makers

At the most basic level, the decision problem facing global decision-makers involves comparing through time:

- The costs of mitigating climate change (i.e., the cost of actions to reduce concentrations of GHGs in the atmosphere and the resulting amount of warming that will occur);
- The costs of adapting to climate change (i.e., the cost of actions to reduce the negative impacts or enhance the positive impacts of a given amount of climate change); and
- The residual damage costs of climate change;

In a global context, several policy objectives are possible. One possible objective could be to maximize the net present value of human welfare under a changing climate, given the changing pattern of these costs over time. Or, put another way, the objective could be to minimize the present value of human welfare losses (or total costs) from climate change over time. The decision problem facing global decision-makers, in its simplest form, is thus to (Fankhauser, 1998):

$$\text{Minimize} \sum_{t=0}^{T} \frac{C_t^M(m)}{(1+r)^t} + \frac{C_t^A(a)}{(1+r)^t} + \frac{C_t^D(m,a)}{(1+r)^t} \qquad \text{Equation 4-1}$$

Where:

C_t^M	=	Mitigation cost at year *t*, which is an increasing function of the level of mitigation, *m* (the higher the level of mitigation, the higher the lifecycle mitigation costs).
C_t^A	=	Adaptation cost at year *t*, which is an increasing function of the level of adaptation, *a* (the higher the level of adaptation, the higher the lifecycle adaptation costs).
C_t^D	=	Residual damage costs of climate change at year *t*, which is a decreasing function of both *m* and *a* (the higher the level of adaptation and the level of mitigation, the lower the residual damage costs).
r	=	Real annual social discount rate.

It is clear from Equation 4-1 that the lower the target level of residual damages, the higher will be the mitigation and adaptation costs of meeting that target. Decision-makers face a trade-off between mitigation and adaptation costs on one hand, and residual damage costs on the other. In the longer-term, decision-makers also have some flexibility to choose between different combinations of mitigation and adaptation; adaptation needs over the next several decades are already somewhat set.

At a global level, decision-makers would look to define the level of mitigation and adaptation that minimized the present value sum of the three cost components. In a cost-benefit analysis framework, this would involve equating the marginal costs of each policy response, both mitigation and adaptation, to the marginal benefits of each policy response, in terms of damage costs avoided. That is, the human welfare losses from climate change are minimized if:

$$\frac{\partial C^M}{\partial m} = \frac{\partial C^D}{\partial m} \text{ (optimal mitigation)}$$

and Equation 4-2

$$\frac{\partial C^A}{\partial a} = \frac{\partial C^D}{\partial a} \text{ (optimal adaptation)}$$

Equation 4-1 focuses on costs – as this typifies the approach that economists would apply to the global decision problem. A more comprehensive approach, however, would also consider the distribution of impacts, the risk of tipping points, climate variability and extremes, and the risk of irreversible damage to unique natural systems.

4.2.1 The decision problem facing local-regional decision-makers

In the context of adaptation planning, local and regional decision-makers are concerned with determining the most appropriate level of adaptation to a given amount of exogenously determined climate change. The assumed amount of climate change is itself based on some given level of globally agreed mitigation (perhaps arrived at by solving Equation 4-1). The adaptation decision problem is therefore concerned with comparing over time only two of the three cost components listed above:

- The residual damage costs of climate change; and
- The costs of adapting to climate change.

The basic approach economists would apply to the decision problem facing local and regional decision-makers would be to, for a given amount of climate change (and mitigation):

$$\text{Minimize} \sum_{t=0}^{T} \frac{C_t^A(a)}{(1+r)^t} + \frac{C_t^D(a)}{(1+r)^t}$$ Equation 4-3

The 'optimal' level of adaptation is that which minimizes the combined adaptation costs and residual damage costs.[5] Formally, the human welfare losses from a given amount of climate change are minimized if:

$$\frac{\partial C^A}{\partial a} = \frac{\partial C^D}{\partial a} \text{, given } m$$ Equation 4-4

That is, at the level of adaptation where the marginal cost of adaptation equals the marginal benefit of adaptation (damages avoided). Further adaptation actions are justified so long as the added costs of implementing them are lower than the added benefits.

In contrast to the decision problem defined by Equation 4-1, the adaptation and residual damage costs are now typically characterized at a local or regional level (or possibly by

[5] An equivalent formulation of the problem of identifying the efficient or optimal level of adaptation would be to maximize the net benefits of adaptation over time, defined as the avoided damages of climate change less the costs of adaptation (Mendelsohn, 2000).

economic sector, or at the level of individual organizations). In principle, global costs are derived by summing individual country costs; national costs are derived by summing regional costs or sectoral costs; and regional or sector costs are derived by summing local costs or costs to individual organizations, respectively.

4.3 Conceptual framework for economic appraisal and evaluation of adaptation actions

Table 4-1 presents a simple conceptual framework for the economic analysis of climate change adaptation. It draws mainly on the work of Sam Fankhauser, John Callaway, and Metroeconomica. The framework provides a consistent structure for defining baselines and future scenarios for estimating the costs of climate change, and the costs and benefits of adaptation.

Table 4-1: Conceptual framework for economic analysis of adaptation decisions

Adaptation response	**Existing climate** (Baseline climate scenario)		**Altered climate** (Climate change scenario)
Adapted to existing climate (Baseline adaptation scenario)	Society today is adapted as best it can to existing climate conditions Precaution	Caution	Future society remains adapted to existing climate variability even though climate is changing
Adapted to altered climate (Extended adaptation scenario)	Future society is adapted to an altered climate state in expectation of change even though climate change cannot yet be detected		Future society is adapted as best it can to altered climate which is being observed

Source: Adapted from Fankhauser (1998), Callaway (2004b), Callaway et al (1998), and Nkomo and Gomez (2006)

The two columns in Table 4-1 distinguish between two climate states, one with climate change and one without climate change. Distinguishing between these two climate states is necessary in order to calculate the *additional* cost of some level of climate change. Column one (left) depicts a scenario where society[6] today is experiencing current meteorological conditions (weather variability and extremes). Column two (right) shows a scenario where a future society is experiencing an altered climate state with associated impacts that are expected to occur at some point in the future. Column one thus defines a baseline scenario against which an analyst can appraise the economic impacts of climate change (by comparison with column 2).

The two rows in Table 4-1 distinguish between two adaptation strategies that decision-makers could pursue. Row one shows the 'best' adaptation strategy to follow in response to current meteorological conditions; that is, in the absence of climate change impacts.[7] The best adaptation strategy to cope with detected climate change is shown across row two. Similar to the columns, row one defines a baseline scenario against which an analyst can appraise the economic impacts of extended adaptation to better cope with climate change (by comparison with row 1).

As explained below, to assess the economic impacts of adaptation an analyst basically need only populate the cells in Table 4-1 with estimates of relevant costs and benefits (see Section 4.3.2). The real difficulty is accurately generating these estimates.

4.3.1 Alternative adaptation pathways for decision-makers

The expectation of climate change by decision-makers today leads them to plan a shift from the upper left cell in Table 4-1 to the lower right cell. Conceptually, society may in principle adapt to climate change along two different paths (Nkomo and Gomez, 2006). Both paths start with the initial situation in the top left cell, where society today is adapted as best it can to the existing climate, given available capital stocks, information and other resources, and the priorities of decision-makers. Throughout the guidebook we refer to the combination of climate and adaptation, from which we are analyzing the costs and benefit of adaptation, as the Reference Case.

Precautionary adaptation involves shifting, first, from the situation in the upper left cell to the lower left cell, where decision-makers undertake extended adaptation to cope with the altered climate state, in expectations of that state occurring. Forecasts about the exact nature of climate change and associated impacts are highly uncertain; the level of expected climate change is not yet being observed and may turn out to be more or less severe than anticipated. An alternative path involves a more cautious approach, involving an initial shift from the situation in the upper left cell to the upper right cell. In this case, future society remains optimally adapted to the existing climate, opting not to further adapt even though there are signs that the climate may be changing in accordance with expectations. The final shift along either path is to the lower right cell, which represents a situation in which future society is adapted as best it can to the altered climate state. In this situation future society has detected this level of climate change in a way that is useful for planning and decision-making, e.g., forecasts about the nature of climate change impacts are deemed sufficiently reliable to inform investment decisions in capital stock to enhance society's resilience to the altered climate state.

[6] To simplify the presentation here, and throughout these guidelines, 'society' may refer to a country, a region, a municipality, an economic sector, an organization, or an individual.

[7] 'Best' could be defined as satisfying the economic efficiency condition set out in Equation 4-4; it could also be defined as satisfying any other criterion or set of criteria relevant to the decision-maker(s). See Section 3.2.1.1.

Delineating these two adaptation pathways is important when it comes to analyzing two key mistakes that decision-makers can make – either under or over adapting to a given level of climate change.

4.3.2 Types of adaptation costs and benefits

Four distinct types of costs that arise along each adaptation pathway can now be defined (and illustrated through the numerical example in Table 4-2).

⇨ **Cost of adaptation** ($C_{i,j}^{A}$)[8]

The first category comprises the life-cycle costs of implementing adaptation actions. In the numerical example in Table 4-2 baseline adaptation costs are assumed to be $9 million per year[9] whereas the costs of extended adaptation are assumed to amount to $17. The incremental adaptation costs to best cope with anticipated climate change are thus $8, i.e., $17 less $9.

⇨ **Cost of climate variability and extremes** ($C_{i,j}^{CV}$)

Society is impacted, both positively and negatively, by current climate variability and extreme weather events. Every year, for example, many Canadians are adversely impacted by floods, droughts and thunderstorms. This category of costs encompasses the monetary value of the net welfare losses resulting from these impacts. It is important to note that these are costs that would still be incurred by society in the absence of climate change. Baseline adaptation will help society avoid some of the impacts from floods, droughts, thunderstorms etc., but not necessarily all of them. It may not be technically or economically feasible to have a situation with zero residual impacts. In the numerical example, the costs of climate variability and extremes are $5 even with optimal baseline adaptation. Extended adaptation, as well as reducing the costs of climate change, further reduces the costs associated with climate variability and extremes, to $3. Extended adaptation may also reduce our exposure or sensitivity to climate variability and extremes.

⇨ **Cost of climate change** ($C_{i,j}^{CC}$)

The third category of costs represents the monetary value of the net welfare losses experienced by future society solely as a result of the physical impacts of climate change. In the numerical example, the costs of climate change when future society is optimally adapted only to current meteorological conditions are assumed to be $13. In contrast, with extended adaptation to anticipated climate change, damage costs from climate change incurred by future society are reduced by $9, to $4. Of course, by definition, these costs are only incurred under the climate change scenario ($C_{0,0}^{CC}$ and $C_{1,0}^{CC}$ are both zero).

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[8] The subscript *i* = the adaptation scenario or strategy, with 0 denoting baseline adaptation and 1 denoting extended adaptation. The subscript *j* = the climate state or scenario, with 0 denoting the baseline climate state and 1 denoting the altered climate state.

[9] Henceforth, for ease of presentation, the "million per year" will be dropped when discussing this example.

⇨ **Other related costs** ($C_{i,j}^{OR}$)

Adaptation actions may have beneficial economic impacts unrelated to climate. Adaptation is closely intertwined with development, sometimes making it difficult to conceptually and practically distinguish the two. Development, for example, generates wealth, making available more resources that can be allocated to reducing risks in general. Projects undertaken primarily to advance economic or social development objectives, or manage non-climate risks, may, in addition, enhance society's climate resilience. Equally, extended adaptation projects may generate multiple benefits, contributing to other environmental, economic or social objectives, or reducing the need for other investments that would have occurred with baseline adaptation. Hurricane shelters, for example, may be used out of season, thereby avoiding the need to build halls for other social or recreational functions. The fourth category of costs in Table 4-2, other related costs, captures these ancillary benefits and avoided cost effects. In the numerical example, it is assumed that extended adaptation reduces investment expenditures required under baseline adaptation by $1, from $6 to $5.

⇨ **Total costs** ($C_{i,j}^{T}$)

Total costs are simply the sum of the four distinct cost categories, as follows[10]:

$$C_{i,j}^{T} = C_{i,j}^{AC} + C_{i,j}^{CV} + C_{i,j}^{CC} + C_{i,j}^{OR} \qquad \text{Equation 4-5}$$

Where:

i = The adaptation scenario or strategy, with 0 denoting baseline adaptation and 1 denoting extended adaptation.

j = The climate state or scenario, with 0 denoting the baseline climate state and 1 denoting the altered climate state.

Total costs defined by Equation 4-5 are analogous to the measure of "total climate risk" used by the Economics of Climate Adaptation Working Group (ECA, 2009).

[10] A simple static formulation is used for ease of presentation; a time dimension should be incorporated when applying the framework.

Table 4-2: Conceptual framework for economic analysis of adaptation decisions - showing types of costs for optimal adaptation under two climate states

Adaptation response	**Existing climate** (Baseline climate scenario) ($ million per year)		**Altered climate** (Climate change scenario) ($ million per year)	
Adapted to existing climate (Baseline adaptation scenario)	Adaptation cost	$C_{0,0}^{A} = 9$	Adaptation cost	$C_{0,1}^{A} = 9$
	Climate variability costs	$C_{0,0}^{CV} = 5$	Climate variability costs	$C_{0,1}^{CV} = 5$
	Climate change costs	$C_{0,0}^{CC} = 0$	Climate change costs	$C_{0,1}^{CC} = 13$
	Other related costs	$C_{0,0}^{OR} = 6$	Other related costs	$C_{0,1}^{OR} = 6$
	Total costs	$C_{0,0}^{T} = 20$	Total costs	$C_{0,1}^{T} = 33$
Adapted to altered climate (Extended adaptation scenario)	Adaptation cost	$C_{1,0}^{A} = 17$	Adaptation cost	$C_{1,1}^{A} = 17$
	Climate variability costs	$C_{1,0}^{CV} = 3$	Climate variability costs	$C_{1,1}^{CV} = 3$
	Climate change costs	$C_{1,0}^{CC} = 0$	Climate change costs	$C_{1,1}^{CC} = 4$
	Other related costs	$C_{1,0}^{OR} = 5$	Other related costs	$C_{1,1}^{OR} = 5$
	Total costs	$C_{1,0}^{T} = 25$	Total costs	$C_{1,1}^{T} = 29$

Source: Adapted from Fankhauser (1998 and 2008)

Notes: Dollar values are illustrative. The first cost subscript *i* defines the adaptation scenario or strategy, with *i* = 0 = baseline adaptation and *i* = 1 = extended adaptation. The second cost subscript *j* defines the climate scenario or state, with *j* = 0 = the baseline climate state and *j* = 1 = the altered climate state.

4.3.3 Economic measures of climate change adaptation impacts – two adaptation strategies and two climate states

Various economic measures characterizing the welfare implications of climate change adaptation can now be developed from the conceptual framework and types of costs presented in Table 4-2.

4.3.3.1 Cost of climate change without extended adaptation

<u>Definition</u>: The net loss in human welfare incurred by future society if the climate changes from the baseline state to the altered climate state, when society remains optimally adapted to the baseline climate state.

The cost of climate change without extended adaptation is estimated by subtracting the total costs in the upper left cell from the total costs in the upper right cell (see Table 4-3):

$$C_{0,1}^{T} - C_{0,0}^{T} = \$33 - \$20 = +\$13 \qquad \text{Equation 4-6}$$

In the numerical example, the cost of climate change without extended adaptation is $13.

4.3.3.2 Net benefits of extended adaptation

Definition: The net improvement in human welfare achieved by optimally adapting to the altered climate state, compared to a situation where future society does not invest in extended adaptation and remains at baseline levels of adaptation.

It is a measure of the climate change damages avoided though optimal adaptation to the altered climate state. The net benefits of extended adaptation are estimated by subtracting the total costs in the upper right cell from the total costs in the lower right cell:

$$C_{1,1}^{T} - C_{0,1}^{T} = \$29 - \$33 = -\$4 \qquad \text{Equation 4-7}$$

Remember that Table 4-2 shows the total costs of different scenarios. A reduction in total costs, indicted by a negative value, actually represents an improvement in welfare. Extended adaptation to climate change in the numerical example thus produces a net benefit (avoided welfare losses) of $4.

4.3.3.3 Imposed costs of climate change

Definition: The net welfare losses from climate change that cannot be avoided by future society even after optimally adapting to anticipated climate change.

The imposed costs of climate change are estimated by subtracting the total costs in the upper left cell (the Baseline Case) from the total costs in the lower right cell (the minimum total costs of climate change[11]):

$$C_{1,1}^{T} - C_{0,0}^{T} = \$29 - \$20 = +\$9 \qquad \text{Equation 4-8}$$

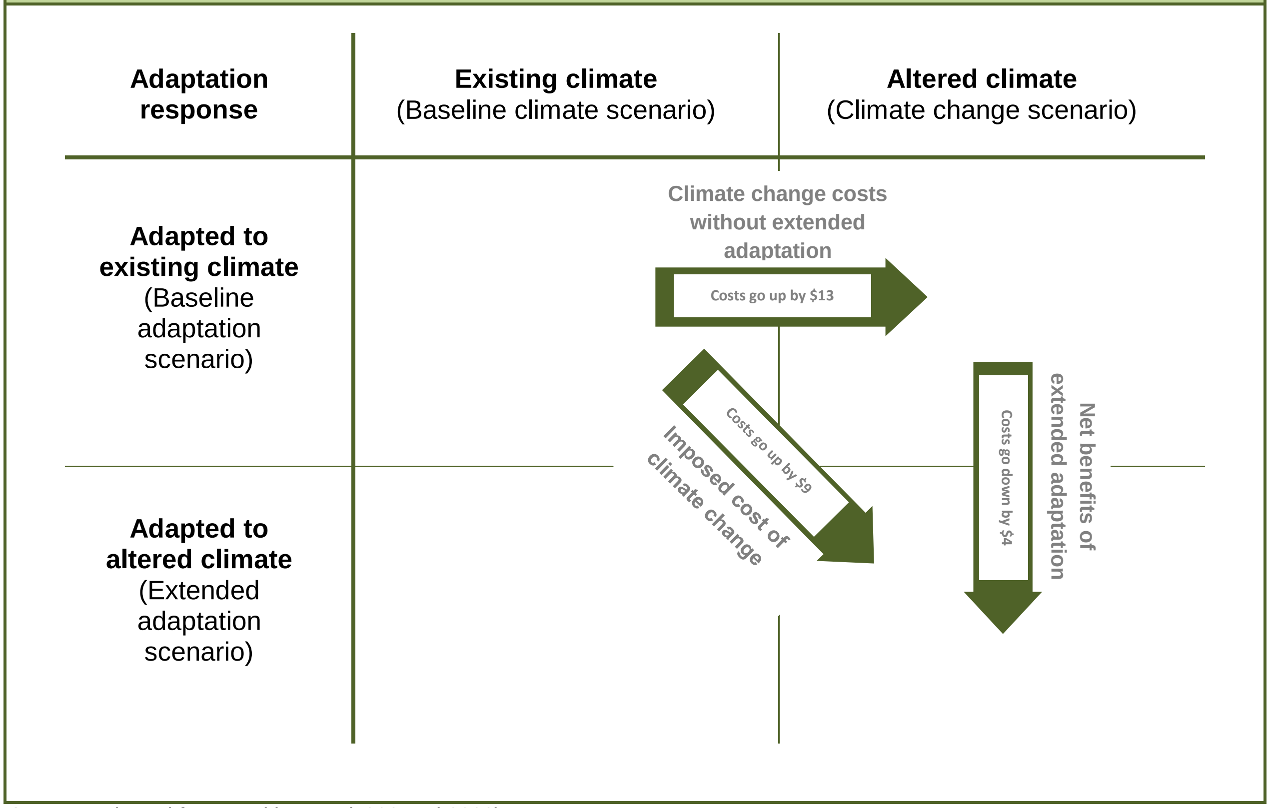
The imposed costs of climate change consist of the following four components:

Change in adaptation costs $\left(C_{1,1}^{A} - C_{0,0}^{A}\right)$	+$17	-	+$9	=	+$8
Change in climate variability costs $\left(C_{1,1}^{CV} - C_{0,0}^{CV}\right)$	+$3	-	+$5	=	-$2
Change in climate change costs $\left(C_{1,1}^{CC} - C_{0,0}^{CC}\right)$	+$4	-	+$0	=	+$4
Change in other related costs $\left(C_{1,1}^{OR} - C_{0,0}^{OR}\right)$	+$5	-	+$6	=	-$1
Change in total costs $\left(C_{1,1}^{T} - C_{0,0}^{T}\right)$	+$29	-	+$20	=	+$9

[11] Total costs in the lower right cell of Table 4-2 represent the minimum costs of climate change because future society is assumed to have adapted as best it can to a given level of anticipated climate change; climate change costs are thus as low as possible.

An important point to note is that the imposed cost of climate change is typically positive; even with optimal (economically efficient) adaptation strategies in place climate change will likely reduce aggregate human welfare. It is generally accepted that most countries, including Canada, will incur net costs from the kinds of temperature change anticipated given existing international negotiations on mitigation.

Table 4-3: Conceptual framework for economic analysis of adaptation decisions - showing measures of economic impact for optimal adaptation under two climate states



Source: Adapted from Fankhauser (1998 and 2008)

4.3.3.4 Costs of under or over adaptation

Decision-makers can make two kinds of mistakes, when *ex-ante* expectations about the future climate are compared to *ex-post* outcomes of the adaptation decision based on those expectations.

Costs of caution

Definition: The cost of assuming *ex-ante* that the baseline climate will not change and therefore extended adaptation is not warranted, but *ex-post* it turns out that the climate did in fact change to the altered state.

Decision-makers may assume *ex-ante* that the climate is not changing, and in response, not undertake extended adaptation. However, it may turn out *ex-post* that the climate did indeed change. This mistake will have cost consequences, since the level of adaptation implemented *ex-ante* will prove to be sub-optimal *ex-post* – i.e., too little adaptation will have been implemented. The cost of this cautious approach is estimated by subtracting the total costs of the lower right cell from the total costs of the upper right cell (Nkomo and Gomez, 2006):

$$C^T_{0,1} - C^T_{1,1} = \$33 - \$29 = +\$4 \qquad \text{Equation 4-9}$$

Note that the cost of caution has the same value as the net benefits of optimal adaptation, but with the opposite sign (positive instead of negative) since the net benefits of optimal adaptation are essentially forgone by under adapting.

Costs of precaution

Definition: The cost of assuming *ex-ante* that the climate will change to the altered state and implementing extended adaptation, when in fact *ex-post* it turns out that the climate did not change, remaining at baseline levels.

Decision-makers may assume *ex-ante* that the climate is changing and in response undertake extended adaptation. But it may turn out *ex-post* that the climate did not change to the altered state. In other words, decision-makers did not act cautiously enough. Again, this mistake will have cost consequences, since the level of adaptation implemented *ex-ante* will prove to be sub-optimal *ex-post*. In this case, too much adaptation will have been implemented. The cost of precaution is estimated by subtracting the total costs in the upper left cell (the Baseline Case) from the total costs in the lower left cell (Nkomo and Gomez, 2006):

$$C^T_{1,0} - C^T_{0,0} = \$25 - \$20 = +\$5 \qquad \text{Equation 4-10}$$

Estimates of the cost of acting too cautiously or not cautiously enough can be used to assess the robustness of various adaptation strategies to a range of different climate strategies. Decision-makers could look to minimize the cost of making an error.

Economic measures of climate change adaptation impacts for the more realistic case facing analysts of multiple adaptation strategies and multiple climate states are developed in ANNEX 4-1.

4.3.4 Using the conceptual framework, cost types and economic measures of impact to perform CBA

The imposed cost of climate change may well be positive, indicating a loss of human welfare, but this does not mean that a decision to implement extended adaptation would fail a standard cost-benefit test. Recall that the Baseline Case for estimating the imposed cost of climate change is the upper left cell, and involves a comparison between total costs in the upper left cell and total costs in the lower right cell of Table 4-2. In contrast, the Reference Case for an economic appraisal of an adaptation strategy is the upper right cell, and involves a comparison between total costs in the upper right cell and total costs in the lower right cell (consider the result of Equation 4-7). A certain amount of climate change is taken as given - in this case, the single altered climate state - and the analyst appraises the costs and benefits of different levels of adaptation to that exogenously determined amount of climate change.

An adaptation action(s) passes a cost-benefit test if the (present value) aggregate *incremental* benefits achieved exceed the (present value) *incremental* adaptation cost (see 8.2). Table 4-2 provided a numerical example of the main types of adaptation costs and benefits for cost-benefit analysis; these are reproduced in Table 4-4.

Incremental adaptation costs in the example are:

$$\Delta C^{A} = C^{A}_{1,1} - C^{A}_{0,0} = \$17 - \$9 = +\$8 \qquad \text{Equation 4-11}$$

The main benefits from the extended adaptation project involve avoided climate-related damages and reductions in other related costs. Extended adaptation reduces the costs of climate change by:

$$\Delta C^{CC} = C^{CC}_{1,1} - C^{CC}_{0,0} = \$4 - \$13 = -\$9 \text{ (a cost saving of \$9)} \qquad \text{Equation 4-12}$$

Remember that a reduction in costs, indicated by the negative sign, is a benefit. In addition, extended adaptation reduces costs associated with current climate variability and extremes by:

$$\Delta C^{CV} = C^{CV}_{1,1} - C^{CV}_{0,0} = \$3 - \$5 = -\$2 \text{ (a cost saving of \$2)} \qquad \text{Equation 4-13}$$

The total climate-related costs avoided by extended adaptation thus amount to \$9 + \$2 = \$11. Adaptation actions may also provide other beneficial economic impacts unrelated to climate. In the example the extended adaptation project generates avoided cost effects or ancillary benefits amounting to:

$$\Delta C^{OR} = C^{OR}_{1,1} - C^{OR}_{0,0} = \$5 - \$6 = -\$1 \text{ (a cost saving of \$1)} \qquad \text{Equation 4-14}$$

Table 4-4: Cost-benefit analysis of extended adaptation project

Cost type	Reference Case	Extended adaptation	Project benefits	Project costs
Incremental adaptation cost	$C^{A}_{0,1} = \$9$ →	$C^{A}_{1,1} = \$17$		Increase in costs = \$8
Climate variability costs	$C^{CV}_{0,1} = \$5$ →	$C^{CV}_{1,1} = \$3$	Reduction in costs = \$2	
Climate change cost	$C^{CC}_{0,1} = \$13$ →	$C^{CC}_{1,1} = \$4$	Reduction in costs = \$9	
Other related costs	$C^{OR}_{0,1} = \$6$ →	$C^{OR}_{1,1} = \$5$	Reduction in costs = \$1	

Source: Adapted from Fankhauser (1998)

In total, extended adaptation produces aggregate incremental benefits (cost savings) of \$9 + \$2 + \$1 = \$12. Extended adaptation in this case passes a standard cost-benefit test, since aggregate incremental benefits exceed incremental adaptation costs (\$12 > \$8), producing a net benefit of \$4. Total costs experienced by future society are thus reduced by \$4 through extended adaptation, which is the same result obtained by Equation 4-7. More generally, the net benefits (NB) of adaptation are given by:

$$\text{NB} = \text{project benefits (B)} - \text{project costs (C)}$$

$$\text{NB} = \underbrace{(\Delta C^{CC} + \Delta C^{CV} + \Delta C^{OR})}_{\text{Project benefits from Table 4-4}} - \underbrace{\Delta C^{A}}_{\text{Project costs from Table 4-4}}$$

Equation 4-15

An adaptation action passes a standard cost-benefit test if:

$$\text{Project benefits (B)} - \text{project costs (C)} > \$0$$

$$(\Delta C^{CC} + \Delta C^{CV} + \Delta C^{OR}) - \Delta C^{A} > \$0$$

Equation 4-16

These decision rules (also known as 'evaluation criteria') are considered in more detail in Section 8.

The output of the CBA is – as stressed in Section 3.2.1.1 - but one input for decision-makers to consider when assembling a comprehensive adaptation strategy.

4.3.4.1 Identifying robust adaptation actions

Knowledge about climate change – in particular, regarding future economic impacts at a regional or local scale – is incomplete, and will likely remain so for the foreseeable future. Hence, decision-makers have no choice but to make adaptation decisions under uncertainty. An added feature of the above framework is that it allows the analyst to explicitly assess whether extended adaptation is warranted, from an economic perspective, even if the magnitude of climate change is not known exactly.

No-regret adaptations

If an action brings about a reduction in damages associated with climate variability and extremes that is greater than the incremental cost of that action, then it is justified on economic grounds even if climate change is not as severe as anticipated and if there are no ancillary benefits. This is the definition of a no-regret adaptation (see Section 9.4). Formally, adaptation is a no-regret strategy if:

$$\Delta C^{CV} > \Delta C^{A} \text{ or } \Delta C^{CV} - \Delta C^{A} > \$0$$

Equation 4-17

In the example shown in Table 4-2, the incremental costs of extended adaptation exceed the resulting reduction in damages from climate variability and extremes. Extended adaptation is therefore not a no-regret activity in this case.

Win-win adaptations

Another special type of adaptation actions of interest to decision-makers are win-win adaptations (see Section 9.4). Adaptation is a win-win strategy if the accompanying reduction in other related costs is greater than the incremental cost of actions that brought about the ancillary benefits. If this is the case, then adaptation is justified even if all climate-related benefits are less than anticipated. Formally, adaptation is a win-win strategy if:

$$\Delta C^{OR} > \Delta C^{A} \text{ or } \Delta C^{OR} - \Delta C^{A} > \$0 \qquad \text{Equation 4-18}$$

In the above numerical example, extended adaptation is not a win-win strategy. In fact, extended adaptation only passes the standard cost-benefit test with the inclusion of avoided climate change costs. Even the sum of avoided damages from climate variability and extremes, plus the ancillary benefits is still less the incremental adaptation costs. The value of avoided climate change damages must be greater than $5 for extended adaptation to be warranted from an economic perspective, which itself is an interesting outcome of the framework.[12]

4.3.5 Constructing the framework in practice

The framework introduced above provides two key inputs to adaptation decision-making:

- ⇨ Quantification of the total costs of climate change facing future society at a particular location; and
- ⇨ Quantification of the net benefits of candidate adaptation actions that can be taken to mitigate these costs.

In doing so, it also indirectly quantifies the residual costs (the imposed costs of climate change) that will persist after future society has adapted as best it can.

Recall that calculating the net benefits of adaptation involves a comparison between total costs in the upper right cell and total costs in the lower right cell of Table 4-2. The Reference Case for the analysis is the upper right cell; the Policy Case is the lower right cell. To perform CBA of candidate adaptation actions the analyst must estimate total costs under both the Policy Case and the Reference Case. Calculating the total costs of climate change, the Reference Case for CBA of candidate adaptation actions, itself involves a comparison between total costs in the upper left cell and total costs in the upper right cell of Table 4-2. The starting point for the entire analysis thus involves calculating total costs in the upper left cell (Baseline Case).

[12] Only if ΔC^{CC} is greater than $5 will extended adaptation pass the cost-benefit test: $(\Delta C^{CC} + \$2 + \$1) - \$8 > \$0$.

Hence, in order to generate both key inputs to adaptation decision-making the analyst should, in sequence:

1. Estimate total costs under the Baseline Case;
2. Estimate total costs under the Reference Case; and
3. Estimate total costs under the Adaptation Policy Case.

(Items 1–2: Costs of climate change without extended adaptation)

(Items 2–3: Net benefits of extended adaptation)

Decision-makers may nonetheless only wish to use the framework to subject a selection of adaptation actions to CBA. In this instance, they need only construct the Reference Case and Policy Case.

In each of these three Cases - with the exception of climate change damages under the Baseline Case that are by definition zero - the analyst should strive to quantify in monetary terms each cost category included in Equation 4-15: ❶ adaptation costs; ❷ climate change damages; ❸ damages associated with climate variability and extremes; and ❹ non-climate-related costs or other ancillary benefits. In practice, nonetheless, the analyst may find it simpler to assume a value of zero for both adaptation costs and non-climate-related costs under the Baseline Case; and only measure these costs under the Policy Case. Furthermore, again to simplify matters, the analyst may assume climate-related damages are zero under the Baseline Case.

For a given decision problem, each of these cost categories may themselves comprise numerous elements (e.g., in the context of urban flooding category ❶ may include infrastructure investment costs, operating costs, terminal values; and categories ❷ and ❸ may include injuries, illness, fatalities, residential and non-residential property loss and damage, temporary accommodation costs, disruption to transport networks, emergency services).

4.3.5.1 Constructing the Baseline Case

Define risk metrics

During the risk assessment stage of the adaptation planning process (see Section 2.2.2.2) high priority risks relevant to the adaptation actions being appraised will have been characterized. The first step in constructing the Baseline Case is for the analyst to define so-called ‘risk metrics’ for each high priority risk. These metrics measure the most important consequences of the risk (DEFRA, 2010).

For example, in the context of water resources a high priority risk may be, say, increased incidence of ‘low flows’ in rivers due to reduced summer rainfall. Possible metrics to measure the consequences of this risk include: ❶ the number of sites meeting environmental flow or water quality standards (number, percentage); or ❷ the number of sites with unsustainable abstraction (number, percentage, Megalitres per day).

Other examples of risk metrics include:

- ⇨ Water demand (Megalitres per day, percentage);
- ⇨ Supply-demand water deficits (Megalitres per day, percentage);

- ⇨ Population affected by supply-demand deficits (number, percentage);
- ⇨ Excess respiratory hospital admissions based on ground-level ozone (cases);
- ⇨ Fatalities from extreme flooding events (deaths);
- ⇨ Number of residential properties affected by flooding (number, percentage);
- ⇨ Crop yield (kg per hectare); and
- ⇨ Habitat loss (hectares, percentage).

A range of potential metrics should be identified for the main consequences of each risk. These can then be examined with sector experts to derive a narrower set of practical metrics that strike the best balance across the following criteria (DEFRA, 2010):

- ⇨ Metric is sensitive to climate variables;
- ⇨ Metric allows the effects of climate change to be disentangled from the effects of socio-economic change;
- ⇨ Metric provides a measure of changing probability or consequences relevant to the current situation (Baseline Case);
- ⇨ High quality data, in the public domain, are available for the metric to establish the current situation (Baseline Case);
- ⇨ Data for the metric can be presented at various scales (national, regional, local);
- ⇨ Metric reflects the economic, environmental and social consequences of climate change;
- ⇨ Metric can be monetized.
- ⇨ Metric is relevant to, has legitimacy with decision-maker.

If evidence does not exist to relate a risk metric to specific climate variables then generating the Reference Case and Policy Case will not be possible. Equally, if the risk metric cannot be readily monetized then CBA will not be possible.

The analyst should document the rationale for selecting particular risk metrics, along with data sources, comments on data quality, and where relevant, calculation methods and allied assumptions and limitations.

Develop response functions for risk metrics

The next task is to develop climate response functions for each of the identified risk metrics. A response function plots the value of the risk metric against key primary (e.g., mean monthly temperature) or derived (e.g., soil moisture content) climate variables, and shows how sensitive the metric is to changing climate conditions. It seeks to link the climate driver for the risk, e.g., rainfall, increasing temperature, etc., with the potential outcome or consequence as measured by the risk metric. On a two dimensional plot, values for the risk metric are measured along one axis and values for the climate variable along the other axis.

Response functions are developed from existing research and sector-specific literature, in consultation with academics and other sector experts. They should encompass:

- ⇨ Present day values of the risk metric and climate variable (e.g. monthly rail buckling frequency and temperature data) in order to estimate Baseline Case outcomes; and

➩ Plausible changes in the metric value due to changes in the climate variable within the range projected under the climate scenario being considered (e.g. additional incidents of rail buckling due to increasing temperatures) in order to estimate Reference Case outcomes.

Depending on the available evidence, response functions may be based on expert elicitation, observations, modeling exercises, or a combination of these. Response functions may therefore be qualitative (see example in Figure 4-1) or quantitative (see example in Figure 4-2) in nature. Since response functions are constructed from observed impact data it is reasonable to assume that resulting outcomes or consequences are additional to baseline adaptation levels. For instance, the function in Figure 4-2 is derived from 15 years of recorded rail buckling incidents, despite actions by rail authorities to mitigate the occurrence of such incidents.

It is important to note that response functions like the examples shown in Figure 4-1 and Figure 4-2 represent a practical use of available evidence to enable analysts to scale the present day consequences of climate conditions in line with projections of climate change. Of course, if an analyst has access to a more established impact model (e.g., like natural catastrophe models used in the insurance industry) then that model should be used. A more fulsome discussion on how to develop response functions or similar impact-quantification models is beyond the scope of this guidebook.

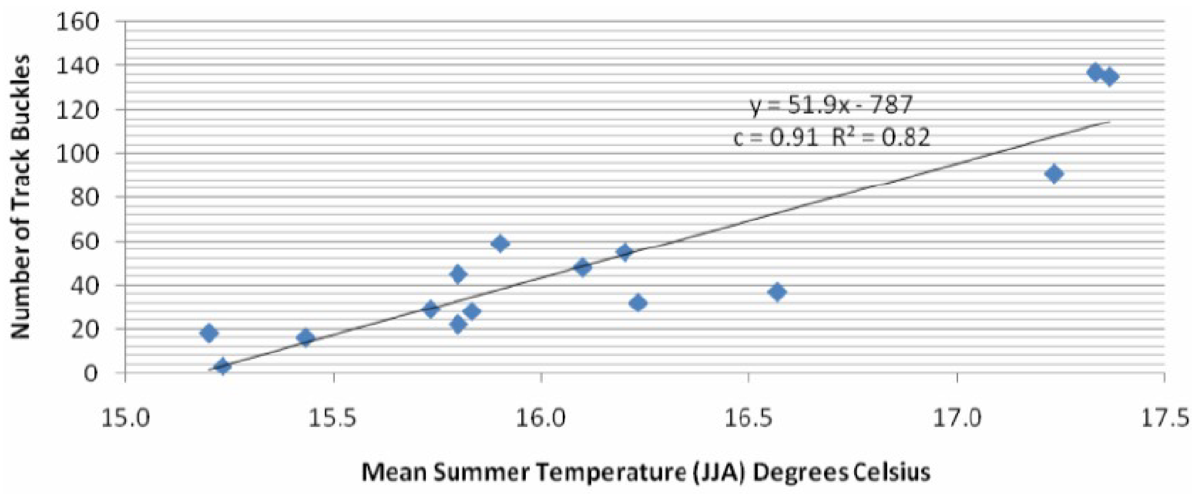
Figure 4-1: Example of qualitative response function for transport sector

(Length of road impacted by landslip in England)

Magnitude class	**Estimated change in metric** Numbers in boxes are the percentage probability of each class being realised						**Estimated Increase in length of at risk road impacted for each magnitude class (km)**	**% of *all* roads**
Very High	0	0	0	0	10	10	5,000	1.7%
High	0	0	20	30	30	30	3,000	1%
Medium	0	30	60	60	50	60	1,500	0.5%
Low	40	70	20	10	10	0	630	0.21%
Very Low	60	0	0	0	0	0	150	0.05%
	-10%	10%	30%	50%	70%	90%		
	Change in winter precipitation from present day (%)							

Source: Thornes *et al* (2012)

Figure 4-2: Example of quantitative response function for transport sector



Source: Thornes *et al* (2012)

Quantify impacts

Impacts of interest under the Baseline Case are quantified either:

- From the data used to construct the response functions. Recall that a response function encompasses the *present day value* of a risk metric, and measures deviations from this value in response to changes in the climate variable; or
- By plugging, into the response functions, relevant baseline climate variables from the future climate projections used to construct the Reference Case. Future climate projections are made with reference to a climatological baseline period – typically a 30-year 'normal' period over which variables are averaged. Many climate models use the period 1961-1990 or 1971-2000 as their climatological baseline. For example, the UKCP09 climate projections for the UK use the period 1961–1990 to define baseline climate conditions (meaning that all projections of future climate change are given relative to the modeled climate during this period). Using observed trends on climate variables from 1961 to date, the analyst can extrapolate modeled values for the period 1961-1990 to a particular base year for the CBA, say 2010[13]. This extrapolated value for the climate variable can then be input to the response function to quantify the risk metric of interest for the year 2010.

Using the former approach, the analyst should ideally average values over several years to avoid quantifying impacts on the basis of an abnormal year. The latter approach obviously avoids this problem, averaging data over a 30-year period. Furthermore, it ensures greater consistency between the Baseline Case and the Reference Case, since modeled values from the same sources are used for both.

[13] An example of how to make this adjustment is found on the UK Climate Projections (UKCP09) website (available at: http://ukclimateprojections.defra.gov.uk/content/view/618/690/).

Depending on the nature of the response function it may be necessary to determine the number and location of exposed 'assets'. Assets here refer to physical structures (buildings, infrastructure, etc.), humans (including vulnerable sub-populations, like the elderly) and elements of natural systems (forested area, riparian area). Consider the example in Box 4-1 below, where the response function characterizes a relationship between domestic water consumption per capita and mean monthly temperature. In order to quantify total water use under the Baseline Case the analyst must also know the population in the study area. Similarly, if a response function characterizes the yield of a particular crop or the incidence of heat-related mortality as a function of climate variables, in order to quantify total impacts the analyst must know, respectively, the total area planted with that crop and the total vulnerable population in the study area.

Since the magnitude, frequency or both of a climate hazard will vary spatially, it is also important for the analyst to account for the spatial distribution of the exposed assets when quantifying impacts – e.g., what is the spatial distribution of people vulnerable to heat-related mortality in, say, cities in Ontario. Current climate conditions and projected changes in climate will vary over an area as large as Ontario.

In general, impacts are quantified according to the following relationship:

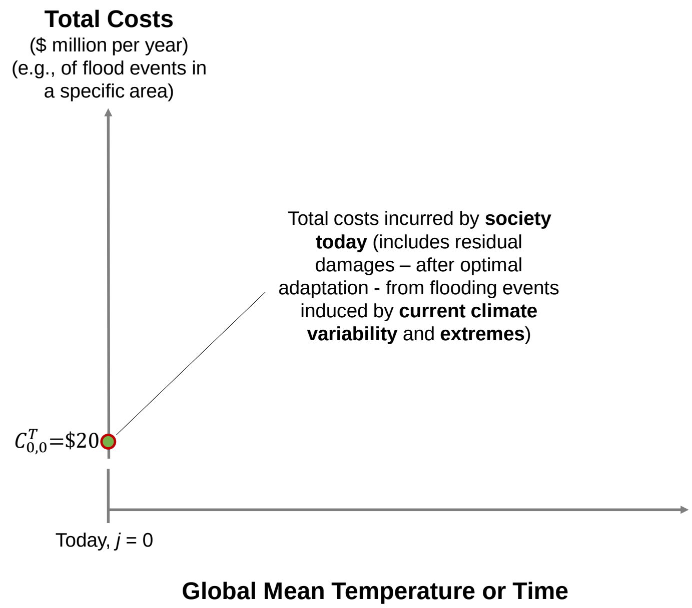
$$\text{Total impact of interest in study area} = \text{Summed over all locations in study area} \left[\text{Relevant risk metric at each location in study area} \times \text{Relevant exposed asset at each location in study area} \right] \qquad \text{Equation 4-19}$$

Monetization of impacts

The final task is to monetize the quantified impacts for the Baseline Case, and aggregate across all monetized impacts to create a measure of total cost. This is the focus of Section 5 and is not expanded further here, except to say the monetary (unit) values are either applied to the estimated risk metric at each location in the study prior to aggregation or to the estimated total impact after aggregation, depending on the nature of available monetary evidence.

Figure 4-3, Figure 4-5, and Figure 4-6 illustrate graphically the process of developing the Baseline, Reference, and Policy Case, using urban flooding as an example. The values in the figures are taken from the numerical example provided in Table 4-2. The culmination of the above tasks is summarized in Figure 4-3, where estimated total costs under the Baseline Case amount to $20 million per year. This is the starting point for analyzing climate change costs. As noted above, it is nonetheless acceptable for the analyst to define a Baseline Case where total costs are assumed to be zero; in this case the costs of climate change and the imposed costs of climate change are measured relative to a starting value of zero dollars. However, the analyst should document the reasons why this assumption is adopted.

Figure 4-3: CBA of extended adaptation – Baseline Case



Source: Adapted from Boyd and Hunt (2006) and Metroeconomica (2004)

4.3.5.2 Constructing the Reference Case

In addition to the costs already faced by society from today's climate, the future costs that decision-makers must understand and act on are also driven by: ❶ the additional risks posed by climate change; ❷ socio-economic developments that might place greater populations and value at risk; and ❸ autonomous adaptations that reduce those risks.

To construct the Reference Case, the analyst must take these three drivers of future risks into account.

Scale risk metrics for climate change

The purpose of this task is to apply data from selected climate projections to the response functions in order to estimate future consequences under climate change.

Future climate conditions are uncertain – both because the evolution of future climate depends largely on human actions (future socio-economic development paths and associated GHG emissions are not know precisely) and because scientific knowledge of the climate system remains incomplete (how much and how fast the climate will change for a given level of GHG emissions is also not known precisely). There is also natural climate variability to contend with. Indeed, the causal chain underlying the climate change-consequence relationship is extremely complex and highly uncertain (see Section 9.2). Scenarios can help analysts convey these uncertainties. Instead of scaling the response functions under only one possible climate future, scenarios covering several possible futures can be used to quantify a range of possible consequences. For example, in their investigations into the economic impacts of climate change for Canada, the National Round Table on the Environment and the Economy (NRTEE) used two divergent scenarios to reflect uncertainty over future global GHG emissions (NRTEE, 2011):

- ⇨ A low climate change future resulting from a convergent low-emissions world with a heightened environmental consciousness, a population that peaks by mid-century, accelerated technological advances, service-focused economies, and equitable economic development.
- ⇨ A high climate change future resulting from a high emissions world of less economically integrated regions, continued population growth, slow-paced technological change, and slow growth in per-capita incomes.

Similarly, the UK Climate Risk Assessment (CCRA) used a high, medium and low GHG emission scenario, resulting in three possible climate futures (DERFA, 2012). At a minimum, the analyst should use two contrasting scenarios, like a low and high emission scenario, to highlight uncertainty over the range of possible climate futures.

As with the NRTEE example above, it is a good idea to provide a qualitative narrative (or 'storyline') highlighting key differences between the chosen scenarios as supplementary information for decision-makers.

When scaling response functions, it is common practice to consider projected consequences for three time periods; the near-term (the 2020s), medium-term (the 2050s), and long-term (the 2080s). This is accomplished by creating 30-year averages from downloaded climate data sets, centered on 2025 (2010-2039), 2055 (2040-2069 inclusive), and 2085 (2070-2099 inclusive). Of course, depending on the needs of decision-makers it is possible to generate 30-year averages for every decade, the 2030s, 2040s, and so on.

It may be the case that projected climate variables of interest do not diverge significantly across the chosen emissions scenarios (e.g., low, medium or high) until the medium term (the 2050s). If this is the case, to reduce the workload the analyst may opt to scale response functions for the near-term on the basis of a single (medium) emission scenario, only using multiple scenarios for the medium-term and long-term, when scenarios begin to diverge.

In those cases where the climate variable needed to scale a response function is a single variable, like annual temperature or seasonal precipitation, downloaded data from the selected climate scenarios can be used directly. In those cases where a derived or combined climate variable, like relative aridity or potential evapotranspiration, is needed for scaling, then the variable may need to be constructed from the downloaded data sets. Where relevant quantitative evidence on climate variables and phenomena is not available from the climate projections, the analyst could consider eliciting expert opinion to scale the response functions.

Climate scenarios should be developed and interpreted in consultation with experts on climate science. An analyst should visit the UK Climate Projections Website for further guidance on the use of climate scenarios (http://ukclimateprojections.defra.gov.uk/content/view/12/689/).

Scale risk metrics for socio-economic development

The future costs that decision-makers must understand and act upon are strongly influenced by socio-economic developments. First, future GHG emissions, and thus the level and rate of projected climate change, are strongly influenced by socio-economic factors, such as population growth, level and structure of economic development, and technological change. Second, the vulnerability and adaptive capacity of future society to a given amount of projected climate change is influenced by the same set of socio-economic factors. In some cases, socio-economic developments may even affect the sign (±) of damage costs. Population growth means that more people will potentially be vulnerable to climate change. More people also means greater demand for housing, food, water, energy, etc. This increases pressure on resources whose availability may already be stressed by climate conditions, thereby further exacerbating vulnerability. Furthermore, as people become wealthier they will have more to lose from climate change (e.g., property and their contents will be more valuable, increasing the damage costs of flooding, other things being equal). The same people, however, will also have enhanced adaptive capacity: have more to spend to protect themselves; have better access to quality health care; be more educated about climate and non-climate risks etc. Changes in the economy and population will also influence the impact of climate change on natural systems, through environmental pollution, land use change and changes in recreational preferences.

Impacts on future society are therefore not determined solely by climate change, but also by contemporaneous economic development and social change (see the example in Box 4-1). Indeed, previous studies have shown that differences between socio-economic developments can be as important as, if not more important than, differences between climate scenarios in determining the absolute scale of impacts (DEFRA, 2010). Hence, it is important for the analyst to assess how risk metrics respond to changes in socio-economic variables as well as climate variables. This is normally accomplished with the use of socio-economic scenarios.

Socio-economic scenarios essentially comprise everything that shapes an economy and society. In the broadest sense, they represent a coherent, internally consistent and plausible description of a possible future state of the population and economy. They may comprise, for example:

- ⇨ Information on the number of people in Canada, provinces, cities, as well as their age, gender, health, education levels, life expectancy, spatial distribution;
- ⇨ Measures of Canada's or its province's economic output, as well as the relative importance of different economic sectors;
- ⇨ Imports and exports;
- ⇨ Unemployment levels;
- ⇨ The distribution of income;
- ⇨ Technology, governance and institutions; and
- ⇨ Land use, water use, and general environmental attitudes.

Box 4-1: Influence of socio-economic drivers on impacts – example of domestic water demand

Assume that annual domestic water demand in the study area under the Baseline Case is calculated as:

150 liters / person / day x 365 days / year x 600,000 persons = 32,850 Ml per year

Per capita consumption is the defined risk metric, for which a response function is computed relating per capita consumption (litres / person / day) to mean monthly temperatures (degrees Celsius). Assume that over the range of mean monthly temperatures projected for the 2050s, per capita consumption increases by four per cent relative to levels corresponding to baseline climate conditions.

The risk metric – as is true in most cases - is also influenced by socio-economic developments, like the penetration of household water-saving technologies, household size, living standards, and attitudes towards water use. Likewise, future values of the exposed 'asset' (e.g., people) is affected by socio-economic developments; specifically population growth.

Suppose that socio-economic variables are assumed to develop along two somewhat different paths:

- ⇨ Water demand falls as a result of low growth and effective demand-side management measures. Consumers install water conservation technologies, grey water systems, and radically reduce the use of public supply water in gardens. The combination of these socio-economic drivers is assumed to decrease baseline per capita consumption by three per cent by the 2050s. Total population is assumed to be one-half a per cent higher than baseline levels.

- ⇨ Water demand increases significantly due to higher living standards, small household sizes, minimal environmental concern, etc. Metering is universally adopted and water prices are high, encouraging the adoption of some low-cost efficiency measures. The combination of these socio-economic drivers is assumed to increase baseline per capita consumption by two per cent by the 2050s. Total population is assumed to be two per cent higher than baseline levels.

Given these assumed socio-economic and climate drivers, annual domestic water demand in the study area under the Reference Case (by the 2050s) is given by:

151 liters / person / day x 365 days / year x 603,000 persons = 33,234 Ml per year

159 liters / person / day x 365 days / year x 612,000 persons = 35,517 Ml per year

The analyst could of course separate the influence of climate change from that of socio-economic developments.

To help understand the need to consider socio-economic developments look at panel (a) in Figure 4-4 which shows the annual average growth rate in Canada's population and real Gross Domestic Product (GDP) per capita over the period 1950-2010. Both these socio-economic variables are key drivers of future costs. Clearly, relative to 1950, society in 2010 has significantly more people exposed to climate risks with individually more wealth to lose, but also with increased capacity to mitigate the consequences of those risks. Given how different society in 2010 is compared with society in 1950, when developing the Reference Case a key question facing analysts is how different will society be in the 2020s, the 2050s, and the 2080s relative to society today.

One option is to assume that future society will be no different to society today. In this case the population is assumed to remain at 2010 levels for the remainder of the century, as illustrated by the dashed horizontal line for the population variable in panel (b) in Figure 4-4. While adopting this assumption clearly simplifies the analysis, it may significantly understate future consequences. Another option is to assume that past trends will continue and extrapolate historical growth rates into the future. This produces the population growth path labeled ❶ in panel (b). However, is this the only possible path that Canada's future population may take? Scenarios help analysts deal with uncertainty over future climate change, so why not also with respect to socio-economic developments? How much the global climate will change in the future as a result of increasing GHG emissions is uncertain, with a range of possible outcomes. To accommodate these uncertainties it is recommended that the analyst employ at least two, divergent climate scenarios. Likewise, to deal with uncertainty over the future value of socio-economic variables, the analyst should also consider different scenarios. In the simplest case, the analyst could consider using a 'rapid growth' scenario (❷ in panel (b)) and a 'slow growth' scenario (❸ in panel (b)), resulting in, respectively, a future population lower than a continuation of historical trends and a future population higher than a continuation of historical trends. This is the approach followed by the NRTEE where:

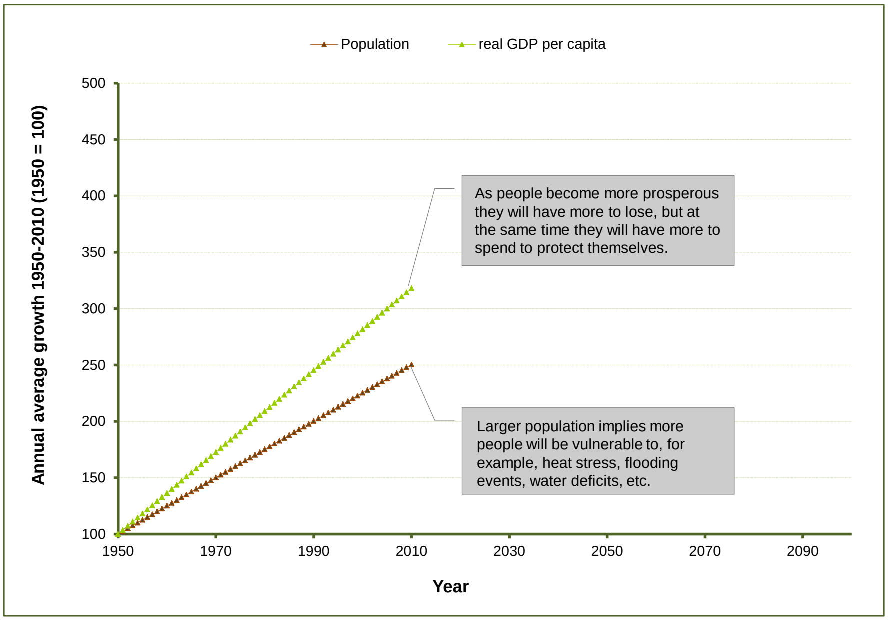
- ⇨ The slow growth scenario represents a Canada characterized by slow population and economic growth (e.g., 1.3 per cent annual growth in GDP); and
- ⇨ The rapid-growth scenario represents a Canada characterized by rapid population and economic growth (e.g., 3.0 per cent annual growth in GDP) (NRTEE, 2011).

In addition to a slow-growth and a high-growth scenario, other plausible pathways may see Canada's population growth fall somewhere in between these two extremes – within the grey area in panel (b). Both the IPCC and the UK Climate Impacts Programme consider four future possibilities for socio-economic development (see ANNEX 4-2 for a brief description of these scenario sets along with one approach an analyst could take to using them).

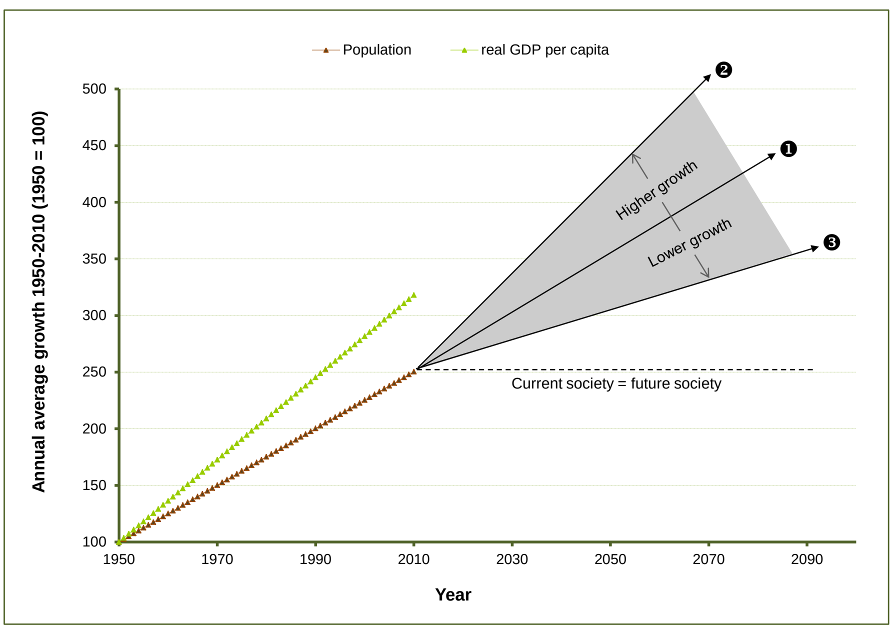
Combining two scenarios for socio-economic variables with two climate scenarios – as done by the NRTEE – produces four possible futures: ❶ slow economic and population growth + low GHG emissions; ❷ slow economic and population growth + high GHG emissions; ❸ rapid economic and population growth + low GHG emissions; and ❹ rapid economic and population growth + high GHG emissions. However, this involves combining socio-economic projections that are not consistent with global climate projections. In particular, some might question the logic of pairing a slow-growth, low population socio-economic scenario with a high, rather than a low, GHG emissions scenario. The logic of pairing a rapid-growth, high population scenario with a low GHG emissions scenario may be equally questioned. The conventional approach in climate impact assessments is to match climate scenarios with the socio-economic scenarios that gave rise to them; recall that socio-economic developments influence future GHG emissions and the level of climate change. A climate impact study that uses a low climate scenario traditionally uses, for consistency, the same values for population, GDP, and other socio-economic variables that were input to the climate models used to generate that climate projection.

Figure 4-4: Illustrating the need to consider socio-economic drivers of consequences for future society

(a)



(b)



Source: Boyd (2009)

The analyst should note that implicit in the decision to maintain consistency between climate scenarios and the underlying scenarios for socio-economic variables is the assumption that Canada is either determining global trends or is itself strongly influenced by global trends. Alternatively, implicit in the decision to pair scenarios for socio-economic variables with inconsistent climate scenarios is the assumption that socio-economic developments in Canada could evolve independently of developments at a global scale. So, while global development patterns and actions determine aggregate GHG emissions and the rate and magnitude of climate change faced by Canada, growth and socio-economic development in Canada could follow a separate path. This is the assumption adopted by the NRTEE. Allowing Canada to follow a separate path from developments at a global scale has the added benefit that it enables the analyst to accommodate significant domestic policies, like a low carbon plan or national energy strategy, where relevant. Moreover, the use of what might be described as 'extreme' combinations of scenarios can be used to examine how sensitive Canada is to different assumptions about future climate change and future socio-economic developments – like a form of sensitivity analysis. Whatever combinations of socio-economic and climate scenarios are used, the analyst should convey the assumptions implicit in those choices to decision-makers.

As stated in Box 4-1 the analyst can quantify consequences of interest under the Reference Case in two equally acceptable ways:

1. Apply relevant climate and socio-economic drivers in a two-step process in order to disaggregate the effects of climate change from those of socio-economic development, so the contribution of both sets of drivers to total impacts and costs, as well as all underlying assumptions, is clear to decision-makers. This approach is used by the UK CCRA (DEFRA, 2010), the NRTEE (NRTEE, 2011) and the UKCIP (Metroeconomica, 2004); or
2. Apply relevant climate and socio-economic drivers jointly in a single step to compute total impacts and costs, without disaggregating the contribution of each set of drivers. This approach is used by the Economics of Adaptation Working Group (ECA, 2009). For some decision-makers, it will be more important to know the magnitude of total costs and adapt accordingly, than to know what proportion of those costs result solely from climate change.

Autonomous adaptation

The standard approach in economic appraisal is to define a baseline that describes what would likely happen in the absence of additional intervention by government. The analyst must therefore define a Reference Case, against which the incremental costs and benefits of planned adaptation actions (the 'interventions') are appraised, that includes autonomous adaptation. That is, planned adaptation actions are introduced on top of autonomous adaptations, to further reduce (enhance) the residual costs (benefits).

In Section 1.6.2 adaptation actions were distinguished by their intent:

- Planned adaptation - the result of a deliberative public policy decision, based on an awareness that climate conditions have changed or are about to (further) change and that action is required to return to, to maintain, or to achieve a desired state of welfare.
- Autonomous adaptation – actions that constitute a spontaneous response by individuals, private organizations or natural systems to climatic stimuli; responses are triggered by

ecological changes in natural systems and by market or welfare changes in human systems, and they take place within an existing public policy framework.

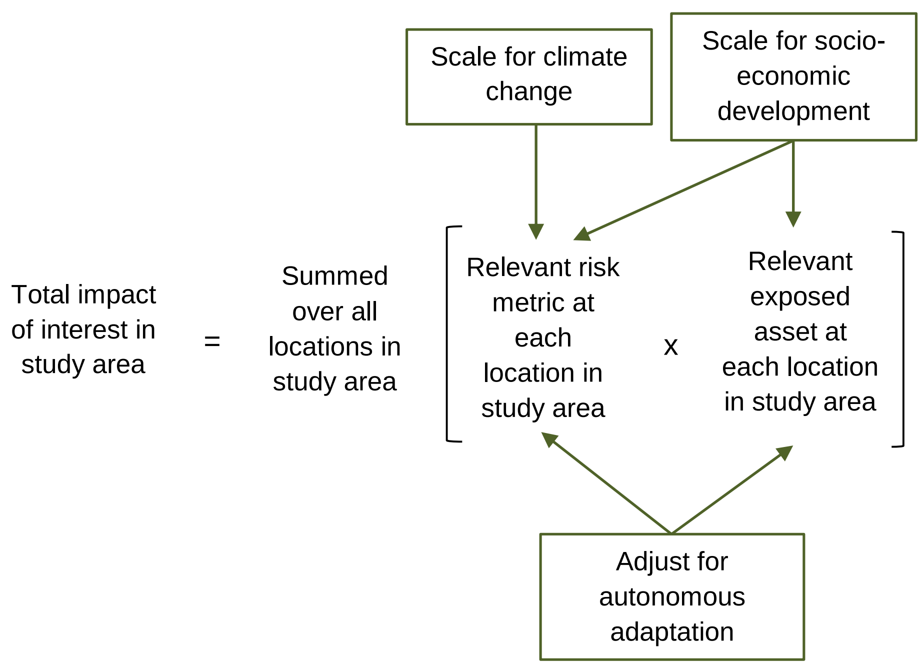
While planned and autonomous adaptation actions are conceptually different, the distinction is not always clear in practice. Furthermore, the distinction between impacts and autonomous adaptations is also blurred. For example, increases in summer cooling demand through thermostatic control are often considered an autonomous adaptation. However, in many impact studies, the resulting increases to utility bills from this autonomous adaptation are treated as a consequence of climate change – i.e., treated as a climate-related cost. In contrast, planned adaptation actions would typically involve changes to building regulations, increased use of passive ventilation in building design, different approaches to spatial planning, etc. Indeed, in many sectors, actions that are by definition autonomous adaptations are commonly treated as a consequence of climate change.

