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Methods and Tools

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EXECUTIVE SUMMARY

The purpose of this chapter is to address several overarching methodological issues that transcend individual sectoral and regional concerns. In so doing, this chapter focuses on five related questions: How can current effects of climate change be detected? How can future effects of climate change be anticipated, estimated, and integrated? How can impacts and adaptations be valued and costed? How can uncertainties be expressed and characterized? What frameworks are available for decisionmaking? In addressing these questions, each section of Chapter 2 seeks to identify methodological developments since the Second Assessment Report (SAR) and to identify gaps and needs for further development of methods and tools.

Detection of Response to Climate Change by Using Indicator Species or Systems

Assessment of the impacts on human and natural systems that already have occurred as a result of recent climate change is an important complement to model projections of future impacts. Such detection is impeded by multiple, often inter-correlated, nonclimatic forces that are concurrently affecting those systems. Attempts to overcome this problem have involved the use of indicator species to detect responses to climate change and to infer more general impacts of climate change on natural systems. An important component of the detection process is the search for systematic patterns of change across many studies that are consistent with expectations, based on observed or predicted changes in climate. Confidence in attribution of these observed changes to climate change increases as studies are replicated across diverse systems and geographic regions.

Since the SAR, approaches to analysing and synthesizing existing data sets from abiotic and biotic systems have been developed and applied to detection of present impacts of 20th-century climate change. Even though studies now number in the hundreds, some regions and systems are underrepresented. However, there is a substantial amount of existing data that could fill these gaps. Organized efforts are needed to identify, analyze, and synthesize those data sets.

Anticipating the Effects of Climate Change

A wide range of methods and tools are now used and available for studies of local, regional, and global impacts. Since the SAR, improvements have included greater emphasis on the use of process-oriented models and transient climate change scenarios, refined socioeconomic baselines, and higher resolution assessments. Country studies and regional assessments in every continent have tested models and tools in a variety of contexts. First-order impact models have been linked to global systems models. Adaptation has been included in many assessments, often for the first time.

Methodological gaps remain concerning scales, data, validation, and integration. Procedures for assessing regional and local vulnerability and long-term adaptation strategies require high-resolution assessments, methodologies to link scales, and dynamic modeling that uses corresponding and new data sets. Validation at different scales often is lacking. Regional integration across sectors is required to place vulnerability in the context of local and regional development. Methods and tools to assess vulnerability to extreme events have improved but are constrained by low confidence in climate change scenarios and the sensitivity of impact models to major climatic anomalies. Understanding and integrating higher order economic effects and other human dimensions of global change are required. Adaptation models and vulnerability indices to prioritize adaptation options are at early stages of development in many fields. Methods to enable stakeholder participation in assessments need improvement.

Integrated Assessment

Integrated assessment is an interdisciplinary process that combines, interprets, and communicates knowledge from diverse scientific disciplines in an effort to investigate and understand causal relationships within and between complicated systems. Methodological approaches employed in such assessments include computer-aided modeling, scenario analyses, simulation gaming and participatory integrated assessment, and qualitative assessments that are based on existing experience and expertise.

Since the SAR, significant progress has been made in developing and applying these approaches to integrated assessment, globally and regionally. However, the emphasis in such integrated assessments, particularly in integrated modeling, has been on mitigation; few existing studies have focused on adaptation and/or determinants of adaptive capacity. Methods designed to include adaptation and adaptive capacity explicitly in specific applications need to be developed.

Costing and Valuation

Methods of economic costing and valuation rely on the notion of opportunity cost of resources used, degraded, or saved. Opportunity cost depends on whether the market is competitive or monopolistic and whether any externalities are present. It also depends on the rate at which future costs are discounted, which can vary across countries, over time, and over generations. The impact of uncertainty also can be valued if the probabilities of different possible outcomes are known. Public and nonmarket goods and services can be valued through willingness to pay for them or willingness to accept compensation for lack of them. Impacts on different groups, societies, nations, and species need to be assessed. Comparison of alternative distributions of welfare across individuals and groups within a country can be justified if they are made according to internally consistent norms. Comparisons across nations with different societal, ethical, and governmental structures cannot yet be made meaningfully.

No new fundamental developments in costing and valuation methodology have taken place since the SAR. Many new applications of existing methods to a widening range of climate change issues, however, have demonstrated the strengths and limitations of some of these methods. For example, many contingent valuation studies have raised questions about the reliability of such evaluations. Similarly, more attention is now paid to the limitations of methods that underlie efforts to reduce all impacts to one monetary value and/or to compare welfare across countries and cultures. Multi-objective assessments are preferred, but means by which their underlying metrics might more accurately reflect diverse social, political, economic, and cultural contexts need to be developed. In addition, methods for integrating across these multiple metrics are still missing from the methodological repertoire.

Treatment of Uncertainties

The Earth's linked climate and social-natural systems are very complex; thus, there are many unresolved uncertainties in nearly all aspects of the assessment of climatic impacts, vulnerabilities, and adaptation. Subjective judgments are inevitable in most estimates of such complex systems. Since the SAR, more consistent treatment of uncertainties and assessment of biases in judgments have been attempted. Progress also has been made in developing methods for expressing confidence levels for estimates, outcomes, and conclusions, based on more consistent quantitative scales or consistently defined sets of terms to describe the state of the science. Notable attempts to provide "traceable accounts" of how disaggregated information has been incorporated into aggregated estimates have been made, but more work is needed. Greater attention to eliminating inconsistent use of confidence terms or including a full range of uncertainty for key results is still needed in future assessments. Whereas significant progress on issues of uncertainty has been achieved in the context of impacts and vulnerability, a major challenge now lies in addressing uncertainties associated with adaptability.

Decision Analytic Frameworks

Policymakers who are responsible for devising and implementing adaptive policies should be able to rely on results from one or more of a diverse set of decision analytical frameworks. Commonly used methods include cost-benefit and -effectiveness analyses, various types of decision analysis (including multi-objective studies), and participatory techniques such as policy exercises, but there are many other possible approaches. Among the large number of assessments of climate change impacts reviewed in this volume, only a small fraction include comprehensive and quantitative estimates of adaptation options and their costs, benefits, and uncertainty characteristics. This information is necessary for meaningful applications of any decision analytical method. Very few cases in which decision analytic frameworks have been used in evaluating adaptation options have been reported. Greater use of methods in support of adaptation decisions is needed to establish their efficacy and identify directions for necessary research in the context of vulnerability and adaptation to climate change.

2.1. Introduction

In assessing impacts, vulnerability, and adaptation to climate change, a large array of methods and tools pertain to specific sectors, scales of analysis, and environmental and socioeconomic contexts. In this chapter, the term *methods* refers to the overall process of assessment, including tool selection and application; the term *tools* refers to the formulated means of assessment. It is not the intent of this chapter to comprehensively canvas this full array of methods and tools; clearly, such appraisal falls more properly within the purview of the individual chapters in this volume. The purpose of this chapter is to address several overarching methodological questions that transcend individual sectoral and regional concerns. In so doing, this chapter focuses on five related questions:

- *How can the current effects of climate change be detected?* Is climate change already having a discernible effect? One of the key methodological problems is how to unequivocally identify a climate change signal in indicators of change in biotic and abiotic systems. This problem is exemplified in Section 2.2 by focusing on biological indicators and methodological advances that have been made since the Second Assessment Report (SAR).
- *How can the future effects of climate change be anticipated, estimated, and integrated*? Since the SAR, an explosion of climate change vulnerability and adaptation studies has occurred around the world, stimulated in large part by the United Nations Framework Convention on Climate Change (UNFCCC) and its national reporting requirements, as well as the availability of international donor support to non-Annex I countries. Section 2.3 reflects on methodological developments and needs for such vulnerability and adaptation studies, and Section 2.4 focuses on methods for regional and cross-sectoral integration.
- *How can impacts and adaptations be valued and costed*? Ultimately, decisions to avoid or reduce the adverse effects of climate change (or enhance the benefits) require some means of appraisal (monetary or otherwise) of projected impacts and alternative adaptation options. Section 2.5 reviews various methods for valuing and costing, including issues of nonmarket effects, equity, integration, and uncertainty.
- *How can uncertainties be expressed and characterized*? From the science of climate change to assessments of its impacts, uncertainties compound, resulting in a "cascade of uncertainty" that perplexes decisionmaking. Section 2.6 canvasses the problems of, and methods for, incorporating uncertainty into policy-relevant assessments.
- *What frameworks are available for decisionmaking*? Once adaptations have been valued, the choice of adaptation requires methods of weighing and balancing options. Section 2.7 summarizes the main decision analytic frameworks (DAFs) that can be used in this context.

In addressing these questions, the following sections seek to furnish a brief description of the state of methods at hand, methodological developments that have occurred since the SAR, and needs and directions for applications and methods development for the future. Section 2.8 contains concluding remarks.

2.2. Detection of Response to Climate Change by Using Indicator Species or Systems

Climate change may cause responses in many human and natural systems, influencing human health (disease outbreaks, heat/cold stress), agriculture (yield, pest outbreaks, crop timing), physical systems (glaciers, icepack, streamflow), and biological systems (distributions/abundances of species, timing of events). In intensely human-managed systems, the direct effects of climate change may be either buffered or so completely confounded with other factors that they become impossible to detect. Conversely, in systems with little human manipulation, the effects of climate change are most transparent. Systems for which we have a good process-based understanding of the effects of climate and weather events, and have had minimal human intervention, may act as indicators for the more general effects of climate change in systems and sectors where they are less readily studied.

2.2.1. Detection in Natural Systems

2.2.1.1. Predicted Physical Responses to Climatic Warming Trends

The cryosphere is very sensitive to climate change because of its proximity to melting. Consequently, the size, extent, and position of margins of various elements of the cryosphere (sea ice, river and lake ice, snow cover, glaciers, ice cores, permafrost) are frequently used to indicate past climates and can serve as indicators of current climate change (Bradley and Jones, 1992; Fitzharris, 1996; Everett and Fitzharris, 1998). In particular, former glacier extent is indicative of past glacials and the Little Ice Age. At high latitudes and high altitudes, ice cores have provided high-resolution annual (and, in some cases, seasonal) records of past precipitation, temperatures, and atmospheric composition. These records stretch back for many hundreds of years, well before the instrumental period, so they have proven to be very valuable in documenting past climates. Borehole measurements provide data on permafrost warming. Later freeze-up and earlier breakup of river and lake ice is measurable at high latitudes.

Interpretation of climate change resulting from changes in the cryosphere is seldom simple. For example, in the case of glaciers, glacier dynamics and extent are influenced by numerous factors other than climate. Different response times are observed for the same climate forcing, so some glaciers can be in retreat while others are advancing. Changes in glacier size can be caused by changes in temperature or in precipitation—or even a nonlinear combination of both. Similarly, changes in sea ice can be a result of changes in ice dynamics (winds, currents) as much as thermodynamics (temperature). Thus, attribution of the exact nature of climate change from changes in the cryosphere is quite complicated.

With many measures of the cryosphere, there frequently is large interannual variability. This makes determination of possible anthropogenic climate trends difficult to distinguish from the natural noise of the data. Another problem is that high-resolution records usually are not available, except from polar or high-altitude ice cores. Changes in the extent of sea ice and seasonal snow are best observed with satellites, but such records are relatively short (from about 1970), so long-term climate change is difficult to distinguish from short-term, natural variability. The first records of cryospheric extent and changes often come from documentary sources such as old diaries, logbooks of ships, company records, and chronicles (Bradley and Jones, 1992). Although these sources are fraught with difficulty of interpretation, they clearly demonstrate climate changes such as the medieval warm period and the Little Ice Age (see Section 5.7, Chapter 16, and Section 19.2).

2.2.1.2. Predicted Biological Responses to Climatic Warming Trends

All organisms are influenced by climate and weather events. Physiological and ecological thresholds shape species distributions (i.e., where species can survive and reproduce) and the timing of their life cycles (i.e., periods of growth, reproduction, and dormancy) (Uvarov, 1931; MacArthur, 1972; Precht *et al.*, 1973; Weiser, 1973; Brown *et al.*, 1996; Hoffman and Parsons, 1997; Saether, 1997) In the face of a local environmental change, such as a systematic change in the climate, wild species have three possible responses:

- Change geographical distribution to track environmental changes
- Remain in the same place but change to match the new environment, through either a plastic or genetic response [a plastic response is a reversible change within an individual, such as a shift in phenology (timing of growth, budburst, breeding, etc.); a genetic response is an evolutionary change within a population over several generations, such as an increase in the proportion of heat-tolerant individuals]
- Extinction.

In many individual studies, careful experimental design or direct tests of other possible driving factors make attribution of response to climate change possible with medium to high confidence. These studies address three questions (see Sections 5.4 and 19.2):

- Are changes observed in natural systems during the 20th century in accord with predictions from known effects of climate and from bioclimatic theory?
- Given that species, communities, and ecosystems are responding to a complex function of factors, do statistical analyses identify climatic components that statistically explain most of the observed change?
- If so, how can these results guide future predictive models of biotic response to climate change?

Studies of responses to past large-scale climatic changes during the Pleistocene ice ages and the early Holocene provide a good basis for predicting biotic responses to current climate change. Overwhelmingly, the most common response was for a species to track the climatic change such that it maintained, more or less, a species-specific climatic envelope in which it lived or bred. Typically, a species'range or migratory destination shifted several hundreds of kilometers with each 1°C change in mean annual temperature, moving poleward and upward in altitude during warming trends (Barnosky, 1986; Woodward, 1987; Goodfriend and Mitterer, 1988; Davis and Zabinski, 1992; Graham, 1992; Baroni and Orombelli, 1994; Coope, 1995; Ashworth, 1996; Brandon-Jones, 1996). Extinctions of entire species, as well as observable evolutionary shifts, were rare. Phenological shifts may have occurred but cannot be detected with Pleistocene data.

For very mobile or migratory animals—such as many birds, large mammals, pelagic fish, and some insects—shifts of species range occur when individuals move or migration destinations change. Thus, these movements actually track yearly climatic fluctuations. In contrast, most wild species, especially plants, are sedentary, living their lives in a single spot because they have limited mobility or because they lack behavioral mechanisms that would cause them to disperse from their site of birth. Rather than occurring by individual movements, range changes in sedentary species operate by the much slower process of population extinctions and colonizations. Intertidal organisms represent a mix of these two extremes: Adults frequently are completely sedentary, but many species have free-floating planktonic larvae. The dispersal of this early life-history phase is heavily governed by ocean currents. As a result, changes in distribution are driven by a combination of changes in strength and pathways of currents as well as general changes in sea temperature.

2.2.1.3. Bioclimatic Models

A variety of modeling techniques have been used to determine the strength of association between suites of biotic and abiotic variables and species distributions. These associations can then be used to predict responses to environmental change, including climatic change. Bioclimatic models encompass a wide range of complexity. The simplest model is described as a "climate envelope." It is designed to describe static associations between a species' distribution and a single set of climatic variables (Grinnell, 1924, 1928). Modern statistical analyses and improved computer power have facilitated determination of complex suites of climatic and nonclimatic variables that correlate with the range boundaries for a given species (e.g., software such as BIOCLIM and GARP) (Stockwell and Noble, 1991). These models incorporate biological realism, such as local adaptation and differences in the nature of range limitations at different edges. Modern biogeographic models have demonstrated a high level of predictive power in cross-validation tests (Peterson and Cohoon, 1999).

2.2.1.4. Strengths and Limitations of Data

In assessing the strengths of studies as indicators of response to climate change, it is helpful to consider where they lie along axes of time, space, and replication (numbers of populations, numbers of species, etc.). To assess changes in species distributions, data over large geographic areas are important, especially for areas that represent the boundaries of a species' range or migratory destination. To assess trends through time, frequent (yearly is ideal) observations over many decades are most informative. And to assess the generality of the result, good replication is necessary, with many populations/census sites per species to indicate distributional changes within species or many species per community to indicate community shifts.