As a result, how the analyst approaches the treatment of autonomous adaptation is best done on a case-by-case basis. How autonomous adaptation is accounted for in the Reference Case will vary across sectors and with existing practice in climate impact studies. The only generic guidance that can be provided to the analyst is to be transparent about all assumptions and make sure they are credible (reflect accepted practice and state of knowledge in the literature). With respect to each risk metric the analyst should provide a narrative setting out (DEFRA, 2010):

- ⇨ Whether autonomous adaptation is incorporated explicitly in the quantification of consequences or monetization of costs or benefits; and
- ⇨ What form the assumed adaptation takes.

Quantify impacts

Using evidence from the previous three steps impacts under the Reference Case are quantified by modifying the relationship in Equation 4-19 as follows:



Equation 4-20

Monetization

Once the net impacts under the Reference Case have been quantified the analyst can monetize them, where possible, following the guidance set out in Section 5.1.

Continuing with the graphical presentation of the analytical steps, Figure 4-5 illustrates progression from the Baseline Case to the Reference Case. In line with the numerical example shown in Table 4-2 total costs under the Reference Case are estimated to amount to $33 million per year; climate change costs are therefore $13 million per year. To simplify the presentation a single (cost) curve is shown. The intention is not to imply that future total costs are known with certainty. As noted above, the analyst should consider multiple scenarios with sensitivity analysis of key assumptions to reflect key uncertainties (producing several cost curves). The shape of the cost curves reflects the fact that impacts are projected to increase non-linearly with climate change (IPCC, 2007).

4.3.5.3 Constructing the Adaptation Policy Case

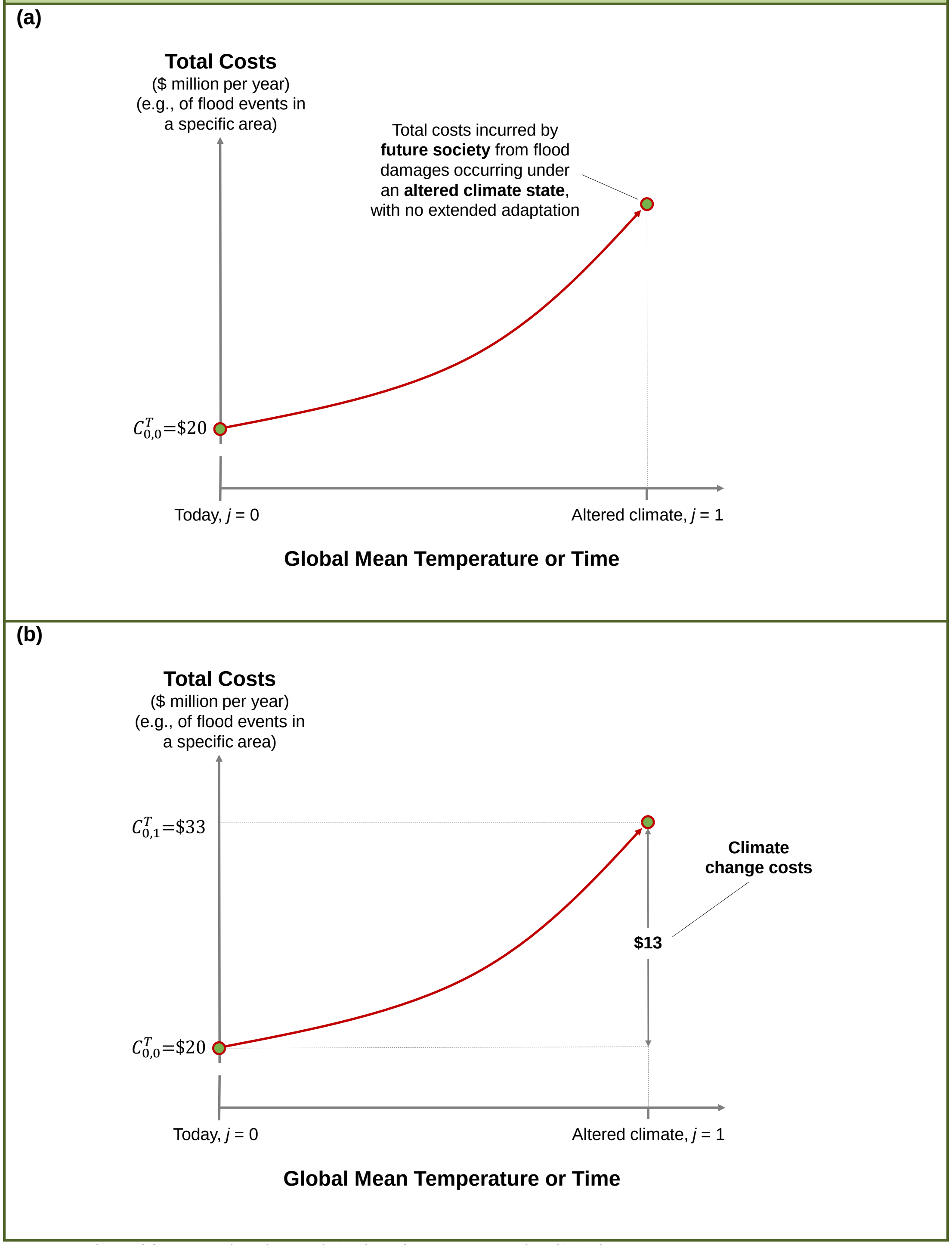
The final stage in applying the conceptual framework is to develop the Adaptation Policy Case.

Identify candidate adaptation actions

During Stage 3 of the adaptation planning process the analyst (see Section 2.2.2.3):

- ⇨ Defined an adaptation goal (or set of goals) for each risk that was deemed to be of sufficient priority to warrant immediate attention. The stated goals must be consistent with the overall objective for the adaptation planning process. At least one adaptation goal was defined for each high priority risk, as well as the time frame over which the organization expects this goal(s) to be accomplished. The time frame chosen should be consistent with the organization's longer-term planning goals, or based on the projected impacts of climate change and the risks those impacts give rise to.
- ⇨ Identified appropriate actions to achieve the defined adaptation goal(s). An adaptation action, in effect, is a policy or project undertaken to achieve a stated adaptation goal(s). The identification exercise started with the effectiveness of known actions in place today before moving on to look at the need to formulate new actions that could be introduced in the future. Furthermore, the net was cast widely in order to develop a comprehensive long-list of different candidate adaptation actions, encompassing both soft and hard responses.
- ⇨ Collected some basic information to qualitatively screen candidate adaptation actions, including: the geographical scale to which the action would be predominantly applied; the time it would likely take to have the action fully operational; stakeholders key to the successful implementation and operation of the action; implementation barriers or constraints; and a rough understanding of the required investment and annual recurring costs, where relevant.

Figure 4-5: CBA of extended adaptation project – Reference Case



Source: Adapted from Boyd and Hunt (2006) and Metroeconomica (2004)

Produce a short-list of feasible candidate adaptation actions

Given the reality that financial and human resources are limited, it is nearly always necessary to prioritize the long-list of identified candidate actions. Similar to the approach recommended for climate risk assessments, an incremental or tiered approach was recommended for appraising and prioritizing the long-listed actions. This process began with a qualitative screening assessment (recall Section 3.2.1). The screening assessment is used to reduce the long-list of candidate actions down to a workable short-list to take forward. In that way, resource intensive quantitative analysis is only applied to a small sub-set of actions.

As a result, during Stage 3 of the adaptation planning process the analyst also qualitatively screened candidate adaptation actions at two levels:

1. Relative to standard project selection criteria (e.g., acceptability, equity, urgency, effectiveness, policy coherence, windows of opportunity); and
2. Relative to the likelihood of them being economically efficient, given the inherent uncertainties (e.g., recognizing the value of no-regret, low-regret, and win-win adaptation actions, or looking for the most robust and flexible actions).

Following the screening assessment, the analyst will have shifted the long-list of candidate actions into one of several broad groups that define what happens next, including those actions for which economic appraisal (CBA or CEA) is required.

Calculate the costs of prioritized candidate adaptation actions

For candidate adaptation actions where economic appraisal is required the next step for the analyst is to develop detailed cost estimates, covering – where relevant – capital expenditures (non-recurring costs) and annual operation and maintenance expenditures net of any resource savings (recurring costs). In addition, the life of each action will need to be defined, as well as the scope for application (i.e., the scale to which the action would be applied and its assumed potential – penetration rate). Calculating the costs of adaptation actions is considered in more detail in Section 5.2.

Calculate the benefits of prioritized candidate adaptation actions

The last task for the analyst is to calculate the costs of climate variability and climate change avoided through the successful implementation of those actions being appraised. Climate-related damages avoided are essentially quantified by revisiting the relationship outlined in Equation 4-20, this time incorporating the effects of the candidate actions. Broadly, adaptation actions may reduce climate-related damages by affecting each element of Equation 4-20. For example:

- Exposure: Actions may reduce the number, area, volume etc. of future assets exposed to a particular climate hazard (e.g., retreat is common response to increasing flood risks, whereby vulnerable households move away from areas prone to flooding);
- Sensitivity: Actions that reduce the sensitivity of the risk metric and ultimately the exposed asset to the climate hazard (e.g., building codes can be changed or land use practices modified so homes and buildings are better able to accommodate flooding or windstorms, thus reducing damages); or

- ⇨ Hazard: Actions that reduce the intensity or likelihood of the climate hazard to which the risk metric is sensitive (e.g., constructing coastal defenses or expanding the capacity of the storm water systems may reduce, or even eliminate, the consequences from a flooding event of given severity).

The effectiveness of autonomous adaptations taken by affected assets may also be influenced by planned adaptations acting on each of these three elements; the analyst should at least be aware of this possibility.

In practice, quantifying the benefits of adaptation actions involves re-running the underlying (physical) model or set of calculations that operationalize Equation 4-20, adjusting the model for changes to the exposure of assets, changes to the sensitivity of risk metrics to climate hazards and changes to the hazards themselves. Providing guidance on how to model the physical impacts of climate change, with and without adaptation, is beyond the scope of this guidebook. It is worth pointing out nonetheless that since the guidebook takes a ‘partial equilibrium’ approach to economic appraisal, it does not take into account possible feedbacks between the implementation of candidate adaptation actions and the evolution of key socio-economic variables over time assumed under the selected socio-economic development scenarios.

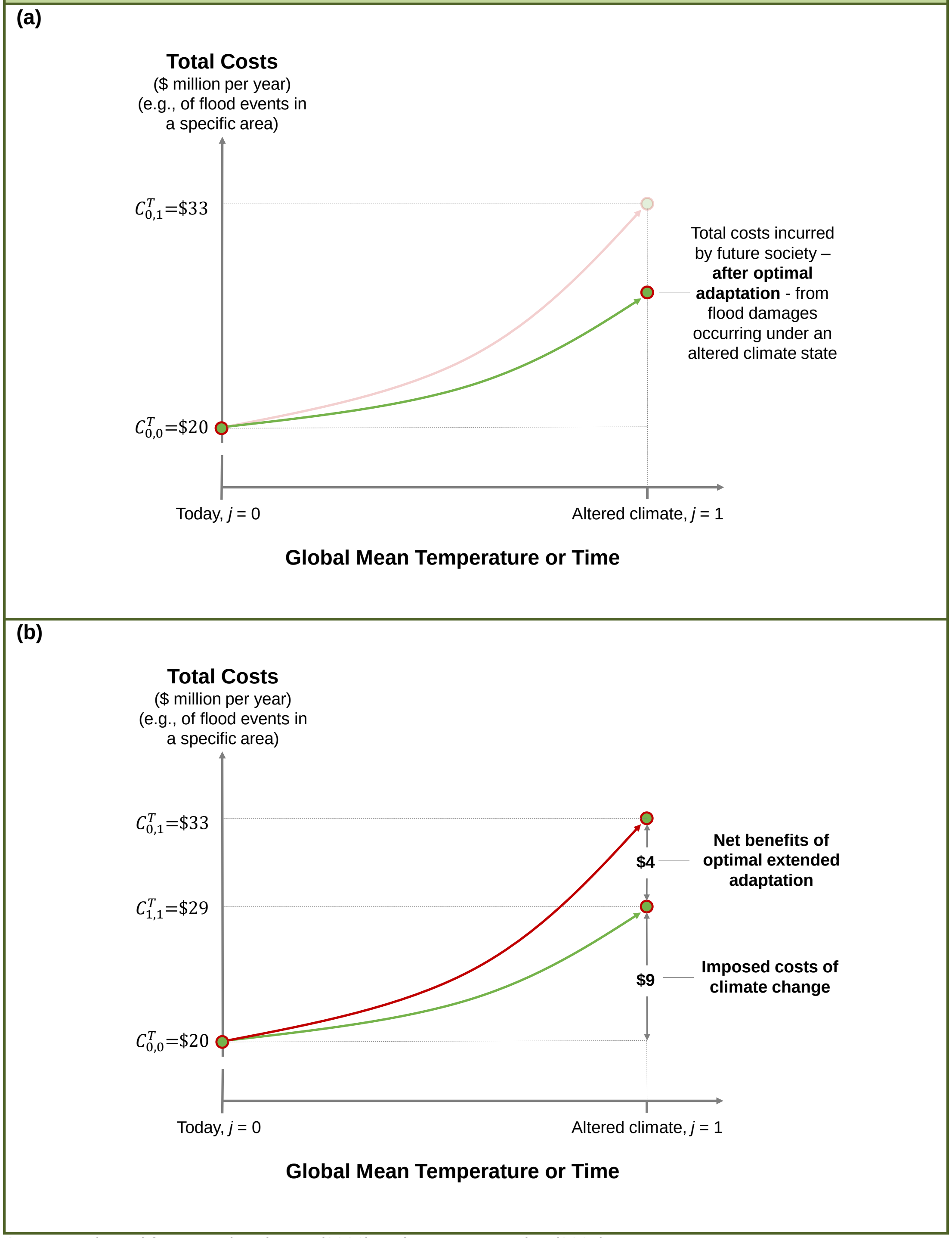
After the analyst has quantified the net impacts under the Adaptation Policy Case, they can be monetized using the same methods and data employed to construct the Reference Case.

Continuing with the graphical presentation of the analytical steps using the example in Table 4-2, Figure 4-6 illustrates the progression from the Reference Case to the Adaptation Policy Case. Total costs under the Adaptation Policy Case are now estimated to amount to $29 million per year, $4 million per year less than under the Reference Case. In other words, the net benefits of extended adaptation are $4 million per year and the imposed cost of climate change amount to $9 million per year. Again, to simplify the presentation a single (cost) curve is shown; in practice the analyst will produce a different curve for each scenario considered.

The analyst, in addition to considering the level of adaptation in this step, may also wish to consider the timing of adaptation decisions, which is of crucial importance from an economic point of view. The issue of timing concerns the decision to adapt early or to wait, and how long to wait. In Section 9.4.2 guidance is provided to help the analyst address these questions.

Upon completion of the economic analysis of candidate adaptation actions the analyst can return to the appropriate point in Stage 3 of the adaptation planning process (see Section 2.2.2.4).

Figure 4-6: CBA of extended adaptation project – Adaptation Policy Case



Source: Adapted from Boyd and Hunt (2006) and Metroeconomica (2004)

4.4 References and further reading

Boyd, R., 2009, Role of Socio-economic Assessment in Adaptation Assessments, Foresight Workshop on Climate Change Impacts and Adaptation in Agriculture, Agriculture and Agri-Food Canada, 11-13 March 2009, Calgary, Canada.

Boyd, R. and Hunt, A., 2006, Costing the Local and Regional Impacts of Climate Change Using the UKCIP Costing Methodology, supporting research commissioned as part of the Stern Review, HM Treasury, London, UK.

Bradfield, R., Wright, G., Burt, G., Cairns, G., and van der Heijden, K., 2005, The Origins and Evolution of Scenario Techniques in Long Range Business Planning, *Futures*, 37, p. 795-812.

Callaway, J., 2003, Adaptation Benefits and Costs: Measurements and policy issues, Environment Directorate, OECD, Paris, France.

Callaway, J., 2004a, Adaptation Benefits and Costs: Are they important in the global policy picture and how can we estimate them, *Global Environmental Change*, 14, p. 273-282.

Callaway, J., 2004b, The Benefits and Costs of Adapting to Climate Variability and Change, in Corfee-Morlot, J., and Agrawala, S. (editors), The Benefits and Costs of Climate Change Policies: Analytical and Framework Issues, OECD, Paris, France.

Callaway, J., Ringius, M. and Ness, L., 1998, Adaptation Costs: A Framework and Methods, in Christensen, J. and J. Sathaye (editors), Mitigation and Adaptation Cost Assessment Concepts, Methods and Appropriate Use, UNEP Collaborating Centre on Energy and Environment, Risø National Laboratory, Roskilde, Denmark.

Chambwera, M. and Stage, J., 2010, Climate Change Adaptation in Developing Countries: Issues and Perspectives for Economic Analysis, International Institute for Environment and Development, London, UK.

Dahlström, K. and Salmons, R., 2005, Building Economic and Social Information for Examining the Effects of Climate Change, BESEECH Generic Socio-economic Scenarios, Final Report, PSI, London, UK.

DEFRA, 2010, Method for Undertaking the CCRA Part II – Detailed Method for Stage 3: Assess Risk, UK 2012 Climate Change Risk Assessment, Department for Environment, Food and Rural Affairs, London, UK.

ECA, 2009, Shaping Climate Resilient Development: A Framework for Decision-making, A Report of the Economics of Climate Adaptation (ECA) Working Group, Climate Works Foundation, Global Environment Facility, European Commission, McKinsey and Company, Rockefeller Foundation, Standard Chartered Bank and Swiss Re.

Evans, E., 2003, Foresight Coastal Defense and Flooding Project: Phase 1 Technical Report – Drivers, Scenarios and Work Plan, Office of Science and Technology, London, UK.

Fankhauser, S., 1998, The Cost of Adapting to Climate Change, Working Paper No 16, Global Environment Facility, Washington, DC.

Fankhauser, S., 2008, An Economic Framework for Adaptation, IDEAcarbon, OECD Expert Workshop on the Economics of Adaptation, April 2008, OECD, Paris, France.

Hughes, N., Tomei, J., and Ekins, P., 2008, Critical Review of the Application of the UKCIP Socio-economic Scenarios: Lessons Learnt and Future Directions, Final Report, Department of Geography, King's College London, London, UK.

IPCC, 2007, Climate Change 2007: Impacts, Adaptation and Vulnerability, Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), Parry, M., Canziani, O., Palutikof, J., van der Linden, P., and Hanson, C. (editors), Cambridge University Press, Cambridge, UK.

Lester, J., and Smith, J., 2010, The Economics of Climate Change Impacts: A Case Study on the Motivation for Government Decisions to Limit Greenhouse Gas Emissions, Assessing the Benefits of Avoided Climate Change: Cost-Benefit Analysis and Beyond, Gulledge, J., Richardson, L., Adkins, L. and Seidel, S. (editors), Proceedings of Workshop on Assessing the Benefits of Avoided Climate Change, March 16–17, 2009, Pew Center on Global Climate Change: Arlington, VA, USA.

Mendelsohn, R., 2000, Efficient Adaptation to Climate Change, *Climatic Change*, 45, p. 583-600.

Metroeconomica, 2004, Costing the Impacts of Climate Change in the UK: Implementation Report, UKCIP Technical Report, UK Climate Impacts Program, Oxford, UK.

Nakicenovic, N., Alcamo, J., Davis, G., de Vries, B., Fenhann, J., Gaffin, S., Gregory, K., Grübler, A., Jung, T., Kram, T., Lebre La Rovere, E., Michaelis, L., Mori, S., Morita, T., Pepper, W., Pitcher, H., Price, L., Riahi, K., Roehrl, A., Rogner, H-H., Sankovski, A., Schlesinger, M., Shukla, P., Smith, S., Swart, R., van Rooijen, S., Victor, N., and Dadi, Z., 2000, IPCC Special Report on Emissions Scenarios, A Special Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, UK.

Nkomo, J. and Gomez, B., 2006, Estimating and Comparing Costs and Benefits of Adaptation Projects: Case Studies in South Africa and Gambia, a final report submitted to Assessments of Impacts and Adaptations to Climate Change (AIACC), Project No. AF 4, the International START Secretariat, Washington, DC.

PBO, 2010, Fiscal Stability Report, Office of the Parliamentary Budget Officer (PBO), Ottawa, Canada.

Roland Berger Strategy Consultants, 2012, Trend Compendium 2030, Roland Berger Strategy Consultants, Chicago, Illinois, USA.

Royal Dutch Shell, 2008, Scenarios: An Explorer's Guide, Royal Dutch Shell, The Hague, The Netherlands.

Royal Dutch Shell, 2008, Shell Energy Scenarios to 2050, Royal Dutch Shell, The Hague, The Netherlands.

Thornes, J., Rennie, M., Marsden, H., and Chapman, L., 2012, Climate Change Risk Assessment for the Transport Sector, UK 2012 Climate Change Risk Assessment, Department for Environment, Food and Rural Affairs, London, UK.

Scenarios to Strategy, 2009, Scenarios: Climate Change Impacts and Adaptation in Agriculture from 2010-2030, Final Report, Agriculture and Agri-Food Canada, Ottawa, Canada.

UKCIP, 2001, Socio-economic Scenarios for Climate Change Impact Assessment: A Guide to their Use in the UK Climate Impacts Programme, UK Climate Impacts Programme (UKCIP), Oxford, UK.

World Bank (2010) The Economics of Adaptation to Climate Change, A Synthesis Report, Final Consultation Draft, The World Bank Group, Washington, DC, USA.

ANNEX 4-1

Economic measures of climate change adaptation impacts – multiple adaptation strategies and multiple climate states

In practice the analyst will likely work with more than one future climate scenario. In Table 4-5 below the conceptual framework depicted in Table 4-2 is recast to deal with multiple climate states[14]. Each cell measures total costs ($C^T_{i,j}$) as a function of the level of adaptation response (*i* = 0, 1, …, *n* across each row) and the climate state (*j* = 0, 1, … *n* across each column).

Although not shown in the table, total costs comprise the sum of four distinct cost categories: ❶ the cost of adaptation, ❷ the cost of current climate variability and extremes, ❸ the cost of climate change, and ❹ other related costs (recall Equation 4-5). Note that the climate states are assumed to become progressively more severe as one moves from left to right across the table.

Table 4-5: Conceptual framework showing total costs for optimal and partial adaptation under multiple climate states

Adaptation response	Climate state (← less severe more severe →)				
	$j = 0$	$j = 1$	$j = 2$		$j = n$
$i = 0$	$\boldsymbol{C^T_{0,0}}$	$C^T_{0,1}$	$C^T_{0,2}$	→	$C^T_{0,n}$
$i = 1$	$C^T_{1,0}$	$\boldsymbol{C^T_{1,1}}$	$C^T_{1,2}$	→	$C^T_{1,n}$
$i = 2$	$C^T_{2,0}$	$C^T_{2,1}$	$\boldsymbol{C^T_{2,2}}$	→	$C^T_{2,n}$
	↓	↓	↓		↓
$i = n$	$C^T_{n,0}$	$C^T_{n,1}$	$C^T_{n,2}$	→	$\boldsymbol{C^T_{n,n}}$

Source: Adapted from Nkomo and Gomez (2006)
Note: As one moves along the diagonal from the top left-hand corner, to the bottom right-hand corner, total costs increase.

The shaded cells along the diagonal represent a situation in which society is adapted as best it can to each climate state. For a specific climate state, the total cost entry in the shaded cell is thus as low as possible. Changing the level of adaptation, either making more or less adjustments to climate conditions, will result in higher total costs for that climate state. For example:

[14] The four cells covering the top two rows and two left most columns are equivalent toTable 4-2.

- ⇨ $\boldsymbol{C^T_{0,0}}$ is an *ex-ante* estimate of minimum costs experienced by society today, given the current climate state, $j = 0$, and level of adaptation, $i = 0$;
- ⇨ $\boldsymbol{C^T_{1,1}}$ is an *ex-ante* estimate of minimum costs experienced by future society, given the altered climate state, $j = 1$, and level of adaptation, $i = 1$; and
- ⇨ $\boldsymbol{C^T_{n,n}}$ is an *ex-ante* estimate of minimum costs experienced by future society, given the altered climate state, $j = n$, and level of adaptation, $i = n$.

Since the climate states become more severe as one moves from left to right across the table:

$$\boldsymbol{C^T_{0,0} < C^T_{1,1} < C^T_{2,2} < \ldots < C^T_{n,n}}$$

Similar to the case of two adaptation strategies and climate states (recall Section 4.3.3) the analyst can construct various economic indicators characterizing the incremental welfare impacts of climate change adaptation from Table 4-5 for the case of multiple adaptation strategies and multiple climate states. These indicators are defined below.

Cost of climate change without optimal adaptation

<u>Definition</u>: The net loss in human welfare incurred by future society if the climate changes from one climate state to a new climate state, when society does not adapt as best it can (or optimally) to the new climate state.

The starting climate state and corresponding optimal level of adaptation defines the Baseline Case. For example, under the current climate state, $j = 0$, the optimal level of adaptation is $i = 0$. If the climate state changed to $j = 2$ and society did not optimally adjust the level of adaptation, perhaps remaining at Baseline Case levels, the *ex-ante* cost of climate change is given by:

$$C^T_{0,2} - C^T_{0,0} \qquad \text{Equation 4-21}$$

Similarly, if the assumed Baseline Case is $j = 2$ and $i = 2$, and the climate changed to $j = n$ with society remaining optimally adapted to the Baseline Case, then the *ex-ante* cost of climate change in this case is given by:

$$C^T_{2,n} - C^T_{2,2} \qquad \text{Equation 4-22}$$

This holds for any pair-wise comparison of climate states. Hence, the cost of climate change relative to any Baseline Case in the absence of optimal adaptation to the new climate state can be generalized to:

$$C^T_{i=x,j=y} - C^T_{i=x,j=x} \qquad \text{Equation 4-23}$$

Where x defines a Baseline Case climate state and corresponding optimal level of adaptation, and y defines a more severe climate state and corresponding optimal level of adaptation[15]. In words, Equation 4-23 is calculating the change in total cost in moving from the Baseline Case (with climate state $j = x$ and optimal adaptation $i = x$) to a more severe climate state $j = y$ where future society remains optimal adapted to the Baseline Case, $i = x$. An analyst may define the Baseline Case as any plausible future climate state; it does not necessarily have to be defined

[15] In terms of the numerical subscripts used in Table 1-5, y is greater than x.

as the current climate. This makes it possible to quantify the incremental welfare losses of different levels of climate change.

Net benefits of optimal adaptation

<u>Definition</u>: The net improvement in human welfare achieved by optimally adapting to a new climate state, compared to a situation where future society is only partially adapted to that state.

In the first example above, the cost of climate change is given by Equation 4-21. If future society optimally adapted to climate state *j* = 2, however, total costs would be equal to $C^T_{2,2}$, which is smaller than $C^T_{0,2}$. In other words, $C^T_{2,2} - C^T_{0,0}$ is less than $C^T_{0,2} - C^T_{0,0}$. Hence, in this example, the *ex-ante* net benefits of optimally adapting to climate state *j* = 2 are given by:

$$\left(C^T_{2,2} - C^T_{0,0}\right) - \left(C^T_{0,2} - C^T_{0,0}\right) = C^T_{2,2} - C^T_{0,2} \qquad \text{Equation 4-24}$$

Taking the second example above, the net benefits of optimally adapting to the new climate state *j* = *n* when society was previously only optimally adapted to the Reference Case (*j* = 2) is given by:

$$\left(C^T_{n,n} - C^T_{2,2}\right) - \left(C^T_{2,n} - C^T_{2,2}\right) = C^T_{n,n} - C^T_{2,n} \qquad \text{Equation 4-25}$$

Generalizing the result to any pair-wise comparison of climate states, the net benefits of optimal adaptation to climate change is specified as:

$$C^T_{i=y,j=y} - C^T_{i=x,j=y} \qquad \text{Equation 4-26}$$

Where *x* and *y* are defined as above. In words, Equation 4-26 is calculating the change in total cost in moving from a situation in which future society is only partially adapted to a more severe climate state (with adaptation *i* = *x* despite climate state *j* = *y*) to a situation in which it is optimally adapted (with adaptation *i* = y). Since $C^T_{i=x,j=y}$ is greater than $C^T_{i=y,j=y}$ optimal adaptation to the new climate state reduces total costs and the net benefits of adapting to climate change are positive.

Imposed costs of climate change:

<u>Definition</u>: The net welfare losses from climate change incurred by future society that cannot be avoided by optimal adaptation. As noted above, it is not necessarily optimal to avoid **all** climate change impacts.

In the first example above, with the current climate state at *j* = 0 and the expected new climate state at *j* = 2, the cost of climate change is given by $C^T_{0,2} - C^T_{0,0}$ (Equation 4-21). The net benefits of optimally adapting to the new climate state are $C^T_{2,2} - C^T_{0,2}$ (Equation 4-24). Note that this is a negative number since the total costs with optimal adaptation to the new climate state ($C^T_{2,2}$) are lower than the total costs with sub-optimal adaptation to the new climate state ($C^T_{0,2}$). Hence, the net benefits of optimal adaptation to the new climate state can also be written as $-C^T_{2,2} + C^T_{0,2}$.

Given the definition of the imposed (or residual) cost of climate change, it must be equal to the cost of climate change without optimal adaptation less the net benefits of optimal adaptation:

$$\left(C^T_{0,2} - C^T_{0,0}\right) - \left(-C^T_{2,2} + C^T_{0,2}\right) = C^T_{2,2} - C^T_{0,0}$$ Equation 4-27

In general, the net welfare loss from climate change that cannot be avoided by future society through optimal adaptation is given by:

$$\left(C^T_{i=x,j=y} - C^T_{i=x,j=x}\right) - \left(-C^T_{i=y,j=y} + C^T_{i=x,j=y}\right) = C^T_{i=y,j=y} - C^T_{i=x,j=x}$$ Equation 4-28

Where *x* and *y* are defined as above. In words, Equation 4-28 is calculating the change in total cost in moving from a situation in which society is optimally adapted to a less severe climate state (*i* = *x* and *j* = *x*) to a situation in which it is optimally adapted to a more severe climate state (*i* = *y* and *j* = *y*).

Costs of caution

Definition: The welfare loss incurred by future society if decision-makers in early time periods under adapt in anticipation of a lower degree of climate change than what actually occurs.

The entries in the off-diagonal cells essentially represent situations in which future society is partially adapted to a given climate state. Similar to the case with two climate states and associated adaptation strategies, entries in these cells have important *ex-post* implications for decision-makers in terms of either under or over adapting to the amount of climate change actually experienced.

Entries in cells that lie above the diagonal in Table 4-5 tell the story of cautious decision-making. For example, society today may assume *ex-ante* that the current climate (*j* = 0) is not changing and in response not undertake any further adaptation. However, it may turn out *ex-post* that the climate did indeed change to, say, climate state *j* = 2. The corresponding costs actually incurred by future society in this situation are equal to $C^T_{0,2}$. But if society had accurately predicted the level of climate change they would have implemented a level of adaptation equal to *i* = 2, which is optimal for climate state *j* = 2. This increased level of adaptation would have resulted in lower total costs, since $C^T_{2,2}$ is less than $C^T_{0,2}$.

The *ex-post* cost of acting too cautiously can be estimated by comparing the total costs of optimal to a given climate state with the total costs of under adaptation to that climate state. For example, if society today anticipated the climate changing to state *j* = 2 and increased adaptations levels to *i* = 2, but climate change turned out *ex-post* to be more severe, with state *j* = *n* occurring, the cost of under adapting is found by comparing $C^T_{2,n}$ and $C^T_{n,n}$.

In general, the welfare loss that will be incurred by future society if decision-makers in earlier time periods optimally adapt to some *ex-ante* predicted climate state (*j* = *x*) when *ex-post* the climate state turns out to be more severe (*j* = *y*) is given by:

$$C^T_{i=x,j=y} - C^T_{i=y,j=y}$$ Equation 4-29

Where *x* and *y* are defined as above. In words, Equation 4-29 is calculating the change in total cost between: ❶ a situation where decision-makers in earlier time periods optimally adapt to a less severe climate state (*i* = *x*) but in the future the climate state turns out to be more severe (*j* = *y*); and ❷ a situation where the same decision-makers got it right and anticipated the degree of climate change (*j* = *y*) correctly and optimally adapted to that climate state (*i* = *y*). As noted above, the cost of caution will have the same value as the net benefits of optimal adaptation but with the opposite sign (positive instead of negative) since the net benefits of optimal adaptation are essentially forgone by under adapting.

Costs of precaution

Definition: The welfare loss incurred by future society if decision-makers in early time periods over adapt in anticipation of a higher degree of climate change than what actually occurs.

Entries in cells that lie below the diagonal in Table 4-5 tell the opposite story, one of precautionary decision-making. For example, society today may expect the current climate to change to j = 2, and therefore increase adaptation levels to i = 2. The corresponding *ex-ante* costs incurred by future society are thus $C^T_{2,2}$. But suppose future society was unable to detect any climate change, and in fact the current climate state (j = 0) prevailed. In this case, the *ex-post* costs incurred by future society are $C^T_{2,0}$, which is higher than $C^T_{2,2}$. Society today therefore over-adapted. If decision-makers today could have predicted the future climate state with perfect certainty, they would have not undertaken extended adaptation to i = 2, but rather left adaptation levels at i = 0 resulting in total costs of $C^T_{0,0}$, which are lower than $C^T_{2,0}$.

The *ex-post* cost of not acting cautiously enough can be estimated by comparing the total costs of optimal to a given climate state with the total costs of over adapting to that climate state. If, for example, society today expected the climate to change to state $j = n$ and in anticipation increased adaptations levels to $i = n$, but climate change turned out *ex-post* to be less severe, with state j = 2 occurring, the cost of over adapting is found by comparing $C^T_{n,2}$ and $C^T_{2,2}$.

In general, the welfare loss that will be incurred by future society if decision-makers in earlier time periods optimally adapt to some *ex-ante* predicted climate state ($j = y$) when in fact the *ex-post* climate state turns out to be less severe ($j = x$) is given by:

$$C^T_{i=y,j=x} - C^T_{i=x,j=x} \qquad \text{Equation 4-30}$$

Where x and y are defined as above. In words, Equation 4-30 is calculating the change in total cost between: ❶ a situation where decision-makers in early time periods optimally adapt to a more severe climate state ($i = y$) but in the future the climate state turns out to be less severe ($j = x$); and ❷ a situation where the same decision-makers got it right and anticipated the degree of climate change ($j = x$) correctly and optimally adapted to that climate state ($i = x$).

ANNEX 4-2

Making use of the IPCC SRES Scenarios and the UKCIP Socio-economic Scenarios

The majority of the work on socio-economic scenarios relating to climate change has been in the context of GHG emission scenarios that have been used to generate projections of global climate change. The most prominent being the IPCC Special Report on Emission Scenario (SRES) projections (Nakicenovic et. al. 2000). The 'SRES scenarios' as they are known were designed to ensure some consistency when modeling climate change, and its impacts, as well as mitigation and adaptation responses. They include different future socio-economic developments that might influence GHG sources and sinks, such as alternative structures of energy systems and land-use change. The SRES scenarios do not include any initiatives, such as the Kyoto Protocol's targets, that explicitly address additional climate change.

The SRES scenarios involve both qualitative and quantitative components; they have a narrative 'storyline' and a number of corresponding quantitative scenarios for each storyline. Four main storylines were produced (Nakicenovic et. al. 2000):

- **A1** – Very rapid economic growth; population peaks mid-century; social, cultural and economic convergence among regions; market mechanisms dominate;
- **A2** – Self-reliance; preservation of local identities; continuously increasing population; economic growth on regional scales;
- **B1** – Clean and efficient technologies; reduction in material use; global solutions to economic, social, and environmental sustainability; improved equity; population peaks mid-century; and
- **B2** - Local solutions to sustainability; continuously increasing population at a lower rate than in A2; less rapid technological change than in B1 and A1.

The storylines do not depict preferred developments, but rather characterize alternative futures shaped by patterns of global socio-economic development thought to be plausible. Each storyline assumes a distinctly different direction for future developments, such that the four storylines differ in increasingly irreversible ways.

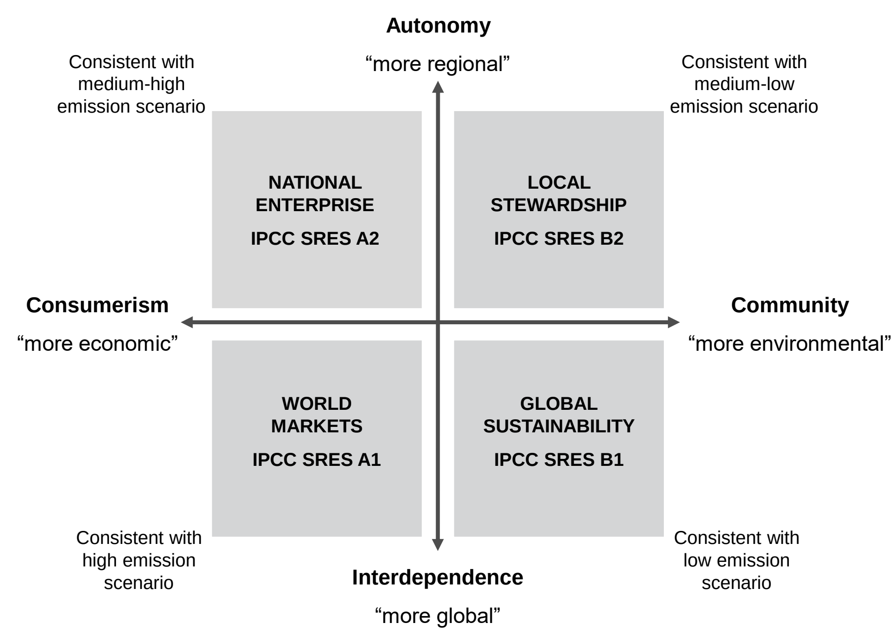
Data sets underlying the SRES scenarios are available at a regional scale from the IPCC Data Center at Columbia University (http://sedac.ciesin.columbia.edu/ddc/index.html).

In the UK, drawing upon the SRES framework and other 'futures' literature, a national set of socio-economic scenarios was developed specifically for application within the UK Climate Impacts Programme. The scenarios are derived from two principle assumptions. First, social and political values, on one hand, and the nature of governance on the other hand, are assumed to be fundamental independent drivers of future change. Second, economic, demographic and technological change, are each assumed to be fundamental outcomes of a dynamic relationship between the social and political values and governance. The result is a future 'possibility space' segmented into four quadrants defined by:

- Values (y-axis in Figure 4-7) - alternative developments in core social and economic values as they might be represented in choices by consumers and policymakers. The spectrum of values ranges from 'consumerism' to 'community'.
- Governance (x-axis in Figure 4-7) - alternative structures of political and economic power and decision-making. The spectrum of governance ranges from interdependence (or globalization) to autonomy.

The resulting model is shown in Figure 4-7. Each quadrant defines four alternative futures (or socio-economic scenarios) based on alternative combinations of 'governance' and 'values' attributes.

Figure 4-7: The UKCIP socio-economic scenarios and corresponding IPCC SRES scenario family



Source: Boyd (2009) based on UKCIP (2001)

For each of the four socio-economic scenarios storylines were created covering key fundamental drivers (UKCIP, 2001).

- **National Enterprise** - This scenario sees people aspiring to personal independence and material wealth within a nationally-based cultural identity. Liberalized markets together with a commitment to build capabilities, and resources to secure a high degree of national self-reliance and security are believed to best deliver these goals. Political and cultural institutions are strengthened to buttress national autonomy.
- **World Markets** - People aspire to personal independence, material wealth and mobility to the exclusion of wider social goals. Integrated global markets are seen as the best way to deliver this. Internationally coordinated policy sets framework conditions for the efficient functioning of markets. Wherever possible, the provision of goods and services

is privatized, under the principle of minimal government. Rights of individuals to personal freedoms are enshrined in law.

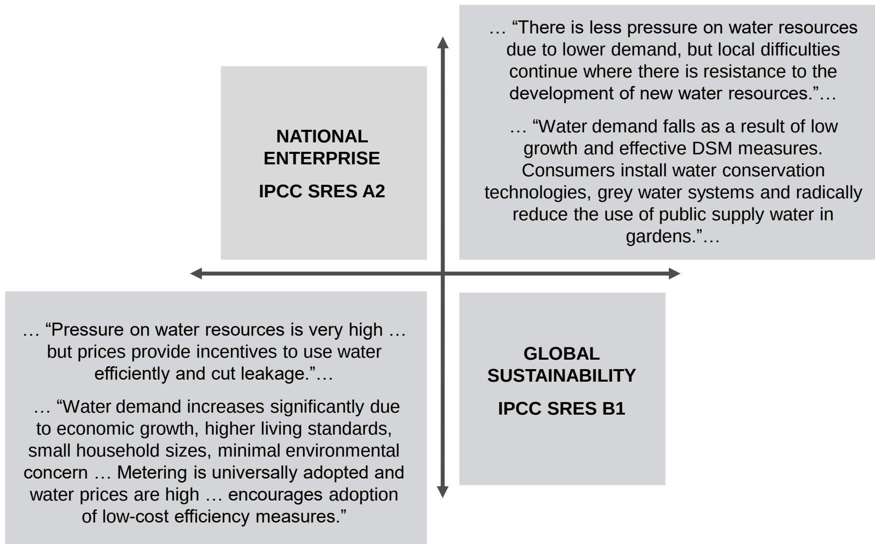
- **Global Sustainability** - People aspire to high levels of welfare within communities with shared values, more equally distributed opportunities and a sound environment. These objectives are thought to be best achieved though active public policy and international cooperation. Social objectives are met through public provision, increasingly at an international level. Markets are regulated to encourage competition amongst national players. Personal and social behavior is shaped by commonly held beliefs and customs.
- **Local Stewardship** - People aspire to sustainable levels of welfare in federal and networked communities. Markets are subject to social regulation to ensure more equally distributed opportunities and a high quality local environment. Active public policy aims to promote economic activities that are small scale and regional in scope, and acts to constrain large-scale markets and technologies. Local communities are strengthened to ensure participative and transparent governance.

To focus the scenarios and make them of practical use to analysts performing impact assessments, narratives were developed for some key areas, including: economic development; planning and the built environment; agriculture; water; biodiversity; coastal zone management (see the example for water demand in panel (a) in Figure 4-8). Relevant quantitative indicators and data sources were also identified for each area and values for each indicator constructed for a mid-1990s baseline and for each of the four alternative futures (see panel (b) in Figure 4-8).

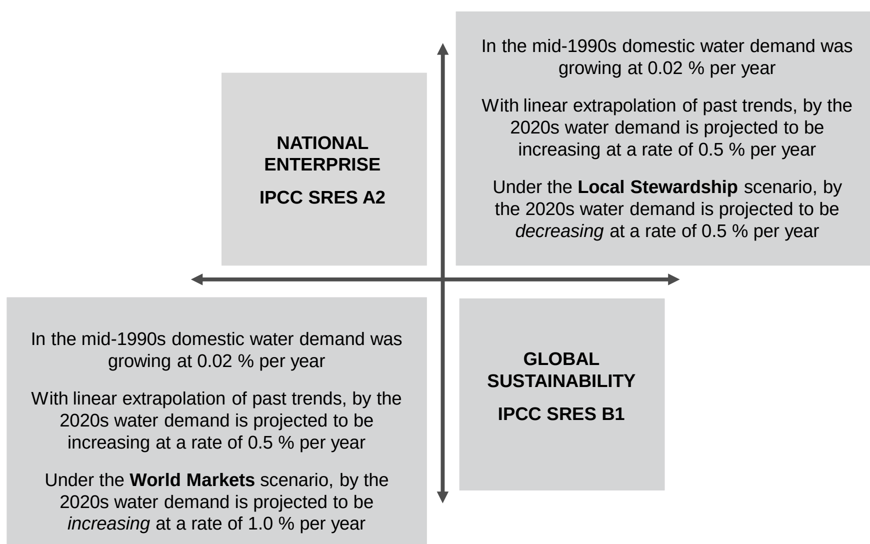
Unfortunately, nothing similar to the UKCIP socio-economic scenarios exist for Canada, or regions of Canada. Various organizations and government departments do nonetheless prepare long-term outlooks (typically encompassing the 2020s) that include forecasts of key socio-economic variables. The Conference Board of Canada, for example, prepares long-term economic outlooks (through 2030) for Canada and each province on an annual basis (available from http://www.conferenceboard.ca/products/economic_data.aspx). In 2010 the Office of the Parliamentary Budget Officer prepared a Fiscal Stability Report for Canada, which contains forecasts to the 2080s for selected socio-economic variables (PBO, 2010). Projections may also be available from provincial governments, such as the Ontario's Long-Term Report on the Economy, which provides an assessment of the province's economic and fiscal environment out to 2030 (available from http://www.fin.gov.on.ca/en/economy/ltr/2010/). Long-term projections of relevant variables will also be available from private sector economic forecasters. Statistics Canada (http://www.statcan.gc.ca/start-debut-eng.html) and the Department of Finance Canada (http://www.fin.gc.ca/fin-eng.asp) will hold historical data sets of key socio-economic variables.

Figure 4-8: The UKCIP socio-economic scenarios – example narratives and indicators for water demand

(a)



(b)



Source: Boyd (2009) based on UKCIP (2001)

Until a set of a coherent, internally consistent and plausible socio-economic scenarios for impact assessments is developed for Canada, the analyst could use the above sources to provide a central projection of basic socio-economic variables; extrapolating the available historical or forecast data to cover the time horizon relevant to the decision problem at hand. The UKCIP scenarios or similar futures scenarios could subsequently be used to develop consistent alternative future states of the population and economy. The analyst could apply the percentage deviations from the linear trends assumed for each of the UKCIP scenarios to the central projections of basic socio-economic variables. Looking at domestic water demand, for example, under the World Markets scenario per capita consumption is assumed to be 100 per cent higher than the linear trend for the 2020s. If domestic water demand in the 2020s under the central projection for the study area was increasing at one per cent per year, then in a future similar to the UKCIP World Markets scenario, domestic water demand may be assumed to be increasing at two per cent per year (i.e., 1% x (1 + 100%)). The resulting alternative futures could be employed in sensitivity analysis.

If considering this option, the analyst should note that the difference between quantitative indicators under the National Enterprise and Global Sustainability scenarios is generally less than between the other diagonally opposed scenarios, World Markets and Local Stewardship. Hence, if the analyst wished to consider extreme outcomes, he or she could use socio-economic scenarios based upon the UKCIP World Markets and Local Stewardship scenarios. The analyst could also consider combining both these scenarios with a low GHG emissions and high GHG emissions climate scenario. That way they could compare the extent to which different development paths contribute to outcomes and costs, given the same amount of climate change.

5 Analysis of Costs and Benefits

The purpose of this section is to:

- ⇨ Explain the concept of Total Economic Value and show how it informs the valuation of adaptation benefits and costs;
- ⇨ Distinguish between willingness-to-pay (WTP) and willingness-to-accept (WTA) compensation as measures of adaptation benefits and costs;
- ⇨ Outline the 'effect-by-effect' approach to benefits analysis;
- ⇨ Identify and describe briefly the main (primary) valuation techniques used in CBA to obtain measures of WTP or WTA and to help analysts chose between these techniques;
- ⇨ Explain how evidence from existing primary valuation studies can be transferred to a new context to value benefits and point the analyst to best practice guidance on the process of value transfer;
- ⇨ Help the analyst decide between primary valuation studies or value transfer as approaches to obtaining measures of WTP or WTA for the adaptation planning problem at hand;
- ⇨ Define the main concepts that underpin cost analysis in CBA;
- ⇨ Distinguish between the top-down and bottom-up approaches to measuring adaptation costs, and identify the main types of cost that need to be measured using the latter approach; and
- ⇨ Explain how the analyst can determine the optimal timing of investment in adaptation actions and redress the risk of cost optimism.

5.1 Benefits Analysis

In order to make an informed decision about the 'best' course of action, candidate adaptation actions need to be systematically compared in terms of their net benefits (i.e., incremental benefits less incremental costs). This requires all relevant benefits and costs for each candidate action to be valued, as far as possible. If it is not feasible or practical to value some benefits or costs, it is still important to account for these items in the decision-making calculus (see Section 11.3.4).

As the term implies, the aim of benefits analysis is to value an action's benefits. 'Valuation' – the process of valuing an action's benefits -- is commonly referred to as 'monetization', since the purpose of valuation is to assign a monetary value (i.e., a dollar amount) to the change in the provision of a good or service attributable to the action. The concept of 'value' in economics has a precise meaning. It is important that this meaning is clearly understood before looking at how to monetize an action's benefits.

Before considering the conceptual basis for valuation, however, it is first worth noting that in an adaptation planning context an action's benefits primarily relate to (climate change) damage costs reduced or avoided. Hence, benefits analysis is actually about valuing changes in damage costs as a result of moving from a climate scenario(s) to an extended adaptation scenario. When we talk about cost analysis in this guidebook, however, we are referring to the assessment of an action's incremental investment and recurring costs (e.g., the costs to set-up and operate a new early warning system for episodes of extreme heat and humidity), plus any associated external costs.

5.1.1 Conceptual foundations for valuation

5.1.1.1 Total Economic Value

The concept of Total Economic Value (TEV) provides an all-encompassing measure of the value that individuals, and collectively society, attach to a good or service potentially affected by climate-related risks. In determining the benefits of an adaptation action what matters is the TEV of the benefits which are secured by implementing that action. As shown in Box 5-1 below, TEV decomposes into:

- ⇨ Use value: arises from either a direct or indirect interaction with a good or service; and
- ⇨ Non-use (or passive use) value: arises due to altruistic motives (for the well-being of contemporaneous others), bequest motives (for the well-being of future generations), or existence motives (for the sake of the good or service itself).

For the purpose of benefits analysis understanding the TEV framework is important for two reasons:

1. To define the affected population

For a particular climate-related risk the TEV framework can help the analyst establish the affected population. Knowing the population over which the monetary value of a change in the provision of good or service applies, is crucial if aggregate measures of costs and benefits are to be generated as input to CBA. In accordance with the TEV framework the two principal affected populations are users and non-users.

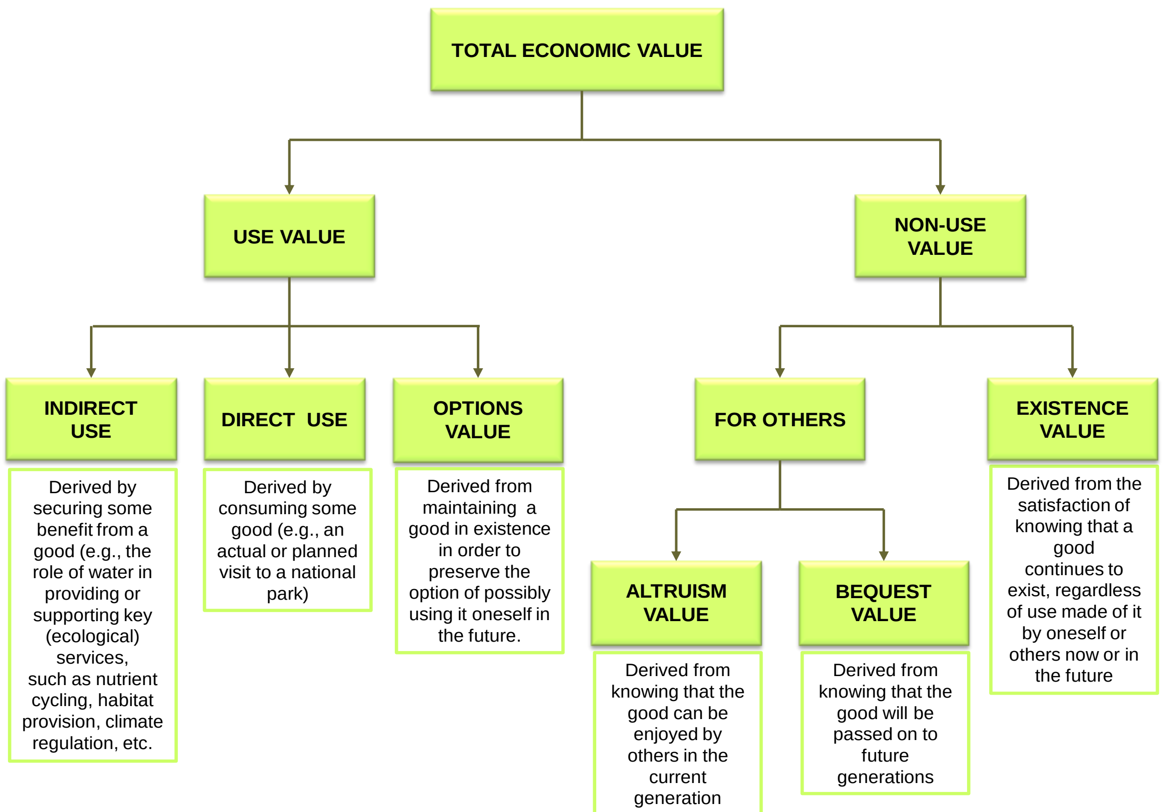
The user population is relatively easy to identify as it consists of those individuals making direct use of the affected good or service (e.g., all households on a municipal wastewater collection or potable water supply network, or all visitors to a particular recreation site). The affected population could also include individuals deriving indirect use values (e.g., households and businesses enjoying flood protection benefits from a forested area within a river catchment). The analyst should be aware that certain use values, and hence the affected population, can be relevant at different scales: the local scale (e.g., camping at a specific recreation site); the regional scale (e.g., the flood protection a forest affords a regional watershed); or the global scale (e.g., terrestrial carbon sequestration).

Box 5-1: Total Economic Value

The Total Economic Value (TEV) of a good or service is comprised of its use value and non-use value:

TEV = use value + non-use value

Each of these two categories further decomposes into a number of sub-categories as shown in the figure below. Note that 'options value' as defined here should not be confused with 'real options value' or 'quasi-options value' as used in Section 9.4.2 in the context of real options analysis.



Source: Pearce, et al (2006)

Non-users comprise the other potentially affected population. They are relatively more difficult to identity, but should not be overlooked. The economic value of a provincial park will be determined not just by the values placed on it by visitors, but also by local residents and people further afield who have not yet visited the park nor intend to do so. Indeed, the non-user population (and non-use value) can be relatively large relative to the user population (and use value), especially when the affected good or service has few substitutes. In practice, it is usually not feasible or practical to decompose the non-user population into individual sub-categories (those holding bequest values versus those holding existence values); nor is it necessary to secure such a breakdown for decision-making.

The affected user and non-user population collectively define the 'economic jurisdiction' relevant to the adaptation planning problem at hand. The economic jurisdiction is the spatial area over which the benefits generated by an adaptation action amass. In many cases it will not exactly mirror provincial or territorial, or municipal jurisdictional boundaries.

2. To establish the relevant evidence base and select valuation techniques

When valuing a specific climate-related impact, the TEV framework is also useful in that it provides the analyst with a check-list of the impacts and effects that, in principle, need to be valued. Not only does this establish the relevant valuation evidence that needs to be compiled, it also helps to identify the appropriate valuation technique to be employed. Valuation techniques, which are described below, differ in their capacity to capture all aspects of the TEV of an affected good or service. In particular, non-use values can only be estimated using stated preference techniques – i.e., by directly asking individuals, via questionnaires (akin to market research), for their valuation of a specified change in the provision of a good or service. Depending on the questionnaire design, stated preference techniques can estimate, either separately or in combination, the various components of TEV; direct and indirect use value and non-use value.

Additionally, some valuation techniques are better than others at valuing different sub-categories of use value. For example, the hedonic property pricing method can value both (site-specific) direct and indirect use values, whereas the travel cost method is limited to only (site-specific) direct use values.

5.1.1.2 Willingness-to-pay and willingness-to-accept

Benefits analysis is concerned with measuring improvements in the well-being (welfare or utility) of individuals. The trade-offs an individual makes between bundles of goods, services, and some form of compensation reveal the value he or she places on these goods and services, and the contribution they make to his or her well-being. Put another way, economic value is measured in terms of how much compensation an individual 'exchanges' (or 'foregoes') in order to obtain a good or service. An individual's willingness to trade compensation for goods or services is measured either as willingness-to-pay (WTP) or willingness-to-accept (WTA). Compensation, and thus WTP and WTA, is typically expressed in monetary terms by economists. In an adaptation planning context faced with a given amount of climate change, WTP is the maximum amount of money an individual would voluntarily exchange to obtain a reduction in climate-related risks. WTA is the minimum amount of money the individual would accept (as compensation) to forego adaptation and tolerate the risks. As noted above, economists have developed specialist valuation techniques to elicit individuals' WTP and WTA.

Economic theory assumes that individuals' welfare or utility can be aggregated. Hence, the social benefit of adaptation (i.e., the benefits accruing to the entire affected population) is simply the sum of individual's WTP or WTA.

Until the late 1990s, which concept of value used for valuation purposes was not thought to be very important. In the context of an (environmental) improvement, analysts could seek either a measure of WTP to secure the improvement or WTA compensation to forego the improvement. And in the context of (environmental) deterioration, it appeared equally valid for the analyst to seek a measure of WTA compensation to tolerate the deterioration or WTP to prevent the deterioration from happening. However, as the use of stated preference techniques grew, it became evident that the theoretical prediction that WTP and WTA should not differ much was false. Studies were showing that substantial differences existed, with WTA-to-WTP ratios as high as 28 (Horowitz and McConnell, 2002). Given these ratios, it clearly matters which measure of value, WTP or WTA, is used in benefits analysis. Using WTP measures – the standard practice in benefits analysis – could mean that actual policy benefits are being (severely) understated. Put another way, the use of WTA in benefits analysis could substantially shift the balance of decision-making in favor of more adaptation than would otherwise be the case.

A range of, sometimes complementary, explanations have been advanced in the literature to explain the difference between WTP and WTA, including *inter alia* income effects, endowment effects, and uncertainty and learning effects (Pearce, et al, 2006). Though there is as yet no consensus among researchers as to why WTP differs from WTA.

Nevertheless, the difference between the two concepts of value does not matter so long as the nature of 'property rights' is clear. As Table 7-1 shows, the choice of WTP or WTA depends on the property rights ascribed to the status quo and to the post-policy context. It is widely acknowledged that anyone with a right to the status quo should have any damages they suffer, relative to that position, valued using WTA. Using WTP may understate the costs (to the losers). Where policies or investments lead to improvements, the situation can be more complex. In contexts where affected individuals have no right to the improvement, but a right to the status quo, WTP is the correct measure of value. What if, however, affected individuals have some right to the post-policy case? For instance, by virtue of legislation or mandatory targets, individuals can be thought of as having been assigned property rights to the improved, post-policy context. In this case, the relevant measure of value is the WTA of the beneficiaries to forego the gains. Using WTP may understate the benefits (to the beneficiaries).

Table 5-1: What property rights imply about choice of WTP or WTA

Individual has right to:	Individual is made worse off by policy	Individual is made better off by policy
The status quo	WTA to endure loss	WTP to secure gain
The post-policy case	WTP to avoid loss	WTA to forgo gain

Source: Adapted from Markandya *et al* (2002)

Since adaptation policy is generally about making people better-off by reducing climate-related risks, the presumption is that WTP (to secure the risk reductions) is the correct measure of value. This is based on the assumption that we have a right to the status quo. However, the status quo in this case is a world with some level of climate change. But do we not actually have a right to a world without climate change? In which case, could it not be argued that property rights reside with the post-adaptation policy context, making WTA (to forgo the benefits of adaptation) the correct measure of value?

Clearly, the nature of the property rights regime in an adaptation planning context may not be so clear cut in practice, involve a mixture of rights, with no general agreement across interested parties. This suggests performing benefits analysis using both WTP and WTA concepts of value, if possible, and presenting both sets of results. The key point here being: "if possible." It is typically more difficult to elicit WTA measures of value. Hence, the analyst may only be able to present WTP measures in practice. The onus is then on the analyst to make the decision-maker aware that there are arguments suggesting that the WTP measures of gain and loss provided might seriously understate true values.

To simplify the discussion throughout the remainder of this section, no distinction is made between WTP and WTA; only WTP is used.

5.1.2 A practical approach to valuation

An adaptation action may address one or more climate-related risks, with each risk in turn potentially giving rise to a number of impacts. A single action may therefore generate multiple benefits in terms of avoiding an array of different impacts. For example, impacts from coastal flooding include damage to property and infrastructure, disruption to business activities, injuries and possibly fatalities, stress and depression, delays on road and rail networks, degradation of habitat, etc. A sea wall, by eliminating flooding events below a given severity, will therefore provide multiple benefits. Ideally, the analyst would like to obtain individual measures of WTP to secure the entirety of these benefits; for example, measures of individuals' WTP to avoid up a 1-in-500 year flooding event. In practice, however, it is rarely possible to obtain a single measure of WTP covering the entirety of benefits provided by a policy or project. Typically, the analyst must separately estimate the WTP for each effect, and then sum the individual estimates to arrive at a measure of total benefits. This tactic is referred to as the 'effect-by-effect' approach (US EPA, 2010).

Several documents already provide excellent guidance on implementing the 'effect-by-effect' approach. The UK government recently published two volumes related to the subject, along with several case study applications (EFTEC 2009, 2010a, 2010b, 2010c and 2010d). The benefits analysis section in the US EPA's Guidelines for Preparing Economic Analysis (2000 and 2010) is also based on the 'effect-by-effect' approach. Consequently, the presentation of this approach to valuation herein is deliberately simplistic; designed to give the analyst only a basic understanding. Throughout the remainder of the section, the analyst is referred to the more detailed guidance provided in these other documents.

5.1.2.1 Analytical framework for 'effect-by-effect' approach

To apply this widely used and practical approach to benefits analysis the analyst requires two core pieces of information:

1. A clear understanding of the change in the provision of each good or service affected by the adaptation actions under consideration; and
2. A valid and robust estimate of WTP for each change in (1).

The basic formula for estimating the annual benefits of an adaptation action simply combines these two core pieces of information. For example, where the change in the provision of each affected good or service is measured in **physical units** (e.g., m^3 of water, m^2 of residential floor space, tonnes of timber), annual benefits are given by:

$$\text{Monetary value of change (\$ per year)} = \text{Physical change (units per year)} \times \text{WTP (\$ per unit)} \qquad \text{Equation 5-1}$$

Total annual benefits are arrived at by aggregating over all affected physical units, for example:

	$ per year	=	m^3 of water per year	x	$ per m^3 water
+	$ per year	=	m^2 of floor space per year	x	$ per m^2 of residential property
+	$ per year	=	tonnes of timber per year	x	$ per tonne timber
=	$ per year	=	annual total benefits		

Similarly, the basic formula for estimating the annual benefits of an adaptation action, where the change in the provision of each affected good or service is measured in **population units** (e.g., households, visitors) is:

Monetary value of change ($ per year)

=

Affected user population (unit per year) x WTP ($ per unit) Equation 5-2

+

Affected non-user population (unit) x WTP ($ per unit per year)

Note that Equation 5-2 combines values over the two main affected population groups, users and non-users (recall Section 5.1.1.1). Again, annual total benefits are arrived at by aggregating over all affected population units, for example:

	$ per year	=	Number of visits per year	x	$ per visit
+	$ per year	=	Number of visitors per year	x	$ per visitor
+	$ per year	=	Number households	x	$ per household per year
=	$ per year	=	annual total benefits		

Annual total benefits for an adaptation action that alters the provision of goods or services measured in both physical and population units is found by simply adding the results of Equation 9-2 to the results of Equation 5-2.