2.2.1.5. Data and Response Types

Ranges of migratory or mobile species can be very sensitive to climate when individuals show an immediate response in their migratory destinations. As with climatic data itself, one then needs long time series to distinguish year-to-year variation (noise) from long-term trends. Distributions of sedentary species have an inherent lag time stemming from limited dispersal abilities. Neither the numbers of populations nor the geographic location of the range limit may fluctuate strongly between adjacent years, and detectable shifts in species ranges may take decades or even centuries. In such cases, data often are not continuous through time, although data for a single year can be taken as representative of the state of the species during the surrounding multi-year period.

In addition to these shifts in species distributions, a suite of more subtle "plastic" responses allow organisms to adjust seasonally to natural variations of climate. Phenological changes—that is, shifts in the timing of events—can be assessed. These events include dates of budburst, flowering, seed set, fruit ripening, hibernation, breeding, and migration (Yoshino and Ono, 1996; Bradley *et al*., 1999; Menzel and Fabian, 1999). Changes in phenologies can be detected in a wide variety of organisms, but this requires studies conducted over several years, in which weekly or daily observations should be made before and during the target event (e.g., flowering). Remote-sensing data have the advantage that they can be analyzed for such effects years after the events, but they are limited to very general, community-wide questions such as dates when the ground begins to turn "green" from spring growth. They indicate trends only for the past 30 years because satellites with suitable detection equipment have been in place only since the early 1970s (Myneni *et al.*, 1997). There are very long-term records (i.e., centuries) in a few unusual cases (Lauscher, 1978; Hameed, 1994; Sparks and Carey, 1995), but most monitoring data also are in the realm of the past 30 years (see Sections 5.4 and 19.2).

A different type of rapid response—probably nongenetic—is exemplified by changes in body size of small mammals and lizards (Sullivan and Best, 1997; Smith *et al.*, 1998). Body size becomes smaller with general warming and larger with either cooling or increased variability of climate. This source of information has been studied with reference to historical climate (Morgan *et al*., 1995; Hadly, 1997; Badgley, 1998); it has been unexplored with respect to current trends and should be given greater attention.

Attribution of an observed biological trend to effects of climate change rests on several grounds (Easterling *et al.*, 2000; Parmesan *et al*., 2000), namely:

- Known fundamental mechanistic links between thermal/precipitation tolerances and species in the studies
- A large body of theory that links known regional climate changes to observed biotic changes
- Direct observations of climate effects in some studies.

2.2.2. Interpretation of Causation from Correlative Data

2.2.2.1. Lines of Evidence

Attribution of observed changes in natural systems to the effects of climate change is analogous to attribution of anthropogenic greenhouse gases (GHGs) as causal factors of recent climate trends. Within the climate realm, the lines of evidence are as follows:

1) Knowledge of fundamental processes of atmospheric forcing by different gases and radiative features
2) Geological evidence that shows changes in particular atmospheric gases associated with changes in global climate
3) General circulation models (GCMs) that accurately "predict" climatic trends of the 20th century, based on fundamental principles of atmospheric forcing
4) Analyses of global mean temperature and precipitation records that indicate large variances within and among station data as a result of genuine climate variance, as well as errors and biases resulting from instrument change, location changes, or local urbanization. There are large differences in the length of records because stations have been added over the century. Total record length may vary widely. This necessitates large-scale analyses that average the effects over many hundreds or thousands of stations so that the true climate signal can emerge.

Analogs in the biological realm are as follows:

1) Knowledge of fundamental responses of organisms to climate and extreme events. This knowledge is based

on experimental work in the laboratory on physiological thresholds and metabolic costs of different thermal/water regimes, as well as experimental work in the field on ecological thresholds and fitness costs of different temperature/water treatments. In addition to these controlled, manipulated experiments, there are onsite observations of individuals and populations before and after particular weather events (e.g., documentation of population evolution of body size in birds caused by a single winter storm or a single extreme drought, or population extinctions of butterflies caused by a single midseason freeze or a single extreme drought year). The biological community generally accepts the assertion that climate is a major influence on the abundances and distributions of species.

2) Geological evidence that shows changes in global mean temperature associated with changes in the distributions of species. Species' ranges typically shifted toward the poles by about 400–2,000 km between glacial and interglacial periods (change of 4°C).
3) Ecological and biogeographic theory and models that accurately "predict" current distributions of species, based on fundamental principles of climatic tolerances.
4) Analyses of biological records starting from the 1700s, when the first researchers began to systematically record the timing of biological events and the locations of species. There are some variances within and among the historical records for any given species or locality as a result of genuine variance of the biological trait as well as small errors resulting from changes in the recorder, methods of recording, local urbanization, and other landscape changes. There are large differences in the length of records because interest in taking such records gradually has increased over the centuries. Total record length may vary from 300 to <10 years. This necessitates large-scale syntheses that assess the effects over many hundreds of species or studies so that any true global climate signal can emerge.

2.2.2.2. *Complex Systems and Responses*

Interpretation of changes in marine organisms is difficult because of the strong influence of oceanic currents on dispersal and local temperatures. As the links between ocean currents and atmospheric conditions become better understood, linking changes in marine biota to climate change will become easier.

Tree rings provide long series of yearly data spanning centuries, and data are easily replicated across taxa and geographic regions. The width of an annual ring indicates growth for that year, but growth is affected by disease, herbivory, acidification, nitrification, and atmospheric conditions [carbon dioxide (CO_2), ozone (O_3), ultraviolet (UV) radiation], as well as by yearly climate (Bartholomay *et al.*, 1997; Jacoby and D'Arrigo, 1997; Briffa *et al.*, 1998). Correlative studies can be conducted to assess the relative impacts of different climatic variables on tree rings by focusing on the 20th century, for which independent climate data exist. If the correlations are strong, one can then attempt to reconstruct past climates (prior to the existence of climate stations) from the derived relationship. One cannot distinguish the primary cause of changes in ring width in any single case (Vogel *et al.*, 1996; Brooks *et al.*, 1998). However, because excellent geographic replication is possible, these complex causal factors can be statistically reduced to those with very large-scale effects; general global climatic conditions are one of the few factors that could simultaneously affect very distant organisms (Feng and Epstein, 1996; Tessier *et al.*, 1997; Briffa *et al.*,1998).

Finally, an evolutionary response (a genetic change in a population/species) is possible (Berthold and Helbig, 1992; Rodríguez-Trelles *et al.*, 1996, 1998a). Modern molecular techniques make it possible to sequence DNA from small samples taken from museum specimens, which could then be compared to the DNA of current populations. Unfortunately, for most species, scientists do not yet know which genes are associated with climatic adaptations, so this method cannot provide useful data for more than a handful of species that have been intensively studied genetically (Rodríguez-Trelles *et al.*, 1996; Rodríguez-Trelles and Rodriguez, 1998).

2.2.2.3. *Methodological Considerations*

Studies that relate observed changes in natural biota to climatic changes are necessarily correlational. It is not possible to address this question through a standard experimental approach, so direct cause-and-effect relationships cannot be established. However, the level of uncertainty can be reduced until it is highly unlikely that any force other than climate change could be the cause of the observed biotic changes. Studies can reduce uncertainty in three ways:

- Maximize statistical power
- Design to control for major confounding factors
- For confounding factors that remain, directly analyze whether they could explain the biotic changes and, if so, quantify the strength of that relationship.

Statistical power is gained by using:

- Large sample sizes (numbers of populations/numbers of species)
- Data gathered over a large region
- Studies conducted over multiple regions
- Studies conducted on multiple taxa (different families, orders, phyla, etc.)
- Selecting populations or species without *a priori* knowledge of changes to minimize sample bias
- Data gathered over a long time period such that bi-directional responses to opposite climatic trends may be detected.

Confounding factors can be addressed in a correlational study. Biologists know that many nonclimatic anthropogenic forces affect population dynamics, community stability, and species distributions. These forces fall largely under the main headings of land-use change, hydrological changes, pollution, and invasive species. The term "land-use change" comprises a suite of human interventions that eliminate or degrade natural habitats, leading to loss of species that are dependent on those habitats. Habitat loss can be overt destruction, as occurs with urbanization, conversion to agriculture, or clear-cut logging. Habitat degradation is more subtle; it usually results from changes in land management, such as changes in grazing intensity/timing, changes in fire intensity/frequency, or changes in forestry practices (coppicing, logging methods, reforestation strategies), as well as irrigation dams and associated flood control. Loss of habitat by either means not only causes extinctions at that site but endangers surrounding good habitat patches by increased fragmentation. As good habitat patches become smaller and more isolated from other good patches, the populations on those patches are more likely to become permanently extinct.

The main airborne pollutants that are likely to affect distributions and compositions of natural biotic systems are sulfates, which lead to acid rain; nitrates, which fertilize the soil; and CO_2, which affects basic plant physiology (particularly the carbon/nitrogen ratio). Urban areas, in addition to having locally high amounts of sulfates and nitrates, are artificial sources of heat. Aquatic and coastal marine systems suffer from runoff of fertilizers and pesticides from agricultural areas and improperly treated sewage, as well as fragmentation from dams and degradation resulting from trawling, dredging, and silting.

These confounding factors cannot be completely eliminated, but their influences can be minimized by (Parmesan, 1996, 2001; Parmesan *et al*., 1999):

- Conducting studies away from large urban or agricultural areas
- Conducting studies in large natural areas (e.g., northern Canada, Alaska, areas in Australia)
- Choosing individual sites in preserved areas (national parks/preserves, field stations)
- Eliminating from consideration extreme habitat specialists or species known to be very sensitive to slight human modifications of the landscape.

If a particular confounding factor cannot be greatly minimized, it should be measured and analyzed alongside climatic variables to assess their relative effects.

Ideal target species, communities, or systems in which to look for biotic responses to climate change meet the following criteria (DeGroot *et al*., 1995; Parmesan, 2001):

- Basic research has led to a process-based understanding of underlying mechanisms by which climate affects the organism or community. This knowledge may come from experimental laboratory or field studies of behavior and physiology or from correlational studies between field observations climatic data.
- The target is relatively insensitive to other anthropogenic influences, so the effects of possible confounding factors are minimized.
- Short (decadal) or no lag time is expected between climate change and response [e.g., tree distributional responses may have a lag time of centuries, so they may not be ideal for looking for distributional changes over recent decades (Lavoie and Payette, 1996)].
- There are good historical records, either from being a model system in basic research or by having a history of amateur collecting.
- Current data are available (from monitoring schemes, long-term research) or are easy to gather.

Use of indicator species or communities is crucial for defining the level of climate change that is important to natural systems and for giving baseline data on impacts. However, caution is advisable when extending these results to predictive scenarios because the indicators often are chosen specifically to pinpoint simple responses to climate change. Thus, these studies purposefully minimize known complexities of multiple interacting factors, such as:

- The direct effects of CO_2 on plants may vary with temperature.
- The outcome of competitive interactions between species is different under different thermal regimes (Davis *et al*., 1998), and, conversely, competitive environment can affect sensitivity and response to particular climatic variables (Cescatti and Piutti, 1998).
- Different species have different lag times for response, which inevitably will cause the breakup of traditional communities (Davis and Zabinski, 1992; Overpeck *et al*., 1992; Root and Schneider, 1995).
- The ability of wild plant and animal life to respond to climate change through movement is likely to be hindered by human-driven habitat fragmentation; those with lowest dispersal will be most affected (Hanski, 1999).

2.2.3. Detection in Managed Systems

2.2.3.1. Human Health

Because many wild organisms serve as vectors for human diseases, and these diseases are very well documented historically (with records going back hundreds of years), one might think of using the distribution and intensity of disease occurrence as an indicator of shifts in wild vector distributions or altered dynamics of pathogen transmission. Many disease vectors are known to be strongly influenced by climate (e.g., the anopheline mosquitoes that carry malaria).

The problem with using disease records is that the presence of the vector is necessary but not sufficient to cause disease transmission. Socioeconomic factors—such as sanitation systems, vaccination programs, nutritional conditions, and so forth—largely determine whether the presence of the disease in wild vectors actually leads to outbreaks of disease in nearby human populations. In fact, transmission and virulence of disease are themselves directly affected by climate. Thus, although disease is a potentially important component of climate change impacts, it is not a useful indicator of the direct effects of climate change (see Chapter 9 and Section 19.2).

2.2.3.2. Agriculture

Crop plants, like plants in general, are more strongly affected by the direct effects of increased atmospheric CO_2 than are animals. Increased CO_2 alters the physical structures and the carbon/nitrogen balance in plants—which in turn alters the plant's growth rate, yield, susceptibility to pest attack, and susceptibility to water stress. These effects interact with the effects of climate change itself in complex ways. In addition, the effects of climate change are buffered in agricultural systems as farming methods are altered to adjust to current climate conditions (e.g., irrigation practices, crop varieties used) (see Sections 5.3 and 19.2). A few selected attributes and systems may be possible indicators of climate change effects. Possible traits are leafing dates of grapevines in orchard with old stock, and planting dates of yearly crops in areas that have not changed seed variety over a given length of time.

2.2.4. Advances since the SAR and Future Needs

Since the SAR, methods have been developed and applied to the detection of present impacts of 20th-century climate change on abiotic and biotic systems. Assessment of impacts on human and natural systems that already have occurred as a result of recent climate change is an important complement to model projections of future impacts. How can such effects be detected? Such detection is impeded by multiple, often intercorrelated, nonclimatic forces that concurrently affect those systems. Attempts to overcome this problem have involved the use of indicator species to detect responses to climate change and infer more general impacts of climate change on natural systems. An important component of this detection process is the search for systematic patterns of change across many studies that are consistent with expectations on the basis of observed or predicted changes in climate. Confidence in attribution of these observed changes to climate change increases as studies are replicated across diverse systems and geographic regions. Even though studies now number in the hundreds, some regions and systems are underrepresented. However, there is a substantial amount of existing data that could fill these gaps. Organized efforts are needed to identify, analyze, and synthesize those data sets.

2.3. Anticipated Effects of Climate Change

2.3.1. Background

This section outlines recent developments of methods and tools that are used to anticipate the effects of climate change—the broad approaches to climate change impact and vulnerability assessment. It considers future research and development needs, particularly to facilitate more informed policy decisions.

Based on interviews with experts and reviews of impacts methodologies, seven questions frame recent progress and needs for impacts methods and tools:

1) What are the appropriate scales of analysis for impact assessments?
2) What should be the baselines for comparison?
3) How should integrated scenarios of climatic and socioeconomic change be used?
4) What are the prospects for assessing the impacts of climatic extremes and variability?
5) How can transient effects be included in methods and tools?
6) What is the recent progress in methods for assessing adaptive capacity?
7) How can vulnerability be related to policies for reducing GHG emissions?

Conclusions are provided in the following subsections; the succeeding subsections provide further insight.

2.3.2. What are the Appropriate Scales of Analysis for Impact Assessments?

Climate change impact assessments must begin with decisions about the scope and scale of the assessment: What are the main policy issues? What and who are exposed to climate change impacts? What is the appropriate scale—time frame, geographical extent, and resolution? Considerable progress has been achieved since the SAR in raising such framing questions at the outset of an assessment cycle, often in conjunction with representative stakeholders (see Carter *et al*., 1994; Downing *et al*., 2000).

Methods for identifying policy issues include checklists and inventories, document analysis, surveys and interviews, and simulations. The process of determining the scope of assessment should be iterative. The project design should specify what and who is exposed to climate change impacts—economic sectors, firms, or individuals. Evaluation of adaptation strategies should be cognizant of actors involved in making decisions or suffering consequences.

The choice of temporal scales, regional extent, and resolution should be related to the focus of the assessment. Often, more than one scale is required, under methods such as strategic scale cycling (Root and Schneider, 1995) or multi-level modeling (e.g., Easterling *et al*., 1998). Linkage to global assessments may be necessary to understand the policy and economic context (e.g., Darwin *et al*., 1995).