The above depiction of the 'effect-by-effect' approach is simplistic. Equation 5-2, for example, does not account for the spatial sensitivity of WTP estimates for user (and non-user) populations. Evidence suggests that average WTP estimates for site-specific goods or services decline markedly as the distance to the site in question increases; a phenomena known as 'distance decay'. In addition, both Equation 9-2 and Equation 5-2 implicitly assume that changes in the provision of a good or service do not alter the WTP estimates. That is, the WTP estimates are assumed to be constant, regardless of the magnitude of change induced by the adaptation action. However, due to what is known in economics as 'diminishing marginal utility', WTP valuations for a small (marginal) change will differ from those associated with a large (non-marginal) change. Specifically, the first unit of an improvement (reduction in risk) will tend to be valued higher the second unit of improvement, which will be valued higher than the third unit, and so on, as we become more satiated with improvements. WTP can also decline due to the presence of substitute goods or services. Hence, not only must the analyst consider whether the effects of the adaptation actions in question are marginal or non-marginal, he or she must also understand how the presence of substitutes might modify WTP values. Both EFTEC 2009 and EFTEC 2010d provide detailed guidance on how to deal with these complexities.

5.1.2.2 Measure the change in the provision of affected goods or services

The first core task for the analyst is to develop a clear understanding of the policy-induced change in the provision of each good or service affected by the adaptation actions under consideration. The 'change' in the provision is the difference between the level of provision without adaptation (i.e., under the Reference Case) and the level of provision with adaptation (i.e., under the Extended Adaptation Scenario). The change itself can be:

- ⇨ A quantity change (e.g., an increase in water flows in a river); or
- ⇨ A quality change (e.g., an improvement in water quality); or both.

In order to measure the change in the provision of affected goods and services, the analyst needs to:

1. Identify those goods and services ('benefit categories') potentially affected by the adaptation actions under consideration. The identification of benefit categories should include both affected market and non-market goods and services (see Box 5-2). Human and financial resources will likely be limited. Later steps in the process will therefore need to focus on benefit categories most likely to influence decision-making. To help rank potential benefits the analyst should assess their likely significance – for example, by answering the following questions (US EPA, 2000):
    - o Are there likely to be observable changes in the benefits category relative to the Reference Case;
    - o Is the benefits category likely to account for a major proportion of total adaptation benefits; and
    - o Are decision-makers likely to want information on the benefits category, even if the magnitude of the change is relatively small;

    The outcome of this first step will be a list of potential market and non-market benefit categories, ranked in order of significance. The analyst will already have completed this exercise if he or she followed the risk-based approach to adaptation planning recommended in Section 2.2;
2. Determine the level of provision of the most significant affected goods and services in the absence of extended adaptation, as well as expectations as to their future provision. This defines the Reference Case. The process for developing the Reference Case was described in Section 4.3.5.2;
3. Qualitatively assess the expected change in the provision of significant affected goods and services attributable to the candidate adaptation actions. This will involve (EFTEC, 2009):
    - o Defining the nature of the change. Is it a change in quantity? Is it a change in quality?
    - o Defining the direction of the change: Is it an increase or decrease (in quantity)? Is it an improvement or deterioration (in quality)?

- Defining the temporal nature of the change: Will it occur immediately or gradually over time? Will it occur for a limited period of time or is it permanent?
- Describe the spatial nature of the change: Where will the change occur?
- Describe the scale of the change: Is the change marginal (relatively small) or non-marginal (relatively large)?

The qualitative assessment should produce a clear description and understanding of the change in the provision of significant affected goods and services. This defines the Extended Adaptation Scenario in qualitative terms (Section 4.3.5.3 describes the process of its development);

4. Quantitatively assess the expected change in significant affected goods and services. To the extent possible, both the direction and magnitude of the change attributable to the candidate adaptation actions should be measured, along with the profile of effects over time (see Section 7.2.2.5). Depending on the nature of the change being evaluated, quantification may include (EFTEC, 2009):
   - Measurement of any quantity change, expressed in physical units (e.g., m^3 of water, m^2 of residential floor space, tonnes of timber);
   - Measurement of any quality change, expressed in terms of physical, chemical or biological parameters (e.g., in terms of biological oxygen demand and dissolved oxygen for water quality improvements, or ambient concentrations of ground-level ozone for air quality improvements);
   - Measurement of any change in the affected population, as the number and type (users and non-users) of individuals consuming or enjoying an affected good or service may change, even if the quality or quantity does not. For example, changes in land-use management upstream in a river catchment may change the number of households downstream benefiting from flood protection; and
   - An assessment of the probability of the change occurring;

   This defines the Extended Adaptation Scenario in quantitative terms (see Section 4.3.5.3). Significant impacts that could not be quantified should still be presented qualitatively. Ideally, the analyst should assess the likelihood that these non-monetized impacts could be large enough to materially affect the broad conclusions of the analysis of candidate adaptation actions (a procedure for doing this is presented in Section 11.3.4);

5. Finally, assess uncertainties. The analyst can use sensitivity analysis to better understand key uncertainties surrounding the definition and quantification of the change in the provision of the affected goods and services (the application of sensitivity analysis is described in Section 9.3.2.1).

Box 5-2: Market versus non-market goods and services
Many goods and services likely to be affected by adaptation actions are so-called ‘market impacts’ (e.g., agricultural and forestry products, property and infrastructure, medical and emergency services, hydroelectricity, etc.). The distinguishing feature of these goods and services is that they have an observable price in the marketplace. Moreover, the market price at which these items are exchanged tells us something about their economic value. From the perspective of the buyer, the price paid reveals the amount of money he or she is at least willing to give up to obtain the good or service. However, the market price is not necessarily the maximum amount buyers would be willing to pay. Many buyers may actually be willing to pay more than the market price to obtain the good or service. In economics, the

difference between the maximum amount a buyer is willing to pay and the actual price paid is referred to as 'consumer surplus', which is essentially an element of benefit obtained for free. Consider a house, for example. A house buyer may be willing to pay up to the developer's suggested market price of $350,000. However, if the agreed-upon sale price is $310,000, then the consumer surplus is $40,000 – i.e., the difference between the buyer's maximum WTP and the market price.

Many goods and services likely to be affected by adaptation actions are also not traded in markets and are accordingly 'un-priced'. Examples of so-called 'non-market impacts' include: acute mortality, recreational activities (fishing, boating, swimming, hiking), aesthetics (views, odor, noise), ecosystem functions (nutrient cycling, biodiversity, water filtration, pest control), non-use values, etc. For the purpose of benefits analysis, measures of WTP are still required for these impacts. In contrast to market impacts, as there is no price paid for the non-market impacts, WTP is composed entirely of consumer surplus. As explained below, economists have developed specialist techniques for estimating individuals' WTP for changes in the provision of non-market goods and services.

When performing qualitative and quantitative assessments it is critical that the units the analyst uses to characterize physical changes can be associated with economic valuation endpoints. Consider a Reference Case defined by a 3 degree Celsius increase in mean annual temperature in the future across a river catchment of interest. The change in mean annual temperature gives rise to deteriorations in river water quality, among other things. Suppose a candidate adaptation action (e.g., increasing releases from an upstream dam, constructing strategically placed wetlands, tightening abstraction and discharge licenses) improves water quality. The analyst could describe and quantify the improvement in terms of a movement from one biological water quality class (say, "poor") to another biological water quality class (say, "very good"). To include the improvement in benefits analysis the change in biological water quality class ultimately needs to be valued in money terms. Techniques for doing this are discussed in Section 5.1.2.3. However, to facilitate valuation, it is essential that individuals' WTP values be applicable to the indicators used to measure physical changes (the changes in water quality classes). For example, given that water quality improves from "poor" to "very good", the valuation sought must correspond to individuals' WTP for this change and not for a change from, say, "poor" to "good" or "good" to "very good". A common problem with benefits analysis is the 'correspondence problem', where the change in physical impacts does not correspond to available valuations in the literature, or equally the change does not correspond to indicators that individuals recognize, making primary valuation impossible. This can make the output of quantitative assessments of limited use in CBA; there is not point measuring the number of life years saved from adaptations to heat stress, if the only available measure of WTP is the Value of a Statistical Life. Scientists, policy analysts, modelers and economists need to work closely together to match physical units with valuation endpoints. Of note, the problem is less of an issue in the context of impacts on market goods and services, which have an observable price.

5.1.2.3 Determine the annual total benefits associated with the change

Definition and measurement of the physical impacts of candidate adaptation actions is only one half of benefits analysis. The analyst still needs to covert these physical impacts into monetary values. To do this WTP estimates relevant to the measured changes are needed. Valuation techniques to obtain measures of WTP can be grouped into three broad categories:

1. Valuations based on data observed in conventional markets (known as market price methods);

2. Valuations based on data revealed in surrogate markets (known as revealed preference methods); and
3. Valuations based on data obtained from hypothetical, constructed markets (known as stated preference methods).

These categories denote ‘primary’ valuation methods (i.e., methods that are designed and employed to generate original WTP evidence for a specific decision-making context of interest). The main distinction between the categories is that market price methods – as the term implies - are generally used to value market goods and services, whereas revealed preference and stated preference methods are generally used to value non-market goods and services. Application of primary valuation methods, however, can be expensive, time consuming, and require significant expert input. Withstanding these challenges, the last several decades have witnessed continued application of these methods. This has generated an extensive body of WTP evidence for a wide array of goods and services. As an alternative to primary valuation methods, analysts can make use of this substantive evidence base through value transfer; a quicker and lower cost process that involves identifying appropriate WTP evidence from the results of existing studies and ‘transferring’ this evidence to the current decision-making context.

5.1.2.4 Primary valuation methods – market price methods

Changes in the provision of market goods and services, and in a few instances, non-market goods and services, can be valued using market price data. For instance, market prices in the form of wage rates can be used to value lost work time from disruption to transport networks, as well as productivity losses, which in combination with medical service and medication costs, can be used to provide a proxy for the cost of illnesses.[16] Also, the market price of agricultural and forestry products can be used to value climate-induced changes in yields. Both HMT (2004) and TBCS (2007) recommend that market prices be used as the first point of reference for valuing benefits. Only in the absence of market price data for the affected good or service in question, should the analyst look to the other two broad categories of valuation techniques. However, market price data may not always be suitable without the analyst making some adjustments prior to use. If the markets from which price data are obtained are not competitive or are distorted by taxes or subsidies, for example, then the observed price will need to be adjusted in order to provide a correct measure of economic value. TBCS (2007) explains when market prices will likely need to be adjusted in a Canadian context. Regulatory policies in labor markets distort wage rates, for example. The effect of these policies on the market wage rate needs to be removed. Making the necessary adjustments may require specialist economic advice.

One technique that can use market price data to value non-market impacts is the **production-function method**. With this method, the value of a change in a non-market good or service is inferred by analyzing changes in the production of a market good that arises as a result of a change in the provision (quality or quantity) of the non-market good or service. To apply this

[16] The true cost of illness (or morbidity) comprises four components (Freeman, 2003):

- The cost of averting behaviors to reduce the risk of illness;
- Treatments costs, such as medical services and medication;
- Opportunity costs, such as lost work time; and
- Intangible costs, such as the impact of discomfort, anxiety, pain, and suffering on an individual’s well-being.

Typically, market-based approaches (e.g., the cost-of-illness method) only capture treatment and opportunity costs, omitting averting expenditures and intangible costs.

method, the level of the non-market good or service (e.g., water quality) must be an argument in the market good's production function (e.g., the equation that describes the cost to produce a cubic meter of potable water at a treatment plant), along with labor, capital, energy and other market inputs. Accordingly, changes in the non-market input will result in changes to either total production costs (if output is held constant) or total output (if other inputs are held constant). The production function method along with numerical examples is described in detail in Section 4.2 of Metroeconomica (2004).

5.1.2.5 Primary valuation methods – revealed preference methods

Where market price data are not available for the affected good or service in question, then the analyst will need to use one of the techniques for deriving measures of WTP from surrogate or constructed markets.

Revealed preference methods value changes in non-market goods and services by observing behavior and, specifically, purchases made by individuals or households in actual markets. These markets essentially function as proxy or surrogate markets for the non-market good or service of interest. For example, the analyst might infer what households are WTP for recreational activities (like swimming, fishing, boating, etc.) provided at a specific park from their travel behavior and associated expenditures. The strength of revealed preference methods is that they are based on actual decisions made by individuals or households. This is in contrast to the stated preferences methods described below, which ask people how they would hypothetically value changes in the provision of non-market goods in a constructed market. This has led many decision-makers to conclude that revealed preference methods provide more reliable measures of WTP because they rely on real behavior and actual market data. The three main revealed preference techniques are:

Hedonic pricing

This method estimates the use value of a non-market good or service by analyzing the relationship between that good or service and the demand for some surrogate, market-priced good. When applied to housing data, it is referred to as the property value approach. When applied to wage data – to measure the value of changes in morbidity or mortality risks – it is often referred to as the (compensating) wage differential or wage-risk approach.

The hedonic property value approach, for example, measures the value of changes in an environmental attribute (like noise, odor, views, etc.) by estimating the influence of these attributes on the price paid for properties. In order to obtain a measure of how a specific attribute of interest affects the well-being of individuals, the technique attempts to:

- ⇨ Identify how much of a price differential across properties with similar structural and neighborhood characteristics is due to a particular environmental difference between properties; and
- ⇨ From this information infer how much people are WTP for an improvement in the provision of the environmental attribute.

Travel cost

This method uses the cost incurred by individuals travelling and gaining access to a specific site (typically a park, forest, river, lake, etc.) as a proxy for the use value of that site. Information on visitors' total costs to visit the site is used to characterize their demand for the (typically recreational) services provided by the site. Among other things, the method assumes that changes in total travel costs are equivalent to changes in an 'admission fee' or the 'price' to visit the particular site. Travel costs incurred by an individual include:

- ⇨ Travel expenditures (e.g., fuel, fares, accommodation, food, etc.); and
- ⇨ The value of time.

Given this, the method predicts changes in demand for using the site in response to changes in the admission fee, thereby tracing out a so-called 'demand curve' for the site (showing visitation rates as a function of admission fees). This demand curve can then be used by the analyst to derive measures of WTP for the site, or specific activities at the site.

Averting behaviors or defensive expenditures

This method infers (typically lower bound) measures of WTP by observing how individuals or households change their behavior in response to changes in the quality of the environment or health and safety. It is based on the premise that people can insulate themselves from a non-market bad through behaviors that are more costly. These behaviors might be more costly in terms of taking up more of an individual's time, or by restricting what they would otherwise wish to do. For example, individuals may attempt to prevent their exposure to outdoor air pollution or extreme heat and humidity through some type of averting behavior (e.g., keeping windows closed or staying indoors). In the latter case, as time use has a market analogue in the form of wages, the allocation of time to avoiding the risk of adverse health impacts provides a mechanism for valuing those impacts.

Alternatively, individuals or households might be able to avoid exposure to non-market bads by purchasing a market good, with an observable price. These purchases are frequently referred to as defensive expenditures. For example, the value of mortality risks can be derived from observations of the amount of money spent on averting activities, such as the purchase of safety helmets. Essentially, the helmet is a market good which, in this example, acts as a substitute for a non-market good (a reduction in the risk of premature death). Similarly, households can install double-glazed windows to decrease exposure to noise. The price paid for each of these purchases provides an implicit price for the non-market good or bad in question.

A brief summary of the main strengths, weaknesses and applications of each of the revealed preference methods is provided in Table 5-2.

5.1.2.6 Primary valuation methods – stated preference methods

Stated preference methods offer a direct survey-based approach to estimating people's WTP for changes in the provision of (non-market) goods and services, by eliciting their intended future behavior in a constructed, hypothetical market. There are two main stated preference approaches to valuation: ❶ the contingent valuation method; and ❷ choice modeling techniques. With the contingent valuation method, individuals are asked in various ways to directly state what they would be WTP for a change in the provision of a specified good or service. With choice modeling techniques, WTP measures are inferred from the choices individuals make in surveys, where one of the options presented includes a monetary component:

Table 5-2: Summary of revealed preference methods

Method	Main strengths	Main weaknesses	Main applications
Hedonic pricing	• Uses observed, market data on property sales or wage rates • Is versatile and has many applications	• Does not measure non-use values • Caution required when worker or house buyer does not have full information on health and safety risks or environmental attributes • Requires extensive data set, which may be expensive and time consuming to collect	• Visual amenity • Noise • Odor • Proximity to sites of interest • Non-environmental neighborhood attributes • Human health – mortality risks • Human health – morbidity risks
Travel cost	• Based on observed data and market prices • Well-tried technique, generally accepted to yield plausible results • Can be used to assess changes in site quality, but typically used to value total benefits	• Does not measure non-use values • Caution required when trips to a site of interest have multiple purposes • Data requirements are considerable	• Natural areas (e.g., parks, woodlands, beaches, lakes, etc.) • Recreational activities (e.g., swimming, boating, fishing, hiking, etc.) • Changes in site quality
Averting behavior	• Provides a useful partial or lower bound estimate to WTP values, based on observed behavior and market prices • Defensive expenditures are usual readily measured	• Does not measure non-use values • Caution required when behavior or expenditure has multiple benefits • Care is needed when using defensive expenditures to measure adaptation benefits in CBA, since they are also, in effect, adaptation costs	• Human health – mortality risks • Human health – morbidity risks • Noise • Air quality

Contingent valuation

With this approach, a hypothetical market is constructed for the provision of a (typically, non-market) good or service of interest. This hypothetical market includes a description of the good or service and the terms and conditions for its provision – e.g., information on the quality, reliability, timing and logistics of provision, how to pay for it (the payment or bid vehicle), and the availability of substitutes. In the context of this hypothetical, constructed market, a random sample of the relevant population is then asked questions to reveal or obtain their WTP for a change in the provision of the good or service. The valuation question(s) can be asked in a number of different ways, including:

- Open-ended questions – where respondents are asked simply to state what they would be WTP for the described hypothetical change in provision of the good or service;
- Payment cards – where respondents are presented with a range of values from which to select;
- Bidding games – where respondents are asked to reply to a specified dollar amount. If they are not WTP the given amount, the amount is decreased until the respondent reaches an acceptable amount. If the respondent is WTP the initial amount, the amount is increased until an unacceptable amount is reached; and
- Referendum questions – where respondents are typically presented with a single dollar amount, which they are asked to accept or reject. In some formats, they may be presented with a follow-up question, asking them to accept or reject a higher (lower) amount if they accepted (rejected) the original amount.

Lastly, statistical methods are applied to the survey results to derive the desired measure of WTP.

A key assumption with the contingent valuation method is that respondents behave as though they are purchasing the change in the provision of the good or service of interest in a real market. However, the hypothetical nature of the scenario presented respondents gives rise to concerns that they will not answer honestly; in particular, that they may exaggerate their valuation if they do not have to pay for it. There are several other issues with contingent valuation studies. For example, respondents may be unwilling to accept the premise of the scenario presented, especially where there are established property rights, which are perceived to be under threat. In these circumstances respondents may answer survey questions with protest bids (i.e., they simply refuse to 'play the game'), which need to be removed from the sample. Other issues include information bias (which arises when the framing of the questions unduly influences the answer) and anchoring bias (which arises when the starting values presented to respondents unduly influences their valuations). Respondents may also ignore budget and other constraints, which they would face in a real market. Nonetheless, widespread application of the technique over the last two decades has led to numerous methodological improvements, reducing concerns over the validity and reliability of estimates produced by properly designed studies.

Choice modeling

With this approach respondents are presented with a number of alternatives for provision of the good or service in question (in the form of a questionnaire) and asked to decide between them. Choice modeling is based on the notion that any good or service can be defined in terms of its individual attributes and the levels that these attributes take. For example, a water body can be defined in terms of its recreational uses, vegetation, fish life, birds and other fauna, etc. Changing the attribute levels via a policy or project essentially changes the value of the good (the water body) that is produced. By including price or cost as one of the attributes of the good, analysts can infer peoples' WTP indirectly from the choices made regarding the alternatives presented.

Respondents are normally presented with no more than five to eight alternatives, with each alternative containing no more than four or five attributes, including price or cost. More options or attributes will likely lead to inconsistent responses due to the cognitive limits of respondents. Faced with a set of alternatives, respondents can choose between them in a number of ways (Pearce *et al*, 2006):

- Choice experiments - respondents are usually asked to choose between two alternatives and the status quo;
- Contingent ranking - respondents rank the set of alternatives from most preferred to least preferred;
- Contingent rating - respondents score alternatives on a scale of, say, one to ten; or
- Paired comparisons - respondents score pairs of alternatives on a similar scale.

WTP for changes in the provision of the good or service in question is inferred from statistical analysis of the choices made by respondents and the monetary trade-offs implied by their choices.

Choice modeling has some advantages compared with the contingent valuation method. For a start, because the monetary valuation is inferred from the choices made, and is not explicitly visible to respondents, choice modeling is less prone to some of the response biases that contingent valuation methods can suffer from. Also, by varying the levels of individual attributes, the analyst can obtain valuations for marginal changes in each attribute, as well as for the good or service as a whole. This is particularly useful when candidate adaptation actions affect some attributes more or less than others. However, choice modeling can place a significant cognitive burden on respondents, especially when confronted with choices between multiple, complex alternatives with many attributes and levels. In these cases, respondents may find it difficult to reply consistently to the multiple choices that they are offered. When choices are inconsistent, the analyst must be careful when making inferences about WTP values.

A key strength of both contingent valuation and choice modeling lies in their flexibility. They are both applicable, in principle, to valuations of almost all non-market goods and services, including those unrelated to current or future use (i.e., non-use values). None of the other valuation techniques described above can elicit non-use values. The range of goods and services addressed by stated preference methods is wide – e.g., water quality, water resources, an array of recreation activities, species preservation, forest protection, air quality, visibility, odor, biodiversity, human health impacts, and natural resource damage, to list but a few. Stated preferences methods can also be used to value situations that that have not yet occurred; revealed preference methods require that an existing surrogate market can be identified to function as a proxy for the good or service of interest.

5.1.2.7 Selecting a primary valuation method

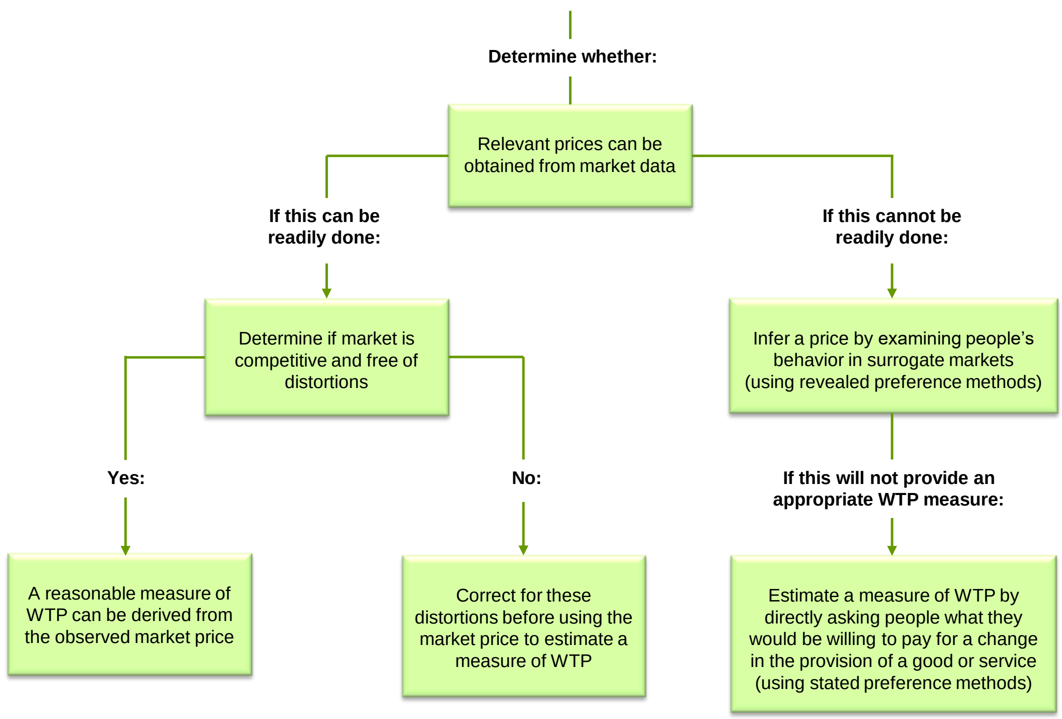
It is not practical in the context of this guidebook to provide detailed guidance on the individual (primary) valuation techniques; each technique would need its own volume. Detailed guidance and example applications can be found among the many references found at the end of this section. For example, Freeman (2003) provides a comprehensive introduction to all principal techniques for economic valuation; Bockstael and McConnell (2007) provides a similar review, focused specifically on revealed preference methods; and Bateman *et al* (2002) and Champ *et al* (2003) provide best practice guidelines for applications of stated preference methods. Metroeconomica (2004) also provides numerous examples of how the techniques are applied in the context of climate impacts and adaptation. For analysts interested in commissioning a primary valuation study, relevant guidance is provided in EFTEC (2010e).

Bearing in mind the perceived strengths and weaknesses of the primary valuation techniques, as a first point of reference, analysts should use market prices, making adjustments for pre-existing market distortions, where necessary. However, in practice, most appraisals of adaptation actions will identify some impacts for which there is no readily available market data. In these cases, the analyst should first consider using revealed preference techniques, and only when the required evidence cannot be provided via surrogate markets, should the analyst consider evidence from hypothetical, constructed markets. The analyst will need to consider revealed preference methods when, for example, there is no proxy market for the good or service in question, values are needed for specific attributes of the good or service, or non-use values are sought. A decision tree for choosing between broad categories of valuation methods is presented in Figure 5-1.

5.1.2.8 Value transfer

It is often not practical or feasible to conduct original valuation studies. Applying primary valuation techniques – in particular, revealed preference and stated preference methods to value non-market goods and services -- can be expensive, time consuming, and require expert input. Fortunately, there is a considerable body of existing evidence on the economic value of many (non-market) goods and services. This presents analysts with the option of taking estimated values from existing studies and applying them to the new problem at hand, so long as the change in the provision of the good or service is similar in both the old and new context. This procedure is frequently called benefits transfer. However, as damages costs can equally be transferred, a more appropriate term is ‘value transfer’. The site (or context) where the original valuation study was conducted is often called the ‘study site’, while the site (or context) where the transferred value is needed is called the ‘policy site’. Value transfer can take place across different sites (i.e., spatial value transfer) or at one specific site over time (i.e., temporal value transfer). Only the former is considered here; guidance on temporal value transfer is provided in Section 6.

Figure 5-1: Decision tree to help analysts decide between broad categories of primary valuation methods



Source: Adapted from HM Treasury (2004)

Approaches to value transfer

There are two main approaches to value transfer, each with two variants:

1. Unit value transfer;
    a. Simple unit value transfer; and
    b. Unit value transfer with adjustments; and
2. Function transfer;
    a. Value function transfer; and
    b. Meta-analysis.

All four variants differ in degree of complexity, data requirements and anticipated reliability; reliability increases, in principle, as we move from 1.a to 2.b.

The most basic approach for transferring WTP estimates from the study site to the policy site is **simple unit value transfer**. With this approach, it is assumed that the well-being experienced by an average individual at the study site for a given change in the provision of a good or service is the same as that which will be experienced by the average individual at the policy site for a similar change in provision of the same good or service. In other words:

$$\mathrm{WTP_s} = \mathrm{WTP_p} \qquad \text{Equation 5-3}$$

The subscripts "s" and "p" denote the study site and policy site, respectively. With this variant of value transfer, a mean or median WTP estimate – for example, mean WTP per visit – is directly transferred from the study site (the original study) to the policy site (the adaptation planning context in which the analysts wishes to now apply the value). Typically, a single WTP estimate is taken from a single existing study, but the analyst can also take the (otherwise unadjusted) mean or median of a number of estimates from several existing studies.

The policy-induced change in the provision of the good or service of interest and the size of the affected population will drive aggregate benefit values. For example:

Annual total benefits ($ per year)

=

mean WTP ($ per visit) } Transferred value

x

change in visitation rate (number of visits per capita per year) } Effect of adaptation action

x

affected population (number) } Aggregation parameter

Clearly, the main strength of this approach to value transfer is its simplicity and ease of application, assuming a suitable study site (or sites) can be identified. However, simple unit value transfer may fail to capture important differences between the characteristics of the original study site(s) and the new policy site. Problems arise if, for example, individuals at the policy site value recreational activities differently from the average individual at the study site(s). This will happen if people at the policy site differ from individuals at the study site(s) in terms of income, education, ethnic group or other socio-economic characteristics that affect their demand for recreation. Even if individuals' at the policy site and study site(s) are identical in all respects, their recreational opportunities might differ because of, for example, the presence of multiple substitute locations surrounding the policy site that provide similar recreational opportunities. If these differences are significant, then simple unit value transfer will likely produce unreliable estimates of WTP for the policy site. In short, simple unit value transfers should only be used if the original valuations at the study site(s) and the required valuation at the policy site are considering the same good or service, the same change in the provision of that good or service, and same affected populations.

Adjusted unit value transfer enables the analyst to account for some key differences between the study site and the policy site. With this approach an adjustment factor (F) is included in Equation 5-3 and applied to the study site values as follows:

$$\mathrm{F} \times \mathrm{WTP_s} = \mathrm{WTP_p} \qquad \text{Equation 5-4}$$

Household income is considered a key determinant of WTP for (non-market) goods and services. Consequently, transferring a measure of mean WTP from a study site with a relatively rich population to policy site with a relatively poor population will likely overstate the true value of the policy good or service for which valuations are sought. A formula commonly used to make adjustments for income differences between sites is:

$$\mathrm{F} = \left(\frac{\mathrm{Y_p}}{\mathrm{Y_s}}\right)^{e} \qquad \text{Equation 5-5}$$

Where $\mathrm{Y_s}$ is the income per capita at the study site, $\mathrm{Y_p}$ is the income per capita at the policy site, and e is the income elasticity of WTP (i.e., the change in WTP associated with a marginal change in per capita incomes). Substituting Equation 5-5 into Equation 5-4 yields:

$$\left(\frac{\mathrm{Y_p}}{\mathrm{Y_s}}\right)^{e} \times \mathrm{WTP_s} = \mathrm{WTP_p} \qquad \text{Equation 5-6}$$

Most evidence suggests that e lies between zero and one, implying that increasing the supply of the good or service will benefit poorer households more than richer households (EFTEC, 2009). An analyst wishing to make this adjustment may be able to find a relevant value for e in the original study from which the unit value is being transferred. However, where a value is not provided, the analyst can adopt a default value of one. Note that if e equals one, then the ratio of WTP at the study site and policy site is simply equivalent to the ratio of per capita incomes at the two sites.

Another common adjustment is made by analysts when transferring values across countries. In this case the adjustment factor (F) is given by:

$$\mathrm{F} = \frac{\mathrm{PPP_{CDN}}}{\mathrm{PPP_s}} \qquad \text{Equation 5-7}$$

Where $\mathrm{PPP_{CDN}}$ is the purchasing power parity (PPP) adjusted exchange rate for Canada and $\mathrm{PPP_s}$ is the purchasing power parity adjusted exchange rate for the study site.[17] Substituting Equation 5-7 into Equation 5-4 yields:

$$\frac{\mathrm{PPP_{CDN}}}{\mathrm{PPP_s}} \times \mathrm{WTP_s} = \mathrm{WTP_p} \qquad \text{Equation 5-8}$$

Both exchange rates should correspond to the base year of the original valuation study. Currency conversions should first take place ‘within’ year (i.e., from 2003 euros to 2003 CDN $) (EFTEC, 2009). Once in the Canadian dollars, a suitable price index can be used to inflate dollar values to the required base year of the CBA (see Section 6.2).

It is also possible to make similar adjustments for other factors, for example, differences in the age structure of the population between the two sites, differences in population density, differences in the number of substitute goods or services, and so on. However, making multiple adjustments of this kind basically amounts to transferring the ‘benefit function’ (i.e., the third

[17] A PPP adjusted exchange rate accounts for the relative cost of living between countries by comparing the price of the same basic basket of goods in all countries. PPP adjusted exchange rates for developed countries are available from OCED Statistics (www.oecd.org/std/prices-ppp).

main approach to value transfer). A benefit function describes – in quantitative terms – the relationship between WTP and changes in its key determinants, such as characteristics of the good or service and the change in its provision, socio-economic and demographic characteristics of the affected population, patterns of use and the availability of substitutes, etc. If the analyst is considering multiple adjustments to the study site WTP value prior to transfer, he or she may be better advised to simply transfer the entire equation used to compute WTP. **Value function transfer** is conceptually more appealing because all pertinent information is transferred.

Suppose, for example, that household WTP for a good at a study site (e.g., the non-use value of a wetland) depends on the income (Y), age (AGE), and educational attainment of the affected population (EDU), as well as the number of substitute sites accessible to the affected population (SUB). Further assume that the original study estimated the following relationship between household WTP and these explanatory variables:

$$\mathrm{WTP_s} = b_0 + b_1 \times \mathrm{Y_s} + b_2 \times \mathrm{AGE_s} + b_3 \times \mathrm{EDU_s} + b_4 \times \mathrm{SUB_s} + \epsilon$$

$$b_0 = +2.0 \quad b_1 = +0.9 \quad b_2 = -0.4 \quad b_3 = +1.3 \quad b_4 = -1.0$$

Equation 5-9

This value function could have been estimated using either revealed preference methods or stated preference methods. In this example, household WTP increases with income and educational attainment, but decreases with age and the number of substitute sites (ϵ is a random error term). With this transfer approach, the entire value function is transferred to the policy site. Specifically, the analyst: ❶ transfers the estimated coefficients for the explanatory variables (i.e., $b_0, \ldots, b_4$); ❷ collects data on the explanatory variables at the policy site (e.g., mean age, mean per capita income, etc.); and ❸ inputs that data into Equation 5-9 in order to calculate households' WTP for a change in the provision of the policy good, as follows:

$$\mathrm{WTP_s} = 2.0 + 0.9 \times \mathrm{Y_s} - 0.4 \times \mathrm{AGE_s} + 1.2 \times \mathrm{EDU_s} - 1.0 \times \mathrm{SUB_s} + \epsilon$$

Enter mean per capita income from policy site

Enter mean age from policy site

Enter mean education level from policy site

Enter number of substitute sites at policy site

$$\mathrm{WTP_p} = 2.0 + 0.9 \times \mathrm{Y_p} - 0.4 \times \mathrm{AGE_p} + 1.2 \times \mathrm{EDU_p} - 1.0 \times \mathrm{SUB_p} + \epsilon$$

Equation 5-10

The following examples illustrate the implications of this approach to value transfer: if the population at the policy site has, on average, attained a higher level of education than the population at the study site, then $\mathrm{WTP_p}$ will be higher than $\mathrm{WTP_s}$ (other things being equal). Similarly, if the population at the policy site has access to more substitutes than the population at the study site, then $\mathrm{WTP_p}$ will be lower than $\mathrm{WTP_s}$ (other things being equal). As with the other approaches to value transfer, to minimize the risk of error the analyst should still choose a study site as similar as possible to the policy site.

Instead of transferring the value function from a single original valuation study, results from several valuation studies can be combined in a 'meta-analysis' to estimate one common value function for application at the policy site. **Meta-analysis** seeks to systematically combine estimates from different studies of WTP for changes in the provision of a good or service, and to explain (and later control for) the reasons behind variation in the estimates. Basically, the results (inputs and outputs) from a number of original valuation studies of the good or service of interest are treated as a single observation within a new analysis of the combined data sets. This enables the analyst to quantitatively explain WTP as a function of not only features of the good or service (including socio-economic characteristics of the affected population), but also methodological characteristics of the original valuation studies (e.g., year of study, sample size, elicitation format, payment vehicle, etc.) The resulting value function estimated across the combined data sets is transferred to the policy site, where data collected for those explanatory variables specific to the policy site, are input to the estimated function to derive an adjusted measure of WTP. The value function estimated from a meta-analysis will look like Equation 5-9, but with additional explanatory variables for methodological characteristics of the original valuation studies.

In theory, the transfer of value functions estimated through a properly conducted meta-analysis offers the greatest accuracy.[18] However, such an exercise requires specialist input and significant time and resources, which some analysts believe diminishes the basic appeal of using value transfer over primary valuation methods in the first place (Pearce *et al*, 2006).

Best practice guidance

Given that value transfer is relatively quick and inexpensive, why do analysts even consider primary valuation studies? The answer is simple: quick and inexpensive does not mean value transfer is easy, void of judgments (see Section 5.1.2.9), and always provides valid and reliable measures of WTP (see Box 5-3). To ensure the competent application of value transfer in environmental policy appraisal, and to complement existing guidance on valuing ecological goods and services, the UK government recently published detailed guidelines for value transfer, comprising an eight-step 'best practice' approach to value transfer, along with a number of illustrative case studies applications (DEFRA, 2007; EFTEC, 2009; and EFTEC, 2010a-e). The guidelines are based on an extensive review of value transfer studies and error tests, and represent state-of-the-art knowledge on the subject. Analysts considering the use of value transfer to measure adaptation benefits should consult the UK guidelines.

5.1.2.9 Deciding between primary valuation studies and value transfer

So far we have introduced a range of primary valuation methods and value transfer as approaches for benefits analysis. But how does the analyst decide which is the most appropriate approach for the decision problem at hand. The discussion below will help analysts answer the question: is secondary evidence from value transfer sufficient or is a primary valuation study required? Figure 3-1 summarizes the discussion in the form of a decision tree.

When selecting between these two broad approaches to valuation, analysts must answer two questions:

1. Is value transfer possible?
2. If so, is a value transfer approach appropriate?

Box 5-3: Reliability of value transfer

[18] A set of 'best practice' guidelines for conducting meta-analysis in the context of benefits valuation is provided by Nelson and Kennedy (2009). Bergstrom and Taylor (2006) also provide a good review of the theory, practice and main steps in using meta-analysis for value transfer.

The reliability of value transfer depends on: ❶ how large the transfer error is relative to the 'true' value at the policy site; and ❷ the level of accuracy that is required in the evidence presented to decision-makers. Transfer errors are typically defined by the mean absolute percentage error (MAPE), which is the percentage difference between two WTP estimates:

$$\text{MAPE (\%)} = \left|\frac{\text{predicted WTP} - \text{observed WTP}}{\text{observed WTP}}\right| \times 100$$

The predicted WTP is the value transferred from the study site using one of the approaches described in the main text; and the observed value is the 'true' value estimated at the policy site using a primary valuation method. By way of example, a transfer error of 100 per cent indicates that the value transferred from the study site is 100 per cent higher or lower than the 'true' value at the policy site.

There is a large literature that has empirically tested the reliability of value transfer. Some studies suggest that transfer errors are small (close to zero), while other studies suggest that errors are very large (into the 1000s). Most studies, however, find transfer errors in the range of zero to 100 per cent, indicating that the transferred value is one to two times higher or lower than the 'true' value at the policy site.

Source: Pearce et al (2006) and EFTEC (2009 and 2010d)

Analysts may find that value transfer is not possible due to lack of information, or time and resource constraints. To determine if sufficient information is available, the analyst needs to consider:

- What is known about key characteristics of the affected goods and services?
- What is known about the change in the provision of affected goods and services?
- What is known about the affected population(s), including socio-economic characteristics?
- What is known about substitute goods and services?
- What (relevant and robust) WTP valuation evidence is available from existing studies?

Where information is lacking, it may be necessary to gather further scientific and economic evidence, or a primary valuation study may be required. However, if time and resources are limited, then primary valuation is not an option, and opportunities to improve the evidence base to facilitate value transfer will also likely be limited. In these cases, analysts will need to consider alternative approaches (e.g., CEA and MCA).

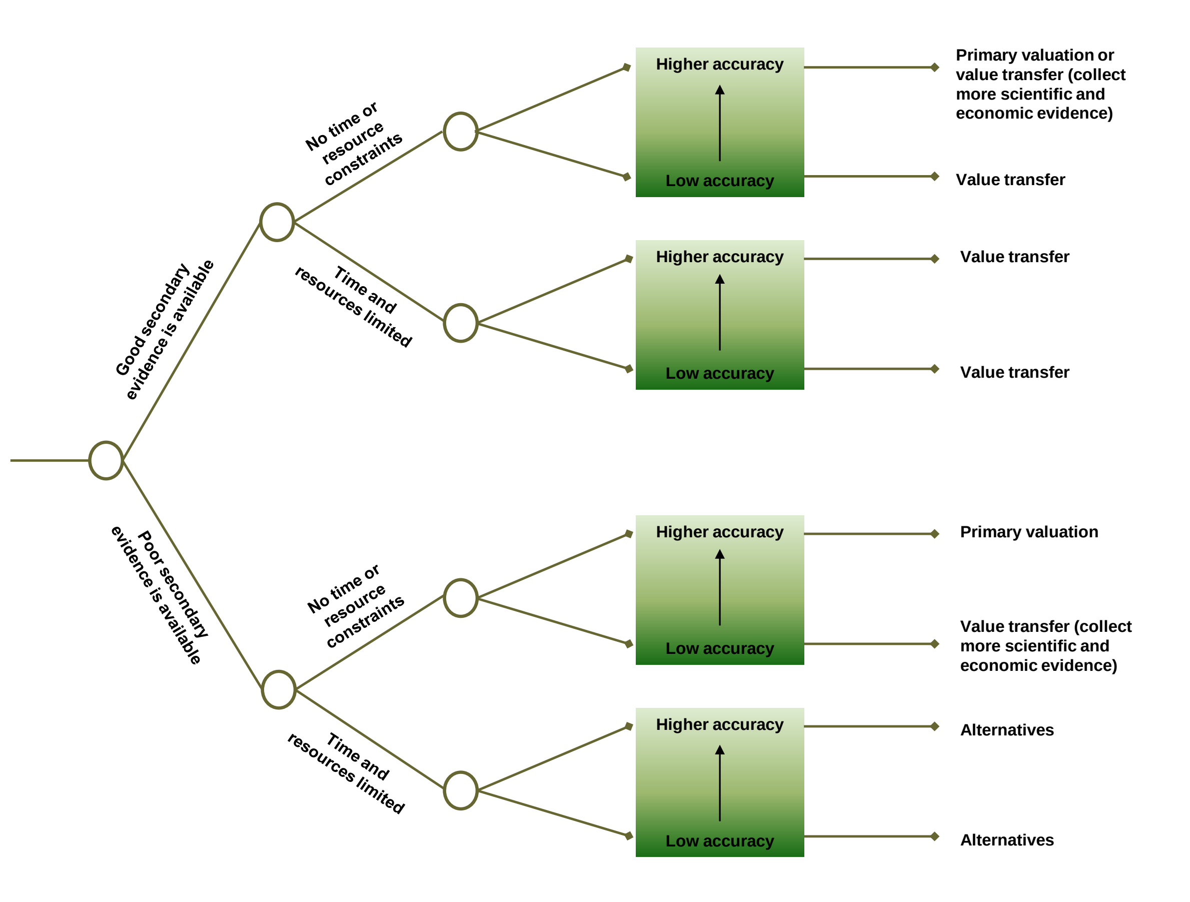
If value transfer is possible, analysts must decide on the level of effort needed. More detailed analysis should be undertaken where the accuracy requirements for evidence are higher, taking account of available time and resources. To determine if there is adequate time or resources available, the analyst must assess if there is sufficient study time before the results are needed, whether the required level of expertise to perform the analysis is available, and whether peer review is needed and available.

If there are no time and resource constraints, the analyst must decide whether primary valuation is warranted; is spending more on a primary valuation study justified by the perceived gains in accuracy? Faced with no constraints, primary valuation studies are often preferred to value transfer. This is especially true when the decision-making context requires a higher level of accuracy from the benefits analysis than can be provided by value transfer.

The need for higher levels of accuracy is often linked to a number of factors, including:

- The phase of the policy cycle – is it initial scoping or final decision time? Where analysis is focused on highlighting the importance of an issue, or if an initial assessment of benefit outcomes is required (as part of a screening exercise), relatively lower levels of accuracy are likely acceptable. Making final decisions requires greater confidence in results and therefore requires increased accuracy.
- The scale of the impacts – how large is the induced change in the provision of an affected good or service? Is the change in relation to the overall decision being made significant? Does the decision involve major investment or expenditure? Is the decision likely to be subject to significant scrutiny or be potentially contentious among some stakeholders?

Figure 5-2: Decision tree to help analysts decide between primary valuation and value transfer



5.2 Cost Analysis

Section 5.1 discussed the process of measuring adaptation benefits. This section discusses the other half of the cost-benefit equation – the measurement of adaptation costs. In general, analysts performing CBA have tended to pay more attention to the valuation of benefits than they have to the measurement of costs. Partly because measuring costs is viewed as a straightforward accounting exercise, and partly because valuing benefits seems infinitely more interesting. Nonetheless, it is equally important to estimate adaptation costs, like adaptation benefits, as accurately as possible.

5.2.1 Relevant cost concepts

There are many overlapping concepts of cost in financial and economic analyses. To avoid any confusion it is useful at the outset to define some key terminology.

5.2.1.1 Social (opportunity) cost

When performing CBA of candidate adaptation actions the correct cost concept to use is 'social cost'. Social cost is the most comprehensive measure of cost, representing the sum of all opportunity costs incurred as a result of implementing an adaptation action. Opportunity cost is the value of what society has to give up (in terms of foregone production or consumption) to gain the adaptation action. It thus captures the total burden that an adaptation action will impose on the economy.

In competitive markets, prices can be used to measure adaptation costs since they will accurately reflect opportunity costs.[19] For example, the value of land input to CBA should be determined by what it could produce in its best alternative use. If there is a reasonably competitive market for land, the market price of land or the present value of its future rent stream will adequately measure its opportunity cost. If an adaptation action uses government-owned land that has no clear market price or rent, a price for the land will need to be estimated by the analyst (where possible, using comparable private sector land values).

Even if markets exist for inputs to adaptation actions, they may not be competitive. In these cases, the analyst must estimate the appropriate opportunity costs of project inputs. As when valuing adaptation benefits using market prices, the market price of inputs to an adaptation action may need to be adjusted for the presence of taxes, subsidies, or other market imperfections, such as monopoly power or government rationing. If these distortions are believed to materially affect the choice between actions (including doing nothing), then market prices will need to be adjusted (e.g. by calculating costs net of taxes or by calculating the marginal cost of producing a good in a monopoly market). In practice, however, the need for such adjustments will be rare. Similar tax or subsidy regimes, for instance, are likely to apply to all actions being appraised. In those cases where adjustments to market prices are deemed necessary, the analyst should seek specialist economic advice - estimating costs net of the distortionary effects of taxes, subsidies or other market imperfections is not straightforward.

[19] In the case of outputs, the price that the consumer is willing to pay represents what he or she is willing to forgo by not purchasing something else. In the case of inputs, the price reflects the amount that other producers would be willing to pay for the particular input.

5.2.1.2 Environmental externalities

An adaptation action may also give rise to what are termed 'environmental externalities'. These arise when certain actions of producers or consumers have unintended spill-over (or external) effects on third parties, who are not fully consenting parties in reaching the decision that gives rise to the external effects, and for which no appropriate compensation is paid. Environmental externalities tend to be negative, with the affected third parties experiencing detrimental impacts, but they can also be positive. An example of a negative externality would be a factory that pollutes as a result of its production process. This pollution may pose health risks for nearby residents or degrade the quality of the air or water. Either way, the owner of the factory does not directly pay the additional cost to address any health issues or to help maintain the quality of the air or water. Social cost includes all the opportunity costs of providing a particular good or service, including the cost of environmental externalities. That is:

Social (opportunity) cost of adaptation		
=		
Private (market) costs	} Adjusted for market distortions and imperfect competition, where needed	Equation 5-11
+		
External environmental costs	} Can be positive or negative	

Hence, when measuring the social costs of candidate adaptation actions, the analyst should account for the costs of any material environmental externalities. For example, the costs of electrical air conditioning units to mitigate the health risks of extreme summer heat and humidity events should be debited for the cost of associated increases in GHG emissions. Likewise, the costs of greening spaces and tree-planting in urban centers to mitigate the same risks should be credited for the carbon they sequester. Failing to do so, the social costs of these actions will be under-estimated (in the case of air conditioners) or over-estimated (in the case of creating green spaces). Valuing material environmental externalities will likely require application of one of the techniques described in Section 5.1.2.

5.2.1.3 Direct, indirect and induced costs

The total social (opportunity) cost of an adaptation action – i.e., both private costs borne by households and firms and environmental externalities borne by third parties -- may comprise direct, indirect and induced cost components (recall Section 1.6.3):

- Direct costs – the costs of adaptation actions that fall directly on specific individuals, communities, firms or sectors;
- Indirect costs – direct adaptation costs will generate a series of ripple effects throughout the whole economy, reflecting changes in the production and consumption, and relative prices, of goods and services in markets related to those where the direct costs are experienced; and
- Induced costs – as price changes due to both direct and indirect adaptation costs ripple through the economy, household incomes (net of taxes and savings) and spending patterns are affected. Changes in household spending in turn generate further changes

in the production and consumption of goods and services, and their relative prices, across the economy.

For a ‘marginal’ or relatively small adaptation action, direct adaptation costs may provide a reasonable estimate of social cost. The effects of the adaptation action will primarily be confined to a single or a small number of closely related markets, and a reasonable estimate of social cost can be derived using partial equilibrium analysis. This form of analysis assumes that the effects of an adaptation action(s) on all other markets will be minimal and can either be ignored or approximated without employing a model of the entire economy (US EPA, 2010). As noted in Section 1.6.3, this guidebook adopts a partial equilibrium approach, focusing on the direct economic effects of adaptation actions.

However, for a ‘non-marginal’ or relatively large adaptation action, significant impacts can be expected across the economy. In this case, the indirect and induced adaptation costs may be at least as large, and sometimes considerably greater than, the direct adaptation costs. Estimating the true social cost of the action will thus require the use of general equilibrium analysis, requiring the analyst to access a model of the entire economy.

5.2.1.4 Accounting costs

The analyst should note that the concept of social cost contrasts, and often conflicts, with the accounting treatment of costs. Economists and accountants mean two different things when it comes to measuring costs. As noted above, economists define cost in terms of the opportunities that are sacrificed when a choice is made. Hence, under the economist’s definition, costs are prospective as seen from the perspective of a decision-maker. Moreover, to an economist, cost is a stock concept -- costs are incurred at an identifiable point in time when decisions are made. Accountants, in contrast, define cost in terms of resources consumed. Hence, from the accountant’s viewpoint, costs are retrospective as seen from the perspective of a detached observer. Accountants also define costs as flows -- costs reflect changes in stocks over a fixed time period. Differences in the economist’s and accountant’s concept of cost has important implications for the treatment of depreciation, interest payments on borrowed capital, and sunk costs in economic CBA.[20]

Interest expense on debt-financed adaptation actions

In economic as opposed to financial CBA all costs (cash outflows), including initial expenditures on capital goods, should be recorded in full at the time cash payments are made.[21] If investment in a coastal defense scheme requires capital expenditures of $5 million in year zero (say, 2012), $10 million in year one, and $5 million in year two, then these amounts are recorded in full in year zero, one and two of the project’s cash flows:

[20] Recall the distinction between economic CBA and financial CBA that was made in Section 1.6.1.

[21] Likewise, all adaptation benefits (cash inflows) should be recorded in full at the time the benefits (cash inflows) are received.

Project costs	Year 0	Year 1	Year 2	→	Year 30
	2012	2013	2014	→	2042
Capital expenditure	$5 million	$10 million	$5 million	→	$0
…	…	…	…	→	…

The discounting procedure discussed in Section 7.2 captures the opportunity cost to investors over time that is associated with the debt-financing of resources they have tied up in the coastal defense scheme – an opportunity cost which, in practice, can also be approximated by the periodic interest payments that would be required on the borrowed capital. For the analyst to include periodic interest payments on borrowed capital in project cash flows, in addition to using the discounting procedure, would amount to double counting project costs.

Depreciation expense

Accountants use depreciation charges to 'expense' the costs of capital expenditures over a fixed interval, usually defined by accounting standards. Depreciation expense is simply an accounting procedure to convert stocks of capital goods into flows over time. As such, depreciation expense does not capture real forgone opportunities, and consequently it should not be included as a cost in economic CBA. Instead, the cost of capital goods should be recorded in full when the purchase is actually made. The discounting procedure automatically takes account of the year in which the purchase is made. Again, adding depreciation expense to project costs in economic CBA would lead to double counting of costs.

Sunk costs

As noted above, the accountant will seek to apportion the historic costs of a pre-owned asset over its useful life, whereas the economist asks "what is the value of that asset now in its best alternative use?" If the answer to this question is zero, then costs that have already been incurred may be disregarded in economic CBA, irrespective of how much of an asset's initial cost remains to be 'expensed'. These costs are considered 'sunk'. What matters in economic CBA are costs about which decisions can still be made; sunk costs are irrevocable and are unaffected by current decisions (HMT, 2004). If, on the other hand, an asset owned prior to the new project of interest has an alternative use with a positive realizable value, then this value should be included in economic CBA, and not treated as 'sunk'.

5.2.2 Measuring adaptation costs

Existing studies of adaptation costs employ one of two broad approaches (UNFCCC, 2010b):

1. An aggregate, top-down approach; or
2. A disaggregate, bottom-up approach.

5.2.2.1 Top-down approach

The former is usually applied at a global, regional or national level, with the aim of characterizing the scale of the adaptation issue as an input to climate negotiations – e.g., informing the balance between adaptation and mitigation efforts, and the overall funding requirements for adaptation. The top-down approach typically proceeds by (World Bank, 2006, UNDP, 2007, and OXFAM, 2007):

1. Estimating the fraction of current national investment flows that are assumed to be 'climate sensitive' (e.g., the World Bank assumed that 2-10 per cent of gross domestic investment, 10 per cent of foreign direct investment and 40 per cent of official overseas development assistance was sensitive to climate change); and
2. Applying a 'mark-up' factor that reflects the assumed cost of 'climate proofing' these investment flows (e.g., the World Bank assumed a climate proofing mark-up of 10-20 per cent).

In the absence of supporting empirical evidence, the assumptions employed in the top-down approach are difficult to substantiate. The fraction of investment flows that are climate-sensitive and the mark-up to climate proof these flows is largely based on expert judgment. Given the scale of investment flows at national and supra-national levels, uncertainty over these assumptions is a concern; small changes in the assumptions can change estimates of adaptation costs by an order of magnitude. Furthermore, there is also a question as to whether the climate proofing mark-up should be applied against investment flows that reflect current trends or to levels that are needed to provide optimal adaptation to current climate conditions (Parry *et al*, 2009). Many regions and nations are highly vulnerable to current climate variability and extremes, implying that existing investment flows to deal with climate-related risks are inadequate. Hence, applying a mark-up to investment flows that reflect current trends will substantially underestimate adaptation costs.

5.2.2.2 Bottom-up approach

The disaggregate, bottom-up approach to measuring adaptation costs is usually applied at a sub-national, local or project-level, to inform:

- ⇨ The prioritization of adaptation as area of public policy;
- ⇨ Decisions between alternative adaptation actions, including doing nothing; and
- ⇨ The financial implications for provincial and municipal budgets.

This guidebook is intended to be used largely in the context of sub-national and local adaptation planning (as noted in Section 1). With the bottom-up approach, adaptation costs may comprise (EEA, 2007):

- ⇨ The costs of implementing, operating, and maintaining a specific adaptation action;
- ⇨ The costs of enhancing the broad adaptive capacity of the affected population; and
- ⇨ The transaction costs associated with the transition to the extended adaptation scenario.

The first two types of cost are associated with a new future state of the world, defined by the extended adaptation scenario (recall Section 4.3.5.3). Tol *et al* (1998) refer to these costs as 'equilibrium costs'. For example, in an agricultural context, relevant equilibrium costs may include the cost of installing and running additional irrigation capacity, the cost of purchasing additional fertilizer, the cost of seeding different crops, or the cost of regulations or policies that incent farmers to undertaken one or more of these actions.

Transaction costs are associated with the adjustment triggered by adaptation actions. In the previous example, transaction costs may include the cost of retraining farmers in new practices, the cost of changing locations, or the cost changing out of and into farming. The majority of assessments fail to account for transaction costs. It is important, however, that the analyst attempts to measure these costs. The fact is that the climate, the economy, and society are in a state of continuous change. Hence, the most significant costs of adaptation may well be the ongoing costs of transitioning from one future state (with a given level of adaptation) to another state (with an increased level of adaptation) (Tol *et al*, 1998).

For both equilibrium and transaction costs, the following types of costs may need to be measured:

Capital expenditures

Capital expenditures include:

- Fixed investments. Fixed investments are typically, but not always, the largest component of total capital expenditures. They involve cash disbursements for various types of fixed assets: the purchase of land or buildings, the purchase and installation or retrofit of infrastructure or equipment, etc. If a fixed asset has residual value at the end of the adaptation project, this value must be recorded within the fixed investment cost stream at the end- or terminal-year. Because it is considered a cash inflow it should be recorded with the opposite sign to the rest of the fixed investments entries. Residual value may be calculated by considering the market value of the fixed asset, as if it were to be sold at the terminal-year;
- Start-up costs. According to standard definitions, start-up costs include: preparatory studies (e.g., feasibility studies), costs incurred during the implementation phase, the cost of contracts for the use of consulting and engineering services, training expenses, research and development costs, and so on; and in some cases
- Changes in working capital. Allowances for changes in working capital will likely be most relevant to adaptation actions within the productive (commercial and industrial) sector, where the initial investment in working capital can be sizable. Working capital is normally defined as the difference between current assets and current liabilities. Current assets include receivables, inventories, cash and other net short term liquid assets; current liabilities include mainly accounts payable to suppliers.

The analyst will need to estimate of the size of all necessary capital expenditures. Depending on the scale of the adaptation action, capital expenditures can be incurred over several early years, as well as for upgrades or replacement in future years. Thus, the analyst will need to define a time horizon (and terminal-year) – i.e., the maximum number of years for which projections of adaptation costs and benefits are required (see Section 7.2.2.5). The choice of time horizon may have an extremely important effect on the results of the appraisal, and therefore should be subject to sensitivity analysis.

Capital expenditures are sometimes referred to as ‘one-time’ or ‘non-recurring’ costs; once they are made at the outset of a project, they tend not to be repeated. Furthermore, as capital expenditures generally do not vary with the level of activity, they are essentially ‘fixed costs’.

Operating expenses

Operating expenses comprise all cash disbursements foreseen for the purchase of goods and services which are consumed by the adaptation action during each year over the assumed time horizon. These costs can be grouped into the following broad categories:

- ⇨ Direct production costs (e.g., costs of materials, energy, water, production labor, maintenance, transportation, etc.); and
- ⇨ General administrative expenses (e.g., wages for non-production staff, professional fees, insurance, communication, other general overheads, etc.).

In general, production costs are directly related to the level of activity, and are functionally equivalent to 'variable costs'. General administrative expenses, in contrast, do not vary with the level of activity, and for all intents and purposes are 'fixed costs'.

In calculating operating expenses, any items that do not give rise to real opportunity costs must be excluded, even if they are items normally included in a standard set of accounts. As stated in Section 5.2.1.4, depreciation expense and interest payments on borrowed capital should be excluded from CBA.

Some adaptation actions may generate multiple benefits, contributing to other environmental, economic or social objectives, or reducing the need for other investments that would have occurred under the projected baseline. Recall the discussion in Section 4.3.2: hurricane shelters, for example, may be used out of season, thereby avoiding the need to build halls for other social or recreational functions. Relevant ancillary benefits and avoided cost effects should be included in the calculation of operating expenses, recorded with the opposite sign to the rest of the operating expense entries.

Operating expenses should be calculated for each year over the assumed time horizon. As they typically occur annually over the life of a project, they are also termed 'recurring costs'.

Incremental costs

The calculation of all adaptation costs – both capital expenditures and operating expenses – should be based on an incremental approach. That is, they should reflect difference in the costs incurred under the reference case (without the adaptation action of interest) and the extended adaptation scenario (with the adaptation action of interest) (see Section 4). Finally, remember that all adaptation costs should be measured on the basis of social (opportunity) cost, as defined above.

5.2.3 Other issues in cost analysis

5.2.3.1 Optimism bias

A well-known phenomenon that affects both private and public sector projects is the tendency for analysts to be overly optimistic (HMT, 2004). Optimism bias occurs when analysts present favorable estimates of net benefits as the most likely or central estimates. Future adaptation benefits may be overestimated *ex ante* (often by assuming unrealistically high annual growth in benefits or minimal construction periods). Conversely, adaptation costs may be underestimated *ex ante*. Cost optimism can happen for several reasons (Pearce et al, 2006): Analysts may simply get their sums wrong, especially for large, one-off public sector projects for which there are no precedents. In addition, project proponents have an incentive to understate costs in order to secure a contract or see their project approved. Contractors can always argue over compensation for cost overruns after a contract is awarded.

An analyst can redress the problem of optimism bias in a number of ways (HMT, 2004):

- ⇨ The first remedy is to use sensitivity analysis, testing the sensitivity of the estimated net benefits to more pessimistic assumptions (see Section 9.3.2.1);
- ⇨ The second remedy is to make explicit, empirically-based adjustments for optimism bias, drawing on past experience with similar projects. Adjustments can take the form of increasing estimates of adaptation costs and decreasing, or delaying the receipt of, estimated adaptation benefits; and
- ⇨ The third remedy is to be transparent about all assumptions adopted in the analysis, particularly forecasting assumptions, and the reasons for those assumptions (see Section 11). Independent, expert assessments could also be obtained in order to develop and justify assumptions. Transparency 'opens up' the analysis to the decision-maker, who is then in a much better position to avoid being misled.

5.2.3.2 Timing of investment expenditures

Not only must adaptation planners decide how much adaptation is optimal, they must also decide the optimal time to invest. To help planners decide when to invest in an adaptation action, the analyst will need to compare the net present value (NPV) of investing now with the NPV of investing at a later date. Fankhauser (2006) shows that the optimal timing of adaptation is driven by three factors:

1. The costs of adaptation actions tend to favor waiting for two reasons. First, the effect of discounting reduces the present value cost of investing at a later date vis-à-vis investing now. Second, potentially cheaper and more effective approaches to adaptation may be developed in the future. However, there are exceptions where investing in adaptation now may be cheaper. In the case of long-lived infrastructure projects, such as water and sanitation systems, bridges, and coastal defense schemes, it may be less expensive to make adjustments early, during project design, rather than incur the substantial expense and disruption of retrofits;
2. The presence of near-term benefits tends to favor early adaptation. An adaptation action will have immediate benefits, irrespective of future climate change, if:
    - o It effectively mitigates impacts from current climate variability and extremes, and these impacts are relatively large; or
    - o It produces large ancillary benefits or reductions in other related costs;

    In other words, win-win and no-regret adaptation actions will favor early investment; and
3. The risk of irreversible impacts tends to favor early adaptation. Early investment in adaptation is justified if it locks in lasting benefits, for example, by preventing long-term damage to natural systems.