The most common set of methods and tools remains various forms of dynamic simulation modeling, such as crop-climate models or global vegetation dynamic models. A major improvement in impact modeling has been applicaton of process-oriented models, often with geographically explicit representations, instead of models that are based on correlations of climatic limits. Data for running and validating models is a recurrent issue. Intermodel comparisons have been undertaken in some areas (e.g., Mearns *et al*., 1999), but much remains to be done.

Climate change is likely to have multiple impacts across sectors and synergistic effects with other socioeconomic and environmental stresses, such as desertification, water scarcity, and economic restructuring. Most studies (especially as reported in the SAR) have focused on single-sector impacts. Relatively few studies have attempted to integrate regionally or even identified segments of the population that are most at risk from climate change.

Vulnerability assessment may be one way of integrating the various stresses on populations and regions arising from climate change (see Briguglio, 1995; Clark *et al.*, 1998; Huq *et al.*, 1999; Kaly *et al.,* 1999; Mimura *et al*., 2000; Downing *et al*., 2001). There are some areas in which formal methods for vulnerability assessment have been well developed (e.g., famine monitoring and food security, human health) and applied to climate change. However, methods and tools for evaluating vulnerability are in formative stages of development.

Further development of methods and tools for vulnerability assessment appears warranted, especially for the human dimensions of vulnerability, integration of biophysical and socioeconomic impacts, and comparison of regional vulnerability. Conceptual models and applications of the evolution of vulnerability on the time scale of climate change are required. Formal methods of choosing indicators and combining them into meaningful composite indices must be tested. Combining qualitative insight and quantitative information is difficult but essential to full assessments. Finally, improved methods and tools should facilitate comparison of vulnerability profiles between at-risk regions and populations and highlight potential reductions in vulnerability, through policy measures or the beneficial effects of climate change.

2.3.3. What should be the Baseline for Comparison?

Climate change impacts generally are agreed to be the difference between conditions with and without climate change. However, there is controversy among researchers about how to set the baseline for estimating impacts (or evaluating adaptation).

Most studies apply scenarios of future climate change but estimate impacts on the basis of *current* environmental and socioeconomic baselines. Although this approach is expedient and provides information about the sensitivity of current systems, it skirts the issue of evolving sensitivity to climatic variations (Parry and Carter, 1998). Even without climate change, the environment and societal baselines will change because of ongoing socioeconomic development and, with climate change, because of system responses and autonomous adaptation (e.g., as described for Bangladesh—Warrick and Ahmad, 1996). Strictly speaking, the effects of climate change should be evaluated by taking the moving baseline into account (further discussion on socioeconomic, climate, and sea-level rise scenarios appears in Chapter 3).

Given the uncertainty of the future and the complexity of the various driving forces affecting any given exposure unit, a wide range of different assumptions about future baselines is plausible. The emission scenarios in the *Special Report on Emissions Scenarios* (SRES) reflect this perspective and are based on multiple projections of “alternative futures” (see Chapter 3). Framing local concerns for adaptation to changing risks may require exploratory scenarios, extending the coarse driving forces inherent in the SRES suite. For example, coping with water shortages in Bangladesh is sensitive to scenarios of regional collaboration with India and Nepal (e.g., Huq *et al*., 1999). For vulnerability and adaptation assessment, there is little apparent consistency regarding elements or procedures for development of these future baselines, including who is exposed, how to select sensitive sectors, and the drivers of social and institutional change at the scale of stakeholders exposed to climate impacts.

2.3.4. How should Integrated Scenarios of Climatic and Socioeconomic Change be Used?

As a result of time lags in the impact assessment research cycle, impact assessment studies included in this Third Assessment Report (TAR) do not necessarily employ the set of Intergovernmental Panel on Climate Change (IPCC) reference scenarios outlined in Chapter 3. This time lag is unavoidable because it takes almost half a year to define emissions of GHG after setting socioeconomic scenarios. Following that, it usually takes several months to produce local climate change data used in impact assessment studies. Thus, most of the impact studies reported in the TAR are based on the set of IS92 emission scenarios developed for the IPCC in 1992 and included in the SAR (e.g., Parry and Livermore, 1999).

To assist researchers, the IPCC took the initiative to create the IPCC Data Distribution Centre (<http://ipcc-ddc.cru.uea.ac.uk/>) and posted the SRES scenarios on the Consortium for International Earth Science Information Network (CIESEN) Web site (<http://sres.ciesin.org/index.html>). The IPCC is responsible for distributing consistent scenarios, including socioeconomic trends and regional climate change data. Consistent use of common scenarios provides a consistent reference for comparing and interpreting the results of different studies.

Vulnerability assessments can be conducted on temporal and spatial scales where the effects of climate change could feed back to GHG emissions and climatic changes. In such cases, there may be reason to ensure that scenarios of climate change that are based on GHG emissions and scenarios of changing social, economic, and technological conditions are consistent. This is essential for global assessments and integrated assessment (see Section 2.4). It may not be as critical for studies of local adaptation where there is little feedback between mitigation and adaptation, particularly over a typical planning horizon of several decades. Downscaling the global reference scenarios to local socioeconomic and political conditions remains a significant methodological challenge.

2.3.5. *What are the Prospects for Assessing the Impacts of Climatic Extremes and Variability?*

Discrete climatic events cause substantial damage. Heavy losses of human life, property damage, and other environmental damages were recorded during the El Niño-Southern Oscillation (ENSO) event of 1997–1998. Details are reported in the regional chapters on Africa, Asia, and the Americas, and Chapter 8 assesses the damages from a financial services perspective. For many policymakers and stakeholders, the impacts of climatic extremes and variability are a major concern (Downing *et al.*, 1999b). The uneven impacts of climatic hazards raises humanitarian concerns for development and equity.

An increase in variability and frequency of extreme events could have greater impacts than changes in climate means (e.g., Katz and Brown, 1992; Mearns, 1995; Semenov and Porter, 1995; Wang and Erda, 1996). Extreme events are a major source of climate impacts under the present climate, and changes in extreme events are expected to dominate impacts under a changing climate (see Section 12.1).

Methodological issues concerning extreme events in the context of climate change include developing climate scenarios, estimating impacts, evaluating responses, and looking at large-scale effects.

2.3.5.1. *Developing Scenarios of Changes in Variability and Extreme Events*

Working Group I discusses methodologies for estimating changes in variability from the results of GCMs (see Sections 9.3.2 and 13.4.2). Despite certain shortcomings, GCMs can provide estimates of trends in climatic variability (TAR WGI Section 9.1.5). Using extreme events from historical data as analogs also is useful.

The frequency of extreme events is likely to change as mean values shift, even without changes in variability. Chapter 3 reviews potential changes in different climatic elements (see Table 3-10).

From the instrumental record, some regional changes in extremes have been identified, although it is difficult to say whether they are related to GHG-induced climate change. For example, there has been a recent increase in heavy and extreme precipitation in the mid to high-latitude countries of the northern hemisphere, and in several regions of east Asia a decrease in the frequency of temperature extremes together with heavy and extreme precipitation have been observed (see TAR WGI Chapter 2).

2.3.5.2. *Estimating First-Order Impacts*

Many models that validate well for present climate conditions may not respond realistically to future climatic conditions and subsequent changes in extreme events. For some sectoral impacts, however, methods for evaluating a system's response to changes in variability change are improving. One example is estimation of changes in flooding by using 10-year return periods given by transient GCMs and applied to a watershed model (Takahashi *et al*., 1998).

2.3.5.3. *Analyzing Institutional and Stakeholder Responses*

Because of nonlinear relationships, an increase in variability can result in a substantial increase in the frequency of extreme impacts. If a climate element exceeds an acceptable risk threshold (e.g., when the design risk threshold for water storage is exceeded and water shortage is experienced with higher frequency), vulnerability will become "unacceptable." One issue in adaptation is the level at which to set acceptable risks in the future. Stakeholder-determined thresholds are an emerging area of research in Australia (see Section 12.1), and methods to evaluate stakeholder and institutional learning in response to changing climatic hazards are being developed (see Bakker *et al*., 1999; see also <http://www.eci.ox.ac.uk>). Decision analytical techniques are described below (Section 2.7). An alternative is an inverse approach that focuses on sensitivity to present risks, characterization of the kinds of changes in hazards that would have large effects, and evaluation of response capacities (Downing *et al*., 1999a).

Research on discrete climatic events is an area that also needs further research. Present GCM resolutions have not achieved the ability to estimate the intensity, route, and frequency of discrete events such as hurricanes (or tropical cyclones) (TAR WGI Sections 9.3.6 and 13.4.2.2). Though there are some indications from GCMs that ENSO-like conditions will become more persistent with global warming (Timmermann *et al*., 1999), it is still difficult to incorporate these estimates into vulnerability assessments (TAR WGI Sections 9.3.6.3 and 13.4.2.1).

Empirical/analog methods are suitable for assessment of discrete events. Such methods were applied for detailed analyses of damages incurred by ENSO in 1997–1998, as well as the 1998 cyclones in Bangladesh. This method is applied to "if-then" (i.e., if climate change occurs, then such and such impacts may be induced) simulations. For example, analogs from the 1930s Dust Bowl period detailing water shortages and reductions in agriculture yields have been used to simulate the impacts of climate change in the U.S. corn belt (Rosenberg, 1993).

2.3.5.4. Large-Scale Effects

Because unique or singular events, referred to as fiasco scenarios (see Section 19.5.3.3)—such as changes in the thermohaline circulation (Broecker, 1997) and potential destabilization of the West Antarctic Ice Sheet (Oppenheimer, 1998)—have not been proven implausible, there is a need for further studies of potential catastrophic events and unacceptable impacts. However, limited knowledge of such large-scale impacts poses a challenge; to date, systematic vulnerability assessments have not been carried out.

2.3.6. How can Transient Effects be Included in Methods and Tools?

Transient climate scenarios are now widely used in impact assessment—an improvement on earlier use of equilibrium climate scenarios (even if scaled to temporal projections) (see Chapter 3). A corresponding shift from static to dynamic, process-oriented impact models is apparent (as shown in the sectoral chapters).

Many models applied for predicting climate change effects on the behavior of an exposure unit are derived from equilibrium models. These include many basin watershed models, crop models for potential agricultural productivity, and potential vegetation models. With such models, the change effected on the unit at a fixed point in time is estimated, ignoring potentially relevant processes of change.

Systems often consist of elements with different time responses to climate change. This means that the present equilibrium will not be maintained in the next point of time. The velocity of change is a key factor in deciding this transient pattern.

Some terrestrial biosphere research illustrates that the world's biomes will not shift as homogeneous entities in response to changing climate and land use (see Section 5.2.1). Competition between individuals and species, modified disturbance regimes (e.g., fires, windstorms), and migration of species all lead to significant time lags in biospheric responses. Furthermore, if mortality from increased disturbance occurs faster than regrowth of other vegetation, there will be a net release of carbon to the atmosphere, which will change climate forcing. Responses may be a function of spatial scale as well. Dynamic global vegetation models illustrate the shift to transient, scalable impact models (e.g., Woodward *et al*., 1995).

To ensure a temporally sensitive assessment, impact models should include the different time responses of the system. For example, impacts of malaria depend on human tolerance to repeated infection (Martens *et al.*, 1999). Alternatively, the value of climate change damages could be related to the rate of change rather than solely to the magnitude of climate change (Tol and Fankhauser, 1996). Understanding of the temporal interactions between climate change, impacts, and responses in a truly transient methodology is still a major methodological challenge.

2.3.7. What Recent Progress has been Made in Assessing Adaptive Capacity?

In recent years, assessment of adaptive capacity has emerged as a critical focus of attention, for two reasons: the realization that the Kyoto Protocol is inadequate to prevent substantial changes in climate, and the rising expectation that social and natural systems can cope with climate change, at least within limits, and that adaptation is a viable option to reduce GHG emissions.

Although there are numerous examples of model calculations for adaptive shifts in flora, far less attention has been paid to assessing the adaptability of the system as a whole (e.g., White *et al.,* 1999). In contrast with other phenomena, such as changes in the water cycle, changes in natural ecosystems are related to a long-term process of adaptation and extinction. As noted above, transient climate change scenarios have become a mainstream research procedure.

The recent literature concerned with the impacts of climate change on the managed environment [e.g., on agriculture (see Section 5.3) and coastal zones (see Section 6.7)] generally considers adaptive strategies (e.g., Rosenzweig and Parry, 1994). Water management, for example, has a long history of evaluation of strategies for adapting to climate change and variation (Frederick *et al.*, 1997). However, adaptation often is approached narrowly in terms of technological options. Adaptation *processes*—including the environmental, behavioral, economic, institutional, and cultural factors that serve as barriers or incentives to adaptation over time—often are not considered.

Five methodological directions could enhance future work on adaptation (see Chapter 18). First, methods for increasing understanding of the relationship between adaptation, individual decisionmaking, and local conditions are required. For example, adaptation by farmers could avoid more than half of the potential impacts of climate change on agriculture (e.g., Darwin *et al.*, 1995; El-Shaer *et al.*, 1997). The mix of appropriate measures depends, however, on the local context of soils, climates, economic infrastructure, and other resources (Rosenzweig and Tubiello, 1997) and how they are perceived by farmers. Assessments of adaptation could address these issues of site-scale characteristics and local knowledge, perhaps through participatory methods (e.g., Cohen, 1997, 1998) or interviews and expert opinion (as in the UK Climate Impacts Programme—Mackenzie-Hedger *et al*., 2000; see <http://www.ukcip.org>).

Second, interactions across scale are likely to be significant for adaptation. In the agricultural sector, for example, adaptive strategies are influenced by multi-scale factors—at the farm, national, and global levels—and their integration into decisionmaking. Methods and tools for examining these multi-scale interactions and their implications for adaptation are required, such as multi-level modeling (Easterling *et al.*, 1998), integrated assessment (see Section 2.4), and agent-based simulation (Downing *et al*., 2000).

Third, specific measures (such as changing planting dates and cultivars) and longer term adaptation strategies and processes (such as monitoring and research) need to be addressed. Many studies focus on the former; assessing the latter is a major methodological challenge.

Fourth, comparative frameworks are required for assessing the priority of adaptation strategies across populations, regions, and sectors, in addition to evaluating specific measures. Fankhauser (1998) devised a list of adaptation policy options, discussed conceptual issues of economic evaluation, and illustrated typical cost/benefit calculation methods. Section 2.5 considers the use of economic evaluation methods, but nonmonetary frameworks are alternatives (see Huq *et al.*, 1999, for a case example). Issues of equity and valuation on indirect benefits and costs are salient.

Fifth, adaptation to extremes and variability already are important areas of assessment (see above) but need to be more explicitly tied to longer term climate change.

Sixth, stakeholder evaluation of adaptation strategies and measures is required—for example, using decision analytical tools, as noted in Section 2.7. Indicators of vulnerability could be used to monitor the effectiveness of adaptative strategies and measures (see Downing *et al*., 2001).

2.3.8. How can Vulnerability Assessments be Related to Policies for Reducing GHG Emissions?

One approach to mitigation policy is to evaluate targets for reducing GHG emissions on the basis of reductions in vulnerability, rather than GHG concentrations or similar indirect measures of dangerous climate change. By applying existing methods for impact analysis, it is possible to invert the assessment procedure and start with defined sets or windows of impacts that are judged to be tolerable for humankind. This procedure results in emission corridors that embrace all future GHG emissions that are compatible with changes defined to be tolerable—the “safe landing” approach (WBGU, 1995; Alcamo and Kreileman, 1996; Petschel-Held *et al.*, 1999). This approach can be extended to include economic, social, or equity aspects—that is, to define tolerable windows for climate-related facets of these sectors and obtain emission corridors that simultaneously satisfy all possible windows (Toth *et al.*, 1997).

Such approaches require that climate impacts should be differentiated between smooth changes and thresholds that mark abrupt shifts in the system’s functioning. In the latter case, the definition of tolerable windows appears to be quite obvious: Damaging, abrupt shifts should be avoided. In the case of smooth changes, specification of tolerable windows is more difficult, confounded in part by uncertainty about adaptation.

Normative decisions on tolerable windows must be a consultative process involving scientists in close cooperation with stakeholders, decisionmakers, nongovernmental organizations (NGOs), and others. There are various designs for this participatory process, such as policy exercises (Toth, 1986, 1988a,b) or what is known as the Delft Process (van Daalen *et al.*, 1998). Nevertheless, specification of windows remains somewhat arbitrary and preferably is used as an assumption in an “if-then” analysis rather than as an ultimate specification.

Methodological challenges include development and validation of reduced-form models, devising robust damage functions, identifying thresholds in adaptive systems, and concerns for equity in relating the distribution of impacts to systemic vulnerability.

2.4. Integrated Assessment

Policymakers require a coherent synthesis of all aspects of climate change. Researchers have spent the past decade developing integrated assessment methods to meet these needs of policymakers. An overview of the framework, including examination of impact and vulnerability, is in the SAR (Weyant *et al*., 1996). In addition, Rotmans and Dowlatabadi (1998) have concentrated on the broader social science components of integrated assessment; as a result, they came closer to presenting a view within which impacts and adaptation might be most fully investigated with and without relying on models. They assert, “Integrated assessment is an interdisciplinary process of combining, interpreting, and communicating knowledge from diverse scientific disciplines in such a way that the whole set of cause-effect interactions of a problem can be evaluated.” Current integrated assessment efforts generally adopt one or more of four distinct methodological approaches:

- Computer-aided modeling in which interrelationships and feedbacks are mathematically represented, sometimes with uncertainties incorporated explicitly (see Chapter 19)
- Scenario analyses that work within representations of how the future might unfold [the MINK study, based on a climate analog of the dust bowl climate of the 1930s, is a classic example (see Rosenberg, 1993, for details)]
- Simulation gaming and participatory integrated assessment, including policy (see Parson and Ward, 1998, for a careful review)
- Qualitative assessments that are based on limited and heterogeneous data and built from existing experience and expertise. Cebon *et al*. (1998) contains a collection of papers that offer similar qualitative coverage; their insights can serve as the basis for a long-run research agenda that looks for regions and sectors in which uncertain futures most significantly cloud our view of where and when impacts might be most severe.

Schneider (1997) has developed a taxonomy of integrated assessments that creates an historically rooted taxonomy of modeling approaches. It begins with “premethodogical assessments” that worked with deterministic climate change, with direct causal links and without feedbacks. It ends with “fifth-generation” assessments that try to include changing values explicitly. In between are three other stages of development, differentiated in large measure by the degree to which they integrate disaggregated climate impacts, subjective human responses, and endogenous policy and institutional evolution.

Methodological bias is an issue in interpreting the results of integrated assessments, as it is in every research endeavor. Schneider (1997) also warns that models composed of many submodules adopted from a wide range of disciplines are particularly vulnerable to misinterpretation and misrepresentation. He underscores the need for validation protocols and explorations of predictability limits. At the very least, integrated assessments must record their underlying value-laden assumptions as transparently as possible. Including decisionmakers and other citizens early in the development of an assessment project can play an essential role in analytical processes designed to produce quality science and facilitate appropriate incorporation of their results into downstream decisions.

In the past decade, several research teams have been working on the development of such frameworks (see Tol and Fankhauser, 1998, for a compendium of current approaches). Known as integrated assessment models (IAMs), these frameworks have been used to evaluate a variety of issues related to climate policy. Although the current generation of IAMs vary greatly, in scope and in level of detail, they all attempt to incorporate key human and natural processes required for climate change policy analysis. More specifically, a full-scale IAM includes submodels for simulating:

- Activities that give rise to GHG emissions
- The carbon cycle and other processes that determine atmospheric GHG concentrations
- Climate system responses to changes in atmospheric GHG concentrations
- Environmental and economic system responses to changes in key climate-related variables.

Although IAMs provide an alternative approach to impact assessment, it is important to note that there is no competition between such integrated approaches and the more detailed sectoral and country case studies discussed in preceding sections. Each approach has its strengths and weaknesses and its comparative advantage in answering certain types of questions. In addition, there are considerable synergies between the two types of studies. Integrated approaches depend on more disaggregated efforts for specification and estimation of aggregate functions and, as such, can be only as good as the disaggregated efforts. Reduced-form integrated approaches make it relatively easy to change assumptions on the "causal chain." That is, one can identify critical assumptions upon which a policy analysis might turn.

In conducting such sensitivity analyses, one can identify where the value of information is highest and where additional research may have the highest payoff from a policy perspective. This can provide some useful guidance to the impacts community about where to direct their efforts to resolve uncertainty. At the same time, integrated models become more useful as uncertainty is narrowed (through the contributions of partial impact assessments); hence, the reduced-form representations become more realistic.

2.4.1. Integrated Assessment Analyses

There are many different approaches within the family of integrated models. This diversity is important for a balanced understanding of the issues because different types of models can shed light on different aspects of the same problem. For example, many analyses start with a particular emissions baseline and examine the economic and ecological implications of meeting a given emissions target (e.g., Alcamo, 1994; Edmonds *et al.*, 1997; Morita *et al.*, 1997b; Murty *et al*., 1997; Yohe, *et al*., 1998; Jacoby and Wing, 1999; Nordhaus and Boyer, 1999; Tol, 1999a,b; Yohe and Jacobsen, 1999). In such analyses, impacts are first assessed under a so-called "business-as-usual" or reference-case scenario. The analysis is then repeated with a constraint on the future. The change in impacts represents the climate-related benefits of the policy.

Other approaches select a different starting point. For example, Wigley *et al.* (1996) begin with atmospheric CO_2 concentrations and explore a range of stabilization targets. For each target they employ "inverse methods" to determine the implications for global CO_2 emissions. Recognizing that a particular concentration target can be achieved through a variety of emission pathways and that impacts may be path-dependent, they identify the implications of the choice of emissions pathway on temperature change and sea-level rise.

Two other approaches—"tolerable windows" (Toth *et al.*, 1997; Yohe, 1997; Petschel-Held *et al.*, 1999; Yohe and Toth, 2000) and "safe corridors" (Alcamo *et al*., 1998)—also utilize inverse methods but begin further down the causal chain. Here the focus is on the range of emissions that would keep emission reduction costs and climate change impacts within "acceptable" limits. Working with policymakers, the analysts identify the set of impacts for consideration. Bounds are specified, and the cost of achieving the objective is calculated. If mitigation costs are deemed too costly, policymakers have the opportunity to relax the binding constraint. In this way, the team is able to move iteratively toward an acceptable solution.

Integrated assessment analyses also can be distinguished by their approach to optimization. For example, the focus of the UNFCCC is cost-effectiveness analysis. Article 2 states that the ultimate goal is "stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system." Mitigation cost is more of a consideration in how the target is to be achieved. The Convention states that policies and measures to deal with climate change should be cost-effective to ensure global benefits at the lowest possible cost. Several analysts, beginning with Nordhaus (1991), have identified the least-cost path for achieving a particular concentration target.

Despite the goal of the UNFCCC, several integrated assessment frameworks are designed for benefit-cost analyses. These models identify the emissions pathway that minimizes the sum of mitigation costs and climate change damages. Such policy optimization models have been developed by Nordhaus (1991, 1992, 1994b), Peck and Teisberg (1992, 1994, 1995), Chattopadhyay and Parikh (1993), Parikh and Gokarn (1993), Maddison (1995), Manne *et al.* (1995), Manne and Richels (1995), Nordhaus and Yang (1996), Yohe (1996), Edmonds *et al.* (1997), Tol (1997, 1999c,d), and Nordhaus and Boyer (1999).

2.4.2 The State of the Art

Treatment of impacts in these models also varies greatly. Generally, however, impacts are one of the weakest parts of IAMs. To a large extent this is a reflection of the state of the art of the underlying research, but it also reflects the high complexity of the task at hand (see Tol and Fankhauser, 1998, for a survey). Despite the growing number of country-level case studies, our knowledge about climate change and climate change impacts at the regional level remains limited. A coherent global picture, based on a uniform set of assumptions, has yet to emerge. The basis of most global impact assessments remain studies undertaken in developed countries (often the United States), which are then extrapolated to other regions. Such extrapolation is difficult and will be successful only if regional circumstances are carefully taken into account, including differences in geography, level of development, value systems, and adaptive capacity. Not all analyses are equally careful in undertaking this task, and not all models rely on the latest available information in calibrating their damage functions.

The actual functional relationships applied in many integrated models remain simple and often ad hoc. This reflects our still poor understanding of how impacts change over time and as a function of climate parameters. Impacts usually are a linear or exponential function of absolute temperature, calibrated around static “snapshot” estimates (such as $2xCO_2$) without distinguishing the different dynamics that may govern impacts in different sectors. Developing a better understanding of these relationships is one of the most important challenges for integrated model development.

Baseline trends—such as economic development, population growth, technological progress, changes in values, natural climate fluctuations, and increased stress on natural ecosystems—have strong repercussions for climate change vulnerability (e.g., Mendelsohn and Neumann, 1999). They must be better understood and their effect incorporated in the models. Unfortunately, these trends are inherently difficult, if not impossible, to predict over the longer term. This generic problem will not go away, but it can be overcome, at least partly, through broad scenario and sensitivity analysis.

Another key challenge is taking adaptation into account. Adaptation can significantly reduce people’s vulnerability to climate change, as shown in Chapter 18. However, adaptation can take many different forms and is correspondingly difficult to model (see Section 19.4). To date there are no IAMs available that can adequately represent or guide the full range of adaptation decisions.

2.5. Methods for Costing and Valuation

Since the SAR, costing and valuation methods have been used increasingly to quantify the cost of potential impacts; these costs include the costs of adaptations required specifically to respond to climate change and climate variability, as well as the costs of residual damages. The bulk of this section focuses on the foundation of economic costs, but there are metrics other than the economic paradigm; these are reviewed briefly in Section 2.3.6.

Researchers have adapted fundamental costing and valuation techniques drawn from the economic paradigm to handle the complexities of increasingly intricate applications. Market mechanisms provide important ways with which we can aggregate across a diversity of individual valuations, but they are tied to historical distributions of resources. Other mechanisms have been exercised, and this section begins by displaying their conceptual foundations within the economic context from which they have all evolved. It proceeds by suggesting how relaxing each underlying economic assumption has been a conceptual challenge. Many of the responses to these challenges, however, are now part of the general economic paradigm.

2.5.1. Elements of Costing and Valuation Methods

2.5.1.1. Opportunity Cost and the Foundations of Valuation Methods

Opportunity cost is the fundamental building block of modern economic analysis. The true economic cost of one unit of some good X reflects the cost of opportunities foregone by devoting resources to its production. This cost measures the economic value of outputs, goods, and services that would have been possible to produce elsewhere with the resources used to produce the last unit of good X. The social opportunity cost of employing a resource for which there is no alternative economic use is thus zero, even if its price is positive, and opportunity cost will be different under conditions of full employment than under circumstances involving large quantities of visible or invisible unemployment. Moreover, opportunity cost applies only to small “marginal” changes from equilibrium in systems for which there are multiple equilibria. Likewise, the marginal benefit from consuming good X is the value of the last unit purchased, measured in terms of a real price that reflects the welfare that would have been enjoyed if the requisite expenditure had been devoted to consuming another good (or goods).

These concepts may appear circular, but that is an artifact of the circular nature of economic systems. Suppliers of some economic goods are consumers of others. The opportunity cost of a good to the producer and the marginal benefit to the consumer are equal when all of the following conditions are obtained:

- All markets are perfectly competitive.
- Markets are comprehensively established in the sense that all current and future property rights are assigned.
- Marketed goods are exclusive (ownership is singular and well defined) and transferable (goods can be bought, sold, or given away).
- The underlying social and legal systems guarantee that property rights are (reasonably) secure.
- There are no transaction costs involved in creating and/or maintaining any current or future market.
- There is perfect and complete information about all current and future markets.

Under these conditions, the marginal opportunity cost of any good with multiple uses or multiple demanders is equal to its marginal benefit. Marginal (opportunity) cost and marginal benefit then match the accounting price that can be read from the market, and economic efficiency is assured in the sense that nobody can be made better off without hurting somebody.

It is not difficult, of course, to think of circumstances in which one or more of these conditions do not hold (and this is not news to the economics profession). Much of modern economics has been devoted to exploring how to measure and compare costs and benefits when these conditions break down. For researchers interested in impacts, however, theoretical results are less important than some practical insight into what to do.

Theory instructs, for example, that producers who have some monopoly power in imperfectly competitive markets would restrict output compared to the quantity that would prevail in a competitive market. Consequently, marginal opportunity cost would fall short of marginal benefit even if all of the other assumptions held, and the market price would overestimate marginal cost by an amount that is related to the price elasticity of demand.

Markets can fail if production or consumption produces a positive or negative externality (i.e., if either provides extra benefit or imposes extra cost on some other actor in the economy). Externalities occur, for example, when a producer who pollutes the air or water or contributes to GHG-induced warming does not pay the cost that this pollution imposes on others. Theory tells us that the private opportunity cost that might be reflected in the market price of even a competitive market would then underestimate or overestimate the true social (opportunity) cost, depending on whether the externality were positive or negative. By how much? There is the rub.

Goods whose consumption is not exclusive tend to be provided publicly. But how much should be provided? Theory reports that public goods should be provided up to the point at which the sum of marginal benefits across all consumers equals the marginal opportunity cost of provision. How much should be charged for “consuming” such a good? That price could fall to zero if the good is truly nonexclusive. In these cases, people have an incentive not to reveal their true preferences, so there is a tendency for such goods to be underprovided.

Transaction costs can drive a measurable wedge between marginal opportunity cost and marginal benefit, sometimes to the point at which markets fail completely. Can opportunity cost or marginal benefit be measured when markets do not exist? If not, what then? The growing field of nonmarket valuation might then apply (see Section 2.3.3).

Uncertainty causes problems as well. Theory speaks of risk premiums and offers models of how people make decisions under uncertainty. Information can reduce risk and uncertainty, so it has value. Uncertainty can even cause markets to fail. The key is to keep track of who knows what and when they know it. It also is essential to understand why people and institutions find some information credible and other information incredible. These are questions whose answers confound cost accounting and valuation exercises.

The passage of time and the prevalence of asymmetric information raise issues of completeness and comprehensiveness. All of the markets that are necessary to sustain efficiency probably do not exist, particularly if future property rights and future participants are not reflected in the current workings of existing markets.

Finally, economic efficiency says little about equity. Indeed, the second theorem of welfare economics indicates that the aforementioned conditions (plus a few technicalities) are sufficient to guarantee that a market-based equilibrium derived from any initial distribution of economic resources will be efficient in the sense that nobody can be made better off without making somebody else worse off (see Varian, 1992, Section 17.7). This does not mean that the market equilibrium would be equitable. Nor does it mean that economics has nothing to say about equity. It also does not mean that there is no cost associated with inequity (even in economic terms). It does mean, however, that care must be taken to keep track of the distribution of resources and to highlight the possible tradeoff between equity and efficiency.

2.5.1.2. *Specifying the Baseline*

Each of the foregoing assumptions represents a qualitative dimension along which the baseline of an impact assessment must be defined. A researcher who wants to estimate the costs or benefits of changing conditions must define as fully as possible the socioeconomic, political, institutional, and cultural environments within which the change will be felt. A “first-best” analysis assumes that everything works efficiently in response to changing conditions in the context of all of the right information; results of first-best analyses reflect benchmarks of “best-news” scenarios. Second-best analyses assume that distortions caused by the failure of some or all of these assumptions to hold will diminish the efficiency of the first-best world; they can produce dramatically different answers to cost and valuation questions. Indeed, baselines that are constructed to reflect the global externalities of climate change by definition reflect second-best circumstances.