To summarize, in the absence of immediate benefits or the risk of long-term irreversible impacts, the effect of discounting adaptation costs will typically favor delaying investment, unless we are talking about long-lived infrastructure projects that would be costly and inconvenient to retrofit.

5.3 References and further reading

Alberini, A., 2005, What Is a Life Worth? Robustness of VSL Values from Contingent Valuation Surveys, *Risk Analysis*, 25(4), p. 783-800.

Alberini, A., Cropper, M., Krupnick, A. and Simon, N., 2004, Does the Value of a Statistical Life Vary with Age and Health Status? Evidence from the US and Canada, *Journal of Environmental Economics and Management*, 48(1), p. 769-792.

Alberini, A., Hunt, A. and Markandya, A., 2006, Willingness to Pay to Reduce Mortality Risks: Evidence from a Three-Country Contingent Valuation Study, *Environmental and Resource Economics*, 33(2), p. 251-264.

Alberini, A., Cropper, M., Krupnick, A. and Simon, N., 2006, Willingness to Pay for Future Risk: How Much Does Latency Matter? *Journal of Risk and Uncertainty*, 32(3), p. 231-245.

Aldy, J. and Viscusi, W., 2007, Age Differences in the Value of a Statistical Life: Revealed Preference Evidence, *Review of Environmental Economics and Policy*, 1(2), p. 241-260.

Agrawala, S. and Fankhauser, F., 2008, Economic Aspects of Adaptation to Climate Change: Costs, Benefits and Policy Instruments, OECD, Paris, France.

Allen, B. and Loomis, J., 2005, The Decision to Use Benefit Transfer or Conduct Original Research in Estimating Benefits for Benefit-Cost Analysis, Draft Paper, Department of Agricultural and Resource Economics, Colorado State University, Fort Collins, Colorado, USA.

Anielski, M. and Wilson, S., 2006, Counting Canada's Natural Capital: Assessing the Real Value of Canada's Boreal Ecosystems, Canadian Boreal Initiative, Ottawa, Canada.

Balmford, A., Rodrigues, A., Walpole, M., Ten Brink, P., Kettunen, M. and Braat, L., 2008, Review on the Economics of Biodiversity Loss: Scoping the Science, ENV/070307/2007/486089/ETU/B2, DG Environment, Brussels, Belgium.

Bateman, I., Carson, R., Day, B., Hanemann, M., Hanley, N., Hett, T., Jones-Lee, M., Loomes, G., Mourato, S., Özdemiroglu, E., Pearce, D., Sugden, R. and Swanson, J., 2002, Economic Valuation with Stated Preference Techniques: A Manual, Edward Elgar, Cheltenham, UK.

Bateman, I., Day, B., Georgiou, S. and Lake, I., 2006, The Aggregation of Environmental Benefit Values: Welfare Measures, Distance Decay and Total WTP, *Ecological Economics*, 60(2), p. 450-460.

Bellavance, F., G. Dionne and M. Lebeau, 2007, The Value of a Statistical Life: A Meta-Analysis with a Mixed Effects Regression Model, Canada Research Chair in Risk Management Working paper 06-12, HEC, Montreal, January 2007.

Bergstrom, J. and Taylor, L., 2006, Using Meta-analysis for Benefits Transfer: Theory and Practice, *Ecological Economics*, 60, pp. 351–36.

Berry, P. 2007, Adaptation Options on Natural Ecosystems, a report to the UNFCCC Financial and Technical Support Division, United Nations Framework Convention on Climate Change (UNFCCC) Secretariat, Bonn, Germany.

Bockstael, N. and McConnell, K., 2007, Environmental and Resource Valuation with Revealed Preferences: A Theoretical Guide to Empirical Models, The Economics of Non-Market Goods and Services: Volume 7, Springer, Dordrecht, Netherlands.

Boyle, K., Kuminoff, N., Parmeter, C. and Pope, J., 2010, The Benefit-Transfer Challenges, *Annual Review of Resource Economics*, 2, p. 161–82.

Brouwer, R. and Bateman, I., 2005, Benefits Transfer of Willingness to Pay Estimates and Functions for Health-Risk Reductions: A Cross-Country Study, *Journal of Health Economics*, 24, p. 591-611.

Brouwer, R., 2000, Environmental Value Transfer: State of the Art and Future Prospects, *Ecological Economics*, 32(1), p. 137-152.

Button, K., 2002, An Evaluation of the Potential of Meta-Analysis, in Comparative Environmental Economic Assessment, Nijkamp, P., Florax, R. and Willis, P. (ed.), Edward Elgar Publishers, Cheltenham, UK.

Cameron, T., Deshazo, J. and Stiffler, P., 2008, Willingness to Pay for Small Reductions in Morbidity and Mortality Risks: Canada and the United States, University of Oregon, Eugene, Oregon, USA.

Champ, P., Boyle, K. and Brown, T. (editors), 2003, A Primer on Non-market Valuation, The Economics of Non-Market Goods and Services: Volume 3, Kluwer Academic Press, Dordrecht, Netherlands.

Chestnut, L., Rowe, R. and Breffle, W., 2004, Economic Valuation of Mortality Risk Reduction: Stated Preference Approach in Canada, a report prepared for Health Canada, Stratus Consulting Inc., Boulder, Colorado, USA.

Chestnut, L. and De Civita, P., 2009, Economic Valuation of Mortality Risk Reduction: Review and Recommendations for Policy and Regulatory Analysis, Policy Research Initiative, Ottawa, Canada.

Collins, A., Rosenberger, R. and Fletcher, J., 2005, The Economic Value of Stream Restoration, *Water Resources Research*, 41, p. 1-9.

Cropper, M. and Sahin, S, 2009, Valuing Mortality and Morbidity in the Context of Disaster Risks, Policy research working Paper 4832, World Bank, Washington, DC, USA.

DEFRA, 2007, An Introductory Guide to Valuing Ecosystem Services, Department for Environment, Food and Rural Affairs (DEFRA), London, UK.

Desvousges, W, Johnson, F. and Banzhaf, H., 1998, Environmental Policy Analysis with Limited Information: Principles and Applications of the Transfer Method, New Horizons in Environmental Economics, Edward Elgar, Cheltenham, UK.

DTLR, 2002, Economic Valuation with Stated Preference Techniques: Summary Guide, Department for Transport, Local Government and the Regions (DTLR), London, UK.

Dumas, C., Schuhmann, P. and Whitehead, J., 2005, Measuring the Economic Benefits of Water Quality Improvement with Benefits Transfer: An introduction for Non-economists, Working Papers 04-12, Department of Economics, Appalachian State University, North Carolina, USA.

Dupont, D. and Renzetti, S., 2008, Good to the Last Drop? An Assessment of Canadian Water Value Estimates, *Canadian Water Resources Journal*, 33(4), p. 363-374.

Ebi, K. 2007, Health Impacts of Climate Change, a report to the UNFCCC Financial and Technical Support Division, United Nations Framework Convention on Climate Change (UNFCCC) Secretariat, Bonn, Germany.

EEA, 2007, Climate Change: the Costs of Inaction and the Costs of Adaptation, European Environment Agency (EEA) Technical Report No 13/2007, Copenhagen, Denmark.

EFTEC, 2009, Valuing Environmental Impacts: Practical Guidelines for the Use of Value Transfer in Policy and Project Appraisal, Value Transfer Guidelines, Department for Environment, Food and Rural Affairs, London, UK.

EFTEC, 2010a, Valuing Environmental Impacts: Practical Guidelines for the Use of Value Transfer in Policy and Project Appraisal, Annex 3 - Glossary of Econometric Terminology, Department for Environment, Food and Rural Affairs, London, UK.

EFTEC, 2010b, Valuing Environmental Impacts: Practical Guidelines for the Use of Value Transfer in Policy and Project Appraisal, Case Study 3 –Valuing Environmental Benefits of a Flood Risk Management Scheme, Department for Environment, Food and Rural Affairs, London, UK.

EFTEC, 2010c, Valuing Environmental Impacts: Practical Guidelines for the Use of Value Transfer in Policy and Project Appraisal, Case Study 7 – Using GIS to Value Ecosystem Impacts, Department for Environment, Food and Rural Affairs, London, UK.

EFTEC, 2010d, Valuing Environmental Impacts: Practical Guidelines for the Use of Value Transfer in Policy and Project Appraisal, Technical Report, Department for Environment, Food and Rural Affairs, London, UK.

EFTEC, 2010e, Valuing Environmental Impacts: Practical Guidelines for the Use of Value Transfer in Policy and Project Appraisal, Annex 1 – Primary Valuation Studies, Department for Environment, Food and Rural Affairs, London, UK.

Egan, K., Herriges, J., Kling, C. and Downing, J., 2009, Valuing Water Quality as a Function of Water Quality Measures, *American Journal of Agricultural Economics*, 91(1), p. 106-123.

Fankhauser, S., 2006, Economics of Adaptation, supporting research commissioned as part of the Stern Review, HM Treasury, London, UK.

Freeman III, A., 2003, The Measurement of Environmental and Resource Values: Theory and Methods, 2nd Edition, Resources for the Future, Washington, DC, USA.

Gardner Pinfold Consulting Inc., 2005 Valuing the Benefits of Improving Municipal Wastewater Treatment in Canada, a report prepared for Environment Canada, Halifax, Nova Scotia, Canada.

Hammitt, J., 2007, Valuing Changes in Mortality Risk: Lives Saved versus Life Years Saved, *Review of Environmental Economics and Policy*, 1(2), p. 228-240.

Hanley, N., Schläpfer, F. and Spurgeon, J., 2003, Aggregating the Benefits of Environmental Improvements: Distance-decay Functions for Use and Non-use Values, *Journal of Environmental Management*, 68, p. 297-304.

HM Treasury, 2004, The Green Book: Evaluation and Appraisal in Central Government, Annex 2, Valuing Non-market Impacts, Treasury Guidance, The Stationary Office, London, UK.

Hoehn J., 2006, Methods to Address Selection Effects in the Meta-regression and Transfer of Ecosystem Values, *Ecological Economics*, 60, p. 389-98.

Horowitz, J. and McConnell, K., 2000, Willingness to Accept, Willingness to Pay and the Income Effect, Department of Agricultural and Resource Economics, University of Maryland, College Park, Maryland, USA.

Horowitz, J. and McConnell, K., 2002, A Review of WTA and WTP Studies, *Journal of Environmental Economics and Management*, 44, p. 426-447.

Johnston, R., Besedin, E., Iovanna, R., Miller, C., Wardwell, R. and Ranson, M., 2005, Systematic Variation in Willingness to Pay for Aquatic Resource Improvements and Implications for Benefit Transfer: A Meta-analysis, *Canadian Journal of Agricultural Economics*, 53, p. 221-48.

Johnston, R. and Thomassin, P., 2010, Willingness to Pay for Water Quality Improvements in the United States and Canada: Considering Possibilities for International Meta-Analysis and Benefit Transfer, *Agricultural and Resource Economics Review*, 39 (1), p. 114-131.

Johnstone, R. and Duke, J., 2009, Willingness to Pay for Land Preservation across States and Jurisdictional Scale: Implications for Benefit Transfer, *Land Economics*, 85(2), p. 217-237.

Kanninen, B. (editor), 2006, Valuing Environmental Amenities Using Stated Choice Studies: A Common Sense Approach to Theory and Practice, The Economics of Non-Market Goods and Services: Volume 8, Springer, Dordrecht, Netherlands.

Kirshen, P., 2007, Adaptation Options and Cost in Water Supply, a report to the UNFCCC Financial and Technical Support Division, United Nations Framework Convention on Climate Change (UNFCCC) Secretariat, Bonn, Germany.

Kochi, I., Hubbell, B. and Kramer, R., 2006, An Empirical Bayes Approach to Combining and Comparing Estimates of the Value of Statistical Life for Environmental Policy Analysis, *Environmental and Resource Economics*, 34(3), p. 385-406.

Krantzberg, G and De Boer, C., 2006, A Valuation of Ecological Services in the Great Lakes Basin Ecosystem to Sustain Healthy Communities and a Dynamic Economy, a report prepared for the Ontario Ministry of Natural Resources, Dofasco Centre for Engineering and Public Policy, McMaster University, Hamilton, Canada.

Kristofersson, D. and Navrud, S., 2005, Validity Tests of Benefit Transfer: Are We Performing the Wrong Tests, *Environmental and Resource Economics*, 30(3), p. 279-286.

Kristofersson, D. and Navrud, S., 2007, Can Use and Non-Use Values be Transferred across Countries? Navrud, S. and R. Ready (editors), Environmental Value Transfer: Issues and Methods, Springer, Dordrecht, Netherlands.

Krupnick, A., Alberini, A., Cropper, M., Simon, N., O'Brien, B., Goeree, R. and Heintzelman, M., 2002, Age, Health and the Willingness to Pay for Mortality Risk Reductions: A Contingent Valuation Survey of Ontario Residents, *Journal of Risk and Uncertainty*, 24(2), p. 161-186.

Kumar, P. (editor), 2010, The Economics of Ecosystems and Biodiversity: Ecological and Economic Foundations, Earthscan, Oxford, UK.

Lindhjem, H. and Navrud, S., 2008, How Reliable is Meta-analysis for International Benefit Transfers? *Ecological Economics*, 66, p. 425-435.

Loomis, J., Kent, P., Strange, L., Fausch, K. and Covich, A., 2000, Measuring the Total Economic Value of Restoring Ecosystem Services in an Impaired River Basin: Results from a Contingent Valuation Survey, *Ecological Economics*, 33, p. 103-117.

Loomis, J. and Rosenberger, R., 2006, Reducing Barriers in Future Benefit Transfers: Needed Improvements in Primary Study Design and Reporting, *Ecological Economics*, 60, p. 343-350.

Lovell, S., Newbold, S., Owens, N. and Wyatt, T., 2004, How Academic Economists can Improve Benefit Transfers at EPA, Association of Environmental Resource Economists (AERE), *Newsletter*, 24(2), p. 25-28.

Mäler, K. and Vincent, J. (editors), 2005, Handbook of Environmental Economics, Volume 2: Valuing Environmental Changes, Elsevier, Amsterdam, The Netherlands.

Markandya, A., Harou, P., Bellu, L. and Cistulli, V., 2002, Environmental Economics for Sustainable Growth: A Handbook for Practitioners, Edward Elgar, Cheltenham, UK.

Markandya, A., Nunes, P., Bräuer, I., Ten Brink, P., Kuik, O. and Rayment, M., 2008, The Economics Of Ecosystems And Biodiversity – Phase 1 (Scoping) Economic Analysis and Synthesis, Final Report for the European Commission, FEEM, Venice, Italy.

McCarl, B. ,2007, Adaptation Options for Agriculture, Forestry and Fisheries, a report to the UNFCCC Financial and Technical Support Division, United Nations Framework Convention on Climate Change (UNFCCC) Secretariat, Bonn, Germany.

Metroeconomica, 2004, Costing the Impacts of Climate Change in the UK: Implementation Report, Section 4, Economic Valuation Guidelines, UKCIP Technical Report, UK Climate Impacts Program, Oxford, UK.

Miller, E. and Lloyd-Smith, P., 2012, The Economics of Ecosystem Services and Biodiversity in Ontario (TEEBO): Assessing the Knowledge and Gaps, a report prepared for the Ontario Ministry of Natural Resources, Peterborough, Canada.

Miller, W., Robinson, L. and Lawrence, R., (ed.), 2006, Valuing Health for Regulatory Cost-Effectiveness Analysis, Institute of Medicine, The National Academy Press, Washington, DC, USA.

Moeltner, K., Boyle, K. and Paterson, R., 2007. Meta-analysis and Benefit Transfer for Resource Valuation Addressing Classical Challenges with Bayesian Modeling, *Journal of Environmental Economics and Management*, 53, p. 250-269.

Mrozek, J. and Taylor, L., 2002, What Determines the Value of Life? A Meta-analysis, *Journal of Policy Analysis and Management*, 21(2), p. 253-270.

Navrud, S. and Bergland, O., 2001, Value Transfer and Environmental Policy, Policy Research Brief No. 8, Cambridge Research for the Environment, Department of Land Economy, University of Cambridge, Cambridge, UK.

Navrud, S. and Ready, R. (editors), 2007, Environmental Value Transfer: Issues and Methods, The Economics of Non-Market Goods and Services: Volume 9, Springer, Dordrecht, Netherlands.

Nelson, J. and Kennedy, P., 2009, The Use (and Abuse) or Meta-analysis in Environmental and Natural Resource Economics: An Assessment, *Environmental and Resource Economics*, 42, p. 345-377.

Nicholls, R. 2007, Adaptation Options for Coastal Zones and Infrastructure, a report to the UNFCCC Financial and Technical Support Division, United Nations Framework Convention on Climate Change (UNFCCC) Secretariat, Bonn, Germany.

Ojea, E., Ghosh, R., Agrawal, B. and Joshi, P., 2009, The Costs of Ecosystem Adaptation: Methodology and Estimates for Forests, BC3 Working Paper Series 2009-10, Basque Centre for Climate Change (BC3), Bilbao, Spain.

Olewiler, N., 2004, The Value of Natural Capital in Settled Areas in Canada, a report prepared for Ducks Unlimited Canada and the Nature Conservancy of Canada, Calgary, Canada.

OXFAM, 2007, Adapting to Climate Change: What is Needed in Poor Countries and Who Should Pay, Oxfam Briefing Paper 104, New York, USA.

Parry, M., Arnell, N., Berry, P., Dodman, D., Fankhauser, S., Hope, C., Kovats, S., Nicholls, R., Satterthwaite, D., Tiffin, R. and Wheeler, T., 2009, Assessing the Costs of Adaptation to Climate Change: A Review of the UNFCCC and Other Recent Estimates, International Institute for Environment and Development and the Grantham Institute for Climate Change, Imperial College, London, UK.

Pagiola, S., von Ritter, K. and Bishop, J., 2004, Assessing the Economic Value of Ecosystem Conservation, Environment Department, Paper No. 101, World Bank, Washington, DC, USA.

Pearce, D., 2000, Valuing Risks to Life and Health: Towards Consistent Transfer Estimates in the European Union, a paper prepared for the European Commission (DGXI) Workshop on Valuing Mortality and Valuing Morbidity, November 13, 2000, Brussels, Belgium.

Pearce, P., Atkinson, G. and Mourato, S., 2006, Cost-benefit Analysis and the Environment: Recent Developments, Chapter 6-9, OECD, Paris, France.

Plummer, M., 2009, Assessing Benefit Transfer for the Valuation of Ecosystem Services, *Frontiers in Ecological and the Environment*, 7(1), p. 38-45.

Project Catalyst, 2009, Adaptation to Climate Change: Potential Costs and Choices for a Global Agreement, Climate Works Foundation, San Francisco, California, USA.

Public Health Agency of Canada, 2009, Investing in Prevention – the Economic Perspective: Key Findings from a Survey of the Recent Evidence, Public Health Agency of Canada, Ottawa, Canada.

Rashid, H., Haider, W. and McNeil, D., 2007, Urban Riverbank Residents' Evaluation of Flood Evacuation Policies in Winnipeg, Manitoba, Canada, *Environmental Hazards*, 7(4), p. 372-382.

Ready, R., Navrud, S., Day, B., Dubourg, R., Machado, F., Mourato, S., Spanninks, F. and Rodriquez, M., 2004, Benefit Transfer in Europe: How Reliable are Transfers between Countries? *Environmental and Resource Economics*, 29(1), p. 67-82.

Richardson, L. and Loomis, J., 2009, The Total Economic Value of Threatened, Endangered and Rare Species: An Updated Meta-analysis, *Ecological Economics*, 68, p. 1535-1548.

Robinson, L., 2007, Review of Current Approaches for Valuing Nonfatal Injury Risk Reductions and Their Applicability to Homeland Security Rules, Industrial Economics Inc., Washington, DC, USA.

Rosenberger, R. and Loomis, J., 2000, Using Meta-analysis for Benefit Transfer: In-sample Convergent Validity Tests of an Outdoor Recreation Database, *Water Resource Research*, 36, p.1097-1107.

Rosenberger, R. and Loomis, J., 2001, Benefit Transfer of Outdoor Recreation Use Values: A Technical Document Supporting the Forest Service Strategic Plan, RMRS-GTR-72, Department of Agriculture, Forest Service, Fort Collins, Colorado, US.

Rosenberger, R. and Stanley, T., 2006, Measurement, Generalization, and Publication: Sources of Error in Benefit Transfers and their Management, *Ecological Economics*, 60(2), p. 372-8.

Santos, J., 2007, Transferring Landscape Values: How and How Accurately? Navrud, S. and Ready, R. (editors), 2007, Environmental Value Transfer: Issues and Methods, The Economics of Non-Market Goods and Services: Volume 9, Springer, Dordrecht, Netherlands.

Shrestha, R. and Loomis, J., 2001, Testing a Meta-analysis Model for Benefit Transfer in International Outdoor Recreation, *Ecological Economics*, 39, p. 67-83.

TBCS, 2007, Canadian Cost-benefit Analysis Guide: Regulatory Proposals, Section 4.2, Measurement of Benefits, Treasury Board of Canada Secretariat, Ottawa, Ontario.

TEEB, 2008, The Economics of Ecosystems and Biodiversity, Chapter 3 – Towards a Valuation Framework, The Economics of Ecosystems and Biodiversity (TEEB) Study, European Communities, Brussels, Belgium.

TEEB, 2009, The Economics of Ecosystems and Biodiversity, Climate Issues Update, The Economics of Ecosystems and Biodiversity (TEEB) Study, European Communities, Brussels, Belgium.

Ten Brink, P., Rayment, M., Bräuer, I., Braat, L., Bassi, S., Chiabai, A., Markandya, A., Nunes, P., Ten Brink, B., van Oorschot, M., Gerdes, H., Stupak, N., Foo, V., J. Armstrong, Kettunen, M. and Gantioler, S., 2009, Further Developing Assumptions on Monetary Valuation of Biodiversity Cost Of Policy Inaction (COPI), Final Report to the European Commission, Institute for European Environmental Policy (IEEP), Brussels, Belgium.

Thomassin, P. J. and Johnston, R. (2007). "Benefit Transfer of Water Quality Improvements From Agricultural Landscapes: A Meta Analysis", Agriculture Canada and Agri-Food.

Tol, R., Fankhauser, S. and Smith, J., 1998, The Scope for Adaptation to Climate Change: What Can We Learn from the Impact Literature? *Global Environmental Change*, 8(2), p. 109-123.

US EPA, 2000, Guidelines for Preparing Economic Analysis, EPA 240-R-00-003, Office of the Administrator, US Environmental Protection Agency, Washington, DC, USA.

US EPA, 2006, Report of the EPA Work Group on VSL Meta-analysis, Report NCEE-0494, National Center for Environmental Economics, US Environmental Protection Agency, Washington, DC, USA.

US EPA, 2007, The Cost of Illness Handbook, US Environmental Protection Agency, Washington, DC, USA.

US EPA, 2007, SAB Advisory on EPA's Issues in Valuing Mortality Risk Reduction, EPA-SAB-08-001, National Center for Environmental Economics, US Environmental Protection Agency, Washington, DC, USA.

US EPA, 2010, Guidelines for Preparing Economic Analyses, National Centre for Environmental Economics, Office of Policy, EPA 240-R-10-001, US Environmental Protection Agency, Washington, DC, USA.

UNFCCC, 2007, Investment and Financial Flows to Address Climate Change, United Nations Framework Convention on Climate Change (UNFCCC) Secretariat, Bonn, Germany.

UNFCCC, 2009, Potential Costs and Benefits of Adaptation Options: A Review of Existing Literature: Technical Paper, FCCC/TP/2009/2, United Nations Framework Convention on Climate Change (UNFCCC) Secretariat, Bonn, Germany.

UNFCCC, 2010a, Report on the Technical Workshop on Costs and Benefits of Adaptation Options, FCCC/SBSTA/2010/9, United Nations Framework Convention on Climate Change (UNFCCC) Secretariat, Bonn, Germany.

UNFCCC, 2010b, Synthesis Report on Efforts Undertaken to Assess the Costs and Benefits of Adaptation Options, and Views on Lessons Learned, Good Practices, Gaps and Needs, FCCC/SBSTA/2010/3, United Nations Framework Convention on Climate Change (UNFCCC) Secretariat, Bonn, Germany.

UNDP, 2007, Human Development Report 2007-08, United Nations Development Program (UNDP), New York, USA.

Viscusi, W. and J. Aldy, 2003, Value of a Statistical Life: A Critical Review of Market Estimates throughout the World, *Journal of Risk and Uncertainty*, 27(1), p. 5-76.

Viscusi, W., Huber, J. and Bell, J., 2008, The Economic Value of Water Quality, *Environmental and Resource Economics*, 41, p. 169-187.

WBCSD, 2009, Corporate Ecosystem Valuation: A Scoping Study, Final Report prepared for the World Business Council for Sustainable Development (WBCSD) by Environment Management Group & Ecosystem Economics LLC, Washington, DC, USA.

Woodward, R. and Wui, Y., 2001, The Economic Value of Wetland Services: A Meta-analysis, *Ecological Economics*, 37, p. 257-270.

World Bank, 2006, Investment Framework for Clean Energy and Development, World Bank, Washington, DC, USA.

World Bank, 2008, Global Purchasing Power Parities and Real Expenditures, World Bank, Washington, DC, USA.

World Bank, 2009, The Costs to Developing Countries of Adapting to Climate Change: New Methods and Estimates, The Global Report of the Economics of Adaptation to Climate Change Study, World Bank, Washington, DC, USA.

Zandersen, M., Termansen, M. and Jensen F., 2007, Testing Benefits Transfer of Forest Recreation Values over a Twenty-Year Time Horizon, *Land Economics*, 83(3), p. 412-440.

6 Inflation and Rising Relative Values

6.1 Purpose

The purpose of this section is to:

- ⇨ Distinguish between nominal (current) prices and real (constant) prices;
- ⇨ Clarify why economic appraisal typically uses real prices, fixed at a specific base year;
- ⇨ Provide a procedure for converting between nominal and real prices, and for fixing prices at a specific base year; and
- ⇨ Explain how prices can increase in real terms over time and provide an approach to account for rising relative valuations of non-market impacts.

6.2 Allowing for Inflation

Economic appraisal looks to identify adaptation actions that are, at the time of approval, expected to provide the highest net economic returns in the future. Prices are used to express quantified impacts in value terms in order to construct measures of costs and benefits. A consistent set of prices should be used for all future costs and benefits.

An analyst can value future costs and benefits using real or nominal prices. Real price is interchangeably used with constant price and nominal price with current price. The nominal price of an impact is simply its stated price, and includes the effects of inflation (increases in the general price level. With the nominal price approach, the impact of expected inflation is thus explicitly reflected in future costs and benefits. The real price of an impact, on the other hand, is its price adjusted to reflect changes in the general price level. Real prices are nominal prices where the effect of inflation has been removed. Where nominal prices are adjusted for inflation, it is assumed that inflation will affect the price of future impacts to the same extent, such that prices retain the same relationship to each other. An impact's real price is therefore its particular price, compared to the general level of all prices.

In economic appraisal, it is customary to price impacts using real prices, fixed at a specific base year. Why?

- ⇨ It ensures that the future costs and benefits of an adaptation action are estimated in the same units as costs and benefits measured at the time the decision to invest is to be made.
- ⇨ Changes in real prices are a better measure of the real economic burden or significance of a price, than are changes in nominal prices.
- ⇨ The demanding data requirements of the nominal price approach, where inflation rates need to be estimated for the entire life of the adaptation action.

A common mistake made by analysts conducting economic appraisal is to confuse discounting with inflation and relative price changes. It is true that inflation is another reason a dollar in the future is worth less than a dollar now.[22] However, as explained in Section 7.2, inflation and discounting are conceptually very different.

Box 6-1: Key inflation concepts

Absolute prices: The value attached to an impact.

Consumer Price Index: The consumer price index (CPI) is a measure of the general price level paid by consumers for a 'basket' of goods and services they purchase. Monthly or annual changes in the CPI provide a good measure of the rate of general price inflation faced by consumers.

Deflation: A decline in the general price level over time. Deflation is the opposite of inflation.

Deflator: The price indicator used to convert (deflate) between nominal (current) and real (constant) values.

General price level: Is given by the weighted average price of a representative basket of consumer goods and services traded in the economy, relative to the price of that basket at some fixed date in the past. The general price level therefore shows what is happening to consumer prices on average, and not what is happening to the price of individual goods and services. An increase in the price of a specific good or service over time does not necessarily mean that the general price level has changed. For example, increases in the price of one item may be offset by decreases in the price of another item, to the extent that the average price level remains unchanged. For the general price level to move upward, i.e., inflate, the prices of a majority of items in the basket must increase.

Gross Domestic Product deflator: A price index which adjusts the overall value of Gross Domestic Product (GDP) according to the average increase in the prices of all output. The GDP deflator equals the ratio of nominal GDP to real GDP. It is an alternative to the CPI as a measure of inflation.

Inflation: An increase in the general price level over time. Inflation is the opposite of deflation.

Inflation rate: The rate at which the general price level increases over a specified time period, e.g., monthly or yearly.

Nominal (current) prices: Prices actually observed at a given time. Prices that include the effects of general price inflation.

Real (current) prices: Prices that have been deflated by an appropriate price index based on prices prevailing in a given base year. Real or constant price variables adjust nominal price variables for changes in the general price level; that is, they are inflation-adjusted prices.

Real rates: Rates deflated to exclude changes in the general price level, e.g., real discount rates are nominal rates adjusted for the rate of inflation.

Relative prices: The value of two impacts in terms of each other.

[22] As a result of inflation, one cannot purchase as many goods and services with a dollar today as one could last year, or the year before that.

6.2.1 Real and nominal discount rates

The social discount rate (SDR), too, can be measured in real terms, as the difference between the nominal SDR (in per cent) and the rate of general price inflation. It is important that real and nominal values (prices and discount rates) are used consistently throughout an economic appraisal. In particular, when the analyst works with nominal (real) prices, the SDR should also include (exclude) the effects of inflation. This reflects the fact that funders of adaptation actions require compensation for anticipated inflation as part of the price of making capital available. With annual compounding, a real SDR is converted into a nominal one as follows:

$$\text{nominal SDR} = (1 + \text{real SDR})(1 + \text{inflation rate}) - 1 \qquad \text{Equation 6-1}$$

Thus, with a real SDR of, say, 3.5 per cent, and an expected annual rate of general price inflation of 2.0 per cent, the correct nominal SDR is 5.6 per cent. Note that the intuitive alternative of summing the real SDR and the expected inflation rate -- to give 5.5 per cent -- slightly underestimates the correct value.

On the other hand, to convert a nominal SDR into a real SDR, the equation is:

$$\text{real SDR} = \frac{(1 + \text{nominal SDR})}{(1 + \text{inflation rate})} - 1 \qquad \text{Equation 6-2}$$

If the nominal SDR is 8.5 per cent and the expected inflation rate is 2.2 per cent, the corresponding real SDR is 6.2 per cent. Note that here the intuitive approach of subtracting the expected inflation rate from the nominal SDR – to give 6.3 – slightly overestimates the correct value.

While expected inflation is difficult to predict, the annual inflation rate is commonly based on recent experience. On the basis that the consumer price index (CPI) is central to capital markets' assessment of the current rate of inflation, it is recommended that the CPI be used to convert between real and nominal SDRs.

6.3 Fixing prices at a specific base year

Economic appraisal of adaptation actions should be undertaken using real values; that is, in the price level of a given year. The choice of year in which prices are to be expressed does not strictly matter. It is only important that one year (the 'base year') is chosen and that all costs and benefits are valued at the prices prevailing in that year. Typically, the year the decision is being taken, the year of the analysis, or the most recent year for which key data are available, is selected as the base year. But it is perfectly acceptable to change the base year to meet with some other need, e.g., to facilitate the comparison of one adaptation study with another. For example, an analyst may be appraising two adaptation options to reduce exposure to a specific priority risk; one option may have been valued at nominal prices in 2001, whereas the other option may have been valued at nominal prices in 2008. If the general price level rose in the intervening period, a direct comparison of the two adaptation options would be misleading.

While it is common practice when performing economic appraisal of adaptation actions to fix prices to essentially the first year of the project, when performing economic evaluation as part of an *ex post* review, the convention is to fix prices to the final year of the project.

To illustrate the procedure to fix prices at a specific base year by netting out the effect of inflation, consider the following example.

Suppose the nominal price of irrigation in 2000-01 and 2006-07 is, respectively, 39 and 63 cents per m^2 (see Box 1-2). Further, assume that general price inflation over the entire period is 19.0 per cent; meaning the appropriate price deflator has an index value of 100 in 2000-01 and 119 in 2006-07. Now suppose it is necessary to fix the price data at 2000-01 prices, because that is the chosen base year for your study. To net out inflation and fix the price of irrigation at 2000-01 real prices, you divide the current price of irrigation in 2006-07 by 1.19 (or 119 ÷ 100):

$$\frac{63}{1.19} = 53 \text{ cents per } m^2$$

In the study, irrigation in 2000-01 and 2006-07 is therefore valued at 39 and 53 cents per m^2, respectively, in constant 2000-01 prices.

If, instead, the chosen base year is 2003-04, you precede by first re-basing the price deflator so it has an index value of 100 in 2003-04. To do this you simply divide the index value in each year by the value in the chosen base year, in this case 110. The re-based value for 2006-07 is thus:

$$\frac{119}{110} \times 100 = 108$$

In other words, general price inflation between 2003-04 and 2006-07 is 8 per cent. To fix the price of irrigation at 2003-04 real prices you proceed as above and divide the nominal price of irrigation in 2006-07 by 1.08 (or 108 ÷ 100):

$$\frac{63}{1.08} = 58 \text{ cents per } m^2$$

At 2003-04 constant prices, irrigation in 2006-07 is now valued at 58 cents per m^2.

6.3.1 Potential price deflators

The price deflator used to convert (deflate) between nominal and real values is a time series measure of inflation, 'grounded' in a particular base year. The most prominent measure of inflation is the Consumer Price Index (CPI). It is a measure of movements in the price paid by consumers for a specific 'basket' of commodities. The CPI can be broken down into sub-indices, which reflect price movements in specific commodities or sub-groups of commodities that make up the overall basket (e.g., clothing, food, transportation, etc.).

Consumer spending is, however, only one part of the economy. Prices can change in other areas, as well, and alternative measures of inflation have been developed by Statistics Canada to reflect this. For example, the Industrial Product Price Index (IPPI) measures price changes for major commodities sold by manufacturers in Canada. Other specialized commodity price indices capture movements in the prices of resource-based commodities (such as energy, raw materials, and agricultural products).

A further measure of inflation is provided by the Gross Domestic Product (GDP) or implicit price deflator. This is a special index designed to capture the overall level of inflation in everything that an economy produces. It is therefore a broader measure of inflation than the CPI, which captures inflation only in consumer markets. The GDP deflator represents the ratio of nominal GDP to real GDP.

Statistics Canada tracks these and many other price movements using a number of key indexes. They are available at: http://www5.statcan.gc.ca/subject-sujet/theme-theme.action?pid=3956&lang=eng&more=0. Estimates of future inflation are available from investment firms, Department of Finance Canada, The Bank of Canada, or the OECD.

Box 6-2: Creating and using price indices

In the table below, assume column A shows the nominal price of irrigating land from 2000 to 2007. This series of numbers can be converted into index numbers as follows:

1. Select a reference year for the base year, say, 2000.
2. Divide the value in the base year by 100 (i.e. 39 ÷ 100 = 0.39).
3. Divide all numbers in the original price series by the result of Step 2.

The resulting nominal price index ('grounded' in whatever base year chosen), which has no units, is given in column B. Using the relationships below, a real (or constant) price index can be created by netting out the effect of inflation:

- ⇨ The nominal price index (series) ÷ by the price deflator × 100 = the real price index (series).
- ⇨ The nominal price index (series) ÷ by the real price index (series) × 100 = the price deflator.
- ⇨ The real price index (series) × the price deflator ÷ 100 = nominal price index (series).

The resulting real price index is given in column E.

	A	B	C	D	E
	Nominal prices	Nominal price index	Price deflator	Real prices	Real price index
	(cents/m^2)	(2000=100)	(2000=100)	(cents/m^2)	(2000=100)
2000-01	39	100	100	39	100
2001-02	45	115	105	43	110
2002-03	50	128	108	46	119
2003-04	54	138	110	49	126
2004-05	58	149	113	51	132
2005-06	60	154	117	51	131
2006-07	63	162	119	53	136

6.4 Accounting for rising relative values

As the above example illustrates, even when the effects of inflation are netted out through the use of real prices, the relative prices of goods or services may still vary as a result of, for example, improvements in productivity, technology change, or even differential inflation. The real price of irrigation in Box 6-2 increased between 2000-01 and 2006-07; the absolute price of irrigation rose faster than the general price level. Put another way, irrigation attracted a higher valuation over that period relative to the 'basket' of consumer commodities (as the CPI was used as the deflator).

In economic analysis, a change in the relative price of an input or output is expected to result in a change in the amount of resources that must be foregone by using that input or output to adapt instead of elsewhere in the economy. Changes in relative prices reflect changes in real resource use. It is therefore important to include any rising (or falling) relative valuations in the economic appraisal of adaptation decisions.

The relative prices of non-market goods and services affected by adaptation decisions may also rise (or fall) over time. It is reasonable to assume that the overall stock of environmental goods and services will likely deteriorate or decline with time. Furthermore, as real incomes grow with time, individuals' willingness-to-pay (WTP) is also likely to grow, reflecting a positive income elasticity of WTP for the environment. For these reasons, each unit of the environment will likely attract a higher valuation (price) into the future.

An analyst can account for rising relative valuations of non-market impacts arising from adaptation decisions using Equation 6-3:

$$P_t = P_0 \times (1 + e \times \dot{y})^t \qquad \text{Equation 6-3}$$

Where:

P_t	=	Real price of non-market good or service at year *t*.
P_0	=	Real price of non-market good or service at year 0, the base year for the study.
e	=	Income elasticity of WTP, i.e., the percentage change in WTP from a given percentage change in real per capita income.
$\dot{y}$	=	Rate of growth in real per capita incomes.

Empirical evidence suggests that the income elasticity of WTP for changes to non-market goods and services is less than unity, with numbers likely between 0.3 and 0.7 (Pearce, 2003). An analyst can use the mid-point of this range (0.5) with sensitivity analysis around values of 0.3 and 0.7. Note, however, that studies of mortality risks suggest values for the income elasticity of the value of a statistical life (VOSL) toward the upper end of the 0.3-0.7 range (Viscusi and Aldy, 2003; Bellavance et al, 2007).

To illustrate how Equation 6-3 is used, assume that real per capita income is projected to grow at a rate of 2 per cent per year over the life of the adaptation option. Taking the mid-point estimate for *e* of 0.5, then for any given year *t*, the real price of an affected non-market good or service in that year is found by multiplying the base-year price by:

$$\left(1 + 0.5 \times \frac{2}{100}\right)^{t} = 1.01^{t}$$

Hence, the price of the affected non-market good or service grows at a real rate of one per cent per year. If the adaptation option had a 50-year time horizon, then the price of the non-market good or service would be multiplied by about 1.65:

$$\left(1 + 0.5 \times \frac{2}{100}\right)^{50} = 1.01^{50} \cong 1.65$$

The effect would be to add close to 65 per cent to the base-year price. This example illustrates how including relative price changes of affected non-market goods or services could have a potentially significant impact on the outcome of an adaptation decision.

6.5 References and further reading

Bellavance, F., Dionne, G., and Lebeau, M., 2007, The Value of a Statistical Life: A Meta-Analysis with a Mixed Effects Regression Model, Canada Research Chair in Risk Management Working paper 06-12, HEC, Montreal, January 2007.

Pearce, D., 2003, Conceptual Framework for Analyzing the Distributive Impacts of Environmental Policies, prepared for the OECD Environment Directorate Workshop on the Distribution of Benefits and Costs of Environmental Policies, OECD, Paris, April, 2003.

Viscusi, W. and Aldy, J., 2003, Value of a Statistical Life: A Critical Review of Market Estimates throughout the World, *Journal of Risk and Uncertainty*, 27(1), p. 5-76.

7 Discounting Future Costs and Benefits

7.1 Purpose

The purpose of this section is to:

- Explain why future costs and benefits are discounted in economic analysis;
- Define basic discounting concepts and provide guidance for calculating present values and future values;
- Outline a procedure for comparing adaptation actions with different lifetimes, and explain why this procedure is necessary;
- Highlight the effect of discounting and the choice of social discount rate on the present value of future costs and benefits;
- Distinguish between the descriptive and prescriptive approaches to deriving an appropriate social discount rate;
- Identify the appropriate social discount rate as revealed by society's savings and investment decisions, and explain under what conditions it is reasonable to use this rate;
- Look at estimates of the weighted average social opportunity cost of capital for Canada as a practical alternative to the social discount rate;
- Explain how to construct a prescriptive discount rate using the Ramsey equation; discuss the range of plausible values in the literature for each of the equation's elements; highlight the value judgments associated with the choice of specific values; and construct a range of plausible social discount rates for Canada;
- Define the shadow price of capital and discuss under what conditions it may need to be applied; and
- Suggest an approach for discounting in the context of adaptation actions, distinguishing between actions with intra-generational and inter-generational effects.

7.2 The process of discounting

7.2.1 Why discount?

Adaptation actions will typically yield streams of costs and benefits that do not occur in the same year, but rather are spread out over many years, even decades. However, decision-makers and the people they represent are not indifferent with respect to the timing of costs and benefits. People prefer to consume goods and services (receive benefits) sooner rather than later, and to pay for those goods and services (incur costs) as late as possible. So, why do people behave as if a dollar in their pocket today is worth more than a dollar in their pocket next year? For a start, if the person receiving a dollar today decided to put it into a savings account, it would earn interest. In a year's time the value of their savings would hopefully be worth more than a dollar in real terms; that person would have more than a dollar to spend on goods and services. We may also expect to be better off in the future than we are today. But, as our incomes and living standards increase, it is generally accepted that we accrue less enjoyment from receipt of an additional dollar. A gain or loss of a dollar to a billionaire, for example, will have much less of an impact on his or her well-being than a gain or loss of a dollar to someone living in poverty. Hence, we prefer to have that dollar now – when we value it more – as opposed to later when hopefully we'll be better off.

In addition, people may simply care less about their own welfare in the future, or indeed, for the welfare of future generations vis-à-vis their generation. This may include an element of impatience – people may not want the inconvenience of having to wait around till next year to receive a dollar because they want to spend it now. There is also the risk of not being around next year to receive the dollar and enjoy its benefits; there is the risk of dying beforehand.

Therefore, it is important that the appraisal of candidate adaptation actions takes account of the time at which costs and benefits occur. The standard way to do this is to discount (or weight) future costs and benefits so that they are comparable to the value placed on present day costs and benefits, when decision-makers must decide between actions. This is accomplished by discounting future costs and benefits to present values.

7.2.2 Basic concepts

7.2.2.1 Future values and present values

Discounting refers to the process of attributing a lower weight to future costs or benefits to reduce them to an equivalent amount of today's dollars. The resulting amount of today's dollars is known as the present value of the future stream of costs and benefits. The present value is calculated using the concept of compound interest. Interest is compounded when a dollar is invested for a number of periods – typically years – and the interest earned each period is reinvested. Interest earned on reinvested interest is known as compound interest. The future value (FV) of a dollar invested for *n* years with interest earned each year compounded at an annual rate r is:[23]

$$\text{future value} = \$1 \times (1 + \text{interest rate per year})^{\text{number of years}}$$

or   Equation 7-1

$$\text{FV} = \$1 \times (1 + r)^n$$

Conversely, the present value (PV) of a dollar received in *n* years with interest compounded annually at rate r is:

$$\text{present value} = \$1 \times 1/(1 + \text{interest rate per year})^{\text{number of years}}$$

or   Equation 7-2

$$\text{PV} = \$1 \times 1/(1 + r)^n = \$1 \times (1 + r)^{-n}$$

The relationship between future values and present values should now be evident; the process of discounting (calculating the present value of a future cash flow) is the opposite of compounding (calculating the future value of a present cash flow). In general terms:

$$\text{FV} = \text{PV} \times (1 + r)^n \ \text{ and } \ \text{PV} = \frac{\text{FV}}{(1 + r)^n} \qquad \text{Equation 7-3}$$

The term in Equation 7-2 that the dollar amount is multiplied by is known as the discount factor:

$$\text{discount factor} = \frac{1}{(1 + r)^n} = (1 + r)^{-n} \qquad \text{Equation 7-4}$$

The discount factor constitutes the weight (*w*) applied to dollars received in future years. It is used to convert future dollar flows into present day equivalents.[24]

Thus far the discussion has focused on a single (dollar) cost or benefit paid or received in a specified future time period, *n* years from now. Now consider the case of multiple costs or benefits occurring for multiple years over a period of *n* years. Dealing with costs or benefits that that are paid or received at different points in time is made easier using a time line that shows both the timing and the dollar value of each cost or benefit in a stream. Thus, a benefit stream of \$100, \$200, \$200, and \$300 at the beginning of each of the next four years can be depicted on a time line like the one shown below:

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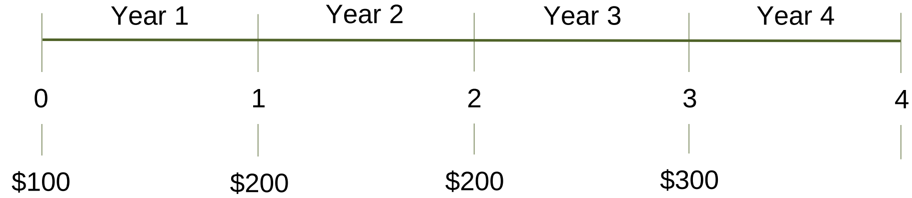
[23] For all intents and purposes the annual rate r is the real annual social discount rate or SDR for short. Derivation of an appropriate SDR is not of immediate concern; it is discussed below.

[24] The link between the rate i and the discount factor can be shown by writing (OXERA, 2002):

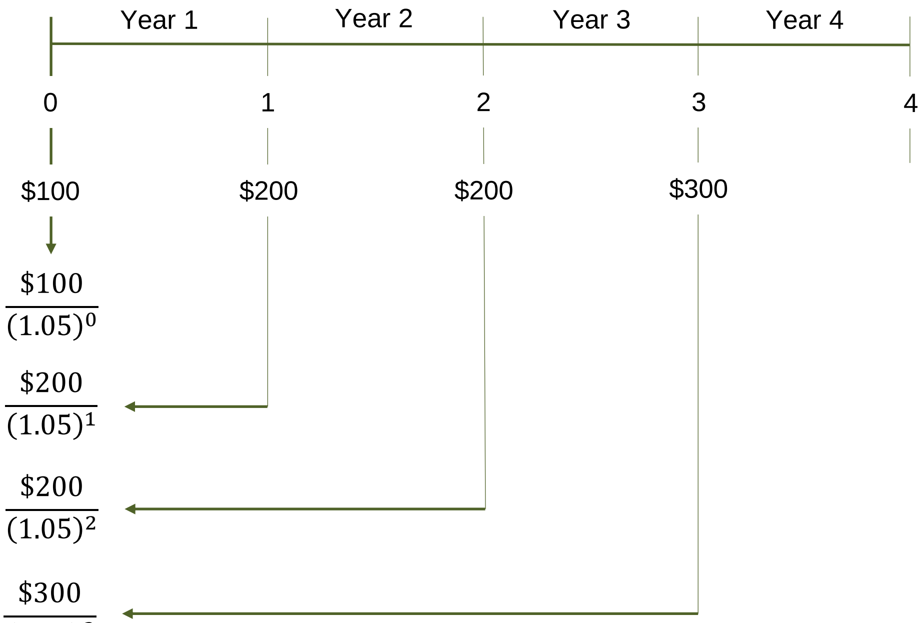
$$r = \frac{w_{n-1}}{w_n} - 1 \text{ since } w_2 = \frac{w_1}{(1 + r)}, w_3 = \frac{w_2}{(1 + r)}, \text{and so on}$$

Written this way, it can be seen that the rate r is constant and does not vary with time. As discussed below, however, there are arguments for the rate r declining the further into the future dollars are received.



In the time line, 0 refers to now. A benefit that occurs at time 0 (t = 0) is therefore already in present value terms and does not need to be adjusted for the time value of money. An important distinction must be made here between a period of time and a point in time. The portion of the time line between t = 0 and t = 1 refers to period one, which, as stated above, is typically one year. The benefit that occurs at the point in time t = 1 refers to the benefit that occurs at the end of period 1, year 1 in this case. Note that in present value terms, a benefit that occurs at the beginning of year 2 is the equivalent of a benefit that occurs at the end of year 1; that is, the benefit is received at t = 1 in both cases and calculating its present value involves discounting it back one period.

To obtain the present value of the above stream of future benefits the analyst needs to calculate the discounted value of each future benefit and add the resulting values together. This is done by repeatedly applying Equation 7-2 to each future benefit, as follows:



$$\$100 = \frac{\$100}{(1.05)^0}$$

$$\$181 = \frac{\$200}{(1.05)^1}$$

$$\$173 = \frac{\$200}{(1.05)^2}$$

$$\$259 = \frac{\$300}{(1.05)^3}$$

$$\$713$$

In this example r is assumed to be 5.0 per cent per year.

In general terms, suppose the dollar value of a benefit received in the future is denoted by B_t where t refers to the point in time when the benefit is received. Further assume these benefits are generated for *n* years. The present value of the resulting stream of benefits is the sum of all annual benefits, with each annual benefit discounted by the appropriate real annual SDR to convert it into present value terms:

$$\text{PV} = \frac{B_{t=0}}{(1+r)^{t=0}} + \frac{B_{t=1}}{(1+r)^{t=1}} + \frac{B_{t=2}}{(1+r)^{t=2}} + \cdots + \frac{B_{t=n-1}}{(1+r)^{t=n-1}}$$ Equation 7-5

Equation 7-5 reduces to the standard equation for the present value of a future stream of project benefits (present value benefits, PVB):

$$\text{PVB} = \sum_{t=0}^{n-1} \frac{B_t}{(1+r)^t}$$ Equation 7-6

The sigma sign ($\sum$) is the symbol for summation. The analogous equation for the present value of a stream of project costs (present value costs, PVC) is:

$$\text{PVC} = \sum_{t=0}^{n-1} \frac{C_t}{(1+r)^t}$$ Equation 7-7

The net benefits (NB) of an adaptation action are simply the difference between project benefits and project costs (NB = benefits – costs). If the stream of project costs includes all initial capital expenditures, where relevant, the difference between present value benefits and present value costs is referred to as the project's net present value (NPV):

$$\text{NPV} = \text{PVB} - \text{PVC}$$ Equation 7-8

Inserting Equation 7-6 and Equation 7-7 into Equation 7-8 produces an expression for calculating the NPV of an adaptation action:

$$\text{NPV} = \sum_{t=0}^{n-1} \frac{B_t}{(1+r)^t} - \sum_{t=0}^{n-1} \frac{C_t}{(1+r)^t}$$

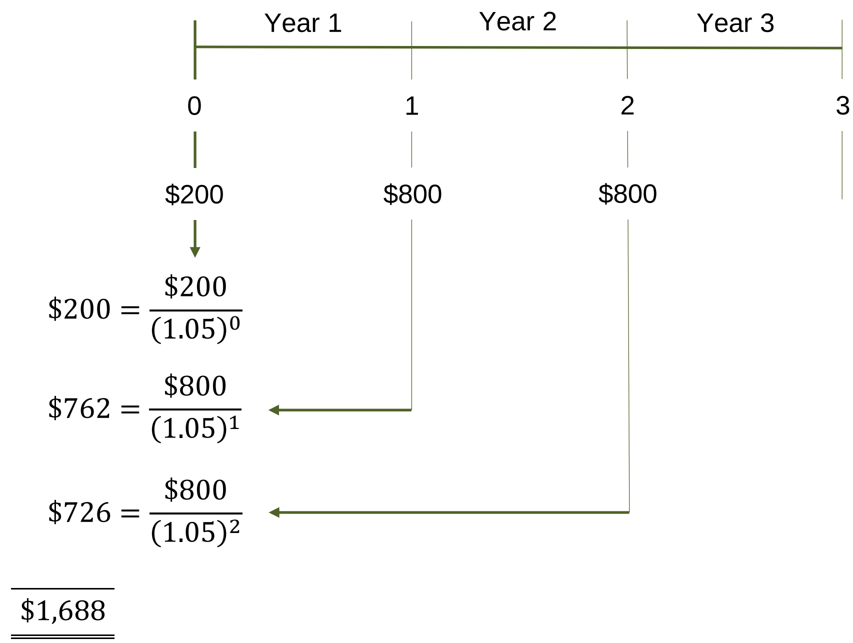
or equivalently Equation 7-9

$$\text{NPV} = \sum_{t=0}^{n-1} \frac{NB_t}{(1+r)^t}$$

To illustrate how Equation 7-9 is applied, suppose that there are two adaptation actions, A and B. Action A has a three-year life, and yields incremental net benefits (inclusive of capital expenditures) of \$200 immediately and \$800 for two further years. In contrast, action B has a four-year life, and yields incremental net benefits of \$200 (inclusive of capital expenditures) immediately, \$450 for the next two years, and \$775 in the final year. If the annual real SDR is 5.0 per cent, the NPV of each adaptation action A is:

$$\text{NPV (A)} = \sum_{t=0}^{2} \frac{\$200}{(1.05)^0} + \frac{\$800}{(1.05)^1} + \frac{\$800}{(1.05)^2} = \$1{,}688 \qquad \text{Equation 7-10}$$

The timeline for action A is:

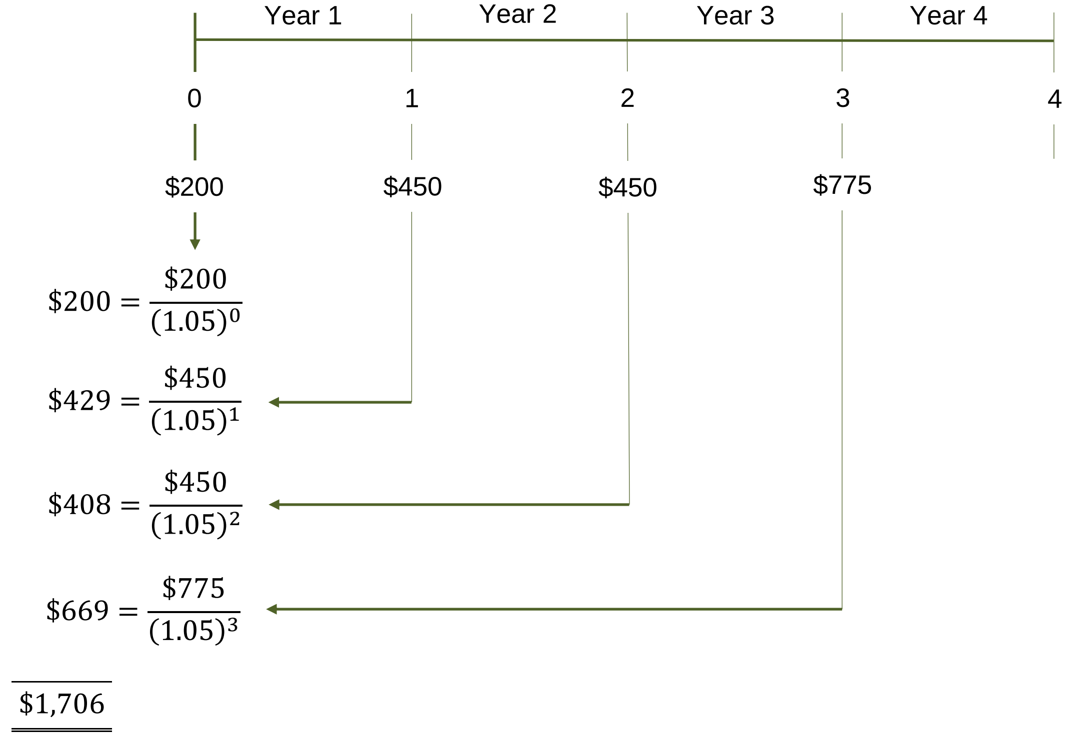


The NPV of each adaptation action B is:

$$\text{NPV (B)} = \sum_{t=0}^{3} \frac{\$200}{(1.05)^0} + \frac{\$450}{(1.05)^1} + \frac{\$450}{(1.05)^2} + \frac{\$775}{(1.05)^3} = \$1{,}706 \qquad \text{Equation 7-11}$$

Adaptation action B has a higher NPV than action A, and may therefore be preferred by decision-makers; decision rules, such as NPV, are explored in more detail in Section 8. As discussed below, and analyst should compare adaptation actions with different lifetimes – as is the case in this example – on the basis of their equivalent annual net benefits (see Section 7.2.2.6).

The timeline for action B is:



Now consider a situation where the appropriate real annual SDR is 10.0 per cent rather than 5.0 per cent - in effect lowering the present value of benefits received in the future. The revised NPVs are:

$$\text{NPV (A)} = \sum_{t=0}^{2} \frac{\$200}{(1.10)^0} + \frac{\$800}{(1.10)^1} + \frac{\$800}{(1.10)^2} = \$1{,}588$$

Equation 7-12

$$\text{NPV (B)} = \sum_{t=0}^{3} \frac{\$200}{(1.10)^0} + \frac{\$450}{(1.10)^1} + \frac{\$450}{(1.10)^2} + \frac{\$700}{(1.10)^3} = \$1{,}563$$

Now adaptation action A has the higher NPV. The effect of the selected SDR on present costs and benefits is explored further below.

7.2.2.2 Timing of costs and benefits

Care should be taken to explicitly state how time periods are designated. As noted above time periods are typically defined as years. Costs and benefits may also be discounted to any base year; the definition of a base year for the appraisal was discussed in the previous section. Furthermore, costs and benefits may be discounted to either the beginning or end of the chosen base year. As a result, the analyst needs to explicitly state when costs and benefits accrue.

The numerical examples presented above all assume that the first cash outflows and inflows from an adaptation action occur immediately, at the beginning of the first year (labeled with the subscript t = 0). That is, all incremental costs or benefits incurred during the course of a year (whether year 1, 2, 3, etc.) are assumed to be paid or received in advance - all at once at the beginning of the relevant year. The timing of net benefits for an adaptation action with a life of four years – with costs and benefits assumed to be realized at the beginning of each year - is shown in Figure 7-1. This mirrors the time lines shown above. Net benefits (NB_a) incurred throughout the first year of the project are assumed to happen now, at t = 0. Consequently, they are not, in effect, discounted; the discount factor evaluated at t = 0 is one. Net benefits (NB_b) incurred during the second year are assumed to accrue at the beginning of that year, at t = 1. Calculating the present value of NB_b thus involves discounting them back one year, from t = 1 to t = 0. The present value of net benefits NB_c incurred during year three is found by discounting them back two years, from t = 2 to t = 0. And so on.

In contrast, the analyst may assume that all costs and benefits incurred throughout a year are paid or received in arrears – all at once at the end of the year. Figure 7-2 shows the time line for the net benefits of an adaptation action with a life of four years - with costs and benefits assumed to be realized at the end of each year. With costs and benefits paid and received at the end of the year, the modified expression for calculating the NPV of an adaptation action is:

$$\mathrm{NPV} = \sum_{t=1}^{n} \frac{B_t}{(1+r)^t} - \sum_{t=1}^{n} \frac{C_t}{(1+r)^t}$$

or equivalently — Equation 7-13

$$\mathrm{NPV} = \sum_{t=1}^{n} \frac{NB_t}{(1+r)^t}$$

Either approach can be used, though assuming payments in advance – at the beginning of each year – is generally closer to actual patterns of expenditure.[25] The analyst should be transparent about the approach followed.

[25] If using the NPV function in Excel it is important to remember that the formula assumes costs and benefits accrue at the end of each year. To convert to the other approach the net benefit estimate for year one must be excluded from the array when prompted to define the 'Value 1' arguments in the NPV formula box, and added to the result of the NPV function.

Figure 7-1: Base date for discounting – beginning of each year

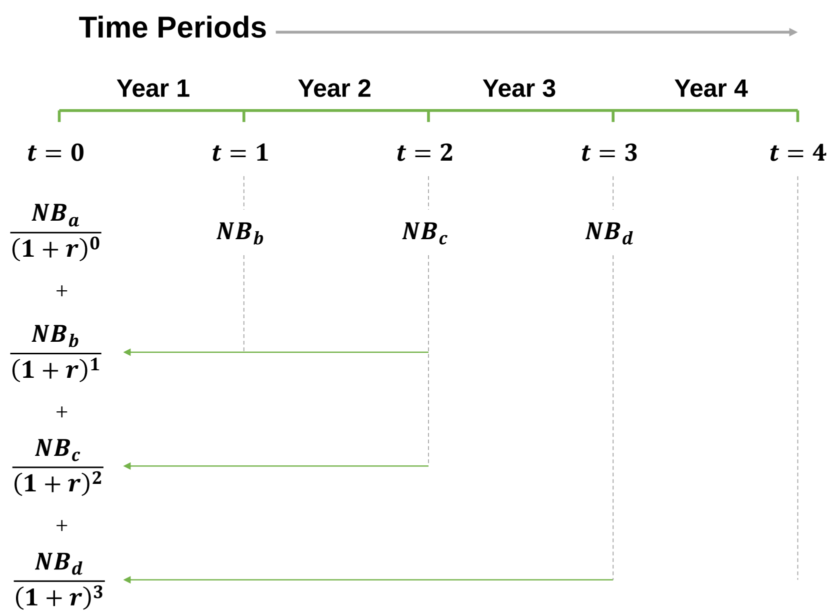
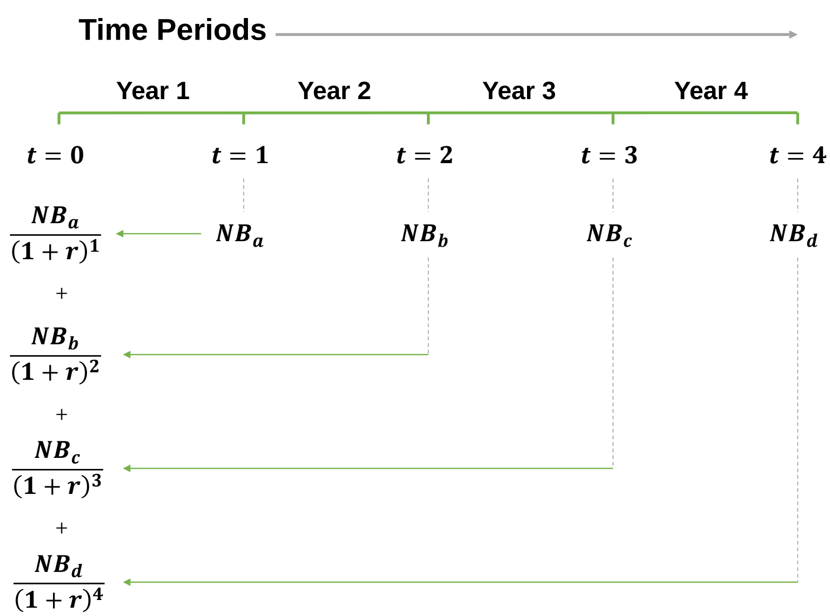


Figure 7-2: Base date for discounting – end of each year



7.2.2.3 Appraisal versus evaluation

Recall from Section 1.5 that economic appraisal techniques can be applied (HMT, 2004):

- At the start – to provide prospective analysis in support of decisions to implement a new adaptation action or to renew or expand existing adaptations. In this context they are informing the *appraisal* part of the adaptation planning process.
- And at the finish – to provide retrospective analysis of an adaptation action at its completion, conclusion or revision. In this context they are informing the *evaluation* of the adaptation planning process.