It may be reasonable to assume that distortions will persist as change occurs over the short run. Making the same assumption over the long run could be a mistake, however. Will information not improve over time? If distortions are costly, they may persist over the long term if the beneficiaries have sufficient power to preserve their advantage. There is no right way to do second-best analysis; it is simply incumbent on the researcher to report precisely what assumptions define the baseline.

2.5.1.3. Discounting the Future

The discount rate allows costs and values occurring at different times to be compared by converting future economic values into their equivalent present values. Formally, the present value of some cost C_t that will come due in *t* years is

$$C_t / (1+d)^t ,$$

where d is the appropriate discount rate. The discount rate is non-negative because resources invested today in physical and human capital usually can be transformed into more resources later on. The IPCC and others have focused an enormous amount of attention on the discount rate (for detailed discussions see Arrow *et al.,* 1996; Portnoy and Weyant, 1999; Chapter 1 of this volume). Toth (2000b) provides a review of this and other more recent literature, with particular emphasis on the implications of discounting to issues of intergenerational equity.

2.5.2. Market Impacts

Cost and valuation exercises work best when competitive markets exist. Even when markets are distorted, they provide some useful information. This section offers brief insights into how the elements described can be applied in these situations.

2.5.2.1. Deadweight Loss

Deadweight loss is a measure of the value of aggregate economic welfare that is lost when marginal social opportunity cost does not equal marginal social benefit. Aggregate economic welfare can be regarded as the sum of the total benefit derived from consuming a specific quantity of a specific good, net of the total opportunity cost of its production. Aggregate welfare is maximized in a competitive market. Deadweight loss therefore can be computed as the difference between economic welfare generated in a distorted market and economic welfare attained at the social optimum of a competitive market. More specifically, it is estimated as the area under a demand curve that reflects marginal social benefits and above a supply curve that reflects marginal social cost between the observed or anticipated outcome and the social optimum—the outcome that would equate marginal social costs and benefits. Moreover, changes in deadweight loss can be deduced by computing the appropriate areas even if the social optimum cannot be identified. In either case, deadweight loss simply is the sum of a change in private benefits, differences between social and private benefits, a change in private costs, and differences between social and private costs.

2.5.2.2. Preexisting Distortions

Market-based exercises that evaluate the costs and benefits of change must carefully account for preexisting distortions in markets. In the presence of one distortion, in fact, creation of another might actually improve welfare. Changes may or may not work to reduce preexisting distortions, so they actually can produce benefits that would be missed entirely if analyses were confined to competitive conditions. Goulder and Schneider (1999), for example, have noted that preexisting subsidies to conventional energy industries reduce the costs of climate policies but that preexisting subsidies to alternative energy industries would increase costs. Moreover, they point out that the opportunity costs of research and development (R&D) could be reduced or even reversed if there were an ample supply of R&D providers rather than a scarcity.

2.5.3. Nonmarket Impacts

Many impacts involve changes in the direct and/or indirect flows of valued services to society. These services can offer a wide range of valuable attributes, but they frequently go unpriced in the economic sense. Markets simply do not exist for some attributes and some services; contemplating markets for some others (e.g., health services) has been questioned even given extensive competiton for services and products. For others, markets that do exist fall short of being comprehensive or complete in the presence of externalities of production or consumption. In either case (and others), researchers have recognized the need to develop alternative means with which to assess value. More precisely, they have tried to extend the scope of the economic paradigm so that implicit and explicit tradeoffs between development and conservation of unpriced resources can be explored within the structures of standard decision analytic tools such as cost-benefit analysis, cost-effectiveness analysis, and so on. Parikh and Parikh (1997, 1998) provide a primer on valuation with case studies.

To be more specific, economists have built a theory of choice on the basis of the notions of consumer sovereignty and rationality. Economists assume, therefore, that individuals are able to value changes in nonmarket goods and services as easily as they can value changes in marketed goods and services. The only difference between the two cases is that markets provide the researcher with some indirect data with which to assess individuals' values of marketed products. Nevertheless, individuals should be able to tell researchers what they would be willing to pay for changes in nonmarket conditions or willing to accept as compensation for those changes. In fact, willingness to accept (WTA) payment for foregoing a good and willingness to pay (WTP) for a good are the two general yardsticks against which values are judged.

It should be noted that WTA and WTPare seldom the same for most nonmarket goods or services. In fact, WTA and WTPcan give wildly different estimates of the value of these services if there are no perfect substitutes (i.e., if it is impossible to fully compensate individuals unit by unit for their loss). When such a substitute does not exist, WTA > WTP. By how much? Cummings *et al.* (1986) report that it is not uncommon for estimated WTA to be more than 10 times larger than estimated WTP. These differences might be derivative of the method of estimation, but they also reflect the fact that WTA and WTPare two different concepts that need not match.

It also should be noted that WTA and WTP have analogs in the market context. Compensated variation (CV) is the extra income that individuals would require to accept an increase in the price of some marketed good; CV is the analog of WTA. Equivalent variation (EV) is the income that individuals would be willing to forego to see the price of some marketed good fall; EVis the analog of WTP. These measures sometimes are used in market-based analysis. It should be no surprise that EV < CV unless the good in question has a perfect substitute.

2.5.3.1. *Direct Methods of Valuation*

Valuation methods usually are divided into two distinct approaches. Direct methods try to judge individuals' value for nonmarketed goods by asking them directly. Contingent valuation methods (CVMs), for example, ask people for their maximum WTP to effect a positive change in their environments or their minimum WTA to endure a negative change. Davis (1963) authored the first paper to report CVM results for environmental goods. Comprehensive accounts of these methods appear in Mitchell and Carson (1989), Hanley and Spash (1993), and Bateman and Willis (1995). This is a controversial method, and current environmental and resource literature continues to contain paper after paper confronting or uncovering problems of consistency, bias, truth-revelation, embedding, and the like. Hanley *et al.* (1997) offer a quick overview of these discussions and a thorough bibliography.

2.5.3.2. *Indirect Methods of Valuation*

Indirect methods of valuation try to judge individuals' value for nonmarketed goods by observing their behavior in related markets. Hedonic pricing methods, for example, assume that a person buys goods for their various attributes. Thus, for example, a house has attributes such as floor area; number of bathrooms; the view it provides; access to schools, hospitals, entertainment, and jobs; and air quality . By estimating the demand for houses with different sets of attributes, we can estimate how much people value air quality. One can thus estimate "pseudo-demand curves" for nonmarketed goods such as air quality. Travel costs are another area in which valuation estimates of the multiple criteria on which utility depends can be finessed out of observable behavior. The hedonic method was first proposed by Lancaster (1966) and Rosen (1974). Tiwari and Parikh (1997) have estimated such a hedonic demand function for housing in Bombay. Mendelsohn *et al.* (2000) brought the hedonic approach to the fore in the global change impacts arena. Braden and Kolstad (1991) and Hanley and Spash (1993) offer thorough reviews of both approaches. Is there a scientific consensus on the state of the science for these methods? Not really. There is, instead, a growing literature that warns of caveats in their application and interpretation (e.g., health services) and/or improves their ability to cope with these caveats. Smith (2000) provides a careful overview of this literature and an assessment of progress over the past 25 years.

2.5.4. ***The Cost of Uncertainty***

This section reviews the primary methods for incorporating uncertainty into analyses of climate impacts. Here we look at how to judge the cost associated with uncertainty. Cost and valuation depend, in general, on the entire distribution of the range of outcomes.

2.5.4.1. *Insurance and the Cost of Uncertainty*

Risk-averse individuals who face uncertainty try to buy insurance to protect themselves from the associated risk (e.g., different incomes next year or over the distant future, depending on the state of nature that actually occurs). How much? Assuming the availability of "actuarially fair" coverage (i.e., coverage available from an insurance provider for which the expected cost of claims over a specified period of time equals the expected income from selling coverage), individuals try to insure themselves fully so that the uncertainty would be eliminated. How? By purchasing an amount of insurance that is equal to the difference between the expected monetary value of all possible outcomes and the certainty-equivalent outcome that insurance would guarantee—the income for which utility equals the *expected utility of all possible outcomes.*

For a risk-averse person, the certainty-equivalent income is less than the expected income, so the difference can be regarded as WTP to avoid risk. In a real sense, therefore, willingly paid insurance premiums represent a measure of the cost of uncertainty. Therefore, they can represent society's WTP for the assurance that nondiversifiable uncertainty would disappear (if that were possible). Thus, this is a precise, utility-based measure of economic cost. The cost of uncertainty would be zero if the objective utility function were risk-neutral; indeed, the WTP to avoid risk is positive only if the marginal utility of economic activity declines as income increases. Moreover, different agents could approach the same uncertain circumstance with different subjective views of the relative likelihoods of each outcome and/or different utility functions. The amount of insurance that they would be willing to purchase would be different in either case. Application of this approach to society therefore must be interpreted as the result of contemplating risk from the perspective of a representative individual. Yohe *et al*. (2000), for example, apply these structures to and offer interpretations for the distributional international impact of Kyoto-style climate policy.

2.5.4.2. The Value of Information

A straightforward method of judging the value of information in an uncertain environment has been developed and applied (see Manne and Richels, 1992, for an early and careful description). The idea is simply to compute the expected cost of uncertainty with and without the information and compare the outcomes. For example, it might be that improved information about the range of uncertainty might change the mean and the variance of associated costs. If the researcher were interested only in the resulting change in costs, however, the value of information would simply be the difference between expected cost with and without the new information, and only the mean would matter. If the same researcher wanted to represent the value of information in terms of welfare that displays some degree of risk aversion so that variance also plays a role, however, a comparison of insurance-based estimates of the WTP to avoid uncertainty would be more appropriate.

2.5.4.3. Uncertainty and Discounting

Uncertainty about costs and/or values that are incurred or enjoyed over time can be handled in two ways. One method calculates the present value across the full range of possibilities; means and distributions of present values are the result. The second method, reported in Arrow *et al.* (1996), converts outcomes at each point in time into their certainty equivalents and then applies discounting techniques. This approach raises the possibility of including risk aversion into the calculation according to the foregoing definition.

The story is quite different when uncertainty surrounds selection of the discount rate itself. It may not be appropriate, in these sorts of cases, to use a certainty-equivalent discount rate (or an average over the range of possible rates). Weitzman (1998) has noted, in particular, that the "lowest possible" discount rate should be used for discounting the far-distant future. The reason, quite simply, is that the expected value of present value over a range of discount rates is not equal to the present value calculated with an average rate. Moreover, the difference between the two is exaggerated in the distant future. Present values computed with low rates, in fact, can dominate those computed with high rates by orders of magnitude when the future is extended; thus, their contribution to the expected value must be recognized explicitly in the selection of a discount rate.

2.5.5. Equity and Distribution

Assessments of the impacts of alternative climate change scenarios require assessments of their impacts on different groups, societies, nations, and even species. Indeed, this report reveals that many sectors and/or regions are at greater risk to climate change than others. This section addresses this need.

2.5.5.1. Interpersonal Comparisons

First principles of economic theory offer two approaches for comparing situations in which different people are affected differently. In the first—the utilitarian approach attributed to Bentham (1822) and expanded by Mills (1861)—a situation in which the sum of all individual utilities is larger is preferred. Because Bentham's view of utility reflected "pleasure" and "pain," this approach embraces the "greatest happiness principle." Many objections have been raised against it, however, primarily because the whole notion of interpersonal comparisons of utility is problematic. Indeed, Arrow (1951 and 1963) objected strenuously in arguing that "interpersonal comparisons in the measurement of utilities has *no meaning* and, in fact, there is no meaning relevant to welfare comparisons in the measurability of individual utility." For example, it is impossible to compare the pleasure that a person receives from listening to a concert with what another gets from watching a dance. Second, maximizing the sum total of utility, if it were possible, would require that the marginal utilities of all individuals be equal. But this would say nothing about the level of utility for each individual. They could be quite different, so the utilitarian rule is insensitive to distributional issues except in the special case in which all individuals have identical utility functions.

These difficulties led to the development of a second approach—the welfarist approach, in which a social welfare function of individual utilities is postulated. Utilitarianism is thus a special case in which the social welfare function is simply the sum of individual utilities. There are other options, of course. The Gandhian principle, for example, can support a function that judges every possible action on the basis of its impact on the poorest of the poor.

It also is possible to compare two situations without defining an explicit social welfare function and without making interpersonal comparisons of individual utilities. The Pareto principle offers one method, by which one judges any situation better than another if at least one person is better off and no one else is worse off. A partial social ordering with which unambiguous comparisons can be made in some (but not all) cases can be constructed from the Pareto principle if cardinal utilities can be added across individuals, if society accepts the principle of anonymity (i.e., only the distribution matters, not which particular person is in a particular place), and if there is an aversion to regressive transfers (i.e., transfers from the poor to the rich). To see how, consider two situations, X and Y. Assume that there are n individuals ordered from poorest to richest. Let them have incomes (or utilities) $\{X_1, ..., X_n\}$ and $\{Y_1, ..., Y_n\}$ in X and Y, respectively. X can be deemed preferable to Yif $X_1 \geq Y_1$, $[X_1 + X_2] \geq [Y_1 + Y_2]$, and so on through $[X_1 +...+ X_n] \geq [Y_1 +...+ Y_n]$, with at least one strict inequality holding. Note that showing that X is not preferred to Y is not sufficient to show that Y is preferred to X.

Rothschild and Stiglitz (1973) took these notions further by showing three alternative but equivalent ways of comparing distributions X and Y. They concluded that X would be preferred to Y if all of the following obtain:

- The Lorenz curve for X were inside the Lorenz curve for Y.
- All those who valued equality preferred X to Y.
- Y could be obtained from X by transfers from the poor to the rich.

Note, in passing, that Lorenz curves simply plot the percentage of income received by various percentiles of populations when they are ordered from least to greatest. Rothschild and Stiglitz (1973) also point out, however, that these measures apply only to a one-good economy. This requirement is equivalent to assuming that income is desired by all individuals and there are no externalities; the implications of more than one good are "substantial."

None of these measures speaks to estimating the cost of inequity when comparisons can be made. But just as insurance can be used as a utility-based measure of the cost of uncertainty, similarly constructed estimates that are based on social welfare functions that display aversion to inequality can be constructed. Insurance premiums computed in these cases simply represent a measure of what society would willingly pay to eliminate inequality. Such an approach assumes the possibility of defining an international social welfare function. Let us now look at the difficulties involved in defining it.

2.5.5.2. Comparisons Across Nations

Comparisons of interpersonal well-being across nations have been the focus of increasing attention over the past few years (see, e.g., Tol, 1999a,b), but it is clear that these comparisons involve more than one element. The conventional approach to making such comparisons is to use purchasing power parity (PPP) to adjust the calculation of gross domestic product (GDP). The technique is flawed, however, in many ways. First, GDP is now widely recognized to be a poor indicator of well-being (e.g., UNDP, 1990). This recognition has inspired many attempts to create other measures, such as the physical quality of life index (PQLI) (Morris, 1979) and various versions of the human development index (HDI) by the United Nations Development Programme (UNDP). However, many researchers, including Srinivasan (1994), have criticized the HDI for theoretical inadequacies. Nevertheless, the major point that GDPmisses too much continues to be emphasized exclusively. Calculations of the Index of Sustainable Economic Welfare (ISEW) by Daly and Cobb (1994) have shown, for example, that the ISEW for the United States has fallen since 1970 even though GDP has grown substantially.

In addition, real-world comparisons must account for many commodities, services, and attributes. This causes enormous index number problems in computing conversion factors such as the PPP. Indeed, one country's income can be higher or lower than another depending on which country is used as the base for the PPP index.

Third, different societies, cultures, and nations have different social structures, mores, and public institutions. The public goods, services, and safety net provisions of each are different. Moreover, activity outside the marketplace can differ substantially. With industrial development, for example, the clan seems to change to a joint family structure, then to a nuclear family, and perhaps to temporary nuclear families in postindustrial societies. More to the point, the nature of social and human capital and the scope of the marketplace are very different from place to place, depending on the stage of development. And if welfare involves having, being, doing, relating, and caring, a more complex measure of welfare is required to accommodate the multiple stresses of climate change.

Fourth, Sen (1985) suggests that equality in persons' "capabilities" that are determined by income and access to public goods, services, social capital, and institutions should be a global objective. Each of these determinants clearly varies from nation to nation.

Fifth, the principle of "anonymity" that is used in welfare comparisons is highly suspect. Deliberations of climate impacts and climate policy clearly should keep track of who is affected and where (within and across countries) they live.

2.5.5.3. Ensuring Equity

All of the complications outlined in Section 2.5.5.2 lead to a sad conclusion: Economics may be able to highlight a large menu of distributional issues that must be examined, but it has trouble providing broad answers to measuring and accounting for inequity, particularly across nations. Recourse to ethical principles clearly is in order.

2.5.6. Alternative Metrics for Measuring Costs

Application and extension of the economic paradigm certainly focuses attention on cost measures that are denominated in currency, but practitioners have been criticized on the grounds that these measures inadequately recognize nonmarket costs. Schneider *et al.* (2000), for example, have listed five numeraires or metrics with which the costs of climate change might be captured. Their list includes monetary losses, loss of life, changes in quality of life (including a need to migrate, conflict over resources, cultural diversity, loss of cultural heritage sites, etc.), species or biodiversity loss, and distributional equity.

Chapter 19 recognizes the content of these diverse numeraires in exploring magnitudes and/or rates of climate change that might be dangerous according to three lines of evidence: threatened systems, distributions of impacts, and aggregate impacts. The implications of the fourth line of evidence, large-scale discontinuous events, are then traced along these three dimensions.

When all is said and done, however, costs denominated in one numeraire must be weighed, at least subjectively, with costs denominated in another—and there are no objective quantitative methods with which to do so. A survey conducted by Nordhaus (1994a), however, offered some insight into 15 researchers' subjective views of the relative importance of several different measures along three different "what if" scenarios. Table 2-1 displays some of the results in terms of anticipated cost denominated in lost world GDP, the likelihood of high-consequence impacts, the distribution of costs across the global population, and the proportion of costs that would be captured by national income accounts. The survey results shows wide disagreement across the first three metrics; this disagreement generally can be explained in terms of a dichotomy of views between mainstream economists and natural scientists. Nonetheless, Nordhaus (1994a) reports that a majority of respondents held the view that a high proportion of costs would be captured in national accounts. It would seem, therefore, that natural scientists think that mainstream economists not only underestimate the severity of nonmarket impacts but also that the implications of those impacts into the monetized economy do not follow.

Multi-attribute approaches also could be applied in climate impact analysis. They have not yet found their way into the literature, however, except to the degree to which they are captured in indirect methods outlined above. Chapter 1 also notes that cultural theory can serve as a valuation framework.

2.6. Characterizing Uncertainty and "Levels of Confidence" in Climate Assessment

Uncertainty—or, more generally, debate about the level of certainty required to reach a "definitive" conclusion—is a perennial issue in science. Difficulties in explaining uncertainty have become increasingly salient as society seeks policy advice to deal with global environmental change. How can science be useful when evidence is incomplete or ambiguous, the subjective judgments of experts in the scientific and popular literature differ, and policymakers seek guidance and justification for courses of action that could cause—or prevent—significant environmental and societal changes? How can scientists improve

Table 2-1*: Subjective expert opinion on climate change (Nordhaus, 1994a).*

Cost Metric	Scenario A[a]	Scenario B[b]	Scenario C[c]
a) Loss in gross world product[d]			
– Mean	1.9	4.1	5.5
– Median	3.6	6.7	10.4
– High	21.0	35.0	62.0
– Low	0.0	0.0	0.8
b) Probability of high-consequence event[e]			
– Mean	0.5	3.0	5.0
– Median	4.8	12.1	17.5
– High	30.0	75.0	95.0
– Low	0.0	0.2	0.3
c) Top to bottom ratio of impacts[f]			
– Mean	4.2		
– Median	3.5		
– High	10.0		
– Low	1.0		
d) Percentage of total in national accounts			
– Mean	62.4	66.6	65.6
– Median	62.5	70.0	80.0

[a] Scenario A postulated 3°C warming by 2090.
[b] Scenario B postulated scenario A continuing to produce 6°C warming by 2175.
[c] Scenario C postulated 6°C warming by 2090.
[d] Percentage of global world product lost as a result of climate change.
[e] Likelihood of a high-consequence event (a loss of 25% of gross world product, comparable to the Great Depression).
[f] Proportion of loss felt by the poorest quintile of income distribution relative to the loss felt by the richest quintile; a value of 1 signifies an equal distribution of burden.

their characterization of uncertainties so that areas of slight disagreement do not become equated with paradigmatic disputes, and how can individual subjective judgments be aggregated into group positions? In short, how can the full spectrum of the scientific content of public policy debates be fairly and openly assessed?

The term "uncertainty" implies anything from confidence just short of certainty to informed guesses or speculation. Lack of information obviously results in uncertainty; often, however, disagreement about what is known or even knowable is a source of uncertainty. Some categories of uncertainty are amenable to quantification, whereas other kinds cannot be expressed sensibly in terms of probabilities (see Schneider *et al.*, 1998, for a survey of literature on characterizations of uncertainty). Uncertainties arise from factors such as lack of knowledge of basic scientific relationships, linguistic imprecision, statistical variation, measurement error, variability, approximation, and subjective judgment (see Box 2-1). These problems are compounded by the global scale of climate change, but local scales of impacts, long time lags between forcing and response, low-frequency variability with characteristic times that are greater than the length of most instrumental records, and the impossibility of before-the-fact experimental controls also come into play. Moreover, it is important to recognize that even good data and thoughtful analysis may be insufficient to dispel some aspects of uncertainty associated with the different standards of evidence (Morgan, 1998; Casman *et al.*, 1999).

This section considers methods to address such questions: first by briefly examining treatments of uncertainties in past IPCC assessments, next by reviewing recommendations from a guidance paper on uncertainties (Moss and Schneider, 2000) prepared for the TAR, and third by briefly assessing the state of the science concerning the debate over the quality of human judgments (subjective confidence) when empirical evidence is insufficient to form clear "objective" statements of the likelihood that certain events will occur.

2.6.1. Treatments of Uncertainties in Previous IPCC Assessments

The IPCC function is to assess the state of our understanding and to judge the confidence with which we can make projections of climate change and its impacts. These tentative projections will aid policymakers in deciding on actions to mitigate or adapt to anthropogenic climate change, which will need to be re-assessed on a regular basis. It is recognized that many remaining uncertainties need to be reduced in each of (many) disciplines, which is why IPCC projections and scenarios are often expressed with upper and lower limits. These ranges are based on the collective judgment of the IPCC authors and the reviewers of each chapter, but it may be appropriate in the future to draw on formal methods from the discipline of decision analysis to achieve more consistency in setting criteria for high and low range limits (McBean *et al.*, 1996; see Raiffa, 1968, for an introduction to decision analysis).

Box 2-1. Examples of Sources of Uncertainty

Problems with Data

1) Missing components or errors in the data
2) "Noise" in data associated with biased or incomplete observations
3) Random sampling error and biases (nonrepresentativeness) in a sample

Problems with Models

4) Known processes but unknown functional relationships or errors in structure of model
5) Known structure but unknown or erroneous values of some important parameters
6) Known historical data and model structure but reasons to believe parameters or model structure will change over time
7) Uncertainty regarding predictability (e.g., chaotic or stochastic behavior) of system or effect
8) Uncertainties introduced by approximation techniques used to solve a set of equations that characterize the model

Other Sources of Uncertainty

9) Ambiguously defined concepts and terminology
10) Inappropriate spatial/temporal units
11) Inappropriateness of/lack of confidence in underlying assumptions
12) Uncertainty resulting from projections of human behavior (e.g., future consumption patterns or technological change), as distinct from uncertainty resulting from "natural" sources (e.g., climate sensitivity, chaos)

Although the SAR on impacts, adaptation, and mitigation (IPCC, 1996b) explicitly links potentially serious climate change with mitigation and adaptation assessment in its Technical Summary, the body of the report is restricted mostly to describing sensitivity and vulnerability assessments (see also Carter *et al.*, 1994). Although this methodology is appropriate for testing sensitivity and vulnerability of systems, it is poorly suited for planning or policy purposes. IAMs available to SAR authors (e.g., Weyant *et al.*, 1996) generate outcomes that are plausible but typically contain no information on the likelihood of outcomes or much information on confidence in estimates of outcomes, how each result fits into broader ranges of uncertainty, or what the ranges of uncertainty may be for each outcome (see Chapter 1 and Section 2.4 for further discussions of integrated assessment issues). However, several studies since the SAR do use probability distributions (e.g., Morgan and Dowlatabadi, 1996, and citations in Schneider, 1997).

IPCC Working Group I (WGI) in its contribution to the SAR (IPCC, 1996a) uses two different methods or techniques to estimate climate change: scenarios and projections. A scenario is a description of a plausible future without estimation of its likelihood (e.g. the individual IS92a-f emission scenarios or climate scenarios generated by GCMs in which a single emission path is used). Scenarios may contain several sources of uncertainty but generally do not acknowledge them explicitly.

Careful reading of the SAR WGI Technical Summary (IPCC, 1996a) reveals that the term projection is used in two senses:

1) Asingle trajectory over time produced from one or more scenarios (e.g., projected global temperature using the IS92a emissions scenario with a climate sensitivity of 2.5°C)
2) Arange of projections expressed at a particular time in the future, incorporating one or more sources of uncertainty (e.g., projected global warming of 0.8–3.5°C by 2100, based on IS92a-f emission scenarios and a climate sensitivity of 1.5–4.5°C at $2xCO_2$).

Projections are used instead of *predictions* to emphasize that they do not represent attempts to forecast the most likely evolution of climate in the future, only *possible* evolutions (IPCC, 1996a, Section F.1). In the SAR, *projection* and *scenario* are used to describe possible future states, with projections used mainly in terms of climate change and sea-level rise. This usage defines climate projection as a *single* trajectory of a subset of scenarios. When used as input into impact assessments, the same climate projections commonly are referred to as climate scenarios.

Projected *ranges* are constructed from two or more scenarios in which one or more sources of uncertainty may be acknowledged. Examples include projections of atmospheric CO_2 derived from the IS92a-f emission scenarios (IPCC, 1996a), global temperature ranges (IPCC, 1996a), and regional temperature ranges (CSIRO, 1996). A range of projections will always be more likely to encompass what actually will transpire than a single scenario. Although projected ranges are more likely to occur than single scenarios, they are not full-fledged forecasts because they incorporate only part of the total uncertainty space. The relationship between scenarios and projected ranges as treated in the SAR is shown schematically in Figure 2-1.

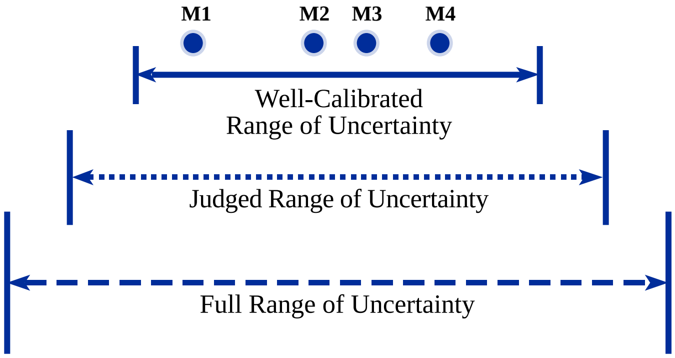

Figure 2-1: Schematic depiction of the relationship between "well-calibrated" scenarios, the wider range of "judged" uncertainty that might be elicited through decision analytic techniques, and the "full" range of uncertainty, which is drawn wider to represent overconfidence in human judgments. M1 to M4 represent scenarios produced by four models (e.g., globally averaged temperature increases from an equilibrium response to doubled CO_2 concentrations). This lies within a "full" range of uncertainty that is not fully identified, much less directly quantified by existing theoretical or empirical evidence (modified from Jones, 2000).

Aprojected range is a quantifiable range of uncertainty situated within a population of possible futures that cannot be fully identified (termed "knowable" and "unknowable" uncertainties by Morgan and Henrion, 1990). The limits of this total range of uncertainty are unknown but may be estimated subjectively (e.g., Morgan and Keith, 1995). Given the finding in the cognitive psychology literature that experts define subjective probability distributions too narrowly because of overconfidence (see Section 2.6.5.3), the inner range represents the "well-calibrated" range of uncertainty. Thus, the wider range of uncertainty represents a "judged" range of uncertainty, based on expert judgments—which may not encompass the full range of uncertainty given the possibility of cognitive biases such as overconfidence. Although the general point remains that there is always a much wider uncertainty range than the envelope developed by sets of existing model runs, it also is true that there is no distinct line between "knowable" and "unknowable" uncertainties; instead, it is a continuum. The actual situation depends on how well our knowledge (and lack thereof) has been integrated into assessment models. Moreover, new information—particularly empirical data, if judged reliable and comprehensive—eventually may narrow the range of uncertainty to well inside the well-calibrated range by falsifying certain outlier values.

If the full range of uncertainty in Figure 2-1 were known, the probability of a particular outcome could be expressed as a forecast (provided we can state the probability). Although there are significant sources of uncertainty that cannot yet be quantified, decision analytic elicitation procedures (Section 2.4) can estimate the full range of uncertainties and conditional probabilities (see Section 2.5.5 for an assessment of the state of the science concerning human judgment). Conditional probabilities may be calculated within a projected range even though the probability of the range itself remains unknown.

Moss and Schneider (1997) document several cases in which the SAR authors in each of the three Working Groups use ranges to describe uncertain outcomes but unfortunately had no consistent criteria for assigning probabilities to range limits or for identifying outlier outcomes (those occurring beyond the well-calibrated range limits). Moreover, there was no consistent use of terms to characterize levels of confidence in particular outcomes or common methods for aggregating many individual judgments into a single collective assessment. Recognition of this shortcoming of the SAR led to preparation of a guidance paper on uncertainties (Moss and Schneider, 2000) for use by all three TAR Working Groups and which has been widely reviewed and debated.

Attempts to achieve more consistency in establishing end points of ranges and outlier values (or the distribution of subjective probabilities within and beyond the range) have not received much attention. Despite the difficulty of assigning a distribution of probabilities for uncertain outcomes or processes, the scientific complexity of the climate change issue and the need for information that is useful for policy formulation requires researchers and policymakers to work together toward improved management of uncertainties. A common basis for characterizing sources of uncertainties is one step; Box 2-1 represents an attempt in the uncertainties guidance paper (Moss and Schneider, 2000) to provide such a common basis.

In this situation, the research community must bear in mind that users of IPCC reports often assume for themselves what they think the authors believe to be the distribution of probabilities when the authors do not specify it themselves. The decision analytic literature (e.g., Morgan and Henrion, 1990) often suggests that it is preferable for scientists debating the specifics of a topic to provide their best estimates of probability distributions and possible outliers, based on their assessment of the literature, than to have users make their own guesses. This information, along with an appraisal of the limitations of the models, would make the ranges more meaningful to other scientists, the policy community, and the public.