In the former context – that of *ex ante* appraisal – common practice is to use the first year of the adaptation action or the year in which the appraisal is being undertaken as the base year. All future streams of costs and benefits are discounted back to the defined base year; that is, the analyst calculates the present value of each cost and benefit. In the latter context – that of *ex post* evaluation - the final year of the adaptation action or the year in which the evaluation is being conducted is normally defined as the base year. All observed streams of costs and benefits are compounded forward to the set base year, with the analyst calculating the future value, rather than the present value, of each observed cost and benefit. When compounding to the end of an evaluation period, observed costs and benefits are divided by the appropriate discount factor ($1/(1+r)^t$) rather than multiplied by the discount factor.

7.2.2.4 Valuation of future costs and benefits

Discounting should not be confused with determining the actual future value of distant costs and benefits. In recognition of the time value of money – that a dollar now is worth more than a dollar next year – discounting is a technique for converting future costs and benefits from one time period to another in order to express them in an equivalent amount of today's dollars. It is not, however, a method for actually determining the value of these future costs and benefits. Discounting is conceptually a process very different from dealing with rising relative valuations of adaptation impacts over time, as discussed in the previous section. Estimating the value of distant costs and benefits and subsequently translating them into present value equivalents should be treated as separate procedures (US EPA, 2000).

7.2.2.5 Defining the time horizon

To apply discounting it is necessary to define a time horizon for the analysis. A basic premise of cost-benefit analysis (CBA) is to account for all the welfare effects of a policy, program or project on those individuals with standing. The time horizon for the analysis should therefore be sufficiently long to capture all major costs and benefits. Put another way, the time horizon ideally should be defined so that the present value of any net benefits beyond that point are anticipated to be close to zero, and therefore will have a negligible impact on calculated NPV. In practice, however, the time horizon is often defined with respect to, for example, the technical life of capital investments or statutory requirements for the policy, program or project. The analyst should explain and document the choice of time horizon.

7.2.2.6 Comparing adaptation actions with different lifetimes

Adaptation actions with different lifetimes should not be compared with one another solely on the basis of NPV. Two modified approaches may help the analyst appraise actions with different lifetimes (Boardman *et al*, 2006):

Rolling over the action with the shorter lifetime

Suppose an adaptation action, A, has a lifetime that is *x* times the number of years as another action, B. To appraise the relative economic merits of these two actions, one method is to assume that action B is repeated *x* times, and then compare the NPV of a stream of *x* back-to-back action Bs with the NPV of a single action A. For example, if action A spans 45 years and action B spans 15 years, the analyst should compare the NPV of action A with the discounted NPV of three (*x* = 3) back-to-back action Bs, as follows:

$$\text{If NPV(A)} - \left[\text{NPV(B)} + \frac{\text{NPV(B)}}{(1+r)^{15}} + \frac{\text{NPV(B)}}{(1+r)^{30}}\right] > 0, \text{accept A}$$

$$\text{If NPV(A)} - \left[\text{NPV(B)} + \frac{\text{NPV(B)}}{(1+r)^{15}} + \frac{\text{NPV(B)}}{(1+r)^{30}}\right] < 0, \text{accept B}$$

Equation 7-14

Note that NPV(B) is the NPV of one 15-year adaptation action B.

Calculating equivalent annual net benefits

An alternative approach is to calculate the equivalent annual net benefit of each adaptation action. This involves finding the 'annualized' dollar amount, *E*, which, over a period of *n* years (the lifetime of the adaptation action) discounted at the real annual SDR, will be equivalent to the NPV of the action. Assuming payments or receipts occur at the beginning of the year, this is expressed as follows:

$$\text{NPV} = \frac{E}{(1+r)^0} + \frac{E}{(1+r)^1} + \frac{E}{(1+r)^2} = \cdots + \frac{E}{(1+r)^n}$$

Equation 7-15

Rearranging and condensing yields:

$$E = \text{NPV} \Big/ \left[\frac{1-(1+r)^{-n}}{r}\right](1+r)$$

or in words

E = NPV / annuity due [evaluated at *r* and *n*]

Equation 7-16

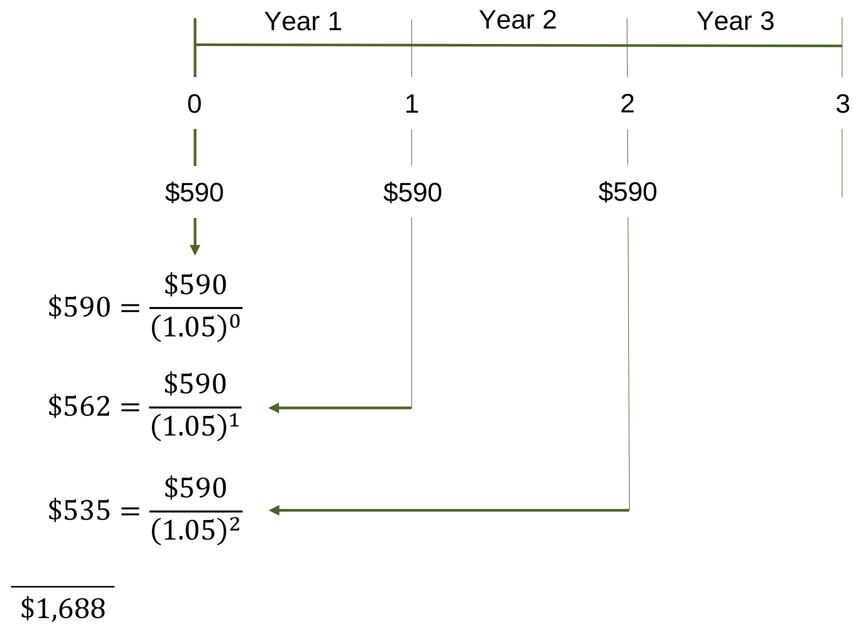
To illustrate how Equation 7-15 is applied, reconsider the two adaptation actions, A and B, introduced above. Recall that action A is a three-year project that yields incremental net benefits of $200 immediately and $800 for two further years; action B is a four-year project that yields incremental net benefits of $200 immediately, $450 for the next two years, and $775 in the final year. If the annual real SDR is 5.0 per cent, the equivalent annual net benefit of adaptation action A is:

$$E(\mathrm{A}) = \$1{,}688 \Big/ \left[\frac{1-(1.05)^{-3}}{0.05}\right](1.05)$$

$$E(\mathrm{A}) = \frac{\$1{,}688}{2.859} = \$590$$

Equation 7-17

The relevant timeline for action A is:



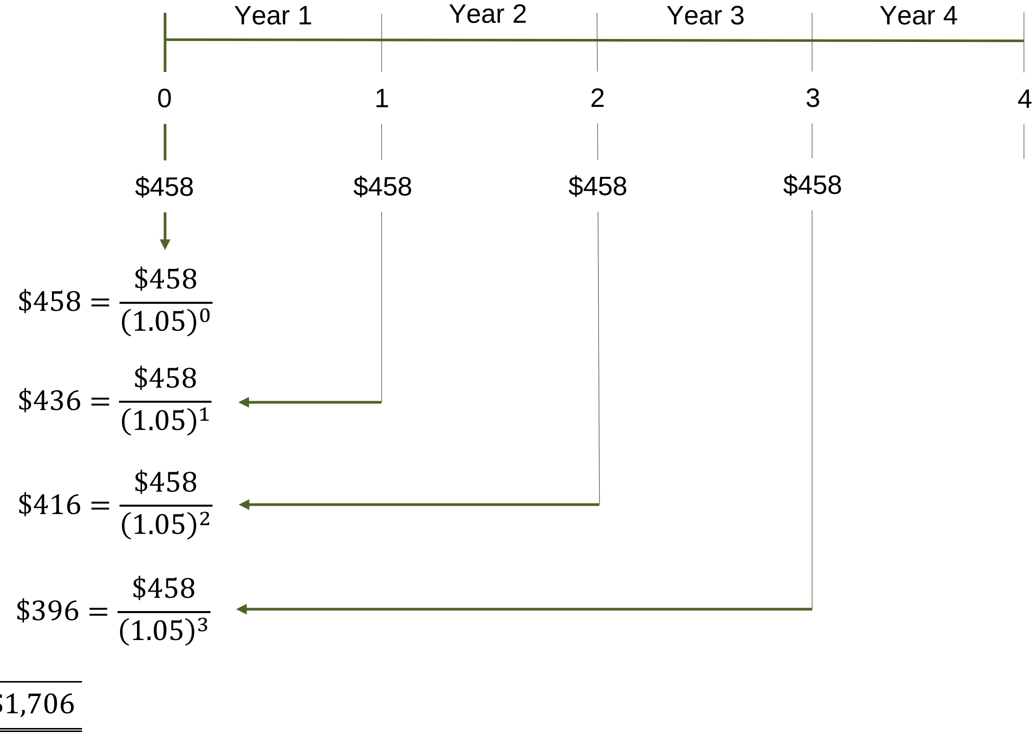
The equivalent annual net benefit of adaptation action B is:

$$E(\mathrm{B}) = \$1{,}706 \Big/ \left[\frac{1-(1.05)^{-4}}{0.05}\right](1.05)$$

$$E(\mathrm{A}) = \frac{\$1{,}706}{3.723} = \$458$$

Equation 7-18

The relevant timeline for action B is:



The analyst should select the adaptation action with the highest net annual benefits – action A in this example.

If costs and benefits are assumed paid or received at the end of each year, then the equivalent annual net benefit of an adaptation action is given by:

$$E = \text{NPV} \Big/ \left[\frac{1-(1+r)^{-n}}{r}\right]$$

Equation 7-19

or in words

E = NPV / ordinary annuity [evaluated at *r* and *n*]

However, as stated above, it can be argued that the more realistic assumption is for costs and benefits to be paid or received in advance.

Before moving on to consider the effects of discounting and the choice of SDR on present values, it is worth noting that actions with shorter lifetimes may offer additional benefits. When a short-lived adaptation action is finished, it does not necessarily have to be 'rolled over'. In the not too distant future, new evidence may have come to light suggesting that a better course of action is available. This additional benefit – of being able to modify adaptation strategies in light of new information without much delay – is called (quasi) option value, and is discussed further in Section 9.4.2.

7.2.3 Effect of discounting on present values

It is evident from Equation 7-4 that the discount factor, *w*, is less than one if *r* and *n* are positive. Discounting thus implies that the weight attached to a cost or benefit realized, say, 100 years from now is lower than the weight attached to the same cost or benefit realized, say, 50 years from now. Indeed, the further into the future the cost or benefit occurs, the lower the weight attached to it.

This bias in favor of today relative to the future is easily illustrated. Consider Figure 2-1, which shows the discount factors corresponding to a constant real SDR of 1.0 per cent and 3.5 per cent per year. With a constant and positive SDR the discount factor or weight given to future costs and benefits declines approximately exponentially. This is why this approach to discounting is often called ‘exponential discounting’.

Suppose an investment in flood management infrastructure yields benefits out to 200 years. At a real SDR of 3.5 per cent per year, the present value equivalents of an annual benefit of $1 million realized 50, 100 and 200 from now are, respectively:

$$PV(B_{50}) = \$1{,}000{,}000 \times \frac{1}{(1+0.035)^{50}} = \$1{,}000{,}000 \times 0.179 = \$179{,}000;$$

$$PV(B_{100}) = \$1{,}000{,}000 \times \frac{1}{(1+0.035)^{100}} = \$1{,}000{,}000 \times 0.032 = \$32{,}000; \text{and}$$

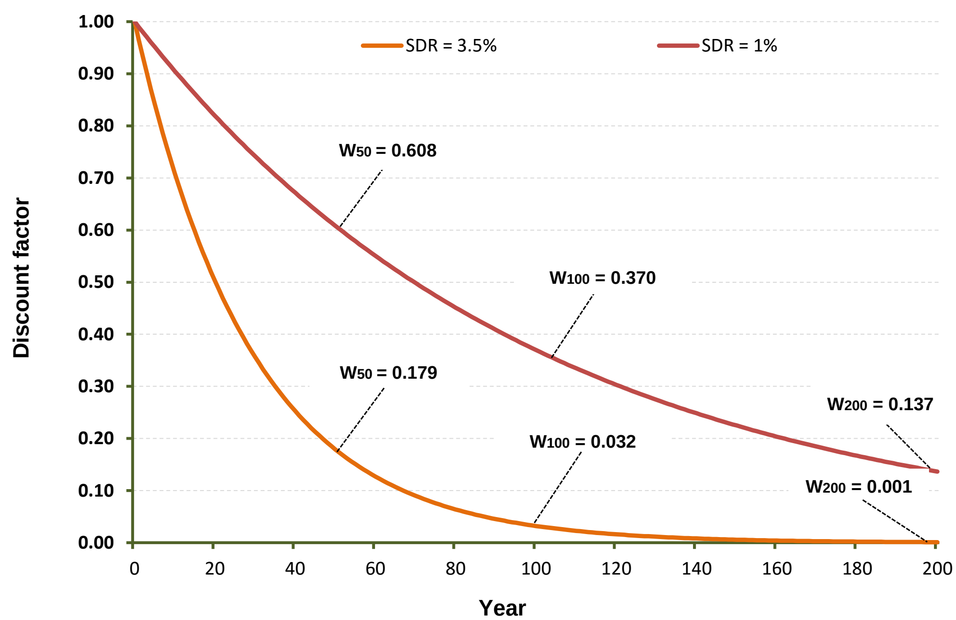
$$PV(B_{200}) = \$1{,}000{,}000 \times \frac{1}{(1+0.035)^{200}} = \$1{,}000{,}000 \times 0.001 = \$1{,}000.$$

Thus, a benefit occurring 100 years from now would be valued at only 3 per cent of its value today. At a lower real SDR of 1.0 per cent per year the same benefit at year 100 is valued at 37 per cent of its value today; the present value of the benefit at year 100 is $370,000, or an order of magnitude higher than it is using a real SDR of 3.5 per cent per year.

This numerical example illustrates the alleged ‘tyranny’ of (positive) discounting in the context of long-term problems like climate change, where the cost of investing today in policies and measures to mitigate climate risks must be justified by the discounted benefits of avoided impacts well into the future. The difference in discount rates in the above example generates over an order of magnitude disparity in benefits by year 100. By year 200 the effects of the different SDRs on the present value of future benefits are even more pronounced. Thus, the choice of SDR will have a significant bearing on whether policies and measures to mitigate climate risks can be justified on economic grounds – i.e., whether present value benefits exceed present value costs. Indeed, due to the long-term nature of the climate change problem, few issues in climate change economics stimulate more controversy than the issue of discounting and the choice of an appropriate SDR (see Box 7-1).

Some commentators argue nonetheless that the tyranny of discounting is likely to be more of an issue for mitigation policy than adaptation policy (UNFCCC, 2009). GHG emission reductions today will mitigate damages in the latter part of this century and beyond, but do little to alter the near-term climate or the present rate of change in climate impacts (over the next several decades). In contrast, the benefits of judicious investment today in adaptation will be realized immediately, as damages associated with current climate variability and extremes, and near-term changes in climate linked to past emissions of GHGs, are reduced. As the above example shows, the impact of discounting and the choice of SDR on present values is less significant the smaller the difference in the timing of costs and benefits. Discounting is likely to play a more important role in determining the optimal timing of investment in adaptation.

Figure 7-3: Discount factors corresponding to a constant real annual SDR of 1.0 per cent and 3.5 per cent



Box 7-1: The importance of the choice of SDR in climate change economics – the case of the Stern Review

The debate that followed the release of the Stern Review on the Economics of Climate Change (Stern, 2006) highlights just how controversial the selection of an appropriate value for the SDR can be. The Review estimated the total cost of climate change to be equivalent to a one-off, permanent 5 per cent loss in global mean per-capita consumption today, and the marginal damage cost per tonne of carbon emitted today was estimated at about $310 (Stern, 2006). These estimates are high in relation to other estimates in the literature, as noted by several prominent commentaries on the Review (e.g., Tol and Yohe, 2006; and Yohe, 2006; Weitzman, 2007; and Nordhaus, 2007). The choice of the SDR by the Review team (approximately 1.4 per cent) was singled out as the principle explanation for this discrepancy. Tol and Yohe (2006) responded that "*the high valuation of climate change impacts reported in the Review can be explained by a very low discount rate*" and "*the discount rate is so low that 40-50 per cent of the reported damages* […] *come from* […] *economic costs that occur beyond the modeled timeframe of 200 years*". Nordhaus (2006) likewise commented that the Review's conclusions are largely based on "*an extreme assumption about discounting*". The high damage cost estimates made an overwhelming economic case for significant reductions in greenhouse gas emissions, as the Review also concluded that "*the costs of* […] *reducing greenhouse gas emissions* [to stabilize concentrations at 500–550 ppm CO2eq] […] *can be limited to around 1 per cent of global GDP each year*". The choice of the SDR had a dramatic impact on the Review's conclusion that "*the benefits of strong early action outweigh the costs*".

7.3 Selecting a discount rate

At the outset it is important to stress that the purpose of this section is not to prescribe a single SDR for all organizations to use when appraising candidate adaptation actions, but rather to provide the analyst with a basic understanding of key issues relating to the choice of an appropriate SDR to enable them:

- ⇨ To make an informed choice in the absence of an existing organization-wide SDR for similar projects; and
- ⇨ To convey the implications of the choice of SDR to decision-makers.

The choice of an appropriate SDR has been debated by economists, philosophers, and others for half a century now, and despite decades of debate, there is still wide disagreement about the rate to be applied, and particularly in policy areas like climate change. The choice of SDR is controversial partly because it is so morally charged; the generations creating the costs of climate change will most likely not overlap the generations bearing those costs. Equally, the generations bearing the costs of reducing GHG emissions will likely not be the generations benefiting from these reductions. These arguments nonetheless appear to be more pertinent to mitigation policy responses than to adaptation.

There are two generally accepted approaches for defining an SDR (Arrow et al, 1996): ❶ a descriptive approach; and ❷ a prescriptive approach. The former focuses on what discount rates people, whether savers or investors, actually apply; the latter focuses on what discount rates they ought to apply from an ethical viewpoint. The descriptive approach leads to relatively high SDRs whereas the prescriptive approach leads to relatively low SDRs (Halsnaes *et al*, 2007).

7.3.1 Descriptive approach

Another basic premise of cost-benefit analysis is that of consumer sovereignty. According to this premise, an analyst should value all impacts affecting all individuals with standing, and those impacts should be monetized using the values that affected individuals would place on them. Equally, the discounting of future costs and benefits should mimic the practices of the same individuals when making choices about consumption in the future versus consumption now.

In economics the rate at which individuals in aggregate discount income over time (and the goods and services that income enables them to consume) is often referred to as the 'consumption rate of interest'. [26] Under a variety of simplifying assumptions, including no taxes, no risk, no transaction costs, and perfect credit markets:

[26] Note that under the prescriptive approach the rate at which individuals in aggregate discount money and associated consumption over time is frequently referred to as the 'social rate of time preference' as opposed to the 'consumption rate of interest'.

Consumption rate of interest (CRI)

=

Market rate of interest (on savings)

=

Market rate of interest (on investment)

=

Rate of return earned on investments by the private sector (ROI).

In this case, an analyst adhering to the principle of consumer sovereignty should use the market rate of interest – as the SDR – to discount the future costs and benefits of candidate adaptation actions. The market rate of interest rate is the unambiguous choice for the SDR.

The rate of return on private investment expresses the fact that capital is productive, i.e. that a dollar invested in productive activities rather than consumed now will generate additional income, and hence additional consumption, in the future. Furthermore, a dollar invested in one productive activity means it is not available to invest in another productive activity, which may return a higher stream of income and consumption. There is thus an opportunity cost involved in spending money on one (lower return) activity rather than another (higher return) activity – the opportunity cost being the forgone incremental return on the latter activity.

If the above simplifying assumptions hold, using the market interest rate as the SDR therefore reflects ❶ the opportunity cost of displacing investment elsewhere in the economy and ❷ the rate at which individuals discount future consumption. In doing so the analyst is – in effect – ensuring that implementing a candidate adaptation action represents the best possible use of society's scarce economic resources.

However, the simplifying assumptions do not tend to hold up in practice. As witnessed in recent years, credit markets do not always work properly. Also, market interest rates observed now only reveal the inter-temporal choices of the current generation and cannot represent the wishes of future generations not yet alive. Moreover, financial markets do not tend to offer (risk-free) products with maturities extending past 30-40 years; thus interest rates are not revealed for time horizons relevant to climate change. In real world situations there also is a vast range of interest rates for different types or borrowing and lending; which of the observed rates reveals the one SDR needed? And there are of course taxes and transaction costs, which means market saving rates (the consumption rate of interest) will not equal market investment rates (the return earned on private sector investments) (see Box 7-2).

These are in fact some of the main grounds on which proponents of the prescriptive approach question the validity of the descriptive approach.

Box 7-2: Taxes drive a wedge between consumption rate and private sector investment rate of interest

Taxes on income from investments will void the equality between the consumption rate of interest and the rate of return on private investment. To illustrate this, supposed the real (i.e., net of inflation) marginal rate of interest on a private investment is 10 per cent. A private investment of $100 now will return $10 in a year's time. Assume that income on investments is taxed at 40 per cent. So, of the $10 returned in a year's time, the government takes 40 per cent or $4, leaving individuals with $6 or a post-tax return of 6 per cent. As a result, the real, post-tax return on investment (the rate at which individuals effectively trade consumption over time) is 6 per cent, which is significantly less than the 10 per cent real, pre-tax rate of return on private investment (the rate at which society can effectively trade consumption over time).

Source: Adapted from US EPA (2000)

Why does it matter that taxes on capital income mean the consumption rate of interest will be lower than the rate of return on private sector investments? It matters if the cost of funding public expenditure on planned adaptation actions displace (or in economic language, 'crowd out') private sector investments. In such cases, society will forgo the higher pre-tax returns on the private investments. Using the post-tax market interest rate on savings (a measure of the consumption rate of interest) as the SDR to appraise public adaptation projects will not properly capture these forgone returns. If a public adaptation action has a negative NPV using the pre-tax rate of return on private investment, then society could obtain a higher return by instead investing in a private sector project. However, the same adaptation action may have a positive NPV when discounted at the post-tax market interest rate on savings, and pass a standard cost-benefit test, yet society could still realize higher returns by investing in the displaced private sector project.

When is public investment in planned adaptation actions likely to displace private sector investment? Public projects in general can be financed from ❶ general tax revenues or ❷ borrowing (deficit-financing). Boardman *et al* (2008) argue that projects financed from taxes will largely reduce consumption as opposed to private investment, since taxes reduce disposal income and most disposable income is spent (consumed) rather than saved (invested). Hence, public planned adaptation actions financed from general tax revenues will primarily displace consumption; not private sector investment.

For deficit-financed public adaptation actions, whether or not private sector investment is displaced depends on the degree to which the Canadian economy is assumed to be closed to foreign capital flows. If the economy is assumed to be closed to foreign capital flows then increased borrowing by government will, in theory, raise interest rates as the overall demand for loans increases. This in turn will raise the cost of financing private sector projects, reducing investment demand, leading to the traditional view that deficit-financed public projects will result in dollar-for-dollar crowding out of private sector investment. In contrast, if the Canadian economy is assumed to be open to foreign capital flows – as empirical evidence suggests – increased borrowing will raise interest rates, depreciate the exchange rate, and thereby attract increased capital flows to Canada.[27] The inflow of capital from abroad will depend on the sensitivity of foreign funds to changes in interest rates, which is believed to be highly elastic (US EPA, 2000). As a result, in an open economy, very little private sector investment is likely to be

[27] As shown below, when deriving an SDR for Canada Jenkins and Kuo (2007) assume that 40 per cent of funds for public sector projects are sourced from abroad.

displaced by deficit-financed public projects (Lind, 1990). The magnitude of any crowding out will depend on the scale of the deficit-financed public project (Boardman *et al*, 2008).

In summary, it is not appropriate to assume that public planned adaptation actions will result in dollar-for-dollar displacement of private sector investment, even if financed from borrowed funds. It is only reasonable to assume displacement of private investment for very large deficit-financed actions, and that may not necessarily be dollar-for-dollar.

7.3.1.1 Weighted average social cost of capital

When a public project (such as a planned adaptation action) is assumed to crowd out investment in the private sector, a common approach to social discounting is to require an efficient adaptation action to earn ROI (the real, pre-tax marginal rate of return on investment) on funds that come at the expense of private sector investment and earn CRI (the real, post-tax return to savings) on funds that come at the expense of consumption, in order to cover the opportunity cost of all the funds it uses. The real annual SDR (i) thus becomes a weighted average of the investment (ROI) and consumption (CRI) rates:

$$\mathrm{SDR} = i = \alpha \times \mathrm{ROI} + (1 - \alpha) \times \mathrm{CRI} \qquad \text{Equation 7-20}$$

Where the weight, α, is equal to the proportion of project financing that displaces private sector investment.[28] Accordingly, the real annual SDR reflects the value lost by displacing investment (given by the higher rate on investment, ROI) and the value lost by displacing consumption (given by the lower rate on savings, CRI).

Governments may also source funds from abroad (foreign borrowing). To account for the social opportunity cost of foreign borrowing, an additional term needs to be added to Equation 7-20, making the real annual SDR equal to:

$$\mathrm{SDR} = i = \alpha \times \mathrm{ROI} + (1 - \alpha - f) \times \mathrm{CRI} + f \times \mathrm{MCF} \qquad \text{Equation 7-21}$$

Where MCF is the marginal cost of foreign borrowing and the weight, *f*, is the proportion of the project financing sourced from abroad.

Equation 7-21 underpins the 8 per cent real annual SDR recommended by the Treasury Board Secretariat in Canada for cost-benefit analysis of federal policies, programs and projects (TBCS, 2007). The recommended rate is based on the central case parameter values estimated by Jenkins and Kuo (2007), and is derived as follows:

$$45\% \times 11.5\% + (1 - 45\% - 40\%) \times 4\% + 40\% \times 6\% \ \cong 8\% \qquad \text{Equation 7-22}$$

[28] As stated by Lind (1982):

> "*The idea underlying this* [approach] *is that the social rate of discount should reflect both the consumption rate of return insofar as consumption is displaced and the marginal rate of return on private investment insofar as private investment is displaced. Therefore, it has been argued that the social rate of discount should be a weighted average of the two rates, the weights being established in proportion to the percentage of the public investment drawn from consumption and from private investment*."

Some of the parameter choices derived by Jenkins and Kuo (2007) have been questioned by Boardman *et al* (2008). Indeed, the estimated value for the ROI is outside the upper bound of other values in the literature – between 5 and 10 per cent (Cline, 1992; and Portney and Weyant, 1999). Boardman *et al* themselves estimate a marginal ROI for Canada at just over 5-7 per cent, depending on whether the ROI relates solely to corporate bonds or includes stocks as well. They also suggest that "*the marginal cost of foreign funds is unlikely to exceed 4 per cent*." The value for the CRI estimated by Jenkins and Kuo is also outside the upper bound of other values in the literature of 1-3 per cent (Cline, 1992; US EPA, 2000; and Howarth, 2009); these values tend to be based on long-term (historical) real, post-tax rates of return on 'safe' assets, such as federal government bonds. To illustrate the effect of these different assumptions of the calculated SDR, suppose that the weights used by Jenkins and Kuo are correct. Now, inputting lower and upper bound values from the above ranges for the ROI and the CRI and a value of 4 per cent for the MCF into Equation 7-22 results in a real annual SDR of about 4-5 per cent:

$$45\% \times 5\% + (1 - 45\% - 40\%) \times 1\% + 40\% \times 4\% \;\cong 4\%$$

$$45\% \times 7\% + (1 - 45\% - 40\%) \times 2\% + 40\% \times 4\% \;\cong 5\%$$

Equation 7-23

Boardman *et al* also query the applicability of the weights used by Jenkins and Kuo, questioning the amount of private investment actually displaced by public expenditure.

Aside from the lack of agreement on appropriate parameter values to use in Equation 7-21 to calculate the SDR, the resulting weighted average social cost of capital may actually not be appropriate for the many adaptation decision problems. For consistency, the same SDR should be applied to both costs and benefit streams. When using the weighted average social cost of capital to discount benefit streams, it is implicit that the specific public project (such as a planned adaptation action) generates more private investment-related benefits than consumption-related benefits. While adaptation actions may produce benefits that increase private sector investment (e.g., enhanced forestry or agricultural productivity, ancillary benefits in the form of operating cost savings) many avoided climate impacts will take the form of 'non-market benefits' that likely affect consumption (e.g., time savings from less disruption to transport networks, fewer injuries from flooding events, reductions in heat-related summer mortality, improvements in air and water quality, increased recreational opportunities, decreased species loss, etc.). In such cases the weighted average social cost of capital approach – with its focus on the economic opportunity costs of the project's funding sources, paying no attention to the proportion of consumption and investment in project benefits – may not be appropriate. The affect is to over discount non-market benefits and the affect is more pronounced the longer the time lag is between costs and benefit streams (US EPA, 2000). Adaptation actions can have significant time lags between costs and benefits.

These concerns are nonetheless recognized by the TBCS. Guidance in TBCS (2007) states that:

> "[…] *where consumer consumption is involved and there are no or minimal resources involving opportunity costs (such as certain human health and environmental goods and services)* […] *the net present value of the results of the analysis can also be carried out using a social discount rate of 3 per cent accompanied by the use of a shadow price of investment that is applied to all the costs of the intervention that results in a postponement or reduction of investment activity*."

The 3 per cent SDR is an estimate of the social time preference rate for Canada (TBCS, 2007). This provides a good lead into discussion of the prescriptive approach to the SDR.

7.3.2 Prescriptive approach

The prescriptive approach to selecting the SDR focuses on what rates should be used to discount future dollar (and associated consumption) flows, from an ethical viewpoint. It is often advocated for public projects that affect future, unborn generations – i.e., projects with greater than 30-year to 50-year time horizons. Recall a major criticism of the descriptive approach is that the market interest rates it relies on can only reflect the choices of those alive today; the preferences of future generations are not represented. Moreover, these time horizons are longer than what is reflected in the observed financial products used to reveal the discounting preferences of the current generation. In addition, relative to shorter time horizons, inter-generational time horizons inevitably involve greater uncertainty – our ability to make predictions a decade or two ahead is much better than 50 or more years ahead.

Two of the main reasons given above for discounting future costs and benefits are: ❶ we may care less about the welfare of future generations than we do about our own, and / or they may not be around; and ❷ as people's incomes increase in the future (as most people expect) the amount of satisfaction they enjoy from an extra dollar declines – so an extra dollar means more to us now when we are relatively less well-off than in the future when we are richer. The prescriptive approach seeks to develop an SDR – referred to as the social time preference rate (*r*) - that explicitly addresses these two reasons for discounting, leading to the so-called Ramsey rule (Ramsey, 1928):

$$\text{SDR} = r = \rho + \eta \times g \qquad \text{Equation 7-24}$$

The first component ρ is the utility discount rate (or pure rate of time preference), which measures the rate at which society discounts utility now versus utility in the future, irrespective of growth in consumption (per capita).[29] The utility discount rate speaks to the first reason for discounting given above. The second component reflects the impact of consumption growth on the welfare of future generations and is the product of two parameters: the elasticity of marginal utility (η) reflecting the responsiveness of changes in utility to changes in consumption; and (g) the expected annual real growth rate in per capita consumption. The elasticity of marginal utility speaks to the second reason for discounting. Note that even if the utility discount rate is zero (the rate at which future utility discounted) – implying that utility now and utility in the future is given the same weight – the social time preference rate is still positive if $\eta > 0$ and $g > 0$.

So what are appropriate values for each of these three parameters, and what is the resulting SDR? Unfortunately, there is no consensus in the literature on the values of ρ and η with ethical judgments and different interpretations of the parameters swaying opinion on the choice of appropriate values.

[29] In economics, utility refers to the level of satisfaction, welfare or well-being a person derives from consuming a good or service.

7.3.2.1 Utility discount rate

The utility discount rate defines the weight placed on a unit of utility in the future compared with an equal unit of utility today. It is generally regarded as reflecting 'impatience' (i.e., our desire for utility to be accrued sooner rather than later). What value ρ takes is controversial, as it characterizes our ethical position regarding future generations. For example:

- If $\rho = 0$: equal weight is given to present and future generations, implying ethical neutrality between the well-being of different generations. Using a value of zero is another way of saying it is unethical to discount utility simply on the basis of birth date.
- If $\rho = 1$: someone born in the 2080s (2085) would be given around half the ethical weight as someone born in 2012; and
- If $\rho = 2$: someone born in the 2080s (2085) would be given around one quarter the ethical weight as someone born in 2012.

Many prominent economists (including Ramsey himself) and philosophers have argued for a value of zero (Ramsey, 1928; Koopmans, 1965; Solow; 1974; Cline; 1999). However, an argument against a low value for ρ was advanced by Arrow (1995), who demonstrated that assuming a value of zero implies – regardless of the return on investment – implausibly high savings ratios, in the order of two-thirds of current income. We do not save anywhere near that ratio. This led Arrow to conclude:

> "[…] *that the strong ethical requirement that all generations be treated alike, itself reasonable, contradicts a very strong intuition that it is not morally acceptable to demand excessively high savings rates of any one generation* […]. *We must accept that the pure time preference rate is positive*. […] *Very tentatively, the pure time preference rate should be about 1 per cent*."

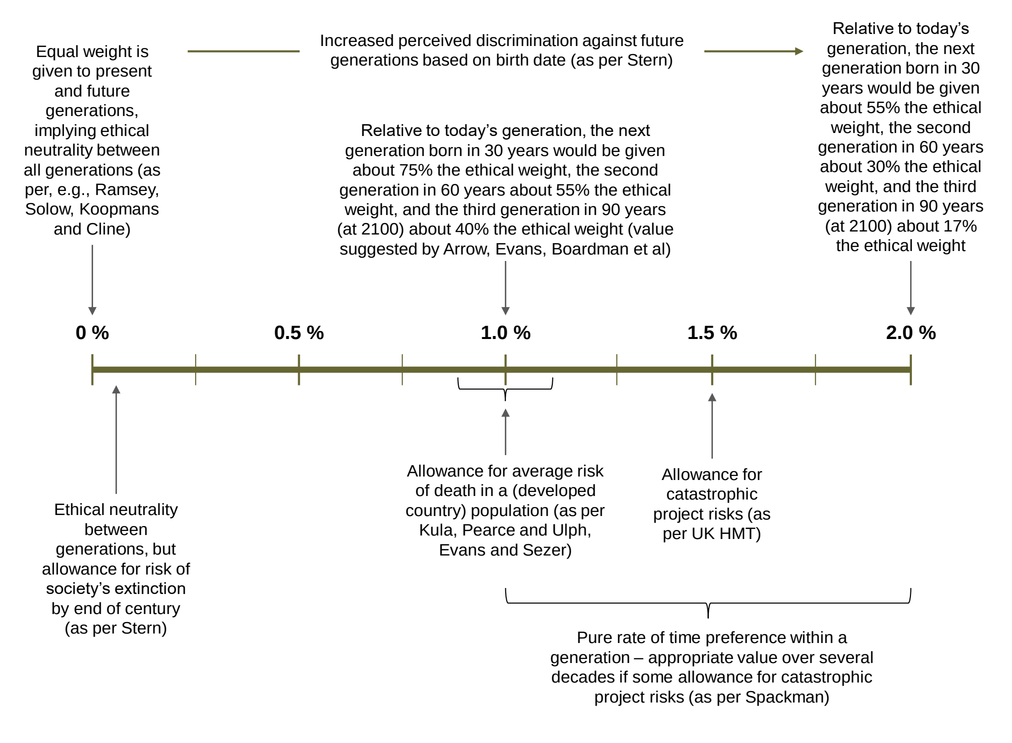
The assumptions made by Arrow in arriving at this conclusion have been challenged by Dasgupta (2008) and Smith (2010). There are nonetheless additional practical arguments in support of ρ being greater than zero.

Our desire to accrue utility sooner rather than later (i.e., our impatience) may be due in part to fear that we or society will not being around later, or fear that the goods and services we want to consume will not be available. Indeed, this has led some economists to view the utility discount rate as having two interpretations (Pearce and Ulph, 1999): ❶ as a pure rate of time preference; and ❷ as an allowance for 'life chances'. Life chances may be understood in several ways. For the individual it may reflect the underlying average risk of death in a population. In many developed countries the average population mortality rate is approximately 1 per cent per year (Kula, 1984; Pearce and Ulph, 1999; Evans, 2005; and Evans and Sezer, 2005). For society, life chances may reflect the annual risk of a man-made or natural catastrophe largely destroying society. Clearly, the likelihood of this happening is much less the 1 per cent per year. The Stern Review assumed that there is a 10 per cent chance of global society not surviving 100 years; equating to a 0.1 per cent annual probability of extinction (Stern, 2006).

There is also a risk that public policies, programs or projects may fail or not perform as anticipated. HMT (2003) refer to this as 'catastrophic risk' and, based on academic studies, adopt a value of 1 per cent per year to reflect a broader set of risk factors affecting public sector investments than the very low (yet serious) risk of society destroying itself. These risk factors include changes to social and political priorities and to possible wider changes in technology, the economy, and society. It is important to note, however, that not all economists agree that adding a ‘risk premium’ to the SDR to reflect project uncertainty is appropriate. If a premium for project risks is included in the SDR, it is usually argued on practical grounds that is easier to defend a rate if specific risks are explicitly included (Spackman, 2002).

Given the range of disparate views and estimates concerning the value of the utility discount rate, a value in the range 0-2 per cent per year seems appropriate, with a mid-point of 1 per cent per year providing a reasonable central value. Figure 7-4 should help the analyst appreciate the implications of selecting a specific value within this range. It is worth noting that values outside this range, nearer 3 per cent per year, have been suggested by Rabl (1996) and Nordhaus (1999). However, both these authors seek a value for ρ that produces an SDR equal to the market interest rate, given η and g (as per the descriptive approach).

Figure 7-4: Implications of selecting a value for the utility discount rate within the range of reported values



7.3.2.2 Marginal elasticity of utility

The second component of the SDR according to Equation 7-24 is the marginal elasticity of utility (η), which measures the percentage decrease in the satisfaction received from income and associated consumption as (per capita) incomes increase by 1 per cent – i.e., it is the responsiveness of utility to a marginal or one-unit increase in income. It is a relatively uncontroversial as a concept; no one challenges the notion that income has diminishing marginal utility as it increases. Thus, insofar as future income levels are higher it is reasonable to assign to an extra unit of future income a lower weight than current income because we currently derive less value from it. The weighting of future income growth (*g*) is given by the marginal elasticity of utility (η). The big question is: by how much less is future income and associated consumption weighted?

There are many ways to derive a value for η. These can be grouped into four broad approaches (Spackman, 2011): ❶ inferences from government policy concerned with income distribution (e.g., empirical estimates from progressive income tax schedules); ❷ inferences from private behavior (e.g., empirical estimates from income and price elasticities or personal savings decisions); ❸ direct elicitation (e.g., evidence from surveys and experiments); and ❹ expert views reflecting ethical perspectives. The range of values reported in the literature range from about 0.5 to 4.0, with a narrower band of empirically derived values clustering between 1.0 and 2.0 (Feldstein, 1965; Kula, 1984 and 1985; Scott, 1989; Blundell *et al*, 1994; Boscollo *et al*, 1998; Cowell and Gardiner, 2000; Evans, 2005; Evans and Sezer, 2005; Stern, 1977 and 2006; Layard *et al*, 2007; Dasgupta, 2008; Dietz and Stern, 2008; and Boardman *et al*, 2008). From a recent review of this literature Spackman (2011) concludes:

> "[…] *the evidence* […] *suggests overwhelmingly that for today's developed economies* η *is greater than 1, but probably no greater than 2. A first glance at the results of the seemingly more reliable methods of estimation suggests a value a little below rather than above 1.5. However, it looks as if the estimation biases tended to be downwards rather than upwards. On balance the case for 1.5 therefore looks to me more robust than that for any lower figure*."

Analyzing the progressivity of income tax schedules in Canada, Boardman et al (2008) estimate values for η between 1.4 (based on 2006 data) and 1.6 (based on 2000 data). Putting these estimates in the context of values in the wider literature they reach a conclusion similar to Spackman:

> "*With prescribed rates* [based on expert views and ethical perspectives] *in the range of 0.5 to 4.0, and empirical estimates somewhere between 1.0 and 2.0, we believe a central estimate of 1.5 is reasonable, with sensitivity analysis at 1.0 and 2.0*."

Thus, in the context of the SDR, what does the selection of a particular value for η within the range of reported values imply? The interpretation of η is difficult, since it can represent three different concepts at once (Anthoff *et al*, 2009): ❶ aversion to inequality across space; ❷ aversion to inequality across time; and ❸ personal risk aversion. And different economists may focus on different concepts resulting in a preference for different values.

Aversion to inequality across space

First, η indicates the degree to which society is concerned for intra-generational equity in the distribution of income (i.e., aversion to inequality across space). Under this interpretation η is a measure of how much less a dollar of extra income means to a rich person relative to a poor person. If c has a value of *z*, this implies that a person with *X* times the income of a similar person, will enjoy only $1/(X \cdot z)$ as much utility from each additional dollar of income. Accordingly, if person A has twice the income of person B (i.e., *X* = 2) and *z* is assumed to be one (i.e., η =1), then the richer individual A will enjoy half (i.e., $1/(2 \cdot 1) = 1/2$) as much satisfaction from an additional dollar as will the poorer individual B; or conversely, the poorer individual B will enjoy twice as much satisfaction from an additional dollar than will the richer individual A. Thus, the higher the selected value for η the greater the weight given to the consumption of the poor relative to the rich, and the higher the SDR.

Aversion to inequality over time

Second, η can be interpreted as the degree to which society is concerned for inter-generational equity in the distribution of income (i.e., aversion to inequality across time). It is generally accepted that society in the future will have higher incomes and wealth than society today. If we are concerned with inter-generational inequality, we will want to avoid the redistribution of income and associated consumption from the present, poorer generation to the future, richer generation. Reconsider the numerical example provided above with an inter-generational perspective. If future society has twice the income of society today (i.e., X = 2) and z is assumed to be (i.e., η =1), then the richer future society will enjoy half (i.e., $1/(2 \cdot 1) = 1/2$) as much satisfaction from an additional dollar as will the poorer present society; or conversely, the poorer present society will enjoy twice as much satisfaction from an additional dollar than the richer future society.

Why does this matter? Investment in an adaptation action will mean that present society has to sacrifice income (and give up some consumption) to generate risk reductions that may benefit both current and future generations. Thus, if society today is averse to inequality between generations, they will not be overly willing to give up consumption to invest in such actions.

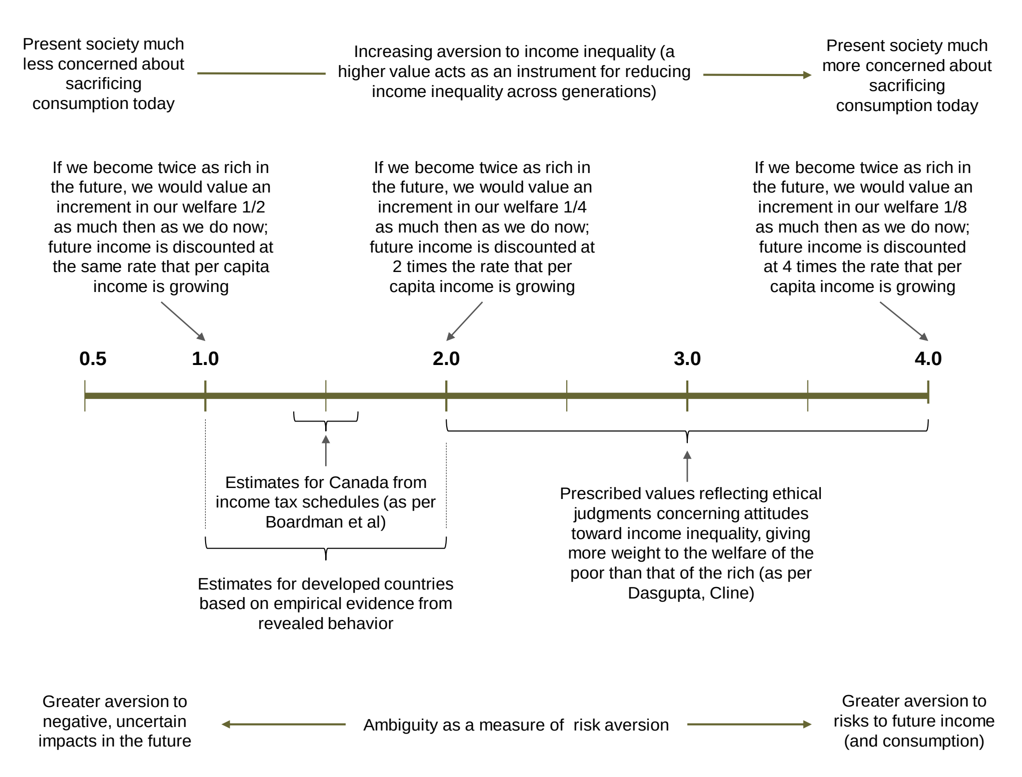
With a lower value for η (and growth in per capita income) the relatively poorer present society will care less about giving up consumption today in pursuit of future additions to income. That is, they will be less concerned about inter-generational inequality resulting from an adaptation action redistributing income from present to future generations. In contrast, the higher the value for η the more consumption is worth to the poorer present society than to the richer future society. Present society will therefore be more concerned about inter-generational inequality resulting from the redistribution of income from present to future generations. A higher value for η leads to a higher SDR, which in turn means that fewer actions with streams of benefits following an initial expenditure will tend have a positive NPV and get accepted.

Personal risk aversion

Third, η can be interpreted as a measure of how averse we are to fluctuations in future outcomes. Under this interpretation, η approximates the premium risk-averse individuals are willing to pay to eliminate fluctuations in income (Anthoff *et al*, 2009). A higher value for η indicates a greater aversion to risks to future income, and – with growth in per capita incomes – leads to a higher SDR and smaller discounted future costs and benefits. In the context of climate change, however, increased personal aversion to risk could mean one is more concerned with uncertain, negative impacts in the future. Consequently, the future value of climate change damages (and therefore the benefits of adaptation actions) should be larger with higher values for η, and not smaller, as they would be when discounted at a relatively high SDR.

While the overall interpretation of a chosen value for η is complicated by its ambiguous role as a measure of personal risk aversion, Figure 7-5 should help the analyst appreciate the implications of selecting a specific value within the range of reported values in the literature.

Figure 7-5: Implications of selecting a value for the marginal elasticity of utility within the range of reported values



7.3.2.3 Expected growth in consumption

The ideal way to derive a future annual growth rate for real per capita consumption (g) is to estimate a long-term development path for the economy, using an appropriate growth model. However, for periods stretching out beyond several decades, any forecast of annual growth prospects will be increasingly uncertain. Historical growth rates in Canada have varied by as much as 0.7 percentage points depending on the period considered (Boardman *et al*, 2008). As an example, Moore *et al* (2001) estimated the annual real growth rate over the period 1973-1995 at about 1.6 per cent, yet over a 45-year period prior to 1973, it was a whole percentage point higher (at 2.6 per cent).

One way to reflect such uncertainty is to use more than one economic forecast. For example, as noted in Section 4.3.5.1, the NRTEE employed two scenarios in its study of the economic impacts of climate change for Canada:

- A low-growth scenario – with an annual average growth rate of real GDP per capita of about 0.8 per cent over the period 2008-2100; and
- A high-growth scenario – with an annual average growth rate of real GDP per capita of about 2.4 per cent over the period 2008-2100.

These values, in particular under the low-growth scenario, do seem outside the range of values for g revealed in past data and prescribed in climate change studies (see below).

An alternative, frequently used approach to estimating g is look at actual growth rates in past data over a sufficiently lengthy time span to cover several economic cycles – noting that the estimated rate does depend on the time period considered. Using CANSIM data covering the period 1971-2006, Boardman *et al* (2008) estimate the underlying trend rate of growth in real per capita consumption at 1.7 per cent. Over the full period 1926-1995, Moore *et al* (2001) estimate g for Canada at about 2.2 per cent.

In the context of climate change, the assumed long-term annual (global) real growth rate in consumption per capita range from 1 per cent (Cline, 1992) to 2 per cent (Weitzman, 2007; and Nordhaus, 2007), with Stern (2006) at 1.3 per cent.

Given the above, the recommendation of Boardman *et al* (2008) for Canada seems reasonable: g = 1.7 per cent as a central value, with sensitivity tests around 1.5 per cent and 2.0 per cent. It is nevertheless important that the analyst ensure consistency between the values used to compute the SDR and the socio-economic data sets used to construct the Baseline and Reference Cases. As a rule, the value(s) adopted for g must be consistent with the assumed economic and population growth paths under the Baseline and Reference Cases.

7.3.2.4 Estimated social time preference rate

Table 7-1 shows possible SDRs (or more precisely, social time preference rates) calculated using the Ramsey equation (Equation 7-24), based on the full range of parameter values discussed above. Estimates in the blue shaded areas represent the most credible values for the SDR, corresponding to each of the values for g suggested by Boardman et al (2008). This suggests a real annual SDR for Canada somewhere between 2.5 and 5.5 per cent (values in the dashed boxes in Table 7-1). If the analyst believes the case for maintaining ethical neutrality between generations important, then an argument can be made for using a value as low as 1.5 per cent.

As stressed above, the intention of this section is not to prescribe an SDR to the analyst, but rather to help them select a rate and understand the implications and implied ethical judgments embedded in their choice. To this end, the analyst can use Figure 7-4 and Figure 7-5 to convey the inferences of any selected SDR to decision-makers. Note also that as values exceed 4.0-5.0 per cent per year they become similar to those generated for Canada under the descriptive approach (see, for example, Equation 7-23).

Due to the range of possible SDRs, and the uncertainty associated with selecting the 'right' one, the appropriate response is to conduct sensitivity analysis using a several values (see Section 9.3.2.1). If sensitivity analysis reveals that the selection of SDR is important – in that it changes the sign of the calculated NPV or the ranking of alternative adaptation actions – then the analyst should give more consideration to the choice of SDR.

Discount factors for the range of credible SRDs derived under both the prescriptive and descriptive approach are provided in Table 7-2.

Table 7-1: Range of possible real annual social time preference rates (SDRs) based on prescriptive approach

Utility discount rate (r)	Marginal elasticity of utility (h): 0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	Annual real growth in per capita consumption (g)
0.0%	0.8%	1.5%	2.3%	3.0%	3.8%	4.5%	5.3%	6.0%	1.5%
0.5%	1.3%	2.0%	2.8%	3.5%	4.3%	5.0%	5.8%	6.5%	1.5%
1.0%	1.8%	2.5%	3.3%	4.0%	4.8%	5.5%	6.3%	7.0%	1.5%
1.5%	2.3%	3.0%	3.8%	4.5%	5.3%	6.0%	6.8%	7.5%	1.5%
2.0%	2.8%	3.5%	4.3%	5.0%	5.8%	6.5%	7.3%	8.0%	1.5%
0.0%	0.9%	1.7%	2.6%	3.4%	4.3%	5.1%	6.0%	6.8%	1.7%
0.5%	1.4%	2.2%	3.1%	3.9%	4.8%	5.6%	6.5%	7.3%	1.7%
1.0%	1.9%	2.7%	3.6%	4.4%	5.3%	6.1%	7.0%	7.8%	1.7%
1.5%	2.4%	3.2%	4.1%	4.9%	5.8%	6.6%	7.5%	8.3%	1.7%
2.0%	2.9%	3.7%	4.6%	5.4%	6.3%	7.1%	8.0%	8.8%	1.7%
0.0%	1.0%	2.0%	3.0%	4.0%	5.0%	6.0%	7.0%	8.0%	2.0%
0.5%	1.5%	2.5%	3.5%	4.5%	5.5%	6.5%	7.5%	8.5%	2.0%
1.0%	2.0%	3.0%	4.0%	5.0%	6.0%	7.0%	8.0%	9.0%	2.0%
1.5%	2.5%	3.5%	4.5%	5.5%	6.5%	7.5%	8.5%	9.5%	2.0%
2.0%	3.0%	4.0%	5.0%	6.0%	7.0%	8.0%	9.0%	10.0%	2.0%

Note: see main text (Section 7.3.2.4) for explanation of shaded areas.

7.3.2.5 Shadow price of capital

Strictly speaking, a prescriptive-based SDR (i.e., social time preference rate) applies to consumption only, since it does not take account of the opportunity cost of displaced private investment. As discussed above, *if* a public project like a planned adaptation action displaces private investments, society loses the higher (pre-tax) returns from the foregone private investments. Discounting the net benefits of public projects using the social time preference rate does not capture the fact that society forgoes these higher returns. Hence, to apply the social time preference rate, the consensus among economists is that all investment flows believed to displace private investment first need to be converted to consumption-equivalents, and second, discounted using the social time preference rate (Lind, 1990; Cline, 1992; US EPA, 2000).

Converting investment flows to consumption-equivalents is accomplished using an adjustment factor known as the ‘shadow price of capital’. This factor is designed to adjust upward those project costs (benefits) believed to displace (enhance) private investment, prior to discounting all costs and benefits at the social time preference rate.[30] Adjusting project costs and benefits upward accounts for the higher social returns produced by a unit of private capital. The adjustment thus makes it more difficult for a public project to pass a standard cost-benefit test;

[30] Note that both costs and benefits are similarly treated when applying the shadow price of capital.

other things being equal, a marginal project's stream of future net benefits needs to be slightly larger in order to produce a positive NPV.

Table 7-2: Discount factors corresponding to range of plausible SDRs for Canada

Prescriptive social ⟷ Descriptive social

Year	Real annual social discount rate											
	2.5%	3.0%	3.5%	4.0%	4.5%	5.0%	5.5%	6.0%	6.5%	7.0%	7.5%	8.0%
0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
1	0.9756	0.9709	0.9662	0.9615	0.9569	0.9524	0.9479	0.9434	0.9390	0.9346	0.9302	0.9259
2	0.9518	0.9426	0.9335	0.9246	0.9157	0.9070	0.8985	0.8900	0.8817	0.8734	0.8653	0.8573
3	0.9286	0.9151	0.9019	0.8890	0.8763	0.8638	0.8516	0.8396	0.8278	0.8163	0.8050	0.7938
4	0.9060	0.8885	0.8714	0.8548	0.8386	0.8227	0.8072	0.7921	0.7773	0.7629	0.7488	0.7350
5	0.8839	0.8626	0.8420	0.8219	0.8025	0.7835	0.7651	0.7473	0.7299	0.7130	0.6966	0.6806
6	0.8623	0.8375	0.8135	0.7903	0.7679	0.7462	0.7252	0.7050	0.6853	0.6663	0.6480	0.6302
7	0.8413	0.8131	0.7860	0.7599	0.7348	0.7107	0.6874	0.6651	0.6435	0.6227	0.6028	0.5835
8	0.8207	0.7894	0.7594	0.7307	0.7032	0.6768	0.6516	0.6274	0.6042	0.5820	0.5607	0.5403
9	0.8007	0.7664	0.7337	0.7026	0.6729	0.6446	0.6176	0.5919	0.5674	0.5439	0.5216	0.5002
10	0.7812	0.7441	0.7089	0.6756	0.6439	0.6139	0.5854	0.5584	0.5327	0.5083	0.4852	0.4632
11	0.7621	0.7224	0.6849	0.6496	0.6162	0.5847	0.5549	0.5268	0.5002	0.4751	0.4513	0.4289
12	0.7436	0.7014	0.6618	0.6246	0.5897	0.5568	0.5260	0.4970	0.4697	0.4440	0.4199	0.3971
13	0.7254	0.6810	0.6394	0.6006	0.5643	0.5303	0.4986	0.4688	0.4410	0.4150	0.3906	0.3677
14	0.7077	0.6611	0.6178	0.5775	0.5400	0.5051	0.4726	0.4423	0.4141	0.3878	0.3633	0.3405
15	0.6905	0.6419	0.5969	0.5553	0.5167	0.4810	0.4479	0.4173	0.3888	0.3624	0.3380	0.3152
16	0.6736	0.6232	0.5767	0.5339	0.4945	0.4581	0.4246	0.3936	0.3651	0.3387	0.3144	0.2919
17	0.6572	0.6050	0.5572	0.5134	0.4732	0.4363	0.4024	0.3714	0.3428	0.3166	0.2925	0.2703
18	0.6412	0.5874	0.5384	0.4936	0.4528	0.4155	0.3815	0.3503	0.3219	0.2959	0.2720	0.2502
19	0.6255	0.5703	0.5202	0.4746	0.4333	0.3957	0.3616	0.3305	0.3022	0.2765	0.2531	0.2317
20	0.6103	0.5537	0.5026	0.4564	0.4146	0.3769	0.3427	0.3118	0.2838	0.2584	0.2354	0.2145
21	0.5954	0.5375	0.4856	0.4388	0.3968	0.3589	0.3249	0.2942	0.2665	0.2415	0.2190	0.1987
22	0.5809	0.5219	0.4692	0.4220	0.3797	0.3418	0.3079	0.2775	0.2502	0.2257	0.2037	0.1839
23	0.5667	0.5067	0.4533	0.4057	0.3634	0.3256	0.2919	0.2618	0.2349	0.2109	0.1895	0.1703
24	0.5529	0.4919	0.4380	0.3901	0.3477	0.3101	0.2767	0.2470	0.2206	0.1971	0.1763	0.1577
25	0.5394	0.4776	0.4231	0.3751	0.3327	0.2953	0.2622	0.2330	0.2071	0.1842	0.1640	0.1460
26	0.5262	0.4637	0.4088	0.3607	0.3184	0.2812	0.2486	0.2198	0.1945	0.1722	0.1525	0.1352
27	0.5134	0.4502	0.3950	0.3468	0.3047	0.2678	0.2356	0.2074	0.1826	0.1609	0.1419	0.1252
28	0.5009	0.4371	0.3817	0.3335	0.2916	0.2551	0.2233	0.1956	0.1715	0.1504	0.1320	0.1159
29	0.4887	0.4243	0.3687	0.3207	0.2790	0.2429	0.2117	0.1846	0.1610	0.1406	0.1228	0.1073
30	0.4767	0.4120	0.3563	0.3083	0.2670	0.2314	0.2006	0.1741	0.1512	0.1314	0.1142	0.0994
35	0.4214	0.3554	0.3000	0.2534	0.2143	0.1813	0.1535	0.1301	0.1103	0.0937	0.0796	0.0676
40	0.3724	0.3066	0.2526	0.2083	0.1719	0.1420	0.1175	0.0972	0.0805	0.0668	0.0554	0.0460
45	0.3292	0.2644	0.2127	0.1712	0.1380	0.1113	0.0899	0.0727	0.0588	0.0476	0.0386	0.0313
50	0.2909	0.2281	0.1791	0.1407	0.1107	0.0872	0.0688	0.0543	0.0429	0.0339	0.0269	0.0213

Note: the shaded green area corresponds to SDRs consistent with the prescriptive approach; the shaded blue area corresponds to SDRs consistent with the descriptive approach; the shaded orange area corresponds to SDRs which overlap both approaches.

In order to apply the adjustment in practice, it is first necessary to identify what fraction of project costs displace private investment (e.g., financed from government borrowing) and what fraction displace consumption (e.g., financed from general tax revenues), as well as what fraction of project benefits increase private investment (e.g., operating cost savings, increased productivity) and what fraction increase consumption (e.g., reduced health impacts). Clearly, this is not an easy exercise for the analyst.

The shadow price of capital is not observable directly in markets however. The calculations to derive it are complicated and involve a certain amount of subjectivity. Based on Lyon's (1990) formulation of the shadow price of capital, Boardman *et al* (2008) estimate the shadow price of capital for Canada at about 1.1.[31] This means that \$1.00 of private investment would generate \$1.10 worth of consumption benefits for society. Two key parameters for calculating the shadow price of capital are the SDR and the ROI. Boardman *et al* used their central estimates for 3.5 per cent and 5.2 per cent for each, respectively. However, combining an SDR of 2.5 per cent with an ROI of 10.0 per cent and an SDR of 5.5 per cent with a ROI of 5 per cent produces, respectively, a shadow price of capital of about 1.6 and 1.0. This provides a range of values for the shadow price of capital for use in sensitivity analysis.

As mentioned in Section 7.3.1, private investment might be displaced if public projects are, for instance, financed by government borrowing and the supply of investment capital in Canada is relatively fixed (the 'closed economy' assumption). In this case, increased demand for investment capital will tend to raise interest rates (effectively increasing the cost of capital) and 'crowd out' private investment that would otherwise have been made. However, in an 'open economy' the extent to which dollar-for-dollar displacement of private investment occurs in practice has been questioned (US EPA, 2000; and Boardman *et al*, 2008). If no displacement occurs, then no adjustment using the shadow price of capital is necessary, and adaptation costs and benefits can simply be discounted at the social time preference rate. Adjustments using the shadow price of capital will be necessary only if:

- The adaptation action is financed by a specific bond issue; or
- The costs or benefits of the adaptation action are very large relative to the flow of investment capital from abroad (which is very unlikely to be the case).

Since these are unlikely outcomes, and bearing in mind the practical difficulties of applying the shadow price of capital (needing to distinguish between investment flows and consumption flows), it is sufficient for the analyst to discount adaptation costs and benefits using the social time preference rate. In those rare cases where the candidate adaptation action(s) is to be financed through a specific bond issue, the analyst could consider applying a shadow price of capital (within the range of 1.0 to 1.6) that is consistent with the chosen SDR, as part of sensitivity analysis.

[31] The shadow price of capital (s) is calculated as (Boardman *et al*, 2008):

$$s = \frac{(\mathrm{ROI} + f) \times (1 - a)}{r - (\mathrm{ROI} \times a) + f \times (1 - a)} = \frac{(5.2\% + 13.5\%) \times (1 - 17.0\%)}{3.5\% - (5.2\% \times 17.0\%) + 13.5\% \times (1 - 17.0\%)} = 1.1$$

Where ROI is the real, pre-tax marginal rate of return on investment, f is the depreciation rate of capital, a is the fraction of the gross return on capital that is reinvested; and r is the SDR. Boardman *et al* used their central estimate for the SDR and ROI (based on corporate bonds) of 3.5% and 5.2%, respectively. As discussed in the main text, central values for the SDR (based on the prescriptive approach) range from about 3.5% to 4.0% (within a plausible range of values from 2.5% to 5.5%), and values for ROI in the literature range from 5% to 10%. These estimates can be combined to yield estimates for s ranging from about 1.0 to 1.6.

7.3.2.6 Declining social time preference rates

There is an emerging consensus in the literature that if social discounting is to be applied to project costs and benefits incurred beyond 30-50 years into the future, that it is no longer appropriate to assume the discount rate remains constant. It is suggested that the discount rate should decline as we look beyond these time horizons in order to reflect increasing uncertainty about, among other things, the rate of growth in per capita income, the future return to capital, the marginal elasticity of utility of distant generations, and the degree to which we sympathize with them (Weitzman, 1998 and 2001; Pearce *et al*, 2003; and Groom *et al*, 2005; Gollier and Weitzman, 2009). Uncertainty around any of these determinants of the SDR is compounded dramatically the further we go into the future. The effect of this growing uncertainty is that the effective discount rate becomes increasingly lower, as illustrated in Box 7-3. Accordingly, it is argued that the further a project's time horizon extends into the future, the lower the rate that should be used to discount costs and benefits.

Box 7-3: The effective discount rate over long time horizons

Suppose there is uncertainty about the SDR. Two rates are believed credible; 2 per cent and 6 per cent per year. Both rates are equally likely. Rows 1 and 2 in the table below show the discount factors and present value of $1 million discounted at 2 per cent over time horizons of 1, 30, 50, 100, 200 and 400 years. Rows 3 and 4 present the same information for an SDR of 6 per cent per year. The expected present value assuming an SDR of 2 per cent and 6 per cent with equal likelihood is presented in row 5; note that it is simply the average of rows 2 and 4 since the likelihood of either rate is 50-50. The average of the discount factors given in rows 1 and 3 – termed the 'certainty-equivalent discount factor' – is shown in row 6. These certainty-equivalent discount factors give the expected present values across row 5. Working backwards, the effective discount rate corresponding to each of the certainty-equivalent discount factors is shown in row 7.

As the table shows, the effective discount rate starts at 4 per cent in year 1 (the average of 2 and 6 per cent), but then declines asymptotically toward 2 per cent in the distant future.

		Time horizon (years from present)					
		1	30	50	100	200	400
1	Discount factor at SDR = 2%	0.9804	0.5521	0.3715	0.1380	0.0191	0.0004
2	PV of $1 million at 2%	$980,392	$552,071	$371,528	$138,033	$19,053	$363
3	Discount factor at SDR = 6%	0.9434	0.1741	0.0543	0.0029	0.0000	0.0000
4	PV of $1 million at 6%	$943,396	$174,110	$54,288	$2,947	$9	$0
5	Expected PV (2% and 6% equally likely)	$961,894	$363,091	$212,908	$70,490	$9,531	$182
6	Certainty-equivalent discount factor	0.9619	0.3631	0.2129	0.0705	0.0095	0.0002
7	Effective (average) discount rate	4.0%	3.4%	3.2%	2.7%	2.3%	2.2%

Source: Adapted from Hepburn (2006)

A number of researchers have investigated time-declining SDRs, resulting in various schedules of time-declining discount factors and corresponding rates (e.g., OXERA, 2002; Gollier, 2002a and 2002b; Newel and Pizer, 2003 and 2004; Weitzman, 2001; and Hepburn *et al*, 2009). The UK government even went as far as officially recommending a step function of declining discount rates; starting at 3.5 per cent for years 1-30, falling to 3.0 per cent for years 31-75, 2.5 per cent for years 76-125, 2.0 per cent for years 126-200, 1.5 per cent for years 201-300, and

1.0 per cent for more than 300 years.[32] This schedule of discount rates is to be applied where (HMT, 2008):

> "[…] *the effects under examination are very long-term (in excess of 50 years) and which involve very substantial and, for practical purposes, irreversible wealth transfers between generations*."

Hepburn et al (2009) produced a schedule of time-declining discount factors (and corresponding discount rates) for Canada, starting at a real annual rate of 3.5 per cent. This schedule is provided in Table 7-3. If an adaptation action has a time horizon in excess of 50 years and costs accrue to one generation and benefits to another, then the analyst could calculate the present value costs and benefits based on the schedule of time-declining discount factors listed in Table 7-3.[33] Note that this schedule starts with a real annual SDR of 3.5 per cent; if the starting discount rate selected by the analyst is different, then the schedule of time-declining discount factors will need to be scaled accordingly – for example, by estimating discount factors at a constant 3.5 per cent per year, taking the ratio of the declining discount factors in Table 7-3 to the estimated discount factors at a constant 3.5 per cent per year, and applying the corresponding ratios to a different initial SDR).

An alternative to applying a time-declining schedule of discount factors and corresponding discount rates – which is empirically equivalent – is to discount future costs and benefits using a lower constant SDR than that selected. For instance, applying a constant rate of about 2.8 per cent approximates the effect of the schedule of time-declining discount factors given in Table 7-3 starting at 3.5 per cent; they both produce the same present value.

It is important for the analyst to be aware that the use of time-declining discount rates can result in 'time inconsistent' (or 'dynamically inconsistent') decision-making. Time inconsistency is considered bad practice in economics, as it can lead to a reduction society's welfare. It occurs – for example – if an adaptation strategy that has been determined to be optimal today at a specific discount rate turns out to be sub-optimal when evaluated at a future date using a different discount rate, and this leads to a reversal of the original decision. Nevertheless, some researchers have argued that the potential for time inconsistency is much less problematic compared with other factors that can lead to changes in decisions (Heal, 1998; Spackman, 2002; Hepburn, 2006).

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[32] Note the when applying a step function of declining discount rates like this: discount net benefits occurring after year 300 at 1 per cent, take the resulting value at year 300 and discount it back to year 200 at 1.5 per cent, again take the resulting value at year 200 and discount it back to year 125 at 2 per cent, and so on.

[33] When the costs of a project accrue to one generation and the benefits to another (or vice versa) it takes on an inter-generational dimension, in contrast to intra-generational projects where the costs and benefits accrue to the same generation. Boardman et al (2009) argue that 50 years is a good practical length of time to delineate intra-generational (near-term) projects from inter-generational (very long-term) projects. Moreover, the most recent guidance from the UK Treasury and the US Environmental Protection Agency similarly employ 50 years to distinguish between the near-term and very long-term (HMT, 2008; US EPA, 2010).

Table 7-3: Schedule of declining SDRs for long-term discounting for Canada

Year	Certainty-equivalent discount factor	Certainty-equivalent discount rate
1	0.96618	3.50
20	0.52604	3.13
40	0.28910	2.99
60	0.16276	2.84
80	0.09369	2.75
100	0.05494	2.67
150	0.01564	2.45
200	0.00491	2.26
250	0.00168	2.07
300	0.00062	1.93
350	0.00025	1.79
400	0.00011	1.61

Source: Hepburn et al (2009)

7.3.3 Suggested approach

The selection of an acceptable SDR is a critical factor determining whether candidate adaptation actions are socially desirable. The timing of adaptation costs and benefits is vital in this respect:

- If both costs and benefits are realized over the near term by the same generation (the analysis has a time horizon of less than 50 years); and
  - The candidate adaptation action is very large or financed by a specific bond issue, then it is reasonable to apply discount rates that reflect forgone returns to private investment (i.e., the weighted average social opportunity cost of capital).
  - The candidate adaptation action is average sized or tax-financed (displacement of private investment is thus negligible), then it is reasonable to apply discount rates as revealed by society's preferences in allocating their consumption (i.e., the post-tax market rate of interest on savings or consumption rate of interest).
- If costs or benefits are realized over the long term (with time horizons greater than 50 years) and are thus experienced by different generations; and
  - The candidate adaptation action is very large or financed by a specific bond issue, then the choice of an appropriate discount rate in part becomes an ethical issue, and should be based on the social time preference rate. Costs (benefits) believed to displace (enhance) private investment flows should be adjusted using the shadow price of capital prior to being discounted at the appropriate (constant) social time preference rate. Alternatively, given the practical difficulties in applying the shadow price of capital, the analyst could use a social time preference rate towards the upper end of credible values.
  - The candidate adaptation action is average sized or tax-financed, then the choice of an appropriate discount rate should be based on the social time preference

rate. Since concerns over the displacement of private investment are negligible, it is reasonable to use a (constant) value towards the lower end of credible values.

In the latter case, the analyst may also consider applying a schedule of time-declining discount factors using an appropriate value for the social time preference rate as a starting point – especially if net benefits are believed to accrue into the far-distant future, extending out over 100 years. In most cases, however, using a slightly lower (constant) social time preference rate is analytically equivalent and will provide a similar result.

Additionally, the analyst should present all future adaptation costs and benefits over time without any discounting.

Furthermore, when discounting, the analyst should:

- Apply the same approach to both costs and benefits;
- Maintain consistency with the use of real or nominal prices; and
- Not attempt to adjust the discount rate for uncertainty surrounding the valuation of costs or benefits.

7.4 References and further reading

Anthoff, D., Tol, R., and Yohe, G., 2009a, Discounting for Climate Change, *Economics: Open Access, Open Assessment E-Journal*, 3, pp. 1-22.

Anthoff, D., Tol, R., and Yohe, G., 2009b, Risk Aversion, Time Preference, and the Social Cost of Carbon, *Environmental Research Letters*, 4(2), pp. 1-7.

Arrow, K., 1995, Intergenerational Equity and the Rate of Discount in Long-Term Social Investment, Paper presented at the IEA World Congress, December 1995.

Arrow, K., Cline, W., Maler, K., Munasinghe, M., Squitieri, R., and Stiglitz., J., 1996, Inter-temporal Equity, Discounting, and Economic Efficiency, in Climate Change 1995: Economic and Social Dimensions of Climate Change, Bruce, J., Lee, H., and Haites., E. (editors), Cambridge University Press, Cambridge, UK.

Beckerman, W., and Hepburn, C., 2007, Ethics of the Discount Rate in the Stern Review on the Economics of Climate Change, *World Economics*, 8(1), pp. 187-210.

Blundell, R., Browning, M., and Meghir, C., 1994, Consumer Demand and the Life-Cycle Allocation of Expenditure, *Review of Economic Studies*, 61, pp. 57-80.

Boardman, A., Greenberg, D., Vining, A., and Weimer, D., 2006, Cost-Benefit Analysis: Concepts and Practice, Third Edition, Pearson Prentice Hall, New Jersey, USA.

Boardman, A., Moore, M., and De Civita, 2009, Proposed Social Discount Rate(s) for Canada Based on Future Growth, Policy Research Institute, Working Paper Series 039, Ottawa, Canada.

Boardman, A., Moore, M., and Vining, A., 2008, Social Discount Rates for Canada, Paper presented at a conference on evidence-based regulatory decision making, March 13, 2008, Ottawa, Canada.

Boscollo, M., Vincent, R., and Panayotou, T., 1998, Discounting Costs and Benefits in Carbon Sequestration Projects, Development Discussion Paper No. 638, Harvard Institute for International Development, Harvard University, Cambridge, MA, USA.

Cline, W., 1992, The Economics of Global Warming, Institute of International Affairs, Washington DC, USA.

Cline, W., 1999, Discounting for the Very Long Term, in Portney, P., and Weyant, J. (editors), Discounting and Inter-generational Equity, Resources for the Future, Washington, DC, USA.

Dasgupta, P., 2007, Commentary: The Stern Review's Economics of Climate Change, *National Institute Economic Review*, 199, pp. 4-7.

Dasgupta, P., 2008, Discounting Climate Change, Journal of Risk and Uncertainty, 37, pp. 141-169.

Evans, D., 2005, Elasticity of Marginal Utility of Consumption: Estimates for 20 OECD Countries, *Fiscal Studies*, 26(2), pp. 197–224.

Evans, D., and Sezer, H., 2004, Social Discount Rates for Six Major Countries, *Applied Economics Letters*, 11, pp. 557-560.

Feldstein, M., 1965, Derivation of Social Time Preference Rates, *Kyklos*, XVIII, 2, pp. 277-287.

Gollier, C., 2002a, Discounting an Uncertain Future, *Journal of Public Economics*, 85, pp. 149-166.

Gollier, C., 2002b, Time Horizon and the Discount Rate, Journal of Economic Theory, 107, pp. 463-473.

Gollier, C., and Weitzman, M., 2009, How should the Distant Future be Discounted when Discount Rates are Uncertain? Working Paper, Harvard University, Cambridge, MA, USA.

Groom, B., Hepburn, C., Koundouri, P., and Pearce, P., 2005, Declining Discount Rates: The Long and Short of it, *Environmental and Resource Economics*, 32, pp. 445-493.

Groom, B., Koundouri, P., Panopoulou, E., and Pantelidis, T., 2007, Discounting the Distant Future: How Much Does Model Selection Affect the Certainty Equivalent Rate? *Journal of Applied Econometrics*, 22(3), pp. 641-656.

Halsnaes, K., Shukla, P., Ahuja, D., Akumu, G., Beale, R., Edmonds, J., Gollier, C., Grubler, A., Duong, M., Markandya, A., McFarland, M., Nikitina, E., Sugiyama, T., Villavicencio, A., and Zou, J., 2007, Framing Issues, in Climate Change 2007: Mitigation of Climate Change, Metz, B., Davidson, O., Bosch, P., Dave, R., and Meyer., L. (editors), Cambridge University Press, Cambridge, UK.

Heal, G., 1998, Valuing the Future: Economic Theory and Sustainability, Columbia University Press, New York, USA.

Hepburn, C., 2006, Discounting Climate Change Damages: Working Note for the Stern Review, mimeo, Oxford University, Oxford, UK.

Hepburn, C., Koundouri, P., Panopoulou, E., and Pantelidis, T., 2009, Social Discounting Under Uncertainty: A Cross-country Comparison, *Journal of Environmental Economics and Management*, 57, pp. 140-150.

HMT, 2008, Intergenerational Wealth Transfers and Social Discounting: Supplementary Green Book Guidance, UK HM Treasury, London, UK.

Hoel, M., and Sterner, T., 2007, Discounting and Relative Prices in Assessing Future Environmental Damages, *Climatic Change*, 84, pp. 265-280.

Jenkins, G., and Kuo, C-Y., 2007, The Economic Opportunity Cost of Capital for Canada - An Empirical Update, QED Working Paper Number 1133, Department of Economics, Queen's University, Kingston, Canada.

Koopmans, T., 1965, On the Concept of Optimal Growth, The Econometric Approach to Development Planning, North-Holland, Amsterdam, The Netherlands, pp. 225-287.

Kula, E., 1984, Derivation of Social Time Preference Rates for the United States and Canada, *Quarterly Journal of Economics*, 99(4), pp. 873-82.

Layard, R., Mayraz, G., and Nickell, S., 2007, The Marginal Utility of Income, London School of Economics, Centre for Economic Performance Discussion Paper 784, London, UK.

Lind, R. (editor), 1982, Discounting for Time and Risk in Energy Policy, Resources for the Future, Washington, DC, USA.

Lind, R., 1990, Reassessing the Government's Discount Rate Policy in Light of New Theory and Data in a World Economy with a High Degree of Capital Mobility, *Journal of Environmental Economics and Management*, 18(2), pp. 8-28.

Lyon, R., 1990, Federal Discount Rate Policy, the Shadow Price of Capital, and Challenges for Reform, *Journal of Environmental Economics and Management*, 18(2), pp. 29-50.

Moore, M., Boardman, A., Vining, A., Weiner, D., and Greenberg, D., 2004, Just Give Me a Number: Practical Values for the Social Discount Rate, *Journal of Policy Analysis and Management*, 23(4), pp. 789-812.

Newell, R., and Pizer, W., 2003, Discounting the Distant Future: How Much do Uncertain Rates Increase Valuations, *Journal of Environmental Economics and Management*, 46(1), pp. 52-71.

Newell, R., and Pizer, W., 2004, Uncertain Discount Rates in Climate Policy Analysis, *Energy Policy*, 32, pp. 519-529.

Nordhaus, W., 1999, Discounting and Public Policies that affect the Distant Future in Portney, P., and Weyant, J. (editors), Discounting and Inter-generational Equity, Resources for the Future, Washington, DC, USA.

Nordhaus, W., 2007, A Review of the Stern Review on the Economics of Climate Change, *Journal of Economic Literature*, 45(3), pp. 682-702.

OXERA, 2002, A Social Time Preference Rate for Use on Long-term Discounting, a report prepared for HM Treasury, Oxford Consulting Ltd, Oxford, UK.

Pearce, D., and Ulph, D., 1999, A Social Discount Rate for the United Kingdom, in Pearce, D. (editor), Economics and Environment: Essays on Ecological Economics and Sustainable Development, Edward Elgar, Cheltenham, UK, pp. 268-85.

Pearce, D., Groom, B., Hepburn, C., and Koundouri, P., 2003, Valuing the Future: Recent Advances in Social Discounting, *World Economics*, 4(2), pp. 121-141.

Portney, P., and Weyant, J. (editors), 1999, Discounting and Inter-generational Equity, Resources for the Future, Washington, DC, USA.

Rabl, A., 1996, Discounting of Long-term Costs: What Would Future Generations Prefer us to Do? *Ecological Economics*, 17, pp. 137-145.

Ramsey, F., 1928, A Mathematical Theory of Saving, *Economic Journal*, 38, pp. 543-549.

Scott, M., 1989, A New View of Economic Growth, Oxford University Press, Oxford, UK.

Sælen, H., Atkinson, G., Dietz, S., Helgeson, J., and Hepburn, C., 2008, Risk, Inequality and Time in the Welfare Economics of Climate Change: Is the Workhorse Model Underspecified, Department of Economics Working Paper Series, No 400, Oxford University, Oxford, UK.

Smith, K., 2010, Stern, Climate Policy and Saving Rates, Climate Policy, 10(3), pp. 289-297.

Solow, R., 1974, The Economics of Resources or the Resources of Economics, American Economic Review Papers and Proceedings, 64(2), pp. 1-14.

Spackman, M., 2002, Observations on Discounting and the Very long Term, UK Department for Communities and Local Government, London, UK.

Spackman, 2011, Government Discounting Controversies: the Valuation of Social Time Preference, Centre for Climate Change Economics and Policy Working Paper No 77, University of Leeds, Leeds, UK.

Stern, N., 1977, The Marginal Valuation of Income, in Artis, M., and Nobay, A. (editors), Studies in Modern Economic Analysis, Basil Blackwell, Oxford, pp. 209-258.

Stern, N., 2006, Stern Review: The Economics of Climate Change, Cambridge University Press, Cambridge, UK.

TBCS, 2007, Canadian Cost Benefit Analysis Guide: Regulatory Proposals, Treasury Board of Canada Secretariat (TBCS), Ottawa, Canada.

Tol, R., and Yohe, G., 2006, A Review of the Stern Review", World Economics, 7 (4), pp. 233-250.

Yohe, G., 2006, "Some Thoughts on the Damage Estimates Presented in the Stern Review, *Integrated Assessment Journal*, 6, pp. 65–72.

Weitzman, M., 1998, Why the Far-distant Future Should Be Discounted at Its Lowest Possible Rate? *Journal of Environmental Economics and Management*, 36(3), pp. 201-208.

Weitzman, M., 2001, Gamma Discounting, *American Economic Review*, 91(1), pp. 260-271.

Weitzman, M., 2007, A Review of the Stern Review on the Economics of Climate Change, *Journal of Economic Literature*, 45(3), pp. 703-724.

UNFCCC, 2009, Potential Costs and Benefits of Adaptation Options: A Review of Existing Literature: Technical Paper, FCCC/TP/2009/2, UN Framework Convention on Climate Change Secretariat, Bonn, Germany.

US EPA, 2000, Guidelines for Preparing Economic Analyses, Office of the Administrator, EPA 240-R-00-003, US Environmental Protection Agency, Washington, DC, USA.

US EPA, 2010, Guidelines for Preparing Economic Analyses, National Centre for Environmental Economics, Office of Policy, EPA 240-R-10-001, US Environmental Protection Agency, Washington, DC, USA.

8 Decision-making Criteria

8.1 Purpose

The purpose of this section is to:

- ⇨ Identify the main criteria commonly used in CBA to recommend (or otherwise) adaptation actions on economic grounds – namely: Net Present Value (NPV), Internal Rate of Return (IRR) and Benefit-Cost Ratio (BCR);
- ⇨ Explain how each criterion is calculated;
- ⇨ Outline the NPV, IRR, and BCR decision rules for simple and complex contexts (e.g., when decision-makers face budget constraints or adaptation actions are mutually exclusive);
- ⇨ Discuss the relative strengths and weaknesses of each criterion;
- ⇨ Explain why the recommended criterion for evaluating adaptation actions on economic grounds is NPV; and
- ⇨ Outline how the Payback Period can be used to provide supplementary information to (mainly private sector) decision-makers.

8.2 Net present value criterion

The Net Present Value (NPV) criterion is widely used by financial analysts and economists to assess the financial or economic attractiveness of a strategy, policy, or project. The NPV of an adaptation action is the algebraic sum of the present values of projected incremental benefits less incremental costs over the action's anticipated life. It is calculated by multiplying the projected incremental benefits (the costs of climate variability and climate change avoided by the action, plus any ancillary benefits) and incremental costs (the non-recurring and recurring costs of the action) incurred each year, by the appropriate discount factor, and summing all the resulting discounted values over the life of the adaptation.

If this sum is less than zero, then the investor cannot expect to earn a rate of return on their investment equal to the discount rate used to determine the discount factor, and they may not even recover the invested capital. Hence, if the investor is a public sector organization the welfare of society is expected to decrease; if the investor is a private sector organization their net worth is expected to decrease. The decline in social welfare or net worth will be equal to the negative amount of the calculated NPV. A decision-maker is therefore not likely to approve an adaptation action with a NPV less than zero, unless there are additional criteria - such as equity, risk, or political acceptability – which are at least as important as economic efficiency (recall Section 3.2.1.1).

A NPV equal to zero implies that the investor can expect to recover their incremental investment, and earn a rate of return on their invested capital equal to the discount rate. In this case, the welfare of society or the net worth of the investor is unaffected. They are not worse off from the investment in adaptation; nor are they better off.[34]

If the calculated NPV is greater than zero, then the investor can expect to accrue an addition to their net worth or an improvement in social welfare, as well as recover the invested capital and earn a rate of return on their investment equal to the discount rate. The addition to social welfare or net worth will be equal to the positive amount of the NPV.

The NPV of an adaptation action is calculated as follows:

$$NPV = \sum_{t=0}^{n} \frac{NB_t}{(1+r)^t} = \frac{NB_0}{(1+r)^0} + \frac{NB_1}{(1+r)^1} + \cdots + \frac{NB_n}{(1+r)^n}$$

or Equation 8-1

$$NPV = \sum_{t=0}^{n} \frac{(B_t - C_t)}{(1+r)^t} = \frac{(B_0 - C_0)}{(1+r)^0} + \frac{(B_1 - C_1)}{(1+r)^1} + \cdots + \frac{(B_n - C_n)}{(1+r)^n}$$

Where NB_t is the incremental net benefit, the difference between incremental benefits (B_t) and costs (C_t), accruing at the beginning of period *t*. Sometimes the term incremental net cash flows may be used instead of incremental net benefits. The final time period (at some point in the future) when the effects of the adaptation action are felt is denoted by *n*. Incremental net benefits are discounted at the real social discount rate (SDR), *r*, the derivation of which is discussed in Section 7.3. Note that the same real SDR should be applied to both incremental costs and the benefits to ensure consistent decision-making. By way of example, Table 8-1 illustrates calculating the net present value of a hypothetical adaptation action.

As noted in Section 7.2.2, this specification of a present value calculation assumes that the initial expenditure (capital outlay) on the adaptation action occurs at the beginning of the first year (i.e., right now), and future costs and future benefits at the beginning of subsequent years.

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[34] This assumes that the discount rate reflects the opportunity cost of capital. In this case, the investor could have simply left the incremental funds in the capital market and earned an equivalent rate of return to investing in the adaptation action.

Table 8-1: Example of calculating NPV of a candidate adaptation action

Year	Adaptation project costs		Adaptation project benefits			Net benefits	Discount factors (r = 3.5 %)	Discounted net benefits
	Non-recurring costs ($ million)	Recurring costs ($ million)	Climate variability costs avoided ($ million)	Climate change damages avoided ($ million)	Ancillary benefits ($ million)	($ million)		($ million)
0	20.0	-	-	-	-	(20.0)	1.000	(20.0)
1	-	0.4	0.7	1.2	0.2	1.7	0.966	1.6
2	-	0.4	0.7	1.2	0.2	1.7	0.934	1.6
3	-	0.4	0.7	1.2	0.2	1.7	0.902	1.5
4	-	0.4	0.7	1.2	0.2	1.7	0.871	1.5
5	-	0.4	0.7	1.2	0.2	1.7	0.842	1.4
6	-	0.4	0.7	1.2	0.2	1.7	0.814	1.4
7	-	0.4	0.7	1.2	0.2	1.7	0.786	1.3
8	-	0.4	0.7	1.2	0.2	1.7	0.759	1.3
9	-	0.4	0.7	1.2	0.2	1.7	0.734	1.2
10	-	0.4	0.7	1.2	0.2	1.7	0.709	1.2
11	-	0.4	0.7	1.2	0.2	1.7	0.685	1.2
12	-	0.4	0.7	1.2	0.2	1.7	0.662	1.1
13	-	0.4	0.7	1.2	0.2	1.7	0.639	1.1
14	-	0.4	0.7	1.2	0.2	1.7	0.618	1.1
15	-	0.4	0.7	1.2	0.2	1.7	0.597	1.0
16	-	0.4	0.7	1.2	0.2	1.7	0.577	1.0
17	-	0.4	0.7	1.2	0.2	1.7	0.557	0.9
18	-	0.4	0.7	1.2	0.2	1.7	0.538	0.9
19	-	0.4	0.7	1.2	0.2	1.7	0.520	0.9
20	-	0.4	0.7	1.2	0.2	1.7	0.503	0.9
NPV = sum of discounted net benefits								**4.2**

Assumed time line for net benefit flows (beginning of each year):

8.2.1 NPV decision rules

The NPV criterion can be stated in terms of four decision rules:

⇨ **Decision rule 1:**

Do not accept an adaptation action unless the NPV is positive when discounted at the appropriate real SDR.

⇨ **Decision rule 2:**

Select the adaptation action with the highest NPV in order to maximize improvements in welfare.

⇨ **Decision rule 3:**

If financial resources are limited, select the adaptation a6ction of package or actions that maximize the NPV of the fixed investment budget.

The larger the number of actions under consideration, the more complex the choice of the best portfolio of actions can become. This is especially true where there is complementarity between actions - that is, where the net benefit stream of one action depends on the acceptance and implementation of another action. If necessary, the analyst could employ mathematical optimizing techniques to investigate all combinations of candidate adaptation actions to select that portfolio which satisfies the given resource constraints on choice and has the greatest NPV.

⇨ **Decision rule 4:**

If investment is not subject to a budget constraint, and a choice must be made between two or more mutually exclusive adaptation actions, then the decision-maker should select the action with the highest NPV, for this will maximize the improvement in welfare (increase in net worth for private investor). Actions are mutually exclusive if they achieve the same adaptation goal – e.g., defenses being considered to protect the same site from flood risk. Decision-makers are frequently confronted with the problem of selecting between mutually exclusive projects.

8.3 Alternative criterion

Decision-makers in the public and private sector also use alternative criteria, such as internal rate of return or benefit-cost ratio, to judge the net worth of strategies, policies, and projects. These alternative criteria, however, have serious flaws relative to the NPV criterion, and if they are used, there is a risk that poor decisions could be made. To help the analyst articulate a case for employing solely the NPV criterion, the strengths and weaknesses of these alternatives are discussed below.

8.3.1 Internal rate of return criterion

To apply the NPV criterion the analyst must establish *ex-ante* a specific real social discount rate. The internal rate of return (IRR), in contrast, is the discount rate ($\hat{\imath}$) that solves the following equation:

$$0 = \sum_{t=0}^{n} \frac{NB_t}{(1+\hat{\imath})^t} = \frac{NB_0}{(1+\hat{\imath})^0} + \frac{NB_1}{(1+\hat{\imath})^1} + \cdots + \frac{NB_n}{(1+\hat{\imath})^n}$$

or Equation 8-2

$$0 = \sum_{t=0}^{n} \frac{(B_t - C_t)}{(1+\hat{\imath})^t} = \frac{(B_0 - C_0)}{(1+\hat{\imath})^0} + \frac{(B_1 - C_1)}{(1+\hat{\imath})^1} + \cdots + \frac{(B_n - C_n)}{(1+\hat{\imath})^n}$$

The IRR sets the NPV equal to zero and is thus consistent with the definition of a zero NPV – that is, investors recover their invested capital and make a rate of return equal to the discount rate, the IRR in this case. If the IRR is greater than the *ex-ante* specified real social discount rate, then the investor can also expect to generate an improvement in social welfare (public) or receive an addition to their net worth (private).

Table 7-1 presents the IRR calculation for the same example adaptation action shown in Table 8-1. The calculated IRR is 5.69 per cent. The IRR is typically calculated by trial and error. In an Excel spreadsheet the analyst can either use (a) the goal seek function in the data menu to 'seek' the discount rate that yields a NPV equal to zero or (b) the IRR function in the formulas menu.

Table 8-2: Example of calculating IRR of a candidate adaptation action

Year	Adaptation project costs		Adaptation project benefits			Net benefits	Discount factors (IRR = 5.69%)	Discounted net benefits
	Non-recurring costs	Recurring costs	Climate variability costs avoided	Climate change damages avoided	Ancillary benefits			
	($ million)	($ million)	($ million)	($ million)	($ million)	($ million)		($ million)
0	20.0	-	-	-	-	(20.0)	1.000	(20.0)
1	-	0.4	0.7	1.2	0.2	1.7	0.946	1.6
2	-	0.4	0.7	1.2	0.2	1.7	0.895	1.5
3	-	0.4	0.7	1.2	0.2	1.7	0.847	1.4
4	-	0.4	0.7	1.2	0.2	1.7	0.801	1.4
5	-	0.4	0.7	1.2	0.2	1.7	0.758	1.3
6	-	0.4	0.7	1.2	0.2	1.7	0.717	1.2
7	-	0.4	0.7	1.2	0.2	1.7	0.679	1.2
8	-	0.4	0.7	1.2	0.2	1.7	0.642	1.1
9	-	0.4	0.7	1.2	0.2	1.7	0.608	1.0
10	-	0.4	0.7	1.2	0.2	1.7	0.575	1.0
11	-	0.4	0.7	1.2	0.2	1.7	0.544	0.9
12	-	0.4	0.7	1.2	0.2	1.7	0.515	0.9
13	-	0.4	0.7	1.2	0.2	1.7	0.487	0.8
14	-	0.4	0.7	1.2	0.2	1.7	0.461	0.8
15	-	0.4	0.7	1.2	0.2	1.7	0.436	0.7
16	-	0.4	0.7	1.2	0.2	1.7	0.413	0.7
17	-	0.4	0.7	1.2	0.2	1.7	0.390	0.7
18	-	0.4	0.7	1.2	0.2	1.7	0.369	0.6
19	-	0.4	0.7	1.2	0.2	1.7	0.349	0.6
20	-	0.4	0.7	1.2	0.2	1.7	0.331	0.6
NPV = sum of discounted net benefits								**0.0**

8.3.1.1 IRR decision rules

Similar to the NPV criterion, the IRR criterion can be stated in terms of a number of decision rules:

⇨ **Decision rule 1:**

Do not accept an adaptation action unless the IRR is greater than the *ex-ante* specified real SDR. Accept the action if $\hat{\imath} > r$.

⇨ **Decision rule 2:**

If investment is not subject to a budget constraint and a choice must be made between two or more mutually exclusive adaptation actions, then the decision-maker should select the action with the higher, or highest, IRR.

8.3.1.2 Shortcomings of the IRR criterion

The IRR has multiple problems as an evaluation criterion, including:

⇨ **A unique IRR may not exist:**

The IRR is, strictly speaking, the root of the NPV equation. If the time profile of incremental net benefits changes sign from negative to positive only once over the life of the adaptation action, then a unique root, or IRR, will exist. The initial capital investment in an adaptation action will cause the incremental net benefits in year one to be negative, but once the investment is made the net benefits in subsequent years may be expected to be positive. However, adaptation actions may exhibit different time profiles for incremental net benefits. After a few years of operation, for example, a piece of equipment may need to be replaced, causing the action's incremental net benefits to become temporarily negative for a second time. Or, actions may require major expenditures at the end of their life for decommissioning, again turning the incremental net benefits negative for a second time. In these cases, there may be more than one root, or IRR. Generally speaking, there can be as many IRRs as there are changes in the sign of the incremental net benefits stream. The presence of multiple IRRs can be problematic for decision-making. For example, assume the computed IRRs of an adaptation action are 2 and 10 per cent, and the real SDR is 6 per cent. Should this adaptation action be accepted?

⇨ **The IRR gives the wrong decision if the adaptation is similar to borrowing:**

Typically, an adaptation action will require an initial capital expenditure, followed by a stream of positive incremental net benefits, as shown by Action 1 in Table 4-1. This is akin to lending; an initial cash outflow is followed by a larger cash inflow. At a real SDR of 5 per cent, the NPV of Action 1 is positive. The IRR is also high and greater than the discount rate. The adaptation action is therefore a desirable investment according to both evaluation criteria. Action 2 in the table exhibits a different time profile of incremental net benefits; more akin to borrowing where an initial cash inflow is followed by a larger cash outflow. In this case, the NPV is negative and the adaptation action should be rejected. However, the IRR is still large and exceeds the real SDR. Employing the IRR criterion and accepting the action would lead to a wrong decision; one which would reduce social welfare or the net worth of the private investor.

Table 8-3: Time profile of incremental net benefit for adaptation actions 1 and 2

Time Period	T = 0	T = 1	NPV (r = 5%)	IRR
Action 1	-$100	+$200	+$90	100%
Action 2	+$100	-$200	-$90	100%

⇨ Wrong ordering of mutually exclusive adaptation actions:

The NPV criterion takes into account the total scale of an adaptation action, in terms of the total required capital investment and difference in scale between actions. The IRR, however, overlooks differences in scale. The IRR is, in effect, a ratio, expressed as a rate per dollar of investment. Hence, it does not indicate how many dollars in total that rate can earn.

For example, consider the two mutually exclusive adaptation actions 3 and 4 in Table 8-4. If Decision Rule 2 for the IRR criterion is employed, then adaptation action 3 is selected, since it has the highest IRR. However, the NPV of action 4 is higher. Selecting action 3 is thus a mistake, as society would forgo a welfare gain equivalent to $272. The problem is that the higher rate of return earned by adaptation action 3 is only made over an investment of $500, whereas the lower rate of return offered by adaptation action 4 is earned over a much larger investment of $5,000; hence, the higher NPV offered by adaptation action 4.

Table 8-4: Time profile of incremental net benefit for adaptation actions 3 and 4

Time Period	T = 0	T = 1	NPV (r = 5%)	IRR
Action 3	-$500	+$750	+$183	50%
Action 4	-$5,000	+$6,000	+$455	20%

⇨ IRR favors adaptation actions with shorter lives:

Consider the time profile of incremental net benefits for adaptation actions 5 and 6 shown in Table 8-5. The sum of the undiscounted positive incremental net benefits of action 5 is noticeably higher than those of action 6 ($500 versus $340, respectively). Nevertheless, the IRR of adaptation action 6 is higher because its incremental net benefits occur earlier. Employing Decision Rule 2 for the IRR criterion would result in a wrong decision being made; society would forgo a welfare gain equivalent to $140. This mistake would not occur following the NPV criterion. In general, the IRR criterion tends to be lower for (and thus is less favorable to) actions which generate an even distribution of incremental net benefits over time; the IRR favors actions where the incremental net benefits are front-loaded.

Table 8-5: Time profile of incremental net benefit for adaptation actions 5 and 6

Time Period	T = 0	T =1	T = 2	NPV (r = 5%)	IRR
Action 5	-$100	+$225	+$275	+$364	213%
Action 6	-$100	+$340	$0	+$224	240%

⇨ Difficult to apply when using time varying discount rates:

IRR Decision Rule 1 requires a comparison between the computed IRR and the *ex-ante* specified real SDR. Clearly, application of this rule is problematic if the analyst is employing a time varying discount rate (see Section 7.3.2.6). With time varying discount rates it is possible that $\hat{\imath}$ is less than the value of r used to discount incremental net benefits for years $t = 0, \dots, 30$, but is greater than the value for r used for all subsequent years as r falls over time. Which value of r should the decision-maker use when applying the IRR criterion?

8.3.2 Benefit-cost ratio criterion

Benefit-cost ratios are popular with decision-makers because they provide a handy rule of thumb and summary statistic. As the term implies, the benefit-cost ratio (BCR) is the ratio of the present value of incremental benefits (or cash inflows) to the present value of incremental costs (or cash outflows). Formally, the BCR of an adaptation action providing streams of incremental benefits and costs over *n* time periods, with annual discounting at a real SDR of *r*, is given by:

$$\mathrm{BCR} = \frac{\sum_{t=0}^{n} \frac{B_t}{(1+r)^t}}{\sum_{t=0}^{n} \frac{C_t}{(1+r)^t}} \qquad \text{Equation 8-3}$$

Where B_t and C_t are the incremental benefits and incremental costs, respectively, incurred during year *t*. The BCR for the example adaptation action presented in Table 8-1 is given by:

$$\mathrm{BCR} = \frac{\frac{0.0}{(1.035)^0} + \frac{2.1}{(1.035)^1} + \cdots + \frac{2.1}{(1.035)^{20}}}{\frac{20.0}{(1.035)^0} + \frac{0.4}{(1.035)^1} + \cdots + \frac{0.4}{(1.035)^{20}}} = \frac{29.8}{25.7} = 1.16 \qquad \text{Equation 8-4}$$

8.3.2.1 BCR decision rules

As with the NPV and IRR criteria, the BCR criterion can be stated in terms of a number of decision rules.

⇨ **Decision rule 1:**

Do not accept an adaptation action unless the BCR is greater than one.

⇨ **Decision rule 2:**

If financial resources are limited, rank projects according to their BCRs. Work down the list, from the acceptable actions (actions with a BCR > 1) with the highest BCR to those acceptable actions with lower BCRs, until the fixed budget is exhausted.

⇨ **Decision rule 3:**

If investment is not subject to a budget constraint and a choice must be made between two or more mutually exclusive adaptation actions, then the decision-maker should select the action with the higher, or highest, BCR.

8.3.2.2 Shortcomings of the BCR criterion

Despite its popularity, the BCR suffers from some serious problems.

⇨ **The BCR is sensitive to the definition of costs and benefits:**

It is not uncommon for an adaptation action to result in cost savings relative to the defined Reference Case (recall the discussion about ancillary benefits in Section 4.3.2). Should these cost savings be deduced from the action's cost stream or added to the action's benefit stream? Regardless, a decision rule should not be sensitive to the classification of costs and benefits; it should be possible to treat all costs as negative benefits and all benefits as negative costs, without changing the accept-reject decision. The BCR is, nonetheless, affected by the classification of costs and benefits, since it is a ratio.

For example, an adaptation action with present value incremental benefits of $120 and present value incremental adaptation costs of $80 and present value incremental cost savings of $20, will produce a BCR of 2.00 (i.e., $120 ÷ ($80 - $20)). However, if the cost savings of $20 is treated as a benefit, the BCR decreases to 1.75 (i.e., ($120 + $20) ÷ $80). The NPV of the adaptation action, $60, in contrast, is unaffected by the classification of costs:

$120 – ($80 + $20) = $60 and ($120 + $20) - $80 = $60.

Multiplying or dividing the denominator and numerator of a ratio by the same number does not change the size of the ratio. But adding (subtracting) the same number to (from) the denominator and numerator of a ratio will change its size. The problem is that decisions about the classification of some costs or benefits are arbitrary, and could easily be used to influence the accept-reject decision if the BCR is employed.

⇨ **Wrong ordering of mutually exclusive adaptation actions:**

Similar to the IRR the BCR is a measure of the rate of return per dollar invested. The BCR criterion therefore suffers from the same problem as the IRR criterion concerning mutually exclusive adaptation actions – namely, it fails to consider the scale of the investment. Moreover, as the example above illustrates, the BCR is very sensitive to changes to the present value of the cost stream and the size of the initial capital expenditure.

Consider Table 8-6, which shows the incremental net cost and benefit streams for two mutually exclusive adaptation actions. According to Decision Rule 2 of the BCR criterion adaptation, action 7 is selected over adaptation action 8 since it has the higher BCR. However, action 8 has the higher NPV; by making the wrong decision and selecting action 7, society will forgo a welfare gain equivalent to $531. The reason action 8 performs poorly with the BCR criterion is that its relatively large initial capital expenditure reduces the rate of return per dollar invested. Society would be better off earning the smaller rate of return (1.09) on an investment of $10,000 as opposed to the larger rate of return (1.36) on an investment of $1,000.

Table 8-6: Time profile of incremental net benefit for adaptation actions 7 and 8

Time Period	T = 0	T =1	T = 2	T = 3
Action 7				
Costs	-$1,000			
Benefits		+$500	+$500	+$500
NPV (r at 5%)	$362			
BCR	1.36			
Action 8				
Costs	-$10,000			
Benefits		+$4,000	+$4,000	+$4,000
NPV (r at 5%)	$893			
BCR	1.09			

8.3.3 Payback period

A final decision-making criterion worth considering briefly because of its common use in the private sector is the Payback Period (PP). One formulation of the PP is the number of years it takes an adaptation action to break even; that is, the number of years over which *discounted* annual net benefits must be summed before the total becomes positive (and remains positive for the remainder of the action's life). The PP for the example adaptation action in Table 8-1 is 16 years. Between years 15 and 16 the sum of discounted net benefits switches from negative $0.4 million to positive $0.6 million, so the PP is 16 years. The decision-maker can then compare the calculated PP with a predefined 'hurdle rate' for other investments with similar risks and accept those actions with a PP less than the hurdle rate.

Another formulation of the PP is the number of years until the initial investment in an adaptation action is recovered. With this formulation, the analyst is typically interested in the number of years over which the *undiscounted* annual net benefits must be summed before that sum exceeds the value of the initial investment. With this formulation the PP of the example in Table 8-1 is 12 years. Between years 11 and 12 the sum of undiscounted net benefits increases from $18.7 million to $20.4 million, which exceeds the original investment cost of $20.0 million. Again, the calculated PP is compared with an established, similarly formulated, hurdle rate.

The PP is a useful criterion for private sector organizations with short planning horizons and concerns about remaining solvent, who therefore cannot afford long delays in recouping capital expenditures. However, the PP has significant weaknesses, including the fact it does not take account of all the information available, i.e., the net benefits for years beyond the payback period are ignored. As a consequence, the PP should only be provided as supplementary information for decision-makers.

8.4 References and further reading

Boardman, A., Greenberg, D., Vining, A., and Weimer, D., 2006, Cost-Benefit Analysis: Concepts and Practice, Third Edition, Pearson Prentice Hall, New Jersey, USA.

Metroeconomica, 2004, Costing the Impacts of Climate Change in the UK: Implementation Report, UKCIP Technical Report, UK Climate Impacts Program, Oxford, UK.

Pearce, D., Atkinson, G., and Mourato, S., 2006, Cost-Benefit Analysis and the Environment: Recent Development, OECD, Paris, France.

TBCS, 2007, Canadian Cost-benefit Analysis Guide: Regulatory Proposals, Treasury Board of Canada Secretariat (TBCS), Ottawa, Canada.

9 Risk and Uncertainty Analysis

9.1 Purpose

The purpose of this section is to:

- ⇨ Describe the deep uncertainties facing adaptation planners and decision-makers, and explain how these uncertainties can lead to maladaptation;
- ⇨ Distinguish between risk and uncertainty in the context of economic analysis;
- ⇨ Outline the main techniques for modeling uncertainty in economic analysis – namely, sensitivity analysis and interval analysis;
- ⇨ Explain how full (quantitative) risk analysis is performed using Monte Carlo Simulation;
- ⇨ Identify a number of practical strategies for handling uncertainty when appraising adaptation actions; and
- ⇨ Describe how Modern Portfolio Theory and Real Options Analysis can be used by analysts to construct robust and flexible adaptation strategy.

9.2 Nature of uncertainties in adaptation planning

Decisions are routinely made under uncertainty; uncertainty itself is not necessarily problematic. Many organizations already take weather, which is inherently uncertain, into account during planning activities. For example, civil engineers regularly use estimates of climate parameters derived from robust historical time series, in order to design flood defenses to cope with local climate conditions. Future climate conditions, however, are highly uncertain and will diverge significantly from past conditions. Using historical probabilities of different flood events and their consequences to design defenses against future events will likely to lead to maladaptation (i.e., adaptation decisions taken now that are found to be inappropriate for the climate that ultimately occurs). In short, the past is no longer an accurate indicator of the future.

Projections of future climate conditions and associated impacts are highly uncertain for several reasons (Jamet and Corfee-Morlot, 2009):

- ⇨ **Economic and technological uncertainty**. Future climate conditions depend on the growth of GHG emissions globally, which in turn is influenced by population growth, growth in GDP, technological progress, the evolution of national energy mixes, etc. Projections of these determinants of future GHG emissions are very uncertain. Moreover, the uncertainty increases the further into the future we look.
- ⇨ **Environmental uncertainty**. The impact of a known level of GHG emissions on the climate is also uncertain because scientific knowledge of the link between emissions and

atmospheric concentrations, and between concentrations and global temperatures, remains incomplete. An important aspect of environmental uncertainty relates to climate sensitivity (i.e., the amount of warming that can be expected with a doubling of atmospheric carbon dioxide concentrations). The IPCC reports that climate sensitivity is likely to be in the range of 2.0ºC to 4.5ºC, with a 'best' estimate of about 3.0ºC, though values below 1.5ºC and in excess of 4.5ºC cannot be ruled out (IPCC, 2007). Given the full range of 'likely' values, the value for climate sensitivity used by an analyst to inform adaptation decisions will obviously have a significant influence on the results.

⇨ **Impact and valuation uncertainty**. The physical and monetary impact on society of a known level of climate change (in terms of temperature, patterns of precipitation, frequency and intensity of extreme weather events, etc.) is also uncertain. Our ability to robustly quantify and value impacts on all potentially relevant non-market goods and services is limited. Uncertainty is further exacerbated given that autonomous adjustments in natural and human systems induced by changes in climate are also difficult to predict with any accuracy. An accurate understanding of these adjustments is important when establishing baseline conditions, against which incremental impacts are measured.

These three broad sources of uncertainty layer on top of each other as one moves along the causal chain linking GHG emissions with their consequences, leading to an explosion of uncertainty in the end cost and benefit estimates (as shown in Figure 9-1). Furthermore, at the level of individual adaptation actions, the informational requirements of decision-makers become more local, specific, and detailed, and as a result uncertainty increases.

Box 9-1: Uncertainty can lead to maladaptation

Failure to appropriately account for uncertainty in future climate impacts exposes society to maladaptation. Maladaptation occurs when decisions are made (for instance, on the basis of a particular climate scenario) that are ultimately found to be unsuitable for the climate that occurs (climate changed according to a different climate scenario). It can take several forms:

⇨ **Under-adaptation**, where either no action is taken or the action that is taken does not go far enough to cope with the climate conditions that ultimately occur;

⇨ **Over-adaptation**, where the action taken proves to be unnecessary (e.g., coastal walls built to withstand 3m of sea-level rise when only a 1m rise occurs); and

⇨ **Incorrect adaptation**, where action is taken, but is later found to either increase risks or not safeguard against the targeted risk.

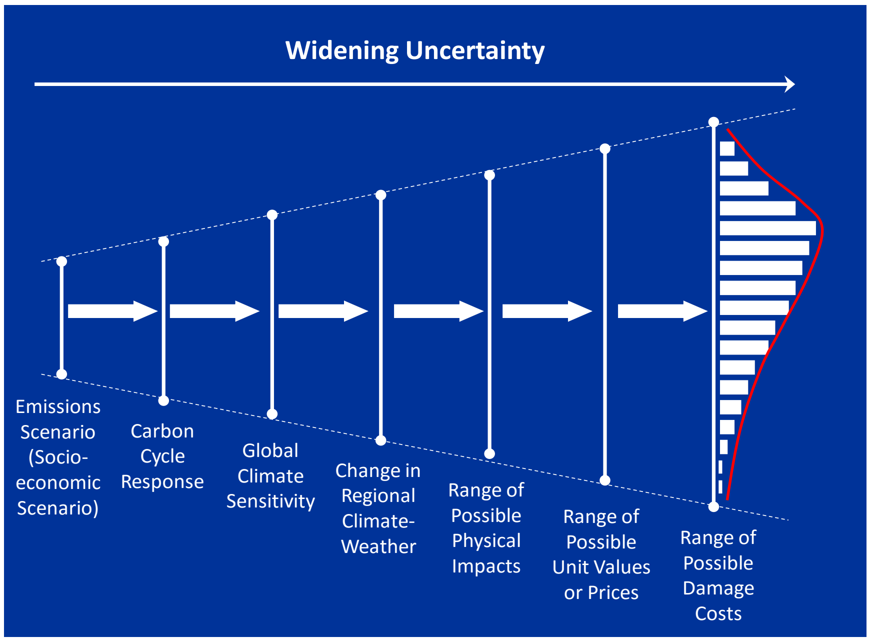
Clearly, maladaptation can mean costly, wasted investments and unnecessary, possibly irreversible, harm to individuals, the built environment, and ecosystems.

Source: Ranger and Garbett-Shiels (2011)

Withstanding economic, technological, environmental, impact, and valuation uncertainties, climate change itself is comprised of changes in many climate variables, which will affect a range of sectors and systems, leading to both market and non-market impacts. This gives rise to the issue of 'completeness'. Typically, only a portion of potential climate change impacts can be covered in any single economic analyses. The incomplete coverage of climate change impacts adds another layer of uncertainty, suggesting that actual impacts (and associated costs and benefits) may actually be much greater than estimated impacts.

In summary, it is not possible to predict with certainty the future climate-related risks to which adaptation is needed. Evaluating the vulnerability of an organization or project to climate variability and projected climate change, and the costs and benefits of possible adaptations, must therefore be undertaken in an environment of high uncertainty. However, the uncertainties outlined above do not need to represent a barrier to good adaptation decision-making. As noted above, decisions are routinely made in the presence of uncertainty. Adaptation planning simply requires new approaches for managing relatively large uncertainties.

Figure 9-1: Explosion of uncertainty along the climate change impacts chain



Source: Adapted from Menne and Ebi (2006)

9.3 Allowing for risk and uncertainty

Up to this point in the guidebook we have assumed that future adaptation costs and benefits are known with a high degree of certainty. The evaluation criteria presented in Section 8 all employ single-point estimates of future adaptation costs and benefits. Yet, as the above discussion stresses, the values of many future adaptation costs and benefits are far from certain. It is therefore important to provide decision-makers with adequate information relating to the margin of error surrounding single-point estimates of an adaptation action's NPV, IRR or BCR. The remainder of this section discusses how the analyst can achieve this. We begin with conventional definitions of the terms 'risk' and 'uncertainty'.

To handle risk and uncertainty in CBA it is necessary to understand some basic concepts in probability and statistics. Analysts unfamiliar with these concepts may wish to read ANNEX 9-1 before proceeding.

9.3.1 Definitions

The terms ‘risk’ and ‘uncertainty’ are typically applied to the analysis of situations with unknown outcomes. This guidebook will adopt the conventional distinction between risk and uncertainty made in the economics literature (see, for example, Pearce, *et al*, 2006). In essence, risk is a quantity that is measureable and known. In a risky situation, it is possible for the analyst to indicate the probability of the realized value of a variable falling within stated limits - typically described by the fluctuations of that variable around the mean of a probability distribution. In contrast, uncertainty is nebulous. In situations of uncertainty, the fluctuations of a variable around the mean value are unknown. Hence, risk and uncertainty are best thought of as representing a spectrum of unknown situations with which an analyst may be dealing, ranging from perfect knowledge of the probability of all possible outcomes at one end (i.e., risk) to no knowledge of the probability of possible outcomes at the other (i.e., uncertainty). Note that it is not the real-world situation itself which is either risky or uncertain, but simply the information available to the analyst which defines it as such. Strictly speaking, all adaptation outcomes are unknown, since they occur in the future and are influenced by a number of variables, each of which may take different values. If the analyst has reliable historical or forecast data, such that a probability distribution can be constructed for pertinent variables, the situation can be modeled as risky. If the analyst does not have such data, the future can only be described in terms of uncertainty.

9.3.2 Modeling uncertainty

The values for variables included in the CBA of adaptation actions are typically the base case estimates. In principle, they should represent expected (or mean) values. It is common practice in CBA to treat base case estimates as if they are certain values. However, predicted impacts and the values assigned to them are rarely – if at all – known with perfect certainty. Sensitivity analysis is the most widely-applied technique for providing information to decision-makers about the effect of errors in base case estimates on a project’s NPV.

9.3.2.1 Sensitivity analysis

Sensitivity analysis involves changing the value of one or more selected variables, which affect the costs or benefits of an adaptation action, and calculating the resultant change in the action’s NPV (or IRR or BCR). Fittingly, sensitivity analysis is also known as ‘what-if’ analysis. It involves:

- ⇨ Testing the action’s NPV for the effects of changes in aggregate costs and benefits (and choice of climate and socio-economic development scenario);
- ⇨ Testing the action’s NPV for the effects of changes in individual underlying variables (e.g., affected areas, crop yields, crop prices in an agricultural context). The choice of variables will usually be based on previous experience with similar projects, detailed sector knowledge, or judgment of the analyst;
- ⇨ Testing the variables one at a time, so as to be able to identify the ones with greatest impact on the action’s NPV;
- ⇨ Testing for delays in benefits or implementation (e.g., shift the benefits stream, and investment costs, forward a year or two); and

- ⇨ Testing likely combinations of variables (especially if these may in practice be linked - e.g., investment costs go up and implementation delays simultaneously occur).

In all 'tests' the analyst needs to determine the extent to which the value of the variable may plausibly differ from the base case estimates. Similar to the choice of variable for testing, alternative values can be assumed on the basis of previous similar project experience, detailed sector knowledge or the judgment of the analyst. Alternative values can be expressed as a percentage change in the base case estimate, where possible. In cases where a percentage change is meaningless (e.g., the timing of investment), the absolute magnitude of the change can be documented by the analyst.

Sensitivity testing generally leads to the calculation of switching values and sensitivity indicators:

- ⇨ A **switching value** (SV) identifies the percentage change in a variable needed for the action's NPV to become zero (e.g., for the decision to switch between accept or reject, mean water resource yields would have to fall by 25 per cent). SVs are sometimes expressed in terms of the absolute value of a variable (e.g., if the affected population fell to 1,000 persons per year the adaptation action's NPV would become negative). Calculating SVs are akin to performing break-even analysis – what value must a variable assume to cause the NPV of an action to switch from positive to negative or vice versa; and
- ⇨ A **sensitivity index** (SI) compares the percentage change in the action's NPV (or IRR or BCR) with a one percentage change in the value of a variable. The higher the index value the more sensitive the action's NPV is to changes in the variable.

Sensitivity testing is extremely easy to perform, as changes to one value in a spreadsheet model will instantly be reflected in estimates of NPV (or IRR or BCR). Indeed, in Microsoft Excel it is easy to create simple one-way and two-way (sensitivity) tables that show how changes in the value of, respectively, one or two specific variables affect the NPV of an adaptation action.

The primary benefit of sensitivity analysis is that it leads to the identification and ranking of key variables to which a particular adaptation action, as originally formulated, is most sensitive. The decision-maker is thereby provided with insights into the impact of key variables in the desired outcomes of an adaptation project. Mitigating action can then be taken, if desired, to minimize the likelihood or consequences of, say, the SV of a key variable being realized in practice. Sensitivity analysis, however, has several shortcomings:

- ⇨ Most fundamentally, it does not evaluate the likelihood of an SV outcome and thus does not provide a precise indication of the riskiness of an action. For example, the SV for a water resource project may be a fall in yields of 25 per cent, but how likely is a fall of this magnitude to occur in practice;
- ⇨ With one-way or two-way sensitivity analysis, the analyst can examine the impact of a single variable or two variables, respectively, on the NPV of an adaptation action, holding constant the values of all the other key variables. In reality, more than two variables will be changing simultaneously. With more than two variables moving together, sensitivity analysis becomes cumbersome to conduct, and difficult to interpret and convey any meaningful judgment about the riskiness of an action to decision-makers; and

- ⇨ Relatedly, to perform sensitivity analysis it is assumed that the different key variables are independent of one another. However, correlations may exist among the key variables. For example, there is typically a negative relationship between the price of a good or service and the quantity of that good or service. An increase in price will thus induce a decrease in the quantity demanded. In sensitivity analysis, such correlations between key variables are commonly not taken into account; to do so requires specialist knowledge, and misunderstanding the extent and nature of correlation between key variables can lead to erroneous results.

9.3.2.2 Interval analysis

Interval analysis addresses one shortcoming of sensitivity analysis: allowing multiple variables – albeit the most extreme values of those variables – to change simultaneously. From the set of key variables identified through sensitivity analysis, the analyst can build two extreme scenarios: best case (or optimistic case) and worst case (pessimistic case). Basically, the full range of values from the set of identified key variables is combined by the analyst to create each scenario. For instance, in a health sector context, the lowest (highest) plausible Value of Statistical Life from the literature would be combined with the lowest (highest) estimate of projected premature deaths from heat stress in a particular year to derive a best case (worst case) estimate of projected climate-related damage costs.

How are the results of interval analysis interpreted? Under the two extreme cases:

- ⇨ If the NPV of an adaptation action is negative in the best case scenario, then it is reasonable for the decision-maker to reject the project; or
- ⇨ If the NPV of an adaptation action is positive in the worst case scenario, then it is reasonable for the decision-maker to accept the project.

Unfortunately, in practice, the results may not be so clear cut. Moreover, interval analysis continues to suffer from the other shortcomings that plague sensitivity analysis. The analyst is still unable to assess the likelihood of the different extreme scenarios because the analysis does not specify probability distributions for the extreme values of the different variables that form the basis for the scenarios. Furthermore, correlations that may exist among the variables are not considered.

9.3.3 Quantitative risk analysis

Due to the shortcomings of sensitivity and interval analysis, other approaches have been developed to better capture the impacts of unknown outcomes on project viability, through quantitative analysis of risk. The primary purpose of quantitative (or full) risk analysis is to provide a means of estimating the probability that an adaptation action's NPV will fall below zero (or the IRR will fall below the social rate of discount, or the BCR will fall below one). The results of sensitivity testing can nonetheless be used as an input to quantitative risk analysis, by identifying which variable(s) should be subject to full risk analysis (i.e., those variables that have relatively low SVs or relatively high SIs).

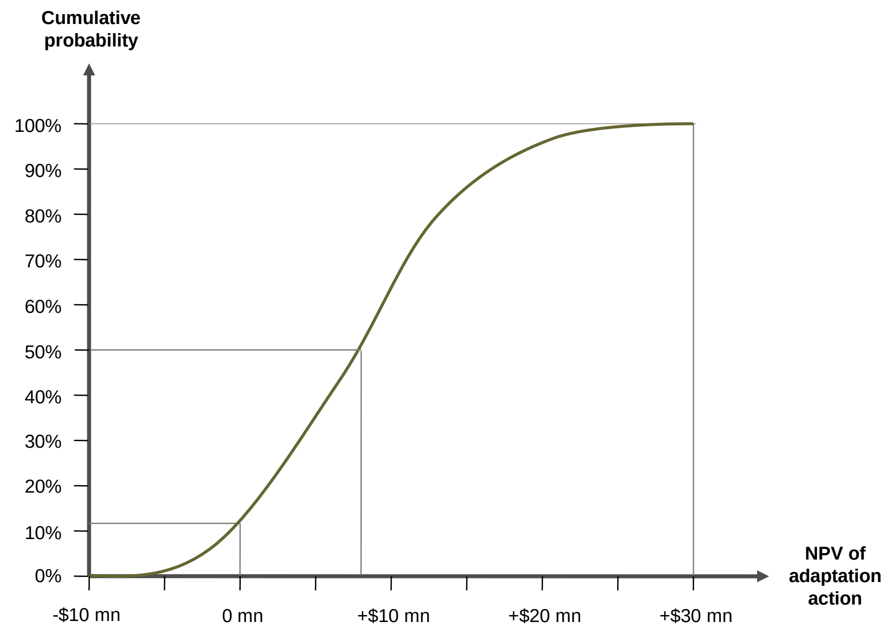
Full risk analysis typically involves the choice of several variables to be varied simultaneously, as the NPV of an adaptation action in reality is likely subject to multiple sources of risk. Due to the mathematical complexity involved in performing the necessary calculations, full risk analysis is nearly always undertaken by some kind of specialist computer software (e.g., @RISK), though simpler simulations can be performed using the solver function in Microsoft Excel. The process which is typically followed is usually referred to as Monte Carlo Simulation.

9.3.3.1 Monte Carlo Simulation

Monte Carlo Simulation is performed as follows:

1. Construct a spreadsheet model of an adaptation action's NPV, ensuring all variables are properly linked via formulas to the estimated NPV;
2. Identify (six to eight) key uncertain variables to which the action's NPV is most sensitive. The selection of key variables can be based on (one-way and two-way) sensitivity analysis;
3. Specify the probability distribution of values for each key variable. Commonly used distributions include the uniform, triangular, and normal distribution (see ANNEX 9-1);
4. Identify correlated key variables. Where key variables are thought to be related in some way, the extent of covariance between them needs to be taken account of when specifying the distribution of the individual variables. Specify the direction (positive or negative) and strength of the correlation that may exist between the key variables;
5. Run the simulation software. Values for individual key variables are selected randomly from their respective probability distributions, combined with other randomly selected values for the other key variables, and these values are used to calculate an estimate of the action's NPV. This process is repeated a large number of times (the number is specified by the analyst and is usually at least 1,000 times, and can be as high as 10,000 times), generating a mean (or expected) NPV and standard deviation, together with the associated probability distribution;
6. Analyze the results. The ultimate outputs of quantitative risk analysis are the summary statistics (mean, variance, standard deviation, etc.) and the cumulative probability distribution for an action's NPV, which together provide valuable information as to the relative attractiveness (in terms of its riskiness) of an adaptation action. From the cumulative probability distribution the analyst can readily determine the probability that an action's NPV may fall below zero. Figure 9-2 presents an example cumulative probability distribution for a hypothetical adaptation action. In this example, the probability of the action's NPV being less than zero as a result of variability in underlying factors is about 12 per cent. For more details on probability distributions and key statistical concepts see ANNEX 9-1.

Figure 9-2: Graph of cumulative (normal) probability distribution for an adaptation action



9.4 Practical strategies for handling risk and uncertainty

Given the prevailing uncertainties, some authors have argued that the best way to approach adaptation planning is to adopt practical strategies that (Fankhauser et al, 1999; Lempert et al, 2006; Lempert and Collins, 2007; Hallegatte, 2009):

1. **Include win-win, no-regret or low-regret adaptation actions**:

An adaptation action that is appraised to be worthwhile on economic grounds now (in that it would yield an immediate reduction in damage costs associated with current climate conditions that exceed the incremental cost of the action), and continues to be worthwhile under any foreseeable climate scenario, is an example of a no-regret action. No-regret actions (e.g., water recycling, demand-side management, leakage control) will prove worthwhile even if no (further) climate change occurs; the benefits of optimally adapting to current climate conditions are sufficient to justify their implementation. Low-regret actions, in contrast, are not justified solely on the basis of mitigating current climate risks. Rather, a small additional cost is incurred to realize comparatively large benefits from adapting to projected climate change. They are considered low-regret actions, since it is very likely that the large anticipated benefits exceed the small incremental outlay required to realize those benefits. Adding (often low-cost) safety margins to the design criteria of water resource or coastal defense schemes, to improve the resilience of the infrastructure to future climate change, is a low-regret adaptation strategy.