2.6.2. “Objective” and “Subjective” Probabilities are not Always Explicitly Distinguished

Some scientists have expressed concern that scientific investigation requires a long sequence of observational records, replicable trials, or model runs (e.g., Monte Carlo simulations) so the results can be specified by a formal statistical characterization of the frequency and frequency distribution of outcomes being assessed. In statistical terms, “objective” science means attempting to verify any hypothesis through a series of experiments and recording the frequency with which that particular outcome occurs. The idea of a limitless set of identical and independent trials that is “objectively out there” is a heuristic device that we use to help us rigorously quantify uncertainty by using frequentist statistics. Although there may be a large number of trials in some cases, however, this is not the same as a “limitless” number, and these trials rarely are truly identical or independent.

Most interesting complex systems cannot possibly be put to every conceivable test to find the frequency of occurrence of some socially or environmentally salient event. The popular philosophical view of “objective science” as a series of “falsifications” breaks down when it confronts systems that cannot be fully tested. For example, because climate change forecasts are not empirically determinable (except by “performing the experiment” on the real Earth—Schneider, 1997), scientists must rely on “surrogate” experiments, such as computer simulations of the Earth undergoing volcanic eruptions or paleoclimatic changes. As a result of these surrogate experiments and many additional tests of the reliability of subcomponents of such models, scientists attain confidence to varying degrees about the likelihood of various outcomes (e.g., they might assign with high confidence a low probability to the occurrence of extreme climate outcomes such as a “runaway greenhouse effect”). These confidence levels are not frequentist statistics but “subjective probabilities” that represent degrees of belief that are based on a combination of objective and subjective subcomponents of the total system. Because subjective characterization of the likelihood of many potentially important climatic events—especially those that might be characterized by some people as “dangerous”—is unavoidable, “Bayesian” or “subjective” characterization of probability will be more appropriate.

Bayesian assessments of probability distributions would lead to the following interpretation of probability statements: The probability of an event is the degree of belief that exists among lead authors and reviewers that the event will occur, given the observations, modeling results, and theory currently available, all of which contribute to estimation of a “prior” probability for the occurrence of an outcome. As new data or theories become available, revised estimates of the subjective probability of the occurrence of that event—so-called “posterior probability”—can be made, perhaps via the formalism of Bayes theorem (see, e.g., Edwards, 1992, for a philosophical basis for Bayesian methods; for applications of Bayesian methods, see, e.g., Howard *et al.*, 1972; Anderson, 1998; Tol and de Vos, 1998; Malakoff, 1999).

2.6.3. Making Estimates

2.6.3.1. Identifying Extreme Values, Ranges, and Thresholds

It is worth noting that by failing to provide an estimate of the full range of outcomes (i.e., not specifying outliers that include rapid nonlinear events), authors of previous assessments were not conveying to potential users a representation of the full range of uncertainty associated with the estimate. This has important implications with regard to the extent to which the report accurately conveyed to policymakers potential benefits or risks that may exist, even if at a low or unknown probability (see Figure 2-1). If it were necessary to truncate the range, it should have been clearly explained what the provided range includes and/or excludes. Furthermore, the authors might have specified how likely it is that the answer could lie outside the truncated distribution.

Pittock and Jones (1999) recommend construction of thresholds that can be linked to projected ranges of climate change. Such thresholds can account for biophysical and/or socioeconomic criteria in the initial stages of an assessment but must be expressed in climatic terms (e.g., above a certain temperature, rainfall frequency, water balance, or combination of several factors). Further analysis compares these thresholds with projected regional climate change. Similar approaches are contained in concepts of tolerable climate change (see Hulme and Brown, 1998).

2.6.3.2. Valuation Issues

Any comprehensive attempt to evaluate the societal value of climate change should include, in addition to the usual monetary value of items or services traded in markets, measures of valued items or services that are not easily marketed. Schneider *et al.* (2000) refer to this costing problem in vulnerability analysis as "The Five Numeraires": monetary loss, loss of human life, reductions in quality of life (including forced migration, conflicts over environmentally dependent resources, loss of cultural diversity, loss of cultural heritage sites, etc.), loss of species/biodiversity, and increasing inequity in the distribution of material well-being. There is little agreement on how to place a monetary value on the nonmarket impacts of climate change, yet such valuation is essential to several analytic techniques to assess the efficiency or cost-effectiveness of alternative climate policy proposals (see Section 2.5.6).

One such technique for valuation is to survey expert opinion on subjective assessment of probability distributions of climate damage estimates (see Nordhaus, 1994a; Morgan and Keith, 1995; Titus and Narayanan, 1996, for examples of decision analytic elicitations of climate effects and impacts; see Morgan and Dowlatabadi, 1996, for examples of how such elicited subjective probability distributions can be incorporated into IAMs that examine "optimal" policies). An alternative valuation framework is to use "cultural theory" (Douglas and Wildavsky, 1982) to identify different value perspectives in designing policy strategies (see van Asselt and Rotmans, 1995, for an application to population growth). With this technique, subjective judgment about uncertainties may be described from the viewpoints of different cultural perspectives. Preferred policy options depend on the perspective adopted. Real policy choice, of course, depends on the logic and consistency of formulating a basis for policy choices (i.e., the role of decision analysis tools) and on the values of decisionmakers at all levels. More formal and explicit incorporation of uncertainties into decision analysis is the emphasis here.

2.6.4. Aggregation and the Cascade of Uncertainty

A single aggregated damage function or a "best guess" climate sensitivity estimate is a very restricted representation of the wide range of beliefs available in the literature or among lead authors about climate sensitivity or climate damages. If a causal chain includes several different processes, the aggregate distribution might have very different characteristics than the various distributions that constitute the links of the chain of causality (see Jones, 2000). Thus, poorly managed projected ranges in impact assessment may inadvertently propagate uncertainty. The process whereby uncertainty accumulates throughout the process of climate change prediction and impact assessment has been described as a "cascade of uncertainty" (Schneider, 1983) or the "uncertainty explosion" (Henderson-Sellers, 1993). The cascade of uncertainty implied by coupling the separate probability distributions for emissions and biogeochemical cycle calculations to arrive at concentrations needed to calculate radiative forcing, climate sensitivity, climate impacts, and valuation of such impacts into climate damage functions has yet to be produced in the literature (see Schneider, 1997, Table 2). When the upper and lower limits of projected ranges of uncertainty are applied to impact models, the range of possible impacts commonly becomes too large for practical application of adaptation options (Pittock and Jones, 1999). This technique is less explicitly applied in assessments where two or more scenarios (e.g., M1 to M4 in Figure 2-1) are used and the results expressed as a range of outcomes. If an assessment is continued through to economic and social outcomes, even larger ranges of uncertainty can be accumulated (see Figure 2-2).

Because of the lack of consistent guidance on the treatment of uncertainties, diversity of subject areas, methods, and stage of development of the many fields of research to be assessed in the SAR, it was not possible to agree on a single set of terms to describe the confidence that should be associated with the many outcomes and/or processes that had been assessed. Thus, the uncertainties guidance paper (see also Box 1-1) suggests that the TAR authors agree on two alternative sets of terms from which writing teams can select (see Figures 2 and 3 in Moss and Schneider, 2000). As noted in the decision analysis literature (e.g., Morgan and Henrion, 1990), *it is important to attach a quantitative range to each verbal characterization* to assure that different users of the same language mean the same degree of confidence.

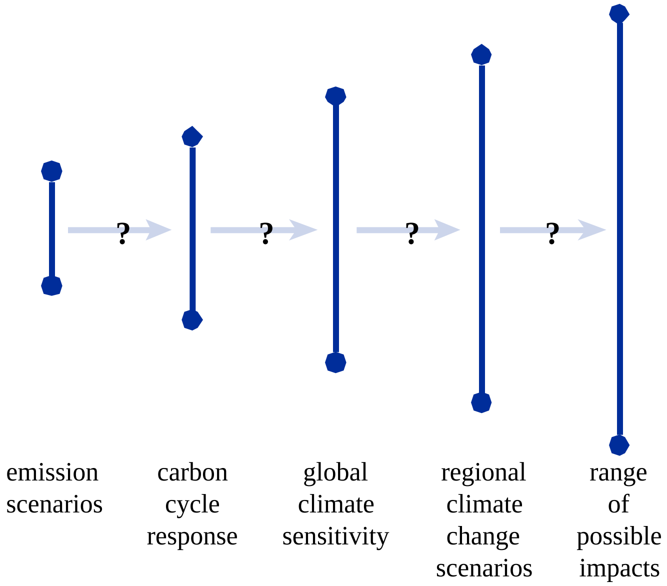

Figure 2-2: Range of major uncertainties that are typical in impact assessments, showing the "uncertainty explosion" as these ranges are multiplied to encompass a comprehensive range of future consequences, including physical, economic, social, and political impacts and policy responses (modified after Jones, 2000, and "cascading pyramid of uncertainties" in Schneider, 1983).

2.6.5. Debate over the Quality of Human Judgment

2.6.5.1. Deficiencies in Human Judgment

At some level, human judgment is an unavoidable element of all human decisions. The question, then, naturally arises: How good is human judgment? Psychological studies of human judgment provide evidence for shortcomings and systematic biases in human decisionmaking. Furthermore, not only do people—including experts—suffer various forms of myopia; they also often are oblivious of the fact. Indeed, statistical linear models summarizing the relationship between a set of predictor variables and a predicted outcome often (repeatedly) perform better than intuitive expert judgments (or subjective expert opinions). Burgeoning empirical evidence suggests that humans, including experts, can be inept at making judgments, particularly under conditions of high uncertainty.

Since the early 1970s, psychologists repeatedly have demonstrated human judgmental error and linked these errors to the operational nature of mental processes. The idea, spelled out in Kahneman *et al.* (1982), is that, because of limited mental processing capacity, humans rely on strategies of simplification, or mental heuristics, to reduce the complexity of judgment tasks. Although this strategy facilitates decisionmaking, these procedures are vulnerable to systematic error and bias.

2.6.5.2. Violation of Probability Laws

In a classic series of publications, Tversky and Kahneman (1974, 1983) and Kahneman and Tversky (1979, 1996) claim that human judgment under uncertainty violates normative rules of probability theory. For example, Tversky and Kahneman (1983) invoke the "judgment by a representativeness" heuristic to explain evidence for the *conjunction fallacy,* whereby a conjunction of events is judged to be more likely than one of its constituents. This is a violation of a perfectly simple principle of probability logic: If Aincludes B, the probability of B cannot exceed A. Nevertheless, respondents consistently give a higher likelihood to the possibility of a subset or joint event than to the whole set, thereby violating the conjunction rule. Typically, respondents judge likelihood by representativeness (or stereotypes) and thus fail to integrate statistically relevant factors.

However, Gigerenzer (1994, 1996) argues that people are naturally adapted to reasoning with probabilities in the form of frequencies and that the conjunction fallacy "disappears" if reasoning is in the form of frequencies. Several studies report that violations of the conjunction rule are rare if respondents are asked to consider the relative frequency of events rather than the probability of a single event.

Kahneman and Tversky (1996) disagree and argue that the frequency format provides respondents with a powerful cue to the relation of inclusion between sets that are explicitly compared or evaluated in immediate succession. When the structure of the conjunction is made more apparent, respondents who appreciate the constraint supplied by the rule will be less likely to violate it.

Kahneman and Lovallo (1993) argue that people have a strong tendency to regard problems as unique although they would be viewed more advantageously as instances of a broader class. People pay particular attention to the distinguishing features of a particular case and reject analogies to other instances of the same general type as crudely superficial and unappealing. Consequently, they fall prey to fallacies of planning by anchoring their estimates on present values or extrapolations of current trends. Despite differing causal theories, both approaches find evidence for poor judgment under uncertainty or, alternatively, evidence that people are better off not attempting to assess probabilities for single events.

Nonetheless, public understanding of likelihood seems to be improved by adoption of frequentist formats. Several studies have shown that experts have great difficulty reasoning with subjective probabilities for unique or single events. However, respondents apparently are much more successful when the same problems are presented with frequencies rather than probabilities. Although experts have difficulties with the probability version—most give wrong answers—most undergraduates readily provide the correct answer to similar problems constructed with frequencies.

Psychological research suggests that measures of risk that are communicated in terms of frequencies rather than probabilities will be more readily understood and rationally responded to, although IAMs need to translate these frequencies into probability distributions (e.g., Morgan and Dowlatabadi, 1996) to portray the wide range of outcomes that currently reflect estimates in the literature and by most IPCC authors.

2.6.5.3. Overconfidence

Overconfidence is another cognitive illusion that has been reported to plague experts'judgments. In the 1970s and 1980s, a considerable amount of evidence was amassed for the view that people suffer from an overconfidence bias. The common finding is that respondents are correct less often than their confidence assessments imply.

However, "ecological" theorists (*cf.* McClelland and Bolger, 1994) claim that overconfidence is an artifact of artificial experimental tasks and nonrepresentative sampling of stimulus materials. Gigerenzer *et al.* (1991) and Juslin (1994) claim that individuals are well adapted to their environments and do not make biased judgments. Overconfidence is observed because the typical general knowledge quiz used in most experiments contains a disproportionate number of misleading items. These authors have found that when knowledge items are randomly sampled, the overconfidence phenomenon disappears. Juslin *et al.* (2000) report a meta-analysis comparing 35 studies in which items were randomly selected from a defined domain with 95 studies in which items were selected by experimenters.

Although overconfidence was evident for selected items, it was close to zero for randomly sampled items—which suggests that overconfidence is not simply a ubiquitous cognitive bias. This analysis suggests that the appearance of overconfidence may be an illusion created by research, not a cognitive failure by respondents.

Furthermore, in cases of judgments of repeated events (weather forecasters, horse race bookmakers, tournament bridge players), experts make well-calibrated forecasts. In these cases, respondents might be identifying relative frequencies for sets of similar events rather than judging the likelihood of individual events. If we compare studies of the calibration of probability assessments concerning individual events (e.g., Wright and Ayton, 1992) with those in which subjective assessments have been made for repetitive predictions of events (Murphy and Winkler, 1984), we observe that relatively poor calibration has been observed in the former, whereas relatively good calibration has been observed in the latter.

It might be concluded that a frequentist rather than a Bayesian approach should be adopted when attempting to elicit judgment. However, there are occasions when there will be events for which no obvious reference class exists and one will be unable to assess likelihood by adopting the frequentist approach. This particularly applies to novel situations for which there is no actuarial history. One might well be able to account for the (no doubt varying) subjective probabilities offered by a sample of people by identifying mental heuristics. However, note that, without a reference class, we have no means of evaluating the validity of any judgments that might be offered. Consequently, any probability given to a unique event remains somewhat ambiguous.

2.6.6. Building Experience with Subjective Methods In a “Science for Policy” Assessment

Although one might be tempted to infer from the foregoing arguments that judgments of likelihood should be considered only with caution, for some decision analytic frameworks that often appear in the climate policy literature (.g., cost-benefit analysis and IAMs), there often are few viable alternatives. However, as noted in the decision analysis frameworks guidance paper (Toth, 2000a; see also Section 2.4), several alternative decisional analytic methods are less dependent on subjective probability distributions; virtually all frameworks do require subjective judgments, however. Although physical properties such as weight, length, and illumination have objective methods for their measurement, there are no objective means for assessing in advance the probability of such things as the value future societies will put on now-endangered species or the circulation collapse of the North Atlantic Ocean from anticipated anthropogenic emissions. Even a highly developed understanding of probability theory would be of little avail because no empirical data set exists, and the underlying science is not fully understood. Some authors have argued that under these circumstances, for any practical application one ought to abandon any attempt to produce quantitative forecasts and instead use more qualitative techniques such as scenario planning (e.g., Schoemaker, 1991; van der Heijden, 1998) or argumentation (Fox, 1994). On the other hand, others—though noting the cognitive difficulties with estimation of unique events—have argued that quantitative estimations are essential in environmental policy analyses that use formal and explicit methods (e.g., Morgan and Henrion, 1990).