Win-win adaptation actions reduce the impacts of climate change, but also deliver other environmental (including GHG mitigation), social or economic benefits. Adaptation is a win-win strategy if these ‘ancillary benefits’ are greater than the incremental cost of actions that brought about the ancillary benefits. In this case, the actions are justified even in the absence of climate change or if all climate-related benefits are less than anticipated. Win-win adaptation actions (e.g., insulating homes, long-term weather forecasting and early warning systems) are primarily implemented for reasons not directly motivated by the need to adapt to climate change, but at the same time may deliver some longer-term adaptation benefits.

Focusing on no regret, low regret, and win-win adaptation actions may go some way towards resolving the decision uncertainty faced by adaptation planners. Recall that the analytical framework presented in Section 4.3.4.1 can be used to explicitly identify no-regret and win-win adaptation actions.

2. Incorporate flexibility:

A second strategy to cope with deep uncertainty over future climate change impacts is to favor reversible (flexible) adaptation actions over irreversible (inflexible) actions – especially concerning ‘hard’ adaptations involving long-lived capital goods, such as dikes, seawalls and reinforced buildings. The idea is to allow for the possibility of adjusting actions in the future (possibly as new information is uncovered) to better cope with the effects of either more or less severe climate change. Allowing for incremental adaptation helps decision-makers minimize the cost of maladaptation – i.e., being wrong about future climate conditions. For example, flood defense infrastructure could be designed to allow for small ‘easy-to-retrofit’ extensions in the medium-term. Major irreversible upgrades could thus be delayed as long as possible to take advantage of new information, as it accumulated with time. The flood defenses could be reappraised in light of new information and extensions to the flood defenses could be brought forward (delayed) if monitoring reveals that the climate is changing more rapidly (slowly) than predicted. This helps planners ensure adaptation decisions, whether involving incremental or major irreversible decisions, are taken at the right time, using the best available information.

Hard actions are not the only way of adapting to climate change. ‘Soft’ adaptation actions, like information, capacity building, policy development, strategic plans, and institutional arrangements can be equally efficient at reducing climate-related risks. An advantage of soft actions is that they often provide greater flexibility than hard actions. For example, insurance schemes, early warning systems, and land-use plans can be adjusted annually, in light of new information, without incurring large ‘sunk costs’. Hence, promoting soft adaptations can also help minimize the risk of maladaptation, given the prevailing uncertainties surrounding future climate change impacts.

The value of flexibility in a decision-making process is often referred to as ‘real options value’. Below, we describe an approach for incorporating real options value into economic analyses to ensure that the estimated NPVs of adaptation actions that provide greater flexibility are not underestimated.

3. Increase robustness:

An alternative strategy to cope with uncertainty over future climate change impacts is to make adaptation actions more robust, so that they function effectively under a wide range of plausible climatic conditions. For example, a bridge could be built slightly higher than it otherwise would have been in order to cope with a greater range of water levels, or a water storage scheme could be built with slightly more capacity than it otherwise would have been in order to cope with a wider range of drought events. Increasing the robustness of an adaptation action, however, does come at a cost. In general, there is a trade-off between, on the one hand, the range of future climate conditions to be tolerated by the capital good, and on the other hand, the initial investment costs or basic performance of the capital good. Modern Portfolio Theory, described below, can help planners assess the trade-offs, and identify adaptation actions that perform adequately well when compared with alternatives across a range of plausible climate futures.

4. Reduce planning horizons:

A final strategy to cope with uncertainty when developing adaptation actions is to reduce investment time horizons. As the decision-making time horizon increases beyond the 2030s, the 2040s, the 2050s, and so on, uncertainty surrounding future climate conditions grows rapidly. Hence, decreasing the time horizon of – normally long-lived, irreversible – investments can reduce uncertainty over expected future outcomes, as the investments can be tailored to relatively more certain near-term climate futures. For example, a commercial forestry could reduce uncertainty over long-term returns by planting species with relatively short rotation times. The leasing of capital goods as opposed to buying can also reduce uncertainty, as leased capital can typically be replaced relatively quickly. The ability for capital goods to turn-over more regularly can help decision-makers keep the capital stock more in step with prevailing climate conditions.

9.4.1 Modern Portfolio Theory

When selecting adaptation actions, a strategy to manage the deep uncertainties associated with estimates of future climate change impacts is to seek actions that are roust to a wide range of plausible climate futures. Modern Portfolio Theory (MPT) can help analysts identify robust adaptation actions. MPT was developed in the early 1950s on the back of Markowitz's seminal paper in 1952, as a way of justifying diversification to hedge against risk when investing in financial assets.

It is commonly accepted that there is a positive relationship between the risk and expected return of a financial asset. That is, when the risk of an asset increases, so does its expected return. What this means for an investor is, by taking on more risk, they expect to be compensated for doing so with a higher return. Equally, if the investor wants to boost the expected return of an investment, they need to be prepared to take on more risk. MPT suggests that an investor can either (a) maximize return for a given level of risk or (b) minimize risk for a given level of return, not by choosing financial assets individually based on their own risk-return profiles, but rather by carefully creating a portfolio of assets, considering how changes in the return of one asset will affect the returns of other assets in the portfolio. By portfolio, we simply mean a collection of financial assets held simultaneously by an investor.

9.4.1.1 Using MPT to inform adaptation decision-making

Illustrating how MPT could be used to inform adaptation planning begins with the analogy presented by Crowe and Parker (2008): just as the market over time can value diverse assets differently, so too can the climate create a future world under a range of climate scenarios where diverse adaptation actions perform differently in terms of mitigating a specific climate-related risk. To implement MPT it is necessary to know:

- The expected returns of potential assets in the portfolio;
- Their standard deviations (standard deviation measures the riskiness of the portfolio, and is derived from the variance of an individual asset's return); and
- The correlation (or covariance) between the returns of potential assets in the portfolio over time.

This in turn requires information on the joint probability distributions of outcomes for all potential assets in a portfolio, which may limit application of MPT.

The financial nomenclature is transcribed to an adaptation planning context as follows:

- The 'investor' is the 'adaptation planner' or 'decision-maker';
- A 'financial asset' is an 'adaptation action';
- The asset 'portfolio' is the 'adaptation strategy' for the climate-related risk at hand; and
- The 'expected return' is the 'expected net present value' of an adaptation action.

Suppose an adaptation planner is developing an adaptation strategy with multiple adaptation actions with uncertain performance. In this case, the net present value of a strategy ($\mathrm{NPV_s}$) comprising n adaptation actions is defined as follows:

$$\mathrm{NPV}_s = \mathrm{w}_1 \times \mathrm{NPV}_1 + \mathrm{w}_2 \times \mathrm{NPV}_2 + \cdots \mathrm{w}_n \times \mathrm{NPV}_n = \sum_{i=1}^{n} \mathrm{w}_i \times \mathrm{NPV}_i \qquad \text{Equation 9-1}$$

Where NPV_i is the NPV of adaptation action i and w_i is the proportion of the strategy comprising action i. Hence, the expected NPV of the strategy is simply the weighted average of the expected NPV of the individual adaptation actions:

$$\mathrm{E}(\mathrm{NPV}_s) = \sum_{i=1}^{n} \mathrm{w}_i \times \mathrm{E}(\mathrm{NPV}_i) \qquad \text{Equation 9-2}$$

The formula for the standard deviation of a portfolio gets very complicated as the number of assets in the portfolio increases. Hence, to simplify the example we only look at an adaptation strategy consisting of two uncertain actions, A and B. The standard deviation of the NPV of a strategy (σ_s) with two uncertain actions is determined as follows:

$$\sigma_s = \sqrt{w_A^2 \times \sigma_A^2 + w_B^2 \times \sigma_B^2 + 2 \times w_A \times w_B \times \sigma_A \times \sigma_B \times \rho} \qquad \text{Equation 9-3}$$

Where ρ is the correlation coefficient of the two actions in the strategy, and $w_A + w_B = 1$. The effectiveness of diversification to increase robustness of the strategy depends on the correlation coefficient of the two actions. The correlation coefficient represents the direction and strength of the relationship between the two actions, and it takes on a value between minus one and plus one. The sign of the correlation coefficient indicates the direction of the relationship: a positive (negative) sign indicates that there is a positive (negative) relationship between the two actions. The strength of the relationship is indicated by the absolute value of the correlation coefficient: the closer the number is to one (zero) the stronger (weaker) the relationship. These relationships can be generalized as follows:

- $\rho = +1$ Means that there is an exact positive relationship between the two adaptation actions - i.e., they move in the same direction;
- $\rho = 0$ Means that there is no relationship between the two adaptation actions - i.e., the relationship is random; and
- $\rho = -1$ Means that there is an exact negative relationship between the two adaptation actions – i.e., they move in opposite direction.

Diversification is most effective at reducing risk when the correlation between the adaptation actions is minus one and it is least effective when the correlation is plus one. Consequently, decision-makers looking to increase the robustness of their strategy need to look for pairs of actions that have a correlation close to negative one.

Case 1: two adaptation actions when $\rho = 0$

To help illustrate the effects of diversification on an adaptation strategy, consider a hypothetical strategy comprising Action A and Action B. The characteristics of the two adaptation actions are as follows:

	Action A	Action B
Expected NPV, $E(NPV_i)$	+\$80 million	30%
Standard deviation, σ_i	+\$60 million	20%

To start with, consider the case where there is a random relationship between the two actions – i.e., the correlation coefficient is zero between the two actions. Armed with this piece of information, we can estimate the expected NPV and the standard deviation of the adaptation strategy using Equation 9-2 and Equation 9-3. First, determine the expected NPV and standard deviation of a strategy with the entire adaptation budget invested in Action A (i.e., w_A = 1.0 and w_B = 0.0):

$$E(NPV_s) = (1.0 \times \$80) + (0.0 \times \$60) = \$80 \text{ million}$$

$$\sigma_s = \sqrt{(1.0^2 \times 0.3^2) + (0.0^2 \times 0.2^2) + (2 \times 1.0 \times 0.0 \times 0.3 \times 0.2 \times 0.0)} = 30.0\%$$

Next, consider the situation where 80 per cent of the budget is invested in Action A and 20 per cent of it invested in Action B (i.e., w_A = 0.8 and w_B = 0.2). The expected NPV and the standard deviation of the adaptation strategy are now given by:

$$E(NPV_s) = (0.8 \times \$80) + (0.2 \times \$60) = \$76 \text{ million}$$

$$\sigma_s = \sqrt{(0.8^2 \times 0.3^2) + (0.2^2 \times 0.2^2) + (2 \times 0.8 \times 0.2 \times 0.3 \times 0.2 \times 0.0)} = 24.3\%$$

The expected NPV and the standard deviation of the adaptation strategy can be calculated for various combinations of w_A and w_B, resulting in the following outcomes:

w_A	w_B	$E(NPV_i)$	σ_i
1.0	0.0	$80 million	30.0%
0.8	0.2	$76 million	24.3%
0.6	0.4	$72 million	19.7%
0.4	0.6	$68 million	17.0%
0.2	0.8	$64 million	17.1%
0.0	1.0	$60 million	20.0%

The expected NPVs and standard deviations of the adaptation strategy for all the various combinations of w_A and w_B can then be plotted, producing the curve shown in Figure 9-3 panel (a). The curve depicted in the graph is known as the efficient frontier; it maps the risk and return relationship of the strategy. The efficient frontier represents the different strategies that are attainable by the decision-maker. Strategies that lie outside the efficient frontier (as represented by the area to upper left of the efficient frontier) are unattainable by the planner.

It is evident from the efficient frontier that the risk level of the adaptation strategy changes as its composition changes. The upper end of the frontier represents the case where the entire budget is invested in the riskier, Action A. As the composition of the strategy switches from only Action A to more and more Action B, the risk level of the strategy falls because Action B is a safer investment. However, the risk level of the strategy 'bottoms out' at a certain combination of Action A and Action B. The particular combination that causes the risk level of the strategy to bottom out (i.e. the lowest level of risk) is known as the minimum variance portfolio. It is not possible for the decision-maker to lower the risk of the strategy any further by changing the combination of Action A and Action B. If the composition of the strategy continues to add more and more of Action B, the risk level of the strategy will rise. The important point is that it is possible for a decision-maker to create a strategy that has a risk level that is lower than the individual risk levels of the two adaptation actions. This is the power of diversification, which allows a decision-maker to lower the risk level of a portfolio beyond the individual risk levels of the actions it contains. From panel (a) in Figure 9-3, we know the minimum variance portfolio is the one that achieves the maximum effect of diversification. The formulas below can be used to help a decision-maker determine the correct combination of w_A and w_B that will produce the minimum variance portfolio:

$$w_A = \frac{\sigma_B^2 - \sigma_A \times \sigma_B \times \rho}{\sigma_A^2 + \sigma_B^2 - 2 \times \sigma_A \times \sigma_B \times \rho}$$

Equation 9-4

$$w_B = 1 - w_A$$

The combination of Action A and Action B that will produce the minimum variance portfolio (assuming they have a random relationship, with ρ = 0) is thus given by:

$$\mathrm{w_A} = \frac{0.2^2 - 0.3 \times 0.3 \times 0.0}{0.3^2 + 0.2^2 - 2 \times 0.3 \times 0.2 \times 0.0} = 0.308 = 30.8\%$$

$$\mathrm{w_B} = 1 - 0.308 = 0.692 = 69.2\%$$

The decision-maker needs to invest about 31 per cent of their budget in Action A and about 69 per cent of it in Action B in order to produce a strategy with the lowest possible level of risk. Using Equation 9-3 the corresponding standard deviation (risk level) of the adaptation strategy is determined as follows:

$$\sigma_{\mathrm{s}} = \sqrt{(0.31^2 \times 0.3^2) + (0.69^2 \times 0.2^2) + (2 \times 0.31 \times 0.69 \times 0.3 \times 0.2 \times 0.0)} = 16.6\%$$

Case 2: two adaptation actions when $\boldsymbol{\rho = +1}$ or $\boldsymbol{\rho = -1}$

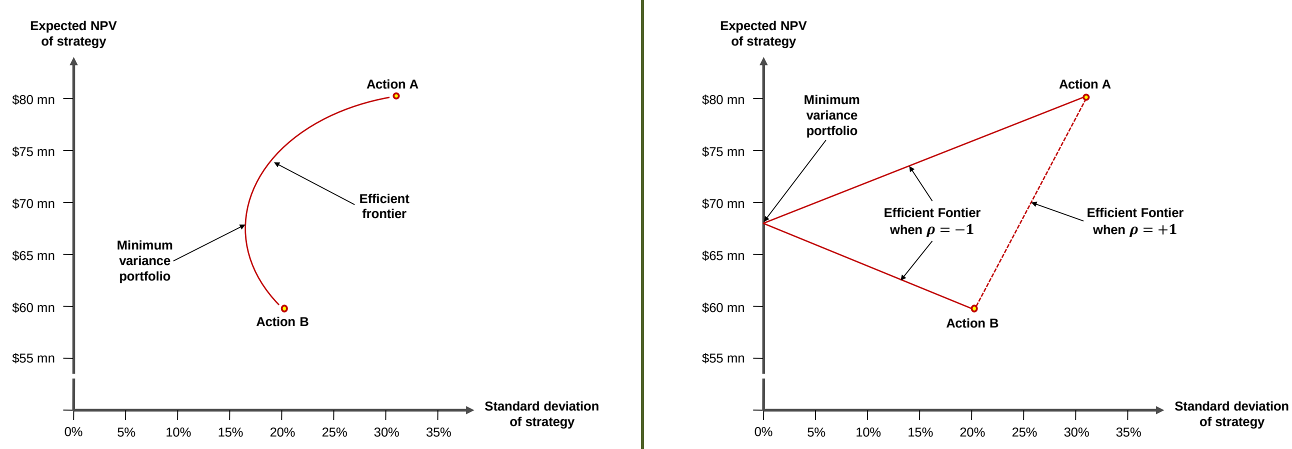
Using Equation 9-2 and Equation 9-3 we can redo the analysis for the two extreme cases: when the correlation coefficient between the two adaptation actions is minus one and when it is plus one. It is important to note that changes in the correlation coefficient will have an impact on the risk level of the adaptation strategy, but will have no impact on its expected NPV. The recalculated standard deviations of the adaptation strategy, for various combinations of $\mathrm{w_A}$ and $\mathrm{w_B}$, are shown below and plotted in panel (b) of Figure 9-3:

$\mathrm{w_A}$	$\mathrm{w_B}$	$\mathrm{E(NPV}_i)$	$\sigma_i\ (\rho = +1)$	$\sigma_i\ (\rho = -1)$
1.0	0.0	$80 million	30.0%	30.0%
0.8	0.2	$76 million	28.0%	20.0%
0.6	0.4	$72 million	26.0%	10.0%
0.4	0.6	$68 million	24.0%	0.0%
0.2	0.8	$64 million	22.0%	10.0%
0.0	1.0	$60 million	20.0%	20.0%

The efficient frontiers plotted in panel (b) of Figure 9-3 confirm the points made in the discussion above: namely, that diversification is most effective when the correlation coefficient is minus one and least effective (or not effective at all) when the correlation coefficient is plus one. In the case of perfect negative correlation between actions (i.e., when $\rho = -1$), it is possible for a decision-maker to create a strategy that has no risk at all. In total contrast, in the case of perfect positive correlation (i.e., when $\rho = +1$), the only way for the decision-maker to minimize risk is to invest the entire budget in the less risky action (i.e., Action B).

Figure 9-3: Possible combinations of two risky adaptation actions and the associated portfolio risk and expected NPV

(a) Correlation coefficient = 0 | (b) Correlation coefficient = +1 and -1

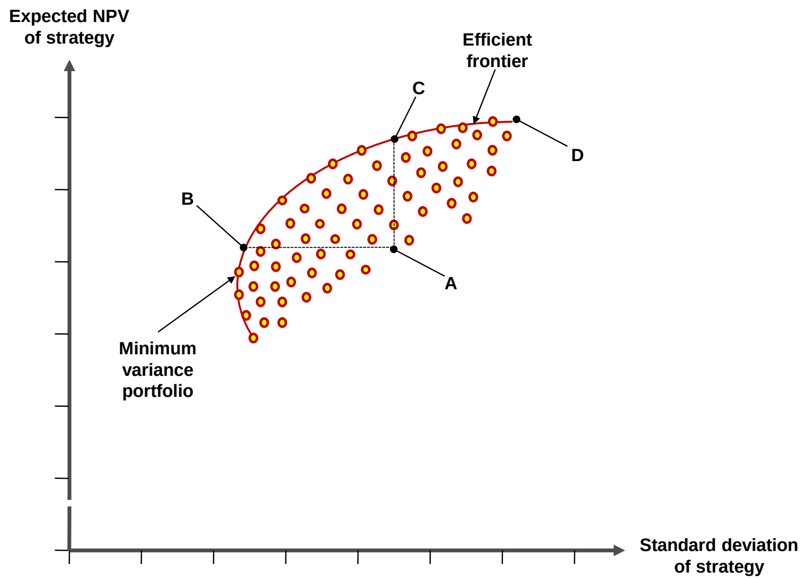


So far, we have looked at three different efficient frontiers for an adaptation strategy comprising two risky actions, under the assumption that the correlation coefficient between the two actions in the strategy had a value of minus one, zero, and plus one. The correlation coefficient can, in practice, take on any value between the extremes of minus one and plus one. As shown in panel (b) of Figure 9-3 the efficient frontiers associated with correlation coefficients of minus one and plus one form a triangle. This triangle represents the boundary that contains all the efficient frontiers associated with other values of correlation coefficient (i.e., $-1 < \rho < +1$).

Case 3: multiple adaptation actions when $-1 < \rho < +1$

Now suppose there are more than two risky adaptation actions for the planner to select from. The set of attainable strategies in the risk-return space is no longer a line segment or curve, as depicted in Figure 9-3, but rather a 'cloud' of attainable strategies, as shown in Figure 9-4. The minimum variance portfolio is the leftmost point of the cloud of attainable strategies. The strategy that offers the maximum return is also evident, being the strategy that comprises solely of the action with the highest expected NPV (Action D). The efficient frontier is the set of strategies on the upper left boundary of the attainable cloud of strategies; along the frontier it is not possible for the planner to re-allocate his or her budget to either increase the expected NPV of the strategy for a fixed level of risk or to decrease the risk of the strategy for a fixed expected NPV.

Figure 9-4: Possible combinations of more than two risky adaptation actions and the associated portfolio risk, expected NPV and efficient frontier



What can we conclude about the four different strategies (A, B, C, and D) in Figure 9-4? Consider the following comparisons:

- Strategy A versus Strategy B: Strategy B is preferred by the decision-maker because it offers the same expected NPV as Strategy A, but at a lower level of risk;
- Strategy A versus Strategy C: Strategy C is preferred by the decision-maker because it offers a higher expected NPV for the same level of risk as Strategy A; and
- Strategy B versus Strategy D: It is difficult to choose between these two strategies. As noted above, Strategy D is the maximum return strategy, but it also has a higher level of risk than Strategy B. Which of these two strategies should the planner choose? Simply put, it will depend on their individual preferences for risk vis-à-vis return. Strictly speaking, they will choose the strategy on the efficient frontier, between the minimum variance portfolio and the maximum return strategy, which maximizes their utility. This point occurs where their (unquantifiable) utility curve is tangential to the efficient frontier (not shown in Figure 9-4).

9.4.2 Real options analysis

Another strategy to manage deep uncertainties when selecting adaptation actions is to seek actions that are flexible. That is, to prioritize actions that have the possibility to be adjusted in the future to cope with impacts that are more or less severe than expected. The benefits of incorporating flexibility are particularly important for large-scale, long-lived and costly adaptation actions, such as public infrastructure projects. These types of projects tend to be irreversible, or the expense of modifications is prohibitive because of very high sunk costs. Furthermore, when designing these types of projects, assumptions must be made about (uncertain) climate conditions over their lifetime (e.g., decisions about the scale, required level of treatment, and location of a wastewater treatment plant on a river depend on assumptions about river flows and water temperatures over the next several decades). If assumptions about future climate conditions are not correct, maladaptation will result, exposing society to increased risks, wasted investment or unnecessary retrofit costs (Reeder and Granger, 2011).

A commonly cited impact of future climate change is coastal flooding from rising sea levels. Typical adaptation responses include managed retreat, flood proofing properties, building sea walls and levee banks. Due to uncertainties over the extent of sea-level rise the benefits of coastal defense schemes are, however, uncertain. Hence, it is difficult for decision-makers to know, for example, exactly how high to build a sea wall, as well as when to build it. Given the uncertainty there is a risk that the default policy response will be to build a sea wall for a worst-case scenario. Yet, assuming a worst-case scenario is unlikely to prove optimal. If sea-level rise turns out to be less severe, then investment made in a relatively high sea wall would result in wasted resources – once the resources are invested in the sea wall they cannot be put to an alternative use. In addition, even a worst-case scenario can change with time as more information about the magnitude and pace of climate change becomes available. While our understanding of future climate change and sea-level rise remains highly uncertain, a better strategy may be to construct a wide base capable of supporting a high, worst-case wall. However, today, the crest of the wall need only be built to a height that optimally mitigates the risks associated with current climate variability and extremes. Or, alternatively, the widened base could be used for sandbagging when needed, as opposed to constructing a low wall.

A wide defense base constructed in a way that enables the crest to be readily raised in the future, should it be required, is an example of a 'real option'. The decision to exercise this option is delayed to a future date when more information on the nature of future climate change impacts is known. The option to raise the crest of the sea-wall, or not, is nonetheless purchased today. The full cost of a high, worst-case scenario wall is not incurred until it is actually needed.

9.4.2.1 Being clear about the definition of real options value

Real options value (or simply an 'option') is a term frequently used by the financial and investment community. An option gives an investor the right to buy a security (e.g., a share) for a contracted price, up to, or on, a specified future date. The investor is not obligated to purchase the security, but rather has the option to. If the share price rises above the contracted price, then the investor can buy it at that price. Since the price of the share in the market is higher than the contracted price, the investor can make a profit by immediately reselling it. On the other hand, if the market price of the share has dropped below the contracted price, then it makes sense for the investor not to exercise the option to buy the share at that price, since it is cheaper to simply buy it on the open market. In this case, the investor is only out of pocket the purchase price of the option originally purchased. Dobes (2008) suggests a couple of 'real' everyday analogies. The first is the purchase of a lottery ticket; the second the purchase of a house (see Box 9-2).

As used by the financial and investment community, real options value essentially refers to the value of information obtained by delaying an uncertain and irreversible investment. In environmental economics and CBA, the value of information obtained by delaying a decision where one or more costs or benefits are uncertain, and where there is the possibility to learn as a result of the delay, is referred to as 'quasi-options value' (Pearce, et al, 2006). In other words, quasi-options value and real options value refer to the same thing. It is important that the analyst does not confuse either of these two terms with another, similar term often used in environmental economics and CBA – that being 'options value'. Options value refers to the difference between 'options price' and the expected value of consumer's surplus, where options price defines an individual's maximum willingness-to-pay now for some future outcome which is uncertain (Pearce, et al, 2006). Our interest here lies solely with real or quasi-options value. The adaptation literature primarily uses the term real options value or 'real options' for short; hence, these are the terms adopted in this guidebook.

Before moving on to look at how a real options approach can be used in the CBA of adaptation actions, it is important for the analyst to note that this approach is likely to prove most useful when adaptation decisions have three properties (HM Treasury, 2009):

- Uncertainty – future adaptation costs and benefits must be uncertain, so there is a risk of making a mistake resulting in maladaptation;
- Learning potential – knowledge about the future impacts of climate change must improve with time if uncertainty is to be reduced – e.g., from improved scientific understanding, from observed changes in the climate, etc.; and
- Flexibility – if the decision is irreversible or flexibility is somehow constrained, the benefits of waiting and generating information are limited.

If an adaptation decision problem does not exhibit these three properties, a real options approach will not significantly improve the efficiency of decision-making.

Box 9-2: Examples of everyday 'real' options

One 'real' every day analogy is the purchase of a lottery ticket:

> "*If the ticket wins, it can be cashed in, but if it does not win it will likely be discarded, and its cost forgone.*"

A second 'real' every day analogy is the purchase of a house by a young couple uncertain about their future needs:

> "*Buying a large house immediately could be unnecessarily costly if they remain childless, or if they delay starting a family for a significant time. But they could buy a smaller, cheaper house on a suitable block of land and extend it later, as required. The smaller house in effect 'embeds' an option to extend, but there is no obligation to do so if the family remains small. The couple can thus delay a final decision on the size (and hence the full cost) of the house until better information becomes available regarding specific family size.*"

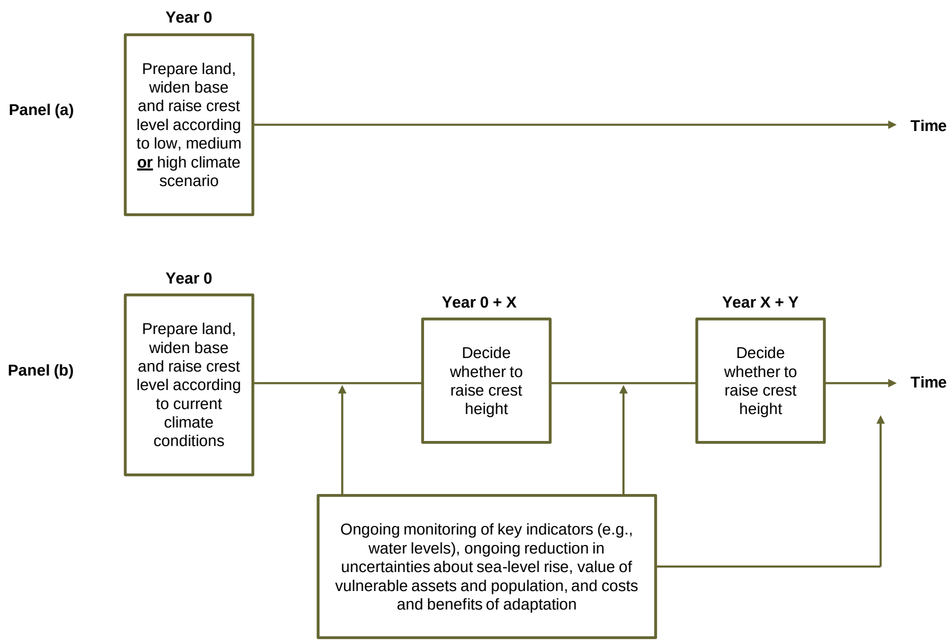
Source: Dobes (2008)

9.4.2.2 Approach to incorporating real options value into CBA

Consider a coastal flood defense scheme that has come to the end of its useful life and requires a major refurbishment. There are a range of possibilities. It could be rebuilt now to provide optimal protection against flooding events anticipated under a low, medium or high climate scenario. Alternatively, the land could be prepared to support a sea wall capable of providing optimal protection under a high climate scenario, but at present the sea wall is only constructed to provide optimal protection against current climate variability and extremes. The idea being that the crest of the wall can be raised in the future, should it be required, as knowledge about the future impacts of climate change is improved and uncertainties are reduced.

The planning problem facing decision-makers is presented in Figure 9-5. One option is to conduct a single CBA at year zero, given the information that is currently available on adaptation costs and benefits, the likelihood of different climate scenarios, and to select the crest height that maximizes expected net benefits. This situation is depicted in panel (a). Instead, the planning problem could be recast as a real options analysis, where decisions are taken sequentially over time as more information becomes available and uncertainty over future adaptation costs and benefits is resolved. This situation is depicted in panel (b). Decisions points (e.g., year 0 + X or year X + Y) are defined in terms of key indicators, such as observed sea levels being reached, with an allowance built in for the lead time needed to raise crest heights. For instance, if monitoring reveals that sea levels are rising faster (slower) than anticipated under climate scenarios, then decision points can be brought forward (put back). In this way, options are appraised at the right time, making best use of available information, and thereby mitigating the risk of maladaptation. The Environment Agency of England and Wales took such a real options approach when developing a tidal flood risk management plan for the Thames Estuary in the UK. An informative summary of the so-called Thames Estuary 2100 (TE2100) project is provided by Reeder and Ranger (2009).

Figure 9-5: Applying real options approach to coastal defense planning



Source: Adapted from Linquiti and Vonortas (2012)

To illustrate how the economics of a real options approach works, consider the following simple example from HM Treasury (2009). Suppose a decision-maker defaults to the worst-case scenario and opts to rebuild the old sea wall to provide optimal protection against the impacts of sea-level rise under a high climate scenario. By optimal, we mean the crest height that maximizes the NPV of the sea wall. To keep the example simple, socio-economic developments are ignored. Furthermore, assume there are only two climate scenarios: low and high, each with equal probability of occurring.

Preparing the land, widening the base and building the wall costs $60 million; note that all dollar values are present values. In the absence of the project, assume the affected area is predicted to incur damage costs of $5 million from current climate variability and extremes, and $50 million and $100 million from sea-level rise under the low and high climate scenarios, respectively. Again, to keep the example simple, there are assumed to be no ancillary benefits (reductions in other related costs). Suppose the wall is projected to completely eliminate damages associated with current climate variability and extremes and to reduce future damages under a high climate scenario by $90 million, leaving residual damage costs of $10 million. (Recall from Section 4.3.3 that optimal adaptation does not necessarily mean zero residual damage costs.) The project's NPV under the high climate scenario is thus:

$$\mathrm{NPV}_{\mathrm{H}}^{\mathrm{S}} = (\$5 - \$0) + (\$100 - \$10) - \$60 = +\$35 \text{ million}$$

Where the first bracketed term is the benefits of adaptation to current climate variability and extremes and the second bracketed term is the benefits of adaptation to future climate change. The superscript “S” denotes the one-off, single decision to invest now, in year 0.

But what if the decision-maker is wrong, climate change is not as severe as anticipated, and the low climate scenario occurs. The high sea wall is assumed to afford complete protection against the impacts of sea-level rise under the low climate scenario. And, of course, it still eliminates all damages associated with current climate variability and extremes. In this case, the project’s NPV is negative:

$$\mathrm{NPV}_{\mathrm{L}}^{\mathrm{S}} = (\$5 - \$0) + (\$50 - \$0) - \$60 = -\$5 \text{ million}$$

The decision-maker has made a mistake, over-adapted, and wasted scarce resources. How can this mistake be avoided?

Suppose, instead, the decision-maker opts to prepare a base capable of accommodating a high wall, but for now only builds a low wall to optimally adapt to current climate variability and extremes, and adopts a wait- and- see approach regarding future climate change. A system is put in place to monitor sea levels and ‘trigger points’ are defined, which when reached instigate a re-analysis of the sea walls crest height. At this time, the crest height can be raised incrementally to optimally adapt to either the low or high climate scenario, whichever looks more likely. In this case, the project’s NPV under the high climate scenario is assumed to be:

$$\mathrm{NPV}_{\mathrm{H}}^{\mathrm{W}} = (\$5 - \$0) + (\$100 - \$10) - \$55 = +\$40 \text{ million}$$

The superscript “W” denotes an approach that entails waiting, with major irreversible investments postponed to year X or Y. The capital cost is assumed to be slightly less than the above project ($55 million as opposed to $60 million) reflecting the fact that some portion of the required investment is pushed into the future and thus has a lower present value cost. A wall built to optimally adapt to the low climate scenario is projected to completely eliminate damages associated with current climate variability and extremes and to reduce future damages from sea-level rise by $45 million, leaving residual damage costs of $5 million. The capital costs of this project are assumed to be $30 million. The resulting NPV is:

$$\mathrm{NPV}_{\mathrm{L}}^{\mathrm{W}} = (\$5 - \$0) + (\$50 - \$5) - \$30 = +\$20 \text{ million}$$

To proceed with a CBA of the two alternative approaches (invest now or wait and see) it helps to construct a decision tree like the one shown in Figure 9-6. A decision tree depicts each stage of a sequential decision-making process assuming specific events occur and specific decisions are made. The ‘trunk’ of the tree is connected to various ‘branches’ via various ‘nodes’.

A decision node is a point where a choice must be made (e.g., to raise the crest height to optimally adapt to sea-level rise anticipated under a low climate scenario or under a high climate scenario). A decision node is typically designated by a square. The branches extending from a decision node are decision branches, each branch representing one of the possible courses of action available at that point. The set of possible actions must be mutually exclusive (if one is selected, the others cannot be selected). A chance node is a point where uncertainty is resolved; a point where the decision-maker learns about the occurrence of an event of interest. A chance node is typically designated by a circle. The branches extending from a chance node comprise the event set, with each branch representing one of the possible events that may occur at that point (e.g., the low climate scenario or the high climate scenario). The set of events must also be mutually exclusive. Each event is associated with a probability of occurrence; the probabilities for the event set must sum to one. Each of the two climate scenarios is assumed equally likely (i.e., $P_H = P_L = 0.5$). The final kind of node is the terminal node. These are the endpoints of a decision tree, representing the final outcome of a combination of decisions and events. Each terminal node has an associated terminal value, often called a payoff (e.g., the estimated NPV of the various flood defense schemes).

So which is the best strategy? The strategy represented by the lower branch in Figure 9-6 (i.e., committing to a one-off, single investment in a high sea wall now) or the real options strategy represented by the upper branch (i.e., waiting for uncertainty to reduce before committing to large, irreversible investments)? To answer this question the analyst needs to compare the expected NPVs of each strategy. The expected NPV of committing to a one-off, single investment in a high sea wall now is $15 million:

$$\mathrm{E(NPV^S)} = \mathrm{P_H} \times \mathrm{NPV_H^S} + \mathrm{P_L} \times \mathrm{NPV_L^S} = 0.5 \times (+35) + 0.5 \times (-5) = +\$15 \text{ million}$$

A two-stage approach is needed to calculate the expected NPV of the real options strategy. First, it is necessary to choose the optimal course of action after deciding to wait and monitor sea levels. What is the optimal decision after deciding to wait? Suppose monitoring and other evidence suggests that sea levels will rise in accordance with the low climate scenario. In this event, raising the crest to optimally adapt to projected sea levels yields a NPV of +$20 million. The NPV of failing to raise the crest of the sea wall, even once it is evident that the low climate scenario will occur, is +$1 million. The wider base and low wall constructed in year zero provide optimal protection against current climate variability and extremes, at a capital cost of $4 million. The benefits of adapting to future climate change are assumed to be zero, with predicted damage costs of $50 million incurred both with and without the action. Clearly, the best decision (with the higher NPV) is to raise the crest to optimally adapt to projected sea levels. The conclusion is the same if monitoring and other evidence suggests that sea levels will rise in line with the high climate scenario; raise the crest to optimally adapt to projected sea levels.

The expected NPV of the real options strategy is thus +$30 million:

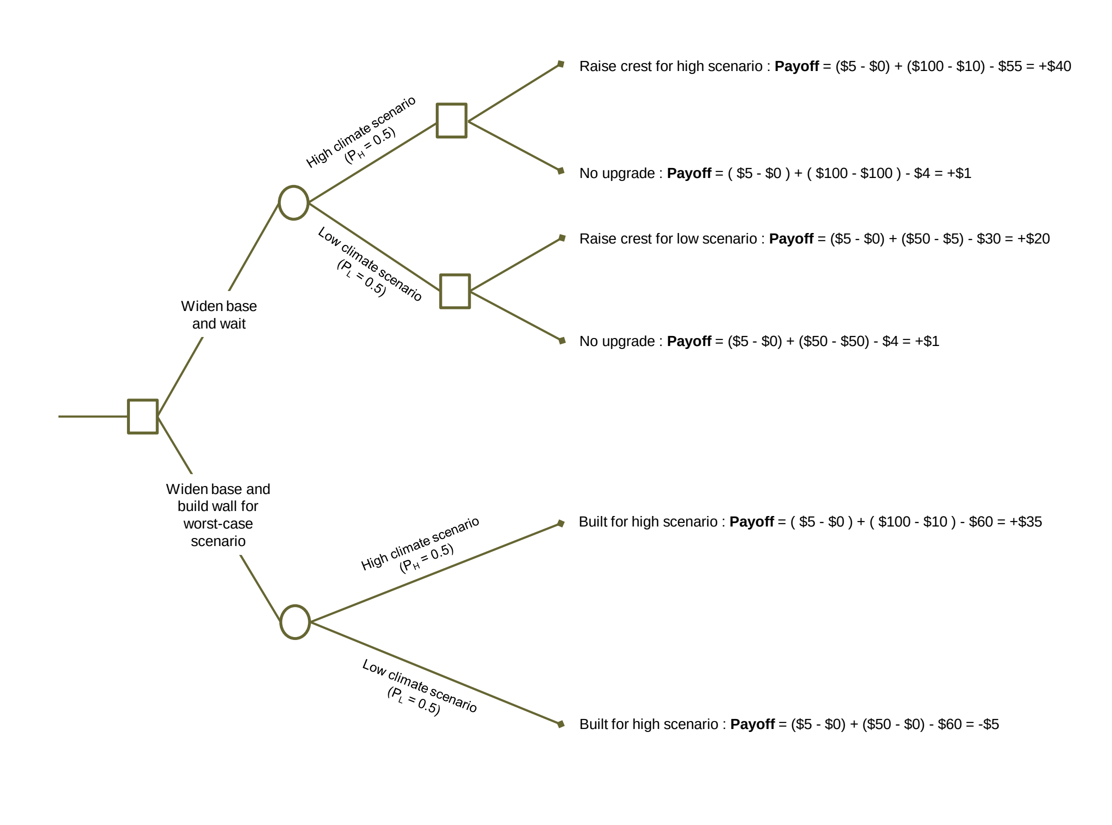
$$\mathrm{E(NPV^W)} = \mathrm{P_H} \times \mathrm{NPV_H^W} + \mathrm{P_L} \times \mathrm{NPV_L^W} = 0.5 \times (+40) + 0.5 \times (+20) = +\$30 \text{ million}$$

Hence, in this simple numerical example, $\mathrm{E(NPV^W)} > \mathrm{E(NPV^S)}$, suggesting that the more efficient decision at year zero is to wait for uncertainty to reduce before committing to a large, irreversible investment in sea walls. The size of the real options value (ROV) or quasi-options value (QOV) is given by the increase in expected NPV associated with waiting (Pearce, et al, 2006). In the numerical example, it is +$15 million:

$$\mathrm{ROV} = \mathrm{QOV} = \mathrm{E(NPV^W)} - \mathrm{E(NPV^S)} = 30 - 15 = +\$15 \text{ million}$$

A final word of caution: the analyst should note that real options value or quasi-options value is not a component of Total Economic Value introduced in Section 5.1.1.1. Rather, real options value or quasi-options value is simply a benefit of better decision-making procedures, like real options analysis.

Figure 9-6: Decision tree for coastal defense scheme



Source: Adapted from HM Treasury (2009)

9.5 References and further reading

Anda, J., Golub, A. and Strukova, E., 2009, Economics of Climate Change under Uncertainty: Benefits of Flexibility, *Energy Policy*, 37, p. 1345-1355.

Ando, A. and Mallory, M., 2012, Optimal Portfolio Design to Reduce Climate-related Conservation Uncertainty in the Prairie Pothole Region, Proceedings of the National Academy of Sciences of the United States of America (available at www.pnas.org/).

Arrow, K. and Fisher, A., 1974, Environmental Preservation, Uncertainty and Irreversibility, *Quarterly Journal of Economics*, 88, pp. 312-319.

Bradford, G., 2007, Modern Portfolio Theory, Purdue University,

Bulte, E., van Soest, D., et al, 2002, Forest Conservation in Costa Rica when Non-use Benefits are Uncertain but Rising, *American Journal of Agricultural Economics*, 84 (1), pp. 150-160.

Burton, I. and van Aalst, M., 2004, Look before You Leap: A Risk Management Approach for Incorporating Climate Change Adaptation into World Bank Operations, Final Report, Global Climate Change Team, Work Bank, Washington, DC, USA.

Clark, H., 2008, Classical Decision Rules and Adaptation to Climate Change, *Australian Journal of Agricultural and Resource Economics*, 52, pp. 487-504.

Crowe, K. and Parker, W., 2008, Using Portfolio Theory to Guide Reforestation and Restoration Under Climate Change Scenarios, *Climate Change*, 89, pp. 353-370.

Dessai, S. and Hulme, M., 2007, Assessing the Robustness of Adaptation Decisions to Climate Change Uncertainties: A Case Study on Water Resource Management in the East of England, *Global Environmental Change*, 17(1), pp. 59-72.

Dixit, A. and Pindyck, R., 1995, The Options Approach to Capital Investment, *Harvard Business Review*, May-June, pp. 105-155.

Dobes, L., 2008, Getting Real about Adapting to Climate Change: Using Real Options to Address the Uncertainties, *Agenda*, 15(3), p. 55-69.

Dobes, L., 2010, Notes on Applying Real Options to Climate Change Adaptation Measures, with Examples from Vietnam, Crawford School of Economics and Government, Centre for Climate Economics and Policy, Canberra: Australian National University, Australia.

Fankhauser, S., Smith, J. and Tol, R., 1999, Weathering Climate Change, Some Simple Rules to Guide Adaptation Investments, *Ecological Economics*, 30(1), pp. 67-78.

Figge, F., 2004 Bio-Folio: Applying Portfolio Theory to Biodiversity, *Biodiversity and Conservation*, 13, pp. 827-849.

Fischer, A. and Hanemann, M., 1990, Option Value: Theory and Measurement, *European Journal of Agricultural Economics*, 17, p. 167-180.

Fisher, A., 2000, Investment under Uncertainty and Option Value in Environmental Economics, *Resource and Energy Economics*, 22, pp. 197-204.

Groves, D. and Lempert, R., 2007, A New Analytical Method for Finding Policy-Relevant Scenarios, *Global Environmental Change*, 17(1), pp. 73-85.

Hallegatte, S., 2009, Strategies to Adapt to an Uncertain Climate Change, *Global Environmental Change*, 19(2), pp. 240-247.

Hertzler, G., 2007, Adapting to Climate Change and Managing Climate Risks by Using Real Options, *Australian Journal of Agricultural Research*, 58, p. 985-992.

HM Treasury, 2004, The Green Book: Evaluation and Appraisal in Central Government, Annex 4, Risk and Uncertainty, Treasury Guidance, The Stationary Office, London, UK.

HM Treasury, 2009, Accounting for the Effects of Climate Change, Supplementary Green Book Guidance, HM Treasury, London, UK.

Jamet, S. and Corfee-Morlot, J., 2009, Assessing the Impacts of Climate Change: A Literature Review, Economics Department Working Paper No 691, ECO/WKP(2009)32, OCED, Paris, France.

Kousky, C. and Cooke, R., 2010, Adapting to Extreme Events: Managing Fat Tails, Resources for the Future, Washington, DC, USA.

Lempert, R., Nakicenovic, N., Sarewitz, D. and Schlesinger, M., 2004, Characterizing Climate Change Uncertainties for Decision-makers, *Climate Change*, 65, pp. 1-9.

Lempert, R., Groves, D., Popper, S. and Bankes, S., 2006, A General, Analytic Method for Generating Robust Strategies and Narrative Scenarios, *Management Science*, 52(4), pp. 514–528.

Lempert, R. and Collins, M., 2007, Managing the Risk of Uncertain Threshold Responses: A Comparison of Robust, Optimum, and Precautionary Approaches, *Risk Analysis*, 27, pp. 1009–1026.

Linquiti, P. and Vonortas, N., 2012, The Value of Flexibility in Adapting to Climate Change: A Real Options Analysis of Investment in Coastal Defenses, *Climate Change Economics*, 3(2), p. 1-33.

Marinoni, O. and Adkins, P., 2009, Joint Application of Cost-Utility Analysis and Modern Portfolio Theory to Inform Decision Processes in a Changing Climate, 18th World IMACS / MODSIM Congress, 13-17 July 2009, Cairns, Australia.

Marinoni, O., Hajkowicz, S., Higgins, A. and Collins, K., 2009, An Investment Decision Support System for Improved Water Management, *Environmental Modeling and Software*, pp. 153-164

Markowitz, H., 1952, Portfolio Selection, *Journal of Finance*, 7, pp. 77-91.

Menne, B. and Ebi, K. (eds.), 2006, Climate Change and Adaptation Strategies for Human Health, Steinkopff Verlag Darmstadt, p. 449.

Metroeconomica, 2004, Costing the Impacts of Climate Change in the UK: Implementation Report, UKCIP Technical Report, UK Climate Impacts Program, Oxford, UK.

Pearce, P., Atkinson, G. and Mourato, S., 2006, Cost-benefit Analysis and the Environment: Recent Developments, Chapter 10, Quasi Option Value, OECD, Paris, France.

Pindyck, R., 2000, Irreversibilities and the Timing of Environmental Policy, *Resource and Energy Economics*, 22, pp. 233-259.

Pindyck, R., 2007, Uncertainty in Environmental Economics, *Review of Environmental Economics and Policy*, 1(1), pp. 45-65.

Ranger, N., and S-L Garbett-Shiels, 2011, How Can Decision-makers in Developing Countries Incorporate Uncertainty about Future Climate Risks in Existing Planning and Policy-making Processes, Grantham Research Institute on Climate Change and the Environment, LSE, London, UK.

Reeder, T. and Ranger, N., 2011, How Do You Adapt in an Uncertain World? Lessons from the Thames Estuary 2100 Project, World Resources Report Uncertainty Series, World Resources Report, Washington, DC, USA.

Rosenzweig, C., 2010, Climate Change Adaptation in New York: Building a Risk Management Response, Annals – New York Academy of Science, Volume 1196, May 2010, New York, USA.

TBCS, 2007, Canadian Cost-benefit Analysis Guide: Regulatory Proposals, Treasury Board of Canada Secretariat, Ottawa, Canada.

Ulph, A. and Ulph, D., 1997, Global Warming, Irreversibility and Learning, *The Economic Journal*, 107(442), p. 636-650.

Vonortas, N. and Dessai, C., 2007, Real Options Framework to Assess Public Research Investments, *Science and Public Policy*, 34(10), p. 699-708.

ANNEX 9-1

Basic probability and statistical concepts for risk analysis

To undertake risk analysis when appraising adaptation actions the analyst needs an understanding of basic probability and statistical concepts. To illustrate key concepts, consider the simple numerical example in Table 9-1, which shows possible NPVs for a particular adaptation action, along with the probability of each NPV occurring. The probability of an event occurring (e.g., like an action's NPV taking a specific value) is the chance or likelihood of it occurring. The probability of an event A, written P_A, can be between zero and one, with P_A = 1 indicating that the event will certainly happen and with P_A = 0 indicating that event A will certainly not happen. In general:

$$\text{Probability} = \frac{\text{the number of successful outcomes of an experiment}}{\text{the number of possible outcomes}} \qquad \text{Equation 9-5}$$

So, for example, if a coin is tossed, the probability of obtaining a head is 0.50 or 50 per cent, since there are only two possible outcomes (heads or tails) and one of these is the 'successful' outcome.

The NPV of the adaptation action in the numerical example is assumed to take one of four discrete values: $10 million, $12 million, $16 million or $18 million. In other words, experimenting with economic analysis of the action has revealed only four possible outcomes. For simplicity, it is assumed that each NPV estimate is equally likely to occur. Given that the sum of the probabilities for the four possible NPVs must equal one (or 100 per cent), the probability of each NPV occurring must be 0.25 or 25 per cent.

Measures of central tendency and dispersion

The analyst now has all the information needed to estimate the expected NPV from the table of possible estimates and associated probabilities. Let NPV_i denote the ith NPV estimate and let P_i denote the probability of the ith NPV estimate. The expected NPV equals the sum of each NPV estimate multiplied by its assigned probability of occurrence:

$$\text{E(NPV)} = \text{P}_1 \times \text{NPV}_1 + \text{P}_2 \times \text{NPV}_2 + \cdots + \text{P}_4 \times \text{NPV}_4 = \sum_{i=1}^{n} \text{P}_i \times \text{NPV}_i \qquad \text{Equation 9-6}$$

For the numerical example, the expected NPV is $14.0 million:

$$\text{E(NPV)} = \$10 \times 0.25 + \$12 \times 0.25 + \$14 \times 0.25 + \$18 \times 0.25 = \$14.0 \text{ million}$$

It is not necessary that the estimated NPVs be equally likely. For instance, the analyst may instead judge the $16 million estimate to have a probability of 55 per cent, with the remaining three estimated NPVs having equal probability of 15 per cent. The expected NPV in this case is $14.8 million:

$$\mathrm{E(NPV)} = \$10 \times 0.15 + \$12 \times 0.15 + \$16 \times 0.55 + \$18 \times 0.15 = \$14.8 \text{ million}$$

Table 9-1: Estimated NPVs for adaptation action with equal probabilities of occurrence

NPV ($ million)	Probability of NPV
10	25%
12	25%
16	25%
18	25%

In statistics, an expected value (e.g., expected NPV) is a measure of the 'central tendency' of the data. The expected value is what we would expect the outcome of an experiment to be on average. Hence, the terms 'average' and 'mean' are used interchangeably with expected value.

What about the variability or dispersion of the data? How does the analyst assess the dispersion of the NPV estimates presented in Table 9-1 around the expected value? The simplest measure of dispersion in a data set is the range. The range is the difference between the largest and smallest possible outcome. Its use, however, is not recommended as it fails to account for the probability of the two extreme outcomes, which may be very unlikely to occur.

Variance (σ^2) is another commonly used to measure the variability or dispersion of a data set. It is calculated by first determining the difference between each value and the expected value (i.e., the deviation from the mean). Next, each deviation from the mean is squared. This is to get rid of any minus signs. Finally, the average of each squared deviation is calculated.

$$\mathrm{Variance(NPV)} = \sigma^2 = \frac{\left(\mathrm{NPV}_1 - \mathrm{E(NPV)}\right)^2 + \cdots + \left(\mathrm{NPV}_4 - \mathrm{E(NPV)}\right)^2}{4}$$

Equation 9-7

$$\mathrm{Variance(NPV)} = \sigma^2 = \frac{\sum_{i=1}^{n}\left(\mathrm{NPV}_i - \mathrm{E(NPV)}\right)^2}{n}$$

For the numerical example, the variance for the NPV estimates is $10.0 million:

$$\sigma^2 = \frac{(\$10 - \$14)^2 + (\$12 - \$14)^2 + (\$16 - \$14)^2 + (\$18 - \$14)^2}{4} = \$10 \text{ million}$$

Because deviations from the expected value are squared to determine the variance, the unit for the variance is actually the square of the NPV. Hence, it is common practice to take the square root of the variance to obtain the so-called standard deviation (σ):

$$\sigma = \sqrt{\sigma^2} \qquad \text{Equation 9-8}$$

Standard deviation is the more frequently used measure of dispersion in a data set. For the numerical example, the standard deviation for the NPV estimates is $3.2 million:

$$\sigma = \sqrt{\$10.0} = \$3.2 \text{ million}$$

Probability distributions

Probability distributions are a useful way of visually describing the probability of observing a particular event (e.g., NPV). Three simple (continuous) probability distributions are useful in economic analysis: ❶ the uniform distribution; ❷ the triangular distribution; and ❸ the normal distribution.

The simplest to understand is the uniform distribution. It can be used in simulations when not much is known about the distribution of an outcome; the analyst need only know the smallest and largest values. Suppose, for example, that the estimated NPV of an adaptation action is distributed uniformly between two values, -$5 million and +$20 million. This means that the NPV can take any value between the two end-points of -$5 million and +$20 million. In addition, there is zero probability that the NPV is either less than -$5 million or higher than +$20 million.

The area under any continuous distribution must equal one (see the probability density function in panel (a) of Figure 9-7). Hence, the height (h) of a continuous uniform distribution is given by:

$$h = \frac{1}{(b-a)} \qquad \text{Equation 9-9}$$

Where a is the smallest possible value and b is the largest possible value. For the numerical example, the height must therefore be 4 per cent:

$$h = \frac{1}{\big(20-(-5)\big)} = \frac{1}{25} = 0.04 = 4\%$$

The expected value (or mean) and variance of a continuous uniform distribution is given by:

$$\text{E(NPV)} = \frac{a+b}{2}$$

Equation 9-10

$$\text{Variance(NPV)} = \sigma^2 = \frac{1}{12} \times (b-a)^2$$

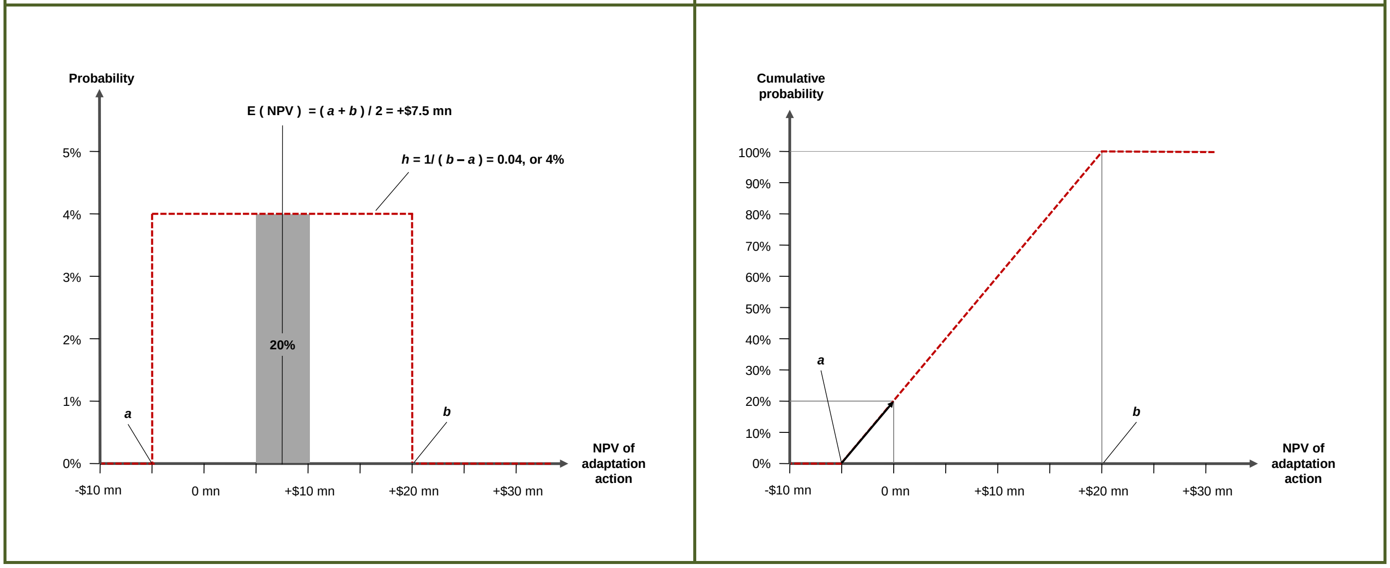
For the numerical example, the expected NPV is $7.5 million. From the uniform probability density function shown in panel (a) of Figure 9-7, it is possible to address the question: what is the probability that the NPV of the action is between, say, $5 million and $10 million? The answer is found by calculating the area of the shaded rectangle between these two endpoints. The probability is 20 per cent that the NPV is between \$5 million and \$10 million:

$$\text{Probability} = 0.04 \times (10 - 5) = 0.20 = 20\%$$

A cumulative probability distribution can readily be calculated from the continuous probability density function. In the case of a uniform distribution the cumulative probability distribution is a straight line, linking the smallest and largest endpoints, with slope $1/(b-a)$. Consider panel (b) of Figure 9-7. From the cumulative probability distribution the analyst can determine the probability that the NPV is less than, say, \$0 million or negative. Starting from the smallest endpoint, move up the distribution till the desired NPV is reached, and read off the cumulative probability from the vertical axis. The probability that the action's NPV is negative is 20 per cent.

Figure 9-7: Example of uniform distribution

(a) Probability density function | (b) Cumulative probability distribution



Another continuous probability distribution commonly used in economic analysis when there is limited information is the triangular distribution. To use the triangular distribution in simulations the analyst only needs knowledge of the smallest and largest values, and the modal value (i.e., the value which the analyst believes will occur most often). In a symmetrical triangular distribution the modal value defines the midpoint of the smallest and largest values.

Again, as the area under any continuous distribution must equal one, the height (h) of a continuous triangular distribution is given by:

$$h = \frac{2}{(b-a)} \qquad \text{Equation 9-11}$$

Where a and b are the smallest and the largest possible values, respectively.

For the same numerical example, the height must therefore be 8 per cent:

$$h = \frac{2}{\left(20 - (-5)\right)} = \frac{2}{25} = 0.08 = 8\%$$

The resulting (non-symmetrical) triangular distribution is shown in Figure 9-8. The expected value (or mean) and variance of a continuous triangular distribution is given by:

$$\mathrm{E(NPV)} = \frac{a + b + c}{3}$$

Equation 9-12

$$\mathrm{Variance(NPV)} = \sigma^2 = \frac{1}{18} \times (a^2 + b^2 + c^2 - a \times b - a \times c - b \times c)$$

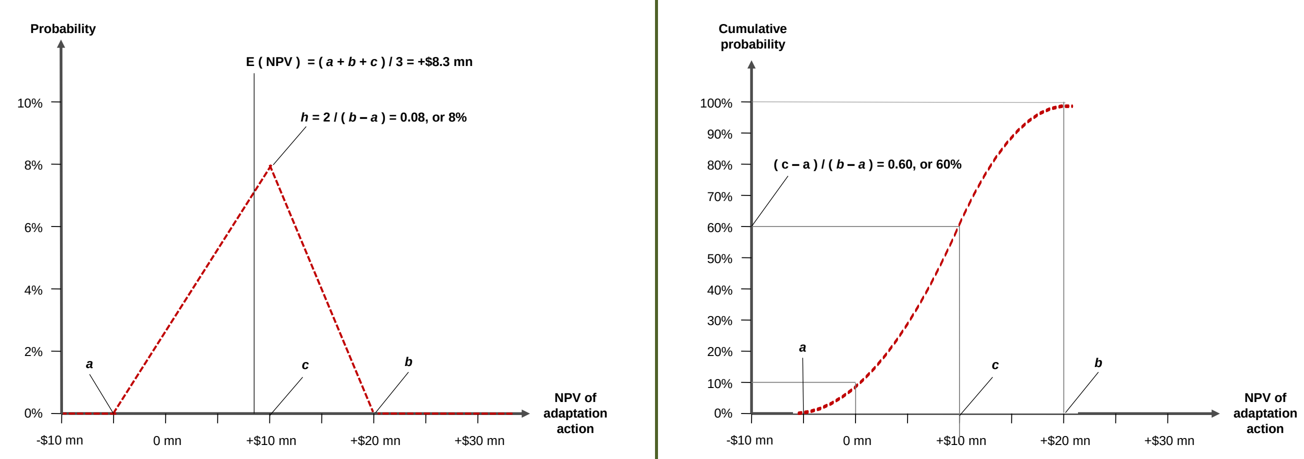
Where c is the modal value. Suppose the analyst believes the most likely NPV is $10 million. The expected NPV in this case is $8.3 million:

$$\mathrm{E(NPV)} = \frac{-5 + 20 + 10}{3} = 8.3$$

From the cumulative probability distribution shown in panel (b) of Figure 9-8, the analyst can determine the probability that the NPV is less than $0 million or negative. Again, this is done by starting from the smallest endpoint, moving up the distribution until the point where the NPV equals $0 million is reached, and reading off the cumulative probability from the vertical axis. The probability that the action's NPV is negative in this case is 10 per cent.

Figure 9-8: Example of a non-symmetrical triangular distribution

(a) Probability density function | (b) Cumulative probability distribution



A final continuous probability distribution commonly used in economic analysis is the familiar bell-shaped normal distribution. To construct a normal distribution for an outcome the analyst needs to know the expected value (mean) and standard deviation of possible outcomes. Suppose that the NPV of an adaptation action follows a normal distribution with an expected value of $10.0 million and a standard deviation of $4.5 million. The corresponding normal distribution is shown in Figure 9-9.

A normal distribution has some interesting properties that allow the analyst to calculate the probability for any range of values in the data. For example, the analyst may wish to know the probability that the NPV of an action is within one standard deviation of the expected value. In formal terms:

$$\text{Prob }(\text{E(NPV)} - \sigma \leq X \leq \text{E(NPV)} + \sigma)$$

$$= \text{Prob }(10.0 - 4.5 \leq X \leq 10.0 + 4.5) = \text{Prob }(5.5 \leq X \leq 14.5) = 68\%$$

For any normal distribution the answer is 68 per cent (this is known as the one sigma rule). Likewise, the analyst may wish to know the probability that the NPV of the action is within two standard deviations of the expected value. The answer in this case is:

$$\text{Prob }(\text{E(NPV)} - 2\sigma \leq X \leq \text{E(NPV)} + 2\sigma)$$

$$= \text{Prob }(10.0 - 2 \times 4.5 \leq X \leq 10.0 + 2 \times 4.5) = \text{Prob }(1.0 \leq X \leq 19.0) = 95\%$$

For any normal distribution the answer is 95 per cent (this is known as the two sigma rule). The probability that the NPV of the action is within three standard deviations of the expected value is 99 per cent (the three sigma rule).

Using these three rules the analyst can answer a number of additional questions. For instance, what is the probability that the NPV of the action is one standard deviation below the expected value? In formal terms:

$$\text{Prob }(X \leq \text{E(NPV)} - \sigma) = \text{Prob }(X \leq 10.0 - 4.5) = \text{Prob }(X \leq 5.5) = ?$$

From the one sigma rule the analyst knows the probability that the NPV is within one standard deviation of the expected value is 68 per cent. The probability that the NPV is more than two standard deviations away from the expected value is thus 100 per cent less 68 per cent, or 32 per cent. That is, the combined probability that the NPV is either more than one standard deviation below the expected value or more than one standard deviation above the expected value is 32 per cent. As a normal distribution is symmetrical around the expected value, the probability of its lower tail must equal the probability of its upper tail. Hence, the probability that the NPV of the action is one standard deviation below the expected value is 16 per cent:

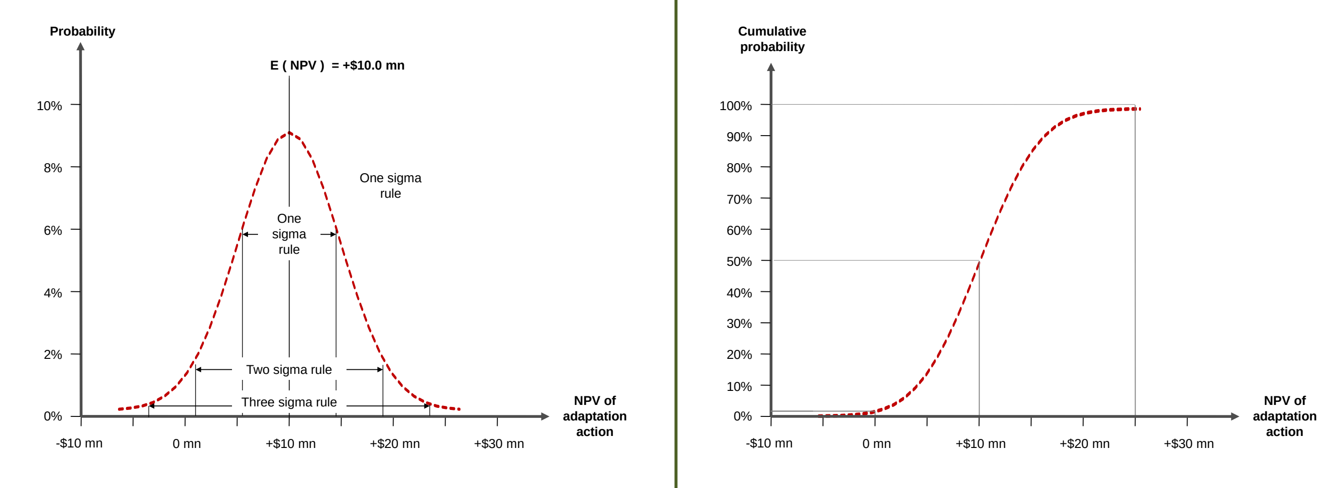
$$\text{Prob }(X \leq \text{E(NPV)} - \sigma) = \text{Prob }(X \leq 5.5) = \frac{0.32}{2} = 0.16 \text{ or } 16\%?$$

The probability that the NPV of the action is two or three standard deviations below the expected value is, respectively, 2.5 per cent and 0.5 per cent.

As noted in the main text of the section, a key output of Monte Carlo Simulation is the cumulative normal probability distribution for an outcome of interest, like an adaptation action's NPV. Similar to the uniform and triangular distributions, from the cumulative probability distribution the analyst can readily determine the probability that the NPV of the action will be negative. The cumulative probability distribution for the numerical example is shown in panel (b) of Figure 9-9. The probability that the action's NPV is negative in this case is just under two per cent.

Figure 9-9: Example of a normal (Gaussian) distribution

(a) Probability density function	(b) Cumulative probability distribution



10 Analysis of Distributional Impacts

10.1 Purpose

The purpose of this section is to:

- Explain why an analyst may wish to investigate the distributional implications of adaptation actions;
- Distinguish between equity assessments and economic impact analyses;
- Provide a three-stage hierarchical approach to equity assessments, which enables the analyst to qualitatively analyze distributional impacts and avoid key controversies that arise when explicitly weighting costs and benefits; and
- Explain the role of stakeholder analysis in qualitative equity assessments and provide a practical approach to stakeholder analysis.

10.2 Why considering distributional impacts is important

Climate change will affect everyone, everywhere. However, the distribution of impacts is expected to be uneven, both across and within countries (Schneider *et al*, 2007). For instance, similar to the adverse impacts of environmental degradation, the economic damages of climate change will tend to fall more heavily on the poor within a society (Mendelsohn *et al*, 2006). The poor tend to live in marginal areas, such as flood plains, which are more sensitive to climate variability and extremes. Wealthier households can afford to live in areas with superior amenities and infrastructure, and can afford to invest in more effective risk mitigation measures. Poorer households, in contrast, tend to invest in less efficacious measures or simply suffer the consequences. Furthermore, wealthier households are better able to exert pressure on decision-makers to ensure adequate protection of their assets. The employment situations and prospects of wealthier households also are better, enabling them, if necessary, to move to reduce their exposure to climate change. Poorer members of society are thus more vulnerable to the impacts of climate change, and also will find it relatively more difficult to adapt due to lower adaptive capacity.

Socio-economic groups across Canada differ on a number of other dimensions, in addition to wealth, that make them more or less vulnerable to climate change impacts – e.g., age, health, source of livelihood, education, skills and knowledge, and location. Likewise, vulnerability to climate change impacts is not homogenous across and within economic sectors, such as industry, commerce, government, and not-for-profits. The vulnerability of industrial sectors, entire firms or individual facilities, will depend on, among other things, the extent to which core operations (e.g., physical assets, production processes, the workforce) or aspects of the value chain (e.g., supplies of raw materials or other inputs to production) are located in climate-sensitive areas or sourced from climate-sensitive sectors, respectively.

The fact that vulnerability to climate change varies considerably across populations and economic sectors within Canada raises important questions about equity. In general, the social acceptability, and hence political viability, of progressive policy reforms is greater than for regressive ones (Boccanfuso *et al*, 2008). Adaptation strategies will be no different. All else being equal, decision-makers will tend to look more favourably on adaptation actions that are seen to be fair with respect to their consequences for key vulnerable groups and economic sectors.

The incidence of adaptation costs and benefits is not only of interest to decision-makers because of concerns over fairness or the rightness of an action. The sustainability of adaptation actions will also depend heavily on who gains and who loses. If, for example, adaptation costs accrue mainly to an influential group, the successful implementation of a proposed action may prove difficult. Similarly, if the benefits of adaptation accrue primarily to a high-profile vulnerable group, political and other support for an action may be more forthcoming.

In short, when designing adaptation actions, decision-makers will likely consider distributional impacts important. The sustainability of an action is strongly affected by who benefits and by how much, relative to who pays.

Economic appraisal techniques are primarily concerned with assessing the efficient allocation of society's resources. Strictly speaking, they help ascertain the economic efficiency of specific actions. CBA, for instance, aggregates incremental costs and benefits across groups or individuals without concern for the equity of the distribution of those costs and benefits. The Kaldor-Hicks compensation test at the heart of CBA implicitly counts a dollar gain to one person as cancelling a dollar loss to another. It assumes a dollar is worth the same to everyone. In other words, CBA is concerned with whether a proposed adaptation action delivers a net gain in dollar value to society as a whole; the incomes or any other characteristics of the individuals who receive the incremental benefits or bear the incremental costs doesn't matter. This 'a dollar is a dollar' assumption separates an action's efficiency effects from its equity or distributional effects. However, as emphasized above, the efficient use of resources is unlikely to be the sole criterion important to decision-makers when assessing the desirability of adaptation strategies or actions. As well as knowing whether an action is welfare-improving, decision-makers likely will want to know whether key vulnerable groups or economic sectors will benefit, and certainly will wish to ensure they will not be made worse off.

10.2.1 Approaches to distributional analysis

Fortunately, there are two ways the analyst can investigate the distributional consequences of adaptation actions for decision-makers (US EPA, 2000):

- ⇨ Equity assessments, which look at how actions affect vulnerable groups in society; and
- ⇨ Economic impact analyses, which look at how actions affect key economic sectors.

The remainder of this section focuses on equity assessments. Good guidance on conducting economic impact analyses is provided in US EPA (2000) and also is available from the Government of Ontario (at http://www.reddi.gov.on.ca/guide_ecimpactassessment.htm).

10.3 Equity assessment

The primary goal of an equity assessment is to investigate the distributional consequences of adaptation actions for specific vulnerable groups in society who are of interest to decision-makers. Practical equity assessment within a cost-benefit analysis framework can be conducted in three stages:

1. Identifying and cataloguing distributional impacts;
2. Implicit weighting of incremental net benefits accruing to different groups; and
3. Explicit weighting of incremental net benefits accruing to different groups.

Kriström (2006) views these steps as a hierarchy. At a minimum, the analyst should undertake Stage 1. While potentially laborious, this stage is relatively straightforward and could offer valuable and additional insights to decision-makers on key winners and losers from adaptation. Furthermore, the more ambitious Stages 2 and 3 cannot be considered without the basic data generated during Stage 1. In proceeding to Stage 2 and on to Stage 3 in particular, informed guesswork and value judgments increasingly must be made on how to interpret the available empirical evidence to develop distributional weights. As highlighted below, there is no consensus on the correct distributional weights to use, and even a small change in the magnitude of the weights can have a significant impact on an action's NPV. In progressing to Stage 3 in the hierarchy, the analyst must decide if the value to decision-makers of explicitly integrating efficiency and equity concerns in a CBA outweighs the controversy it is likely to stir up because of the necessary judgments made regarding society's distributional preferences. Until controversy surrounding the correct weights to use in distributional analysis is resolved, the analyst may not wish to progress beyond computing implicit weights.

10.3.1 Stage 1: Identifying distributional impacts

To ensure resources are used in the most effective manner possible, the analyst should begin by undertaking a scoping exercise in order to screen out those impacts unlikely to produce significant equity concerns for decision-makers. This scoping exercise comprises a number of sequential tasks (US EPA, 2000):

1. Determine which groups and equity dimensions are likely to be affected by the proposed adaptation action or set of actions. Groups can be distinguished broadly as consumers, business and government, which can be further subdivided. For instance:
   - ⇨ Within the consumer group it may be necessary to distinguish sub-groups according to income, geographical location, age, family unit, ethnic or cultural background, levels of information held, current or future generations.
   - ⇨ Within the business group, sub-groups can be defined along industry or sectoral lines, by type of activity, or by size of business.
   - ⇨ Within the government group, sub-groups can be defined along levels of government – including federal, provincial or territory, or municipal government - and/or by departments at each level.

Potential equity dimensions (and relevant groups) of interest to decision-makers include *inter alia*: ❶ entity size (e.g., SMEs); ❷ poverty (e.g., individuals or households below income thresholds); ❸ minority status (e.g., First Nations); ❹ age (e.g., children or the elderly); and ❺ time (e.g., current or future generations). Only groups likely to be affected require further consideration.

2. For all affected groups, determine whether the proposed action or set of actions is likely to impose significant economic effects. Only those affected groups likely to experience meaningful costs or benefits warrant further investigation.

3. For those affected groups likely to experience significant economic effects, determine which equity dimensions are likely to be of greatest concern for the decision at hand. If multiple dimensions are identified for further consideration, prioritize the relevant dimensions according to the level of concern they generate. To this end, stakeholder analysis is a useful tool for identifying those groups that stand to lose or gain most from the adaptation action being appraised, and therefore that have a significant interest in the proposal, and that also have the power to potentially affect the action's success (see Section 10.4).

4. The final task is to quantify specific economic effects across the priority equity dimensions and population groups. The analyst, where possible, should disaggregate the estimated incremental benefits and costs from the CBA, and document how they accrue (over the duration of the adaptation action) to the relevant population groups. This draws attention to potential equity issues by identifying potential winners and losers and the possible magnitude of their gains and losses.

When this information is presented to decision-makers, it is then up to them to decide whether important distributional impacts or equity issues are raised by the adaptation action under consideration and whether these need to be addressed. If distributional outcomes are a concern:

- ⇨ Are there any measures that could be designed into the proposed adaptation action that will mitigate the expected "unfair" impacts, without making the action's NPV negative?; and
- ⇨ Are there alternative adaptation actions that could meet the same objectives without the unwanted distributional outcomes, and which still have acceptable NPVs?

10.3.2 Stage 2: implicit distributional weights

The analyst should at least complete Stage 1 as doing so clarifies for decision-makers the potential trade-offs between efficiency and equity embedded in the adaptation decision at hand. Stage 2, if undertaken, involves calculating implicit distributional weights. That is, it determines, for example, what weight would need to be assigned to the gains of a particular group in order to make a non-economic adaptation action socially valuable?

10.3.2.1 Incorporating distributional weights into NPV calculations

To illustrate the process of implicit weighting (and in the subsequent section, explicit weighting), first consider an adaptation action that affects two population groups, X and Y. Assume that the present value (PV) incremental net benefits (NB) accruing to each group are:

- Population group X = +$4 million; and
- Population group Y = -$2 million.

The NPV of this adaptation action is given by[35]:

$$NPV = PVNB^X + PVNB^Y = +\$2 \text{ million} \qquad \text{Equation 10-1}$$

The proposed adaptation action generates a positive NPV, and therefore passes a standard cost-benefit test in the sense that it represents an efficient use of resources.

Distributional weights are easily introduced into Equation 10-1 by assigning a weight a^k to the present value incremental net benefits accruing to each population group (and assuming a^k equals one for now):

$$NPV = a^X \times PVNB^X + a^Y \times PVNB^Y = +\$2 \text{ million} \qquad \text{Equation 10-2}$$

In general terms, the NPV Decision Rule 1 (recall 8.2) can be recast with distributional weights -- an adaptation action should be accepted if:

$$NPV = \sum_k a^k \times PVNB^k > 0 \qquad \text{Equation 10-3}$$

Equation 10-3 says to not accept an adaptation action unless the sum of the distributionally weighted present value incremental net benefits is positive.

Conventional CBA assumes that the distributional weight a^k equals 1 for all population groups *k* (in the numerical example a^X =1 and a^Y = 1). Costs and benefits are all viewed equally, regardless of who they accrue to. This view may be justified when the distribution of income in society is considered to be optimally distributed (see Box 3-1). But, what if the distribution of income is judged to be sub-optimal? Say, for example, individuals in group Y, the net losers if the adaptation action is implemented, are poor relative to individuals in group X, the net beneficiaries of the action. In this case, going ahead with the project will only exacerbate an already unequal distribution of income. Some see this as a reason for varying the weights assigned to the incremental net benefits accruing to different groups, if it can be argued that differences in the socio-economic characteristics of affected groups reflect legitimate distributional concerns. In effect, the adaptation project would be used as a mechanism to improve the distribution of income in society.

[35] The present value incremental net benefits experienced by group X are given by: $PVNB^X = d_0 \times NB_0^X + d_1 \times NB_1^X + d_2 \times NB_2^X + \cdots + d_n \times NB_n^X$ where *d* is the appropriate discount factor valued at the real social discount rate *r*.

Box 10-1: Rationale for distributional weighting on basis of income

Income-based distributional weighting usually is justified with reference to:

- **The diminishing marginal utility of income**. A dollar received, or a dollar lost, by a low income individual has a greater impact on their utility, than it would on the utility of a wealthy individual.
- **The distribution of income is sub-optimal**. The existing distribution of income is less equal than it should be, and making it more equal would increase social welfare. In this case, a dollar increase in the income of low income individual would produce a larger increase in social welfare than a dollar increase in the income of a wealthy individual.

Explicitly incorporating (income-based) distributional weights into the NPV formula will result in:

- Some inefficient adaptation actions passing the standard cost-benefit test, providing they make income distribution sufficiently more equal.
- Some efficient adaptation actions not passing the standard cost-benefit test because they lead to a more unequal distribution of income.

These potential outcomes have generated considerable controversy about the relative merits of explicitly integrating distributional weights into CBA (Harberger, 1978). Even accepting the potential efficiency losses, there is much disagreement amongst economists as regards the correct weights to actually use (Bångman, 2006).

10.3.2.2 Computing implicit weights

A way around these problems is to determine what set of distributional weights would be needed to switch a recommendation to go ahead with a proposed adaptation action (a positive NPV) to not going ahead (a negative NPV), or vice versa (Kanninen and Kriström, 1993). To calculate a so-called 'switching value', the analyst must determine how large the implicit weight for a specific group, say group Y, would need to be to affect the decision about the economic worth of the adaptation action. In the above numerical example, this would involve setting a^X equal to one and the NPV equal to zero in Equation 10-2, and solving for the distributional weight a^Y – as follows:

$$0 = 1 \times \$4 + a^Y \times (-\$2), \text{ which yields } a^Y = \$4/\$2 = 2 \qquad \text{Equation 10-4}$$

In this case, the implicit weight assigned to group Y is two. Equally, one could ask, for a^Y equal to one, what value must the implicit weight assigned to group X take in order to make the action uneconomic – as follows:

$$0 = a^X \times \$4 + 1 \times (-\$2), \text{ which yields } a^X = \$2/\$4 = 0.5 \qquad \text{Equation 10-5}$$

The implicit weight for group X is thus one-half. But the real question is how the analyst then uses this information. One option is to present the implicit weight (or set of weights) to the decision-makers, so they may ask themselves whether it is warranted, in the sense that it reflects society's preferences for distributional outcomes, or is consistent with what is politically acceptable. To help address these questions, the decision-maker may consider the relative income differences between the affected groups or between each group and some accepted threshold level of income that defines poverty levels. For instance, in the numerical example, individuals in group Y are assumed to be poor relative to individuals in group X. In the opinion of decision-makers, this income differential, if sufficiently large, may justify assigning the implicit weight of two (or one-half) to the net incremental benefits accruing to group Y (group X).

Another option is to compare the estimated implicit weights with explicit distributional weights based on recommended parameter values drawn from the literature (see below).

As a practical matter, determining implicit weights works best if:

- ⇨ There are just two population groups (one relatively advantaged and one relatively disadvantaged); and
- ⇨ There is a trade-off between efficiency and equity (i.e., if the PVNB of the disadvantaged group and the PVNB of the advantaged group are of opposite sign).

10.3.3 Stage 2: explicit distributional weights

An alternative, more prescriptive, approach is to assign explicit weights to the net incremental benefits accruing to specific groups. Actually deriving practical weights based on the rationales outlined in Box 3-1 is nonetheless problematic. Both the marginal change in utility or social welfare associated with a marginal change in income need to be established for a typical member of each group of interest. Weights can then be estimated as the ratio of the values between the different groups. The information needed to compute these ratios is extremely difficult to derive persuasively. For a start, there is no definitive knowledge about the nature of individual preferences and utilities. Furthermore, there is no consensus regarding the specific relationship between a given change in income and social welfare (except to say that the relationship is positive and larger for relatively disadvantaged groups vis-à-vis relatively advantaged groups).

Consequently, researchers have to rely on a variety of indirect approaches to derive, and empirically estimate, the values of distributional weights. One approach to deriving weights is to make an *à priori* assumption about the nature of the social welfare function or the marginal utility of income (e.g., Brent, 1996; Tol, 2001). With these approaches, distributional weights are formulated as a continuous function with a constant elasticity in relation to income, and calibrated to equate to one for average income:

$$a^k = \left(\frac{\bar{Y}}{Y^k}\right)^{\eta} \qquad \text{Equation 10-6}$$

Where:

a^k	=	The distributional weight assigned to the incremental net benefits accruing to population group *k*.
Y^k	=	The actual income (per capita) of population group *k*.
$\bar{Y}$	=	Mean (per capita) income.

η = The "elasticity of marginal utility" with respect to consumption or society's valuation of an increment to group *k*'s income.

Typically, data are readily observable for the parameters Y^k and $\bar{Y}$. However, the value of η can, in principle, range from zero to infinity. Conventional CBA, for instance, assigns a value of zero to η, yielding distributional weights equal to one. Consequently, costs and benefits are treated equally – regardless of who incurs them. At the other extreme, as η approaches infinity, any adaptation action that adversely affects a group with income levels below the mean (per capita) income would struggle to pass a weighted cost-benefit test (given by Equation 10-3). Equally, as η approaches infinity, an action that positively affects a poor group would be almost certain to pass a weighted cost-benefit test.

Fortunately for the analyst, as the discussion in Section 7.3.2.2 shows, the literature suggests a much narrower range of values for η, in the range of 0.5 – 4.0. For the purpose of calculating the real social discount rate, a value for η of 1.5 is recommended, with sensitivity tests employing values equal to 1.0 and 2.0. If the analyst opts to explicitly weight costs and benefits accruing to different population groups with varying income levels, then the same values for η should be used. Imputing a value of 1.0 for η implies that one dollar is worth ten times more to someone with one-tenth of the mean (per capita) income than it is to someone with the mean (per capita) income. Similarly, assuming η equals 2.0 implies that one dollar is worth one hundred times more to someone with one-tenth of the mean (per capita) income than it is to someone with the mean (per capita) income.

For analysts computing distributional weights using Equation 10-6, a value for η of 1.5 is recommended, with sensitivity analysis around values of 1.0 and 2.0. Box 10-2 provides an example to illustrate how explicit distributional weighting works. Statistics on income, spending and wealth, as well as the distribution of income among families and individuals, is available from CANSIM, Statistics Canada's key database for socio-economic information (available at: http://www5.statcan.gc.ca/cansim/a01?lang=eng).

10.3.3.1 A cautionary note – implications of assumed parameter values

Table 10-1 shows the effect of the choice of η on the NPV of the numerical example introduced above. It is assumed that the income of group X is 50 per cent higher than the mean income level and, conversely, the income of group Y is 50 per cent below the mean income level. In general, adopting any value for η greater than zero reduces the (absolute value of) incremental net benefits incurred by the relatively wealthy group, X, and increases the (absolute value of) incremental net benefits incurred by the relatively poor group, Y. Furthermore, the larger the value for η that is assumed by the analyst, the greater the change in projected incremental net benefits. It is evident from the example in Table 10-1 that higher values for η can produce extreme distributional weights for population groups with income levels below the population mean; this in turn, significantly affects the economic acceptability of proposed adaptation actions. As a general rule, because of the potential influence of weighting on an action's NPV, an analyst should always report unweighted values alongside weighted values.

Table 10-1: The effect of different values for η on NPV – numerical example

Value for η	PVNB group X	PVNB group Y	NPV
0.0	+$4.0 mn	-$2.0 mn	+$2.0 mn
0.5	+$3.3 mn	-$2.8 mn	+$0.4 mn
1.0	+$2.7 mn	-$4.0 mn	-$1.3 mn
1.5	+$2.2 mn	-$5.7 mn	-$3.5 mn
2.0	+$1.8 mn	-$8.0 mn	-$6.2 mn

Box 10-2: Illustration of explicit distributional weighting

To demonstrate how the distributional weighting method works, suppose that two candidate adaptation actions, A and B, reduce climate change damages from storms across different areas of a city (with different average incomes) as set out in the table below.

Area	Average income ($ per capita)	Affected dwellings	Damages avoided ($ per dwelling per year)		Total damages avoided by area ($ millions per year)	
			Action A	Action B	Action A	Action B
SW	$37,167	384,170	400	125	153.7	48.0
SE	$29,737	297,635	100	350	29.8	104.2
NW	$32,434	127,025	300	200	38.1	25.4
NE	$29,696	425,280	200	275	85.1	117.0
Total	**$32,225**	**1,234,110**			**306.6**	**294.6**

The above table shows that the total annual benefits are $306.6 million for action A compared with $294.6 for action B. For simplicity, the issues of discounting and the cost of the two adaptation actions have been set aside. However, action B provides substantially greater benefits to affected households in poorer areas of the city (e.g., $350 per affected household in the SE compared with $100 per affected household in action A, as well as larger benefits to affected households in the NE area).

Assume that the target beneficiaries of the adaptation actions are affected households in the two lower income areas of the city. The analyst thus calculates and applies weights to the benefits that favor these groups and which disadvantages the two higher income areas. The calculated weights and resulting weighted total annual benefits are shown in the table below. The weights are estimated using Equation 10-6 assuming a central value for η of 1.5.

Area	Average income ($ per capita)	Weights	Damages avoided ($ per dwelling per year)		Total damages avoided by area ($ millions per year)	
			Action A	Action B	Action A	Action B
SW	$37,167	0.81	400	125	124.1	38.8
SE	$29,737	1.13	100	350	33.6	117.5
NW	$32,434	0.99	300	200	37.7	25.2
NE	$29,696	1.13	200	275	96.1	132.2
Total	**$32,225**				**291.5**	**313.6**

The total annual benefits of action B ($313.6 million) now exceed those of action A ($291.5 million), suggesting that the decision-maker should select action B.

10.4 Stakeholder analysis

Stakeholders in general are organizations, groups, or individuals who either:

- ⇨ Have something to gain or lose through the outcomes of an adaptation action; or
- ⇨ Could affect the action's success.

Powerful stakeholders can help achieve, or block, a welfare-improving adaptation action. It is thus crucial that decision-makers appreciate the interests and requirements of these power stakeholders (so-called 'agents of change').

The purpose of stakeholder analysis is to identify an adaptation action's key stakeholders, assess their interests in the action and the ways in which these interests may affect design and implementation, and to take corrective measures where necessary.

The benefits of stakeholder analysis include:

- ⇨ The views of the most powerful stakeholders can be used to shape an adaptation action at an early stage. Not only does this make it more likely that they will support the action, their input can also improve the quality of the action. Stakeholders can be a valuable source of information given the knowledge and skills they bring to the climate change risk management process.
- ⇨ Gaining support from the most influential stakeholders can help win an adaptation action more resources; this in turn, can make it more likely that the action will be successful.
- ⇨ Communicating with stakeholders early and frequently will help ensure that they fully understand what the action seeks to do and the anticipated benefits it seeks to cause: this will help secure their buy-in and active support when necessary.
- ⇨ It helps designers and implementers anticipate what people's reaction to the proposed adaptation may be, which allows for corrective measures to gain their support to be built into the implementation plan.

Stakeholder analysis comprises four steps:

10.4.1 Step 1 – Identify stakeholders

The first step is to identify who the (internal and external) stakeholders are. To this end, brainstorm all the organizations, interest groups, or individuals that are likely to be affected by the proposed adaptation action, that have influence or power over it, or that have an interest in its successful or unsuccessful implementation. Ask:

- ⇨ Who stands to lose or gain significantly from the proposed action?
- ⇨ Whose behavior could potentially affect the action's success?

The analyst should strive to produce a suitably exhaustive list to ensure no potentially key players are left out. Remember that although stakeholders may be organizations and groups, communication ultimately is with people. Hence, the analyst should identify the appropriate individuals within an organization or group.

Table 10-2 lists some categories of potential stakeholders, which might be a useful starting point for the brainstorming exercise.

Table 10-2: Categories of potential stakeholders

Private sector stakeholders	Public sector stakeholders	Civil society stakeholders
Corporations Business leaders Business associations Professional bodies Financial institutions	Ministers and advisors Elected representatives Political parties Civil servants Municipal councils Commissions Regulatory authorities	Media Schools and universities Trade unions Consumer advocacy groups National NGOs International NGOs

10.4.2 Step 2 – Understand the stakeholders

The next step is to build-up an understanding of the identified stakeholders: How are they likely to feel about, and react, to the proposed adaptation action? What is needed from them to design and implement a successful action? Addressing the following questions may help in developing an understanding of the identified stakeholders:

- ⇨ What financial interest do they have in the proposed adaptation action's outcomes? What emotional interest do they have in the action's outcomes? Are these interests positive or negative?
- ⇨ What motivates the stakeholder most of all?
- ⇨ What information do they want re the action? How do they want to receive this information? What is the best way of communicating with them?
- ⇨ What is their current opinion of the main proponent of the action? Is it based on good information?
- ⇨ Who influences their opinions generally, and who influences their opinion of the main proponent of the action? Do some of these influencers become important stakeholders in their own right?
- ⇨ If their opinion is not positive, what will win them around to support the proposed action?
- ⇨ If they cannot be won around, how can their opposition to the proposed action be managed?
- ⇨ Who else might be influenced by their opinions? Do these people also become stakeholders in their own right?

The best way to answer these questions is to talk directly to the identified stakeholders. Asking people's opinions is also often the first step in building a successful relationship with them.

10.4.3 Step 3 – Prioritize the identified stakeholders

Building on the understanding of the affected stakeholders developed during Step 2, the next step is to work out their relative power and interest, in order to know who should be the focus of communication efforts and other management strategies.

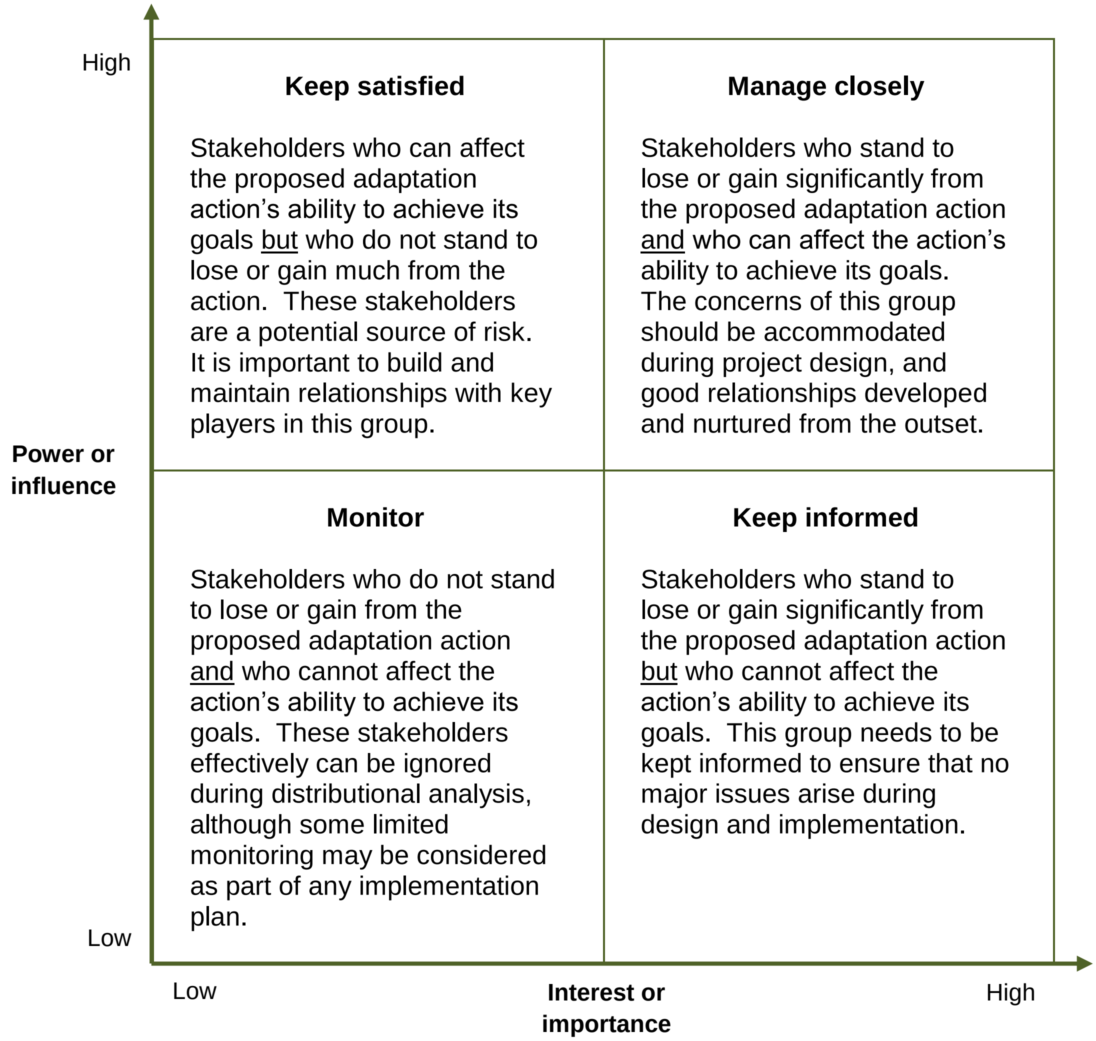
- ⇨ Power measures the influence stakeholders can exert on the proposed action and the extent to which they can affect outcomes; and
- ⇨ Interest measures the extent to which stakeholders are likely to be affected, either positively or negatively, by the proposed action and therefore how important it is to them.

A matrix or grid similar to that shown in Figure 10-1 can be used to organize stakeholders according to their power (along the x-axis) and interest (along the y-axis). This creates four broad categories of stakeholders and management strategies:

- ⇨ High power, interested stakeholders – people in this category must be fully engaged and kept satisfied from the outset;
- ⇨ High power, less interested stakeholders – people in this category are a source of risk and should be monitored and engaged just enough to keep them satisfied;
- ⇨ Low power, interested stakeholders – people in this category should be kept adequately informed and engaged to ensure that no major issues arise. These people also are often a helpful source of skills and knowledge relevant to the proposed adaptation action; and
- ⇨ Low power, less interested stakeholders – people in this category should be monitored only and can be effectively ignored during design, evaluation and operation.

When plotting the identified stakeholders in the matrix, it is useful to recognize those who are expected to be blockers or critics of the proposed adaptation action, and those who are likely to be advocates and supporters or the proposal. One way of doing this is by color coding the stakeholders: showing advocates and supporters in, say, green and blockers and critics in, say, red, and neutral parties in, say, orange. The understanding of stakeholders developed in Step 2 can be used to perform this classification.

Figure 10-1: Power-interest grid for stakeholder prioritization



10.4.4 Step 4 – Plan engagement strategies

The final step is to develop a strategy for how best to engage and communicate with stakeholders who should be kept satisfied, informed and managed closely (see, for example, Covello and Sandman, 2001). In general, the more informed stakeholders are about the process, the nature and scope of climate risks, and relevant scientific, technical and factual information, the more likely any proposed adaptation action(s) will be successful.

The analyst will wish to determine:

- Whether the proponent of the adaptation action is communicating effectively with key stakeholders?
- What extra can be done to get more from supporters or to win over critics?

⇨ How best to frame key messages and information to be useful to stakeholders?

The analyst can address these issues on the basis of the understanding of stakeholders developed during Step 2. As part of any developing communication strategy, it is also important to identify who will contact each stakeholder, and how and when. On timing, it is worth remembering that an adaptation action takes on greater significance to key stakeholders the closer it gets to implementation, as impacts become imminent.

10.5 References and further reading

Azar, C., 1999, Weight Factors in Cost-benefit Analysis of Climate Change, *Environmental and Resource Economics*, 13, p. 249-268.

Azar, C. and Sterner, T., 1996, Discounting and Distributional Considerations in the Context of Global Warming, *Ecological Economics*, 19, p. 169-184.

Bångman, G., 2006, Equity in Welfare Evaluations – The Rationale for and Effects of Distributional Weighting, Universitetsbiblioteket, Örebro, Sweden.

Boccanfuso, D., Estache, A. and Savard, M., 2008, Intra-country Distributional Impact of Policies to Fight Climate Change: A Survey, ECARES Working Paper 2008_038, ECARES, Brussels, Belgium.

Brent, R., 1996, Applied Cost-Benefit Analysis, Edward Elgar, Cheltenham, UK.

Carlsson, F., Duravala, D. and Johansson-Stenman, O., 2005, Are People Inequality Averse or just Risk Averse? *Economica*, 72, p. 375-396.

Conde, C. and Lonsdale, K., 2004, Engaging Stakeholders in the Adaptation Process, Section II, Chapter 2, Adaptation Policy Framework, Burton, I., Lim, B. and Huq, S. (editors), United Nations Development Program, New York, USA.

Covello, V. and Sandman, P., 2001, Risk Communication: Evolution and Revolution, Wolbarst, A. (editor), Solutions to an Environment in Peril, John Hopkins University Press, Baltimore, Maryland, USA.

DFID, 1995, Guidance Note on How to Do Stakeholder Analysis of Aid Projects and Programs, UK Department for International Development, London, UK.

Fankhauser, S., Tol, R. and Pearce, D., 1997, The Aggregation of Climate Change Damages: A Welfare Theoretical Approach, *Environmental and Resource Economics*, 10, p. 249-266.

Gardiner, S., 2004, Ethics and Global Climate Change, *Ethics*, 114, p. 555-600.

Harberger, A., 1978, On the use of Distributional Weights in Social Cost-Benefit Analysis, *Journal of Political Economy*, 86(2), p. 87-119.

HM Treasury, 2004, The Green Book: Evaluation and Appraisal in Central Government, Annex 5, Distributional Impacts, Treasury Guidance, The Stationary Office, London, UK.

Johansson-Stenman, O., 2005, Distributional Weights in Cost-Benefit Analysis: Should We Forget about Them? *Land Economics*, 81(3), p. 337-352.

Kanninen, B. and Kriström, B., 1993, Welfare Benefit Estimation and Income Distribution, Beijer Discussion Paper Series No. 20, Beijer Institute of Ecological Economics, Stockholm, Sweden.

Kriström, B., 2006, Framework for Assessing the Distribution of Financial Effects of Environmental Policy, Serret, Y. and Johnstone, N. (editors), 2006, The Distributional Effects of Environmental Policy, Edward Elgar, Cheltenham, UK.

Mendelsohn, R., Dinar, A. and Williams, L., 2006, The Distributional Impacts of Climate Change on Rich and Poor Countries, *Environment and Development Economics*, 11, p. 159-178.

Metroeconomica, 2004, Costing the Impacts of Climate Change in the UK: Implementation Report, Section 5.11, Assessing Distributional Effects, UKCIP Technical Report, UK Climate Impacts Program, Oxford, UK.

OECD, 2003, Poverty and Climate Change: Reducing the Vulnerability of the Poor through Adaptation, OECD, Paris, France.

Pearce, P., Atkinson, G. and Mourato, S., 2006, Cost-benefit Analysis and the Environment: Recent Developments, Chapter 15, Equity and Cost-benefit Analysis, OECD, Paris, France.

Serret, Y. and Johnstone, N. (editors), 2006, The Distributional Effects of Environmental Policy, Edward Elgar, Cheltenham, UK.

Schelling, T., 1992, Some Economics of Global Warming, *American Economic Review*, 82, p. 1-14.

Schneider, S., Semenov, S., Patwardhan, A., Burton, I., Magadza, C., Oppenheimer, M., Pittock, A., Rahman, A., Smith, J., Suarez, A. and Yamin, F., 2007, Assessing Key Vulnerabilities and the Risk from Climate Change, Climate Change 2007: Impacts, Adaptation and Vulnerability, Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Parry, M., Canziani, O., Palutikof, J., van der Linden, P. and Hanson, C. (editors), Cambridge University Press, Cambridge, UK.

Start, D. and Hovland, I., 2004, Tools for Policy Impact; A Handbook for Researchers, ODI, London, UK.

TBCS, 2007, Canadian Cost-benefit Analysis Guide: Regulatory Proposals, Section 4.6, Impacts on Stakeholders, Treasury Board of Canada Secretariat, Ottawa, Canada.

Tol, R., 2001, Equitable Cost-benefit Analysis of Climate Change Polices, *Ecological Economics*, 36, p. 71-85.

Tol, R., Downing, T., Kuik, O. and Smith, J., 2004, Distributional Aspects of Climate Change Impacts, *Global Environmental Change*, 14, p. 259-272.

US EPA, 2000, Guidelines for Preparing Economic Analysis, Chapter 9, Distributional Analysis, EPA 240-R-00-003, Office of the Administrator, US Environmental Protection Agency, Washington, DC, USA

11 Presentation of Analysis

11.1 Purpose

The purpose of this section is to:

- Outline a number of principles that serve as a guide for presenting the results of economic analyses;
- Provide a suggested structure for the final report;
- Outline the information (the 'metrics') that needs to be presented to decision-makers;
- Identify examples in other guides and published studies of how tables and figures can be used to succinctly present these metrics to decision-makers – following the guiding principles; and
- Explain how the benefit threshold approach can be used to integrate non-monetized impacts with monetized impacts in the decision-making process.

11.2 Guiding principles

The final task in the process is to write-up the analysis, which includes the recommendations to the decision-maker(s). The resulting report should enable the decision-maker(s) to satisfactorily answer the questions: What did the analyst do? Why did they do it? What did they conclude? What are the major sources of uncertainty? How do these affect the conclusions? Before providing more detailed guidance on the content of the report, we first set out a number of general principles that the report writer should adopt.

11.2.1 Completeness

The full richness of information collected during the analysis should be presented to the decision-maker, not just the narrow sub-set of impacts that could be monetized. All meaningful impacts should be listed. Taking account of the costs of data acquisition, cleaning, and modeling, as many of these impacts as possible should, of course, be monetized. Potentially significant impacts that could not be monetized, if possible, should be quantified (e.g., the expected change in the number of deaths due to heat stress in the City of Toronto). Potentially significant impacts that could not be quantified should be presented qualitatively – noting the directional impact on key variables (e.g., the incidence of deaths in the City of Toronto due to extreme heat and humidity is expected to increase). Ideally, the analyst should assess the likelihood that these non-monetized impacts could be large enough to materially affect the broad conclusions of the analysis of different adaptation actions (see below).

Communicating the full richness of cost and benefit information should include conveying key uncertainties in the data and models used, as well as major assumptions made to run the models. At a minimum – for quantitative inputs and results – this should involve reporting an expected (central) value, supplemented by a range (upper and lower bound), or confidence interval. As suggested in Section 9.3.2.1, the analyst may use sensitivity analysis to provide a quantitative assessment of the importance of all major sources of uncertainty.

11.2.2 Clarity, transparency, and relevance

The report should not only clearly present the results and conclusions of the analysis undertaken, it should also:

- ⇨ Clearly state the methodology used (e.g., the basic framework used for modeling, highlighting key components that affect the results);
- ⇨ The assumptions made in reaching the results;
- ⇨ The justification for the methodology and the assumptions; and
- ⇨ The robustness of the conclusions to all assumptions made, and models and data used (i.e., communicate all key uncertainties).

All economic analyses make assumptions for convenience and tractability. When reporting the results, all assumptions should be clearly presented and the reasons for making each assumption discussed in turn. It is important that the decision-maker can test any assumptions made by the analyst against all the evidence assembled – economic or otherwise – for a particular adaptation decision problem.

The decision-maker should be able to see how the economic analysis enabled the analyst to reach the presented conclusions. To this end, the report should be understandable to non-economists.

11.2.3 Relevance

Presentation of the results and the underlying economic analysis should be relevant to the adaptation planning process. Hence, the report should be presented in a timely manner and in a format that complies with the requirements of existing decision-making processes.

11.2.4 Reproducibility

The data, methodology, and assumptions should be presented in a manner that allows the decision-maker to replicate the analysis without having to seek more information from the analyst. Raw data should be provided wherever possible – the aggregation and cleaning of data may have a significant impact on the outcome of the analysis, so it is important that the decision-maker have access to the underlying data. The analyst should also explain why the chosen data is suitable for the analysis undertaken, how data has been compiled, and what steps have been taken to ensure its reliability. Where references to literature have been made, these should be cited and made available to the decision-maker. Access to the underlying data and references is critical to the reproducibility, and hence the credibility, of the analysis.

11.3 Report content

Your organization, or the organization commissioning the economic analysis you are preparing, may have its own requirements for presenting technical analyses in support of adaptation planning, or in support of other decision-making processes. In these cases, the report should – at a minimum – meet these requirements. In the absence of, or in addition to, any existing reporting requirements, the material in the remainder of this section should prove useful in preparing a final report. At all times when preparing the report, remember the guiding principles listed above.

11.3.1 Suggested structure

The final report could be structured as follows:

- First, an executive summary of no more than five pages, which should be accessible to non-economists;
- Second, a summary report, which needs to include:
  - A description of the background to the adaptation planning problem;
  - The objectives, adaptation goals, and scope of the economic appraisal;
  - A description of the appraisal framework, the baseline scenario(s), and the climate scenario(s);
  - Details of the adaptation alternatives to be appraised and how they were derived;
  - A list of major assumptions underpinning the analysis and the nature of the data sources;
  - Constraints considered in conducting the analysis and in defining the adaptation actions;
  - A description of all relevant impacts;
  - Details of the time profile of costs, benefits, and net benefits, and information on how costs and benefits were estimated, including the price basis and base year;
  - Details of the discount rate(s) used, the length of the evaluation period selected, and how both were derived;
  - Measures of economic worth for the alternatives appraised (i.e., estimated net present values, as well as benefit-cost ratios, internal rates of return or payback periods, where calculated);
  - The results of uncertainty analysis (e.g., how robust are the conclusions to changes in key inputs, what are the plausible upper and lower limits of cost and benefit items, how are major areas of uncertainty to be managed, etc.);
  - A summary of consultations taken during the course of the analysis, and how they were done;

- Details of distributional effects – what major stakeholders are likely to be impacted, by how much and when;
- Information on non-monetized costs and benefits, and discussion of qualitative items;
- A comparison of the preferred adaptation action, with alternative actions considered, conclusions and recommendations (e.g., what is the ranking of actions based on the initial appraisal, and after sensitivity tests and qualitative items have been taken into account); and
- A proposed framework for conducting ex-post evaluation of the analysis, conclusions and recommendations; and

⇨ Third, a technical appendix, or appendices, presenting the methodology and results in much greater detail. All technical appendices and the summary report should, of course, be totally consistent with each other.

11.3.2 Suggested metrics

All significant impacts should be listed whether or not they could be quantified or monetized. This applies to both costs and benefits. To ensure they are understood by decision-makers they should be succinctly described in non-technical language. Furthermore, to minimize the risk of 'double-counting,' the listed impacts and descriptions should be mutually exclusive. The analyst may also consider grouping benefits into consistent categories – e.g., under the headings of human health, operating cost savings, built environment, etc. Similarly, costs can be grouped under the headings of non-recurring (investment or capital) costs and recurring (annual) costs.

In order to convey the physical scope of the adaptation actions being appraised, it is recommended that monetized impacts are expressed in physical (i.e., number) as well as dollar terms, where monetization is possible. For example, if estimating premature deaths from temperature-related stress, the change in the number of deaths per unit time as a result of climate change should be presented alongside the estimated damage cost (in this case the product of additional premature deaths per year and the Value of a Life Year Lost or Value of a Statistical Life). Similarly, if estimating changes in temperature-related cases of salmonella, the change in the number of cases per unit time should be reported along with the estimated damage cost (in this case the product of additional salmonella cases per year and the maximum willingness-to-pay to avoid a case). Where monetization is not possible, quantified impacts should still be presented in physical terms.

For both quantified and monetized impacts the analyst should be clear about their timing – e.g., are they non-recurring, one-off impacts? Are they recurring, annual impacts? Do they occur over the entire time horizon of the analysis or are they confined to a fixed period, say, the first ten years?

If impacts vary significantly between affected sub-populations or economic sectors, then the analyst should report physical impacts and estimated costs, benefits, and net benefits separately for each group. This will enable decision-makers to readily assess the equity of outcomes alongside the efficiency of outcomes.

It is also recommended that all monetized impacts be presented as both undiscounted and discounted (constant dollar, present value) sums in the selected base year. All impacts reported in physical terms are, of course, not discounted.

Depending on the time horizon of the analysis, the analyst may consider presenting monetized impacts as 30-year undiscounted annual averages centered on, for example, 2025, 2055, and 2085, as opposed to reporting point estimates for the selected years. In other words, a single cost, benefit, or net benefit estimate is produced for the 2020s (the average of undiscounted annual costs, benefits, or net benefits over the period 2011-2040), the 2050s (the average of undiscounted annual costs, benefits, or net benefits over the period 2041-2070), and the 2080s (the average of undiscounted annual costs, benefits, or net benefits over the period 2071-2100).

Box 11-1: Communicating confidence in results

Analysts could describe relevant uncertainties or levels of confidence in the results using the hierarchy given below, assigning the appropriate alphabetical letter to estimated costs, benefits, or net benefits (ranging from expressions of less to more confidence and less to more probabilistic approaches as one moves down the hierarchy):

- **A** Direction of change is ambiguous or the item assessed is not amenable to prediction;
- **B** An expected trend or direction can be identified (e.g., increase, decrease, no significant change);
- **C** An order of magnitude can be given for the degree of change (i.e., sign and magnitude to within a factor of 10);
- **D** A range can be given for the change in a variable as upper and lower bounds, or as the 5th and 95th percentiles, based on objective analysis or expert judgment;
- **E** A likelihood or probability of occurrence can be determined for an event or for representative outcomes (e.g., based on multiple observations, model ensemble runs, or expert judgment); or
- **F** A probability distribution can be determined for changes in a continuous variable either objectively or through use of a formal quantitative survey of expert views.

A descriptive "level of confidence" based on a numerical scale could also be used to characterize uncertainty, drawing upon the judgment of the analyst as to the correctness of an estimated cost, benefit, or net benefit – for example, drawing on the table below:

Very high confidence	At least a 9 out of 10 chance of being correct
High confidence	About an 8 out of 10 chance
Medium confidence	About a 5 out of 10 chance
Low confidence	About a 2 out of 10 chance
Very low confidence	Less than a 1 out of 10 chance of being correct

Source: IPCC (2005)

For those impacts that could be monetized, it is also useful to identify:

- ⇨ The main climatic driver associated with each impact (e.g., mean temperature, mean precipitation, extreme temperatures, extreme precipitation, storms (wind), growing season, drought, etc.);[36]

[36] Many studies only consider changes in mean climate and fail to consider extremes. For instance, an appraisal of adaptation actions for coastal zones will typically focus on gradual sea level rise and not consider storm surges or extreme scenarios of sea level rise. It is important that the decision-maker is aware of the specific climate-related risk that is being addressed by the adaptations under consideration, and thus what potential risks are not being addressed.

- ⇨ The proxy measure of welfare change used to monetize the physical impact (e.g., heat-related mortality valued on the basis of a "WTP-based Value of a Life Year Lost", changes in agricultural yields valued on the basis of "gross margins based on market prices"); and
- ⇨ An indicator of the uncertainties or level of confidence the analyst places on the results, using a simply alphabetical or numerical scale (e.g., see Box 11-1)[37].

Finally, care should be taken to avoid asserting too much certainty in the analysis through over-specification of the dollar impacts. Cost and benefit estimates should be rounded accordingly, taking account of the level of confidence the analyst places on the results.

11.3.3 Visual aids

There are a number of good examples in the other guides and published studies of how tables and figures can be used to succinctly convey the above metrics to decision-makers – following the guiding principles. The US EPA (2010), for example, provides a number of useful templates for presenting the results from economic analyses of environmental regulations:

- ⇨ The template in Table 11.1 allows the analyst to provide a quick-glance overview of a regulation's costs and benefits, and the extent to which they were quantified and monetized;
- ⇨ Table 11.2 provides the analyst with a template for presenting quantified regulatory benefits;
- ⇨ Table 11.3 provides the analyst with a template for presenting monetized regulatory benefits; and
- ⇨ Table 11.4 provides a template for pulling all this information together to provide a summary of regulatory costs, benefits, and net benefits, including physical quantities by item, dollar estimates by item, as well as information on how they were measured.

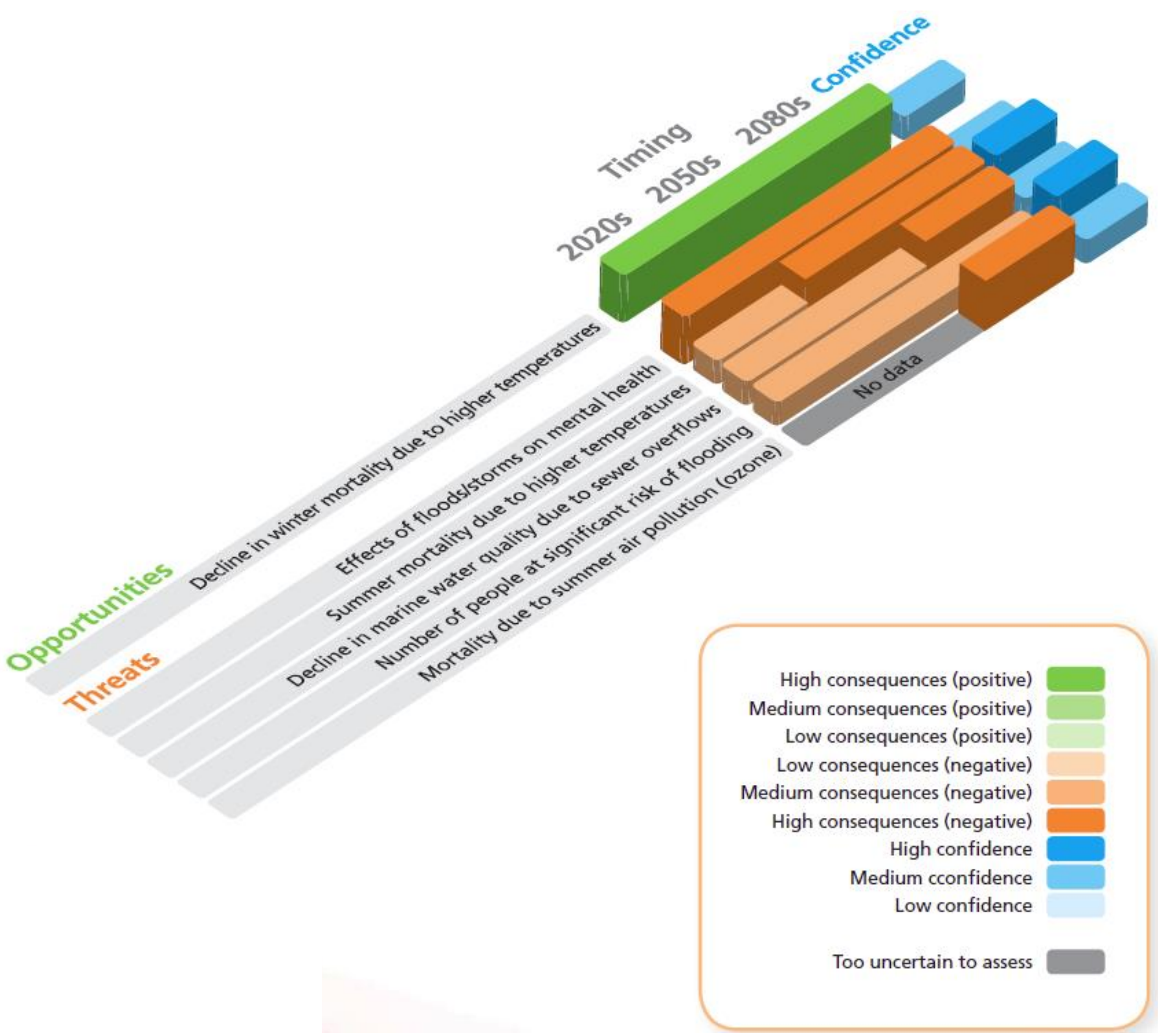
These templates are equally useful for presenting the results from economic analyses of adaptation plans. Similar, though less detailed, templates specifically for presenting adaptation costs, benefits, and net benefits in tabular form can be found in Boyd and Hunt (2006) and Hunt (2006).

The NRTEE, in their report on The Economic Impacts of Climate Change for Canada (NRTEE, 2011), make excellent use of very simple tables and figures to present their results, which may provide useful guides. Consider, for example, Figure 16 and Tables 12, 14, and 18 in Chapter 5: Human Health. The UK's Climate Change Act 2008 requires the Government to prepare a series of assessments of potential risks and opportunities for the UK, under both current conditions and over the long term, at five year intervals. The first Climate Change Risk Assessment (CCRA) was released in 2012. It makes use of a simple graphic to provide a high-level summary of sector-specific impacts, which would be appropriate for an Executive Summary (see Box 11-2). The Economics of Climate Adaptation Working Group – in an effort to help decision-makers identify adaptation actions to minimize the impact of climate change at the lowest cost to society – introduced the concept of an 'adaptation cost curve' as a way of conveying a wealth of useful information to adaptation planners in a single diagram. The

[37] This is in addition to reporting an upper and lower bound or confidence interval around the central estimate.

concept is outlined in Box 11-3 and is intended as a starting point for discussions on developing a cost-efficient adaptation strategy.

Box 11-2: Summary graphic of impacts on human health and well-being from UK 2012 Climate Change Risk Assessment



Source: DEFRA (2012)

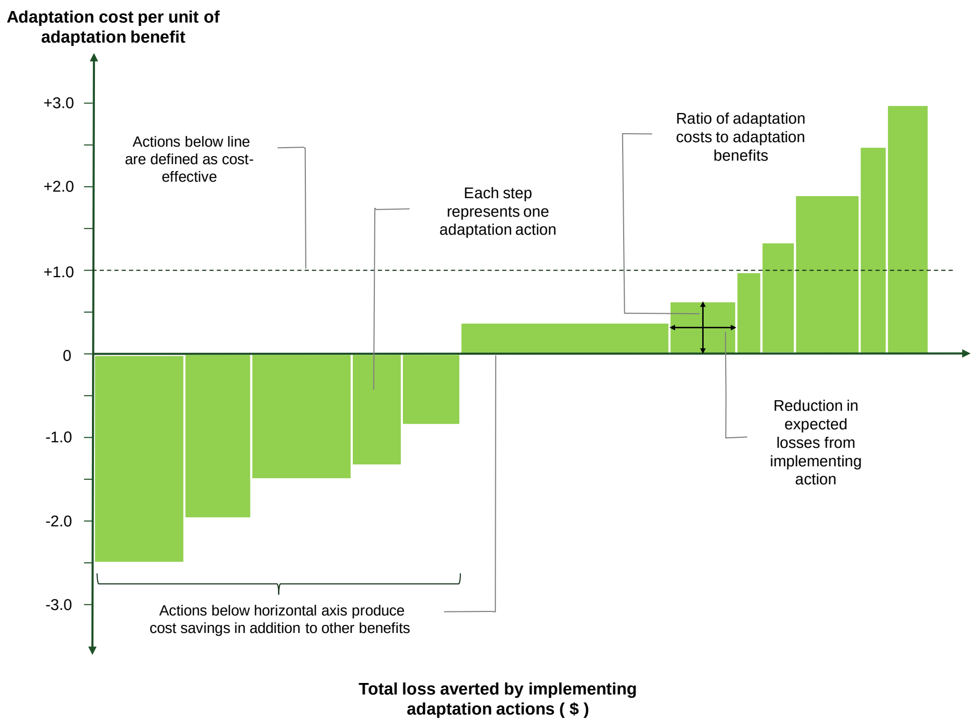
Box 11-3: Concept of an adaptation cost curve for guiding decision-making

Information from cost-benefit analyses of adaptation actions can be used to produce a so-called 'adaptation cost curve', which depicts a range of adaptation actions around which an efficient adaptation strategy for a specific location can be developed. Each appraised adaptation action is set out on the curve and arranged – from left to right – in order of cost-efficiency. The most cost-efficient actions are plotted on the far left of the curve and the least cost-efficient actions are plotted on the far right. The vertical axis measures the adaptation cost per unit of adaptation benefit generated by each measure, providing an indicator of an action's cost-efficiency. The horizontal axis measures the cumulative climate-related losses averted through the implementation of the appraised adaptation actions.

From the cost curve a decision-maker can readily identify three categories of adaptation actions:

1. Cost-efficient actions with negative costs, which produce cost savings in addition to adaptation benefits;
2. Cost-efficient actions with a ratio of one, where the present value of adaptation benefits exceeds the present value of adaptation costs; and
3. Cost-inefficient actions with a ratio greater than one, where the present value of adaptation benefits is less than the present value of adaptation costs.

The information displayed on the cost curve can be used, for example, to maximize climate-related damages at a location subject to a budget constraint.



Source: Adapted from ECA (2009)

11.3.4 Integrating non-monetized impacts

Listing all significant impacts will help ensure that the lack of a dollar estimate for a specific climate-related impact does not mean that impact is overlooked in the decision-making process. However, the decision-maker may want some feeling for the likelihood that non-monetized impacts could materially alter the conclusions of the analysis and the choice of recommended adaptation action. One way of providing this information is to perform a variation of sensitivity analysis (discussed in Section 9.3.2.1) – known as the benefit threshold approach. It considers the magnitude of the non-monetized impacts – referred to as the benefit threshold - necessary to make an unfavourable (negative) net present value favourable (positive). [38]

The benefit threshold is calculated as follows:

$$\text{benefit threshold} = \text{present value costs} - \text{present value benefits} \qquad \text{Equation 11-1}$$

It basically considers, first, whether the estimated adaptation benefits are less than the cost of providing them, and if so, second, whether the non-monetized adaptation benefits could potentially amount to the difference.

Once the analyst has determined the magnitude of the benefit (or cost) threshold, the likelihood of the non-monetized impacts amounting to this value can be qualitatively assessed. The larger the magnitude of the benefit threshold, for example, the greater the qualitative weight that needs to be attached to non-monetized adaptation benefits, or the greater the need to allocate more resources to the monetization of these benefits so they can be explicitly included in the estimated present value benefits.

A switching value derived from Equation 7-4 may help the analyst assess the likelihood that non-monetized impacts may amount to the value of the benefit threshold. It indicates the percentage change in monetized present value benefits that would need to result from the inclusion of non-monetized impacts in order to change the net present value of the adaptation action from negative to positive, or vice versa.

The switching value implied by Equation 7-4 is given by:

$$\text{switching value (\%)} = \frac{(\text{present value costs} - \text{present value benefits})}{\text{present value benefits}} \qquad \text{Equation 11-2}$$

A numerical example of how to apply the benefit threshold approach can be found on pages 5-90 to 5-92 of Metroeconomica (2004).

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[38] This approach was originally conceived to take account of non-monetized benefits in decision-making, but there is no reason why it cannot equally be applied to non-monetized costs. In this case the analyst considers the magnitude of the non-monetized impacts – which we may refer to as the cost threshold - necessary to make a favourable (positive) net present value unfavourable (negative).

11.4 References and further reading

Boardman, A., Greenberg, D., Vining, A., and Weimer, D., 2006, Cost-Benefit Analysis: Concepts and Practice, Third Edition, Pearson Prentice Hall, New Jersey, USA.

Boyd, R. and Hunt, A., 2006, Costing the Local and Regional Impacts of Climate Change Using the UKCIP Costing Methodology, Metroeconomica paper submitted to the Stern Review, HM Treasury, London, UK.

DEFRA, 2012, Summary of the Key Findings from the UK Climate Change Risk Assessment 2012, UK Department for Environment, Food and Rural Affairs, London, UK.

ECA, 2009, Shaping Climate resilient Development: A Framework for Decision-making, A Report of the Economics of Climate Adaptation (ECA) Working Group, Swiss Re, McKinsey, Global Environment Facility, European Commission, the Rockefeller Foundation, Climate Works, and Standard Chartered Bank, Zurich, Switzerland.

Hunt, A. (editor), 2006, Climate Change Impacts and Adaptation: Cross-Regional Research Program, Project E – Quantify the Cost of Future Impacts, report prepared by Metroeconomica for the UK Department for Environment, Food and Rural Affairs, London, UK.

IPCC, 2005, Guidance Notes for Lead Authors of the IPCC Fourth Assessment Report on Addressing Uncertainties, Intergovernmental Panel on Climate Change, Geneva, Switzerland.

Metroeconomica, 2004, Costing the Impacts of Climate Change in the UK: Implementation Report, UKCIP Technical Report, UK Climate Impacts Program, Oxford, UK.

NRTEE (Canada), 2011, Paying the Price: Impacts of Climate Change for Canada, Climate Prosperity Report 4, National Round Table on the Environment and Economy, Ottawa, Canada.

TBCS, 2007, Canadian Cost Benefit Analysis Guide: Regulatory Proposals, Treasury Board of Canada Secretariat (TBCS), Ottawa, Canada.

US EPA, 2000, Guidelines for Preparing Economic Analyses, Office of the Administrator, EPA 240-R-00-003, US Environmental Protection Agency, Washington, DC, USA.

US EPA, 2010, Guidelines for Preparing Economic Analyses, National Centre for Environmental Economics, Office of Policy, EPA 240-R-10-001, US Environmental Protection Agency, Washington, DC, USA.