Given its potential utility in applied and conservation ecology, it seems surprising that Bayesian analysis is relatively uncommon. However, logical and theoretical virtue is not sufficient to encourage its use by managers and scientists. The spread of a new idea or practice is an example of cultural evolution (in this case, within the scientific community). It is best understood as a social and psychological phenomenon (Anderson, 1998).

Helping to achieve such penetration of awareness of uncertainty analyses will be a multi-step process that includes “1) consistent methods for producing verbal summaries from quantitative data, 2) translation of single-event probabilities into frequencies with careful definition of reference classes, 3) attention to different cognitive interpretations of probability concepts, and 4) conventions for graphic displays” (Anderson, 1998). The latter also is advocated in the uncertainties guidance paper (Moss and Schneider, 2000), and an example is provided in Chapter 7 (Figure 7-2).

Although all arguments in the literature agree that it is essential to represent uncertainties in climatic assessments, analysts disagree about the preferred approach. Some simply believe that until empirical information becomes available, quantitative estimates of uncertain outcomes should be avoided because “science” is based on empirical testing, not subjective judgments. It certainly is true that “science” itself strives for “objective” empirical information to test, or “falsify,” theory and models (caveats in Section 2.5.2 about frequentism as a heuristic notwithstanding). At the same time, “science for policy” must be recognized as a different enterprise than “science” itself. Science for policy (e.g., Ravetz, 1986) involves being responsive to policymakers’needs for expert judgment at a particular time, given information currently available, even if those judgments involve a considerable degree of subjectivity. The methods outlined above and in Moss and Schneider (2000) are designed to make such subjectivity more consistently expressed (linked to quantitative distributions when possible, as needed in most decision analytic frameworks) across the TAR and more explicitly stated so that well-established and highly subjective judgments are less likely to get confounded in media accounts or policy debates. The key point is that *authors should explicitly state their approach in each case*. Transparency is the key to accessible assessments.

2.7. Decision Analytic Methods and Frameworks

This section presents basic principles of decision analytic frameworks that have been or could be used in assessing adaptation decisions in sectors and regions. Thus, it provides a common base for decision analysis-related discussions in sectoral and regional chapters of this report.

2.7.1. Decision Analysis to Support Adaptive Decisions—Introduction to Frameworks and Principles

Decisionmakers who are responsible for climate-sensitive economic sectors (e.g., forestry, agriculture, health care, water supply) or environmental assets (e.g., nature reserves) face questions related to undertaking adaptation measures on the basis of what impacts might be expected if global GHG emissions continue unabated or as a result of globally agreed mitigation action at different levels of control. The starting point for adaptation decisions is to explore the possible range of impacts to which one would need to adapt. This is a complex task in itself because it involves understanding possible regional patterns of climate change, the evolution of key socioeconomic and biophysical components of the sector or region under consideration, and the dynamics of the impacts of changing climatic conditions on the evolving social system.

Adaptation decisions in private sectors operating under free-market conditions will be made largely as part of a business-as-usual approach and will rely on analytical frameworks that are compatible with the management culture. The emerging literature on adaptation describes this as autonomous adaptation. The flexibility of private-sector actors and thus the range of options they are able to consider in adapting to any external impact (not only climatic ones) can be severely constrained by market distortions or by a lack of resources to implement any transformation. Under such circumstances, the potential for autonomous adaptation is limited. Planned adaptation will be required, and the importance of public policy is larger.

A standard example for autonomous adaptation is the farmer who switches from one cultivar of a given crop to another or from one crop to another in response to perceived changes in weather patterns, simultaneously considering changes in relative prices of input factors and agricultural commodities, the evolving technological and agronomic conditions behind them, and other factors affecting his profits. However, if prices are distorted by a quota system or state subsidy, decisions are excessively dominated by these considerations, which could lead to maladaptation. Similarly, subsistence farmers in less-developed countries are not profit maximizers, and they may not possess the resources required to make even minor shifts in response to changes in their external conditions. Under these conditions, the only possibility for them might be to give up their livelihood altogether.

With a view to the already significant atmospheric load of GHGs since the industrial revolution, as well as the huge inertia and long delays characterizing the atmosphere-ocean-biosphere system, adaptation to anthropogenic climate change appears inevitable over the coming decades. It is worth looking at some of the key differences in applications of DAFs that deal with climate change mitigation (reducing GHG emissions) and adaptation (managing and counterbalancing the impacts of climate change).

The most crucial difference between mitigation- and adaptation-oriented DAF applications is to whom the benefits of action accrue. Except for “no-regret” options, benefits of mitigation will become a globally shared public good. Adaptation actions will predominantly benefit agents who adapt, in the case of private actors, or gains will be shared by the community in the case of local/regional public goods and services, such as flood protection.

The second important difference between mitigation and adaptation decisions is related to the timing of policy options. If climate protection were needed, as many scientists and policymakers maintain, policies and technologies that help reduce GHG emissions at the lowest possible social costs would be required immediately. On the adaptation side, in contrast, the bulk of more significant impacts of climate change may be felt 30, 50, or 100 years from now. This leaves a longer time period (compared to mitigation action) to steer the development of climate-sensitive sectors so that their climate vulnerability will be lower and, more important, to develop technologies that will help reduce remaining negative impacts by the time they really happen. Nevertheless, forethought and action might well be required in sectors with long-lived infrastructure and large social inertia (e.g., changing institutions such as misallocated property rights) to foster adaptation to future climate.

In terms of public policies, the foregoing analysis implies urgency on the mitigation side to formulate and put in place appropriate measures; by contrast, in general there is more time on the adaptation side to sort out potential impacts, adaptation needs, institutional and technological options involved in various adaptation measures, and public policies to develop and deliver them. At the same time, however, in many countries around the world that suffer from current climatic variability and extremes, there is an urgent need for appropriate adaptation policies and programs to be designed and implemented now to lessen adverse impacts; such actions also will help to build adaptive capacity for future climate changes.

Several other differences between mitigation and adaptation decisions must be considered in framing DAFs appropriately. Mitigation decisions are to be crafted globally, and their implementation may entail a global spread to reduce costs, whereas adaptation decisions are more limited to nations or subnational regions. The region in this context is intentionally defined loosely and given a broad interpretation. In considering climate change impacts and adaptation policies, a region typically would be a sociogeographical unit under the jurisdiction of a legally recognized policy entity within a country. However, a region in this sense also could correspond to a whole country, especially if it is relatively small and geographically homogeneous. Moreover, regional climate impact and adaptation studies also are conceivable (and in some cases have been undertaken) at the level of a supranational region, provided it has a recognized policymaking entity (e.g., the European Union).

Many market-sector impacts can be relieved at least partially by a combination of regional adjustments and interregional trade (especially in the agriculture and livestock sectors), but regions remain the prime focus of adaptation policies even in these cases. In terms of the public policy agenda, mitigation decisions have to be made today in the context of current short-term economic problems, social challenges, and policy debates. Adaptation and adaptation-related analyses will have to be developed in the context of long-term socioeconomic and technological development, with a special view to economic and technological trends in climate-sensitive economic sectors and environmental systems. This makes adaptation-oriented DAF applications easier because options to factor them in are much broader, but it also makes them more difficult because the future is difficult to predict and there is a clear need for policies that will be successful across a broad range of plausible futures (these policies commonly are called robust). The information base for adaptation decisions will improve over time, whereas DAFs to support near-term mitigation decisions must cope with current knowledge plagued with enormous uncertainties.

2.7.2. Major DAFs and their Use in Adaptation Studies

A broad range of DAFs could be used in principle; to date, however, only a few have been used in practice to provide substantial information to policymakers who are responsible for adaptation decisions at various levels. This subsection lists DAFs that appear to be most relevant for analyzing adaptation decisions. Many DAFs overlap in practice, and clear classification of practical applications sometimes is difficult. The IPCC Guidance Paper on DAFs (Toth, 2000a) provides a more comprehensive, yet incomplete, catalog.

Just as in analyzing decision options for overall climate policy (i.e., at what level should concentrations of GHGs be stabilized, considering the costs and benefits involved?) or for mitigation decisions (timing, location, ways and means of emission reductions), the proper mode to conduct analyses to support adaptation decisions also is sequential decisionmaking under uncertainty and considering future learning. The principal task is to identify adaptation strategies that will take regions or sectors to the best possible position for revising those strategies at later dates in light of new information about expected patterns of regional climate change, socioeconomic development, and changes in climate-sensitive sectors. Consequently, applications of all DAFs in adaptation studies should be formulated in the sequential decisionmaking mode.

The complexities involved in climate change decisionmaking and selecting appropriate tools to support it stem from the interconnectedness of the various realms of decisionmaking. Analysts provide advice for setting the global climate policy target at the global scale; these targets become external constraints when adaptation strategies are sought at the regional scale that are socially just, environmentally sustainable, and compatible with regional development objectives.

DAFs that are applicable in adaptation assessments can be distinguished according to whether they rely solely on "desk studies" (involving or not involving formal models) or entail participation of clients, stakeholder groups, or others. Model-based DAFs tend to focus primarily on structuring the problem, apply convenient simplifications, and find efficient solutions to the problem. Participatory DAFs, in contrast, can better accommodate diverse views on climate change impacts and often conflicting interests and options to restrain them. Insights from both kinds of studies are crucial for policymakers to craft effective and broadly acceptable policies.

2.7.2.1. Decision Analysis

Decision analysis (DA) is the product of integrating utility theory, probability, and mathematical optimization (see French, 1990; Morgan and Henrion, 1990; Chechile and Carlisle, 1991; Keeney and Raiffa, 1993; Kleindorfer *et al*., 1993; Marshall and Oliver, 1995; Clemen, 1996). The process starts with problem identification and preparation of a possibly comprehensive list of decision options. Structural analysis would organize options into a decision tree, carefully distinguishing decision nodes (points at which the outcome is chosen by the decisionmaker) and chance nodes (points at which the outcome results from stochastic external events). Next, uncertainty analysis would assign subjective probabilities to chance nodes, and utility analysis would stipulate cardinal utilities (in terms of absolute values) for outcomes. Finally, optimization produces the best outcome according to a selected criterion, typically maximizing expected utility or any other that best reflects the risk attitude of the decisionmaker.

Advanced DA provides various extensions of the foregoing conceptual framework and supports a huge diversity of applications. In the literature, some features (sequential decisionmaking, hedging), specific versions (multi-criteria analysis), distinctive applications [risk assessment (RA)], or basic components (multi-attribute utility theory) of DA sometimes are emphasized and taken as separate DAFs, although they all are rooted in the same theoretical framework. As indicated, sequential decisionmaking is an indispensable mode of analysis of climate change in any DAF. It refers to framing of the analysis rather than a distinctive DAF. DA can be performed with a single criterion or with multiple criteria; multi-attribute utility theory provides the conceptual underpinnings for the latter. Finally, DA adapted to managing technological, social, or environmental hazards constitutes part of RA, in which a range of other methods also is available. RA involves estimation of the nature and size of risks. Its objective is to identify quantitative measures of hazards in terms of magnitude and probability. RAmethods are diverse; the choice depends on the disciplinary focus and the nature of the hazard to be assessed, but all methods rely on extrapolation (see Kates and Kasperson, 1983). See Chapter 12 for applications of RA in climate impact assessment.

DA is a promising DAF for use in adaptation assessments. Problem formulation in DAallows for consideration of a broad range of uncertain outcomes, different probability distributions assigned to them, and a variety of possible adaptation actions. Structuring the DAmodel in an intertemporal fashion is helpful for identifying robust adaptation strategies that prove to be effective under a broad range of possible futures and retain a sufficient degree of freedom for course correction.

2.7.2.2. *Cost-Benefit Analysis*

Cost-benefit analysis (CBA) involves valuing all costs and benefits of a proposed project over time on the basis of willingness to pay (or willingness to accept compensation) on the part of project beneficiaries (affected people) and specifying a decision criterion to accept or turn down the project (see Ray, 1984; Morgenstern, 1997). This criterion usually is the compensation principle, implying that those who benefit from the project should be able to compensate the losers. The applicability of CBA as a DAF for climate policy has been a fiercely debated issue. Although the debate continues about the extent to which traditional CBAcan provide useful information for global-level decisionmaking, there is more agreement on its usefulness in adaptation decisions at the national and regional scales.

In practical applications, all costs (C) and benefits (B) are defined as follows:

$$B = \sum_{t=0}^{n} \frac{B_t}{(1 + i)^t} \quad \text{and} \quad C = \sum_{t=0}^{n} \frac{C_t}{(1 + i)^t}$$

where i is the social discount rate, n is the project life, and t denotes the year. One can use different cost-benefit criteria for ranking projects or choosing the best among them: the cost-benefit ratio, $CBR = B/C > 1$; the net present value, $NPV = B - C > 0$; and the internal rate of return, $IRR > i$, where IRR is the discount rate to make $B = C$. When we evaluate a single project, these criteria lead to the same conclusion. In choosing the most desirable alternative, however, these criteria indicate different orders of desirability.

A CBA in the adaptation context takes potential regional climate change scenarios and their impacts as its starting point. The next step is to establish costs of alternative adaptive measures as a function of their scales of application—the marginal cost curve. A related task is to estimate how much damage can be averted by increasing the adaptation effort—WTP (marginal benefit curve). The decision principle suggests undertaking adaptive measures as long as marginal averted damages (benefits) exceed marginal costs. This rule of thumb is easier to apply in sectoral adaptation decisions, in which costs and benefits can be derived from market prices. Difficulties arise in nonmarket sectors in which the valuation behind the marginal cost and benefit curves often is debated. Difficulties multiply, in a regional context, when costs and benefits must be aggregated across many sectors.

A frequent critique of CBA and its applicability in adaptation studies is that the underlying measurements are incomplete (especially in regional studies, which do not cover all important aspects), inaccurate (even the costs and benefits of adaptive actions included in the analysis are impossible to measure precisely), and debated (related to the two preceding points; the inclusion and exact valuation of many costs and benefits involve inherently subjective value judgments). These criticisms are largely valid. However, it is still better to get at least the measurable components right and complement them with a combination of judgments on hard-to-measure items and sensitivity tests to assess their implications than to abandon the whole method simply because it does not get everything perfect. Nevertheless, it is important that users of these tools and their results fully understand the limitations and confidence attached to them. Duke and Kammen (1999) argue that accounting for dynamic feedback between the demand response and price reductions from production experience can be used to account for deadweight loss and other market dynamics that determine the benefit-cost ratio of economic and policy measures to expand the market for clean energy technologies. These results further support a broader role for market transformation programs to commercialize new environmentally attractive technologies. The same dynamic feedback processes also are relevant for CBA applications to adaptation decisions. For example, consider changing precipitation patterns that would increase the frequency of high-water conditions. Take flood-related damages as the function of flood return periods: Annual flooding may cause the least damages, whereas a 5-year return flood will cause somewhat more, a 20-year return flood even more, and so on. Adaptation costs increase along the same axis because it takes higher dikes and larger flood protection reservoirs to control a 50-year return flood than a 5-year return flood. The level at which a given society will decide to protect itself against floods depends on local economic conditions and geographical and technological endowments. A CBAsuggests that it should be in the neighborhood of where marginal costs of additional flood protection would be equal to WTP for additional flood protection.

2.7.2.3. *Cost-Effectiveness Analysis*

Cost-effectiveness analysis (CEA) takes a predetermined objective (often an outcome negotiated by key stakeholder groups in a society) and seeks ways to accomplish it as inexpensively as possible. The thorny issues of compensations and actual transfers boil down to less complex but still contentious issues of burden sharing.

CBA will always be controversial because of the intricacies of valuing benefits of many public policies, especially intangible benefits of environmental policies, properly. CEA takes the desired level of a public good as externally given (a vertical marginal benefit curve) and minimizes costs across a range of possible actions. Like other target-based approaches, CEA often turns into an implicit CBA, especially if even the minimum costs turn out to be too high and beyond the ability to pay of the society. In this case, the target is iteratively revised until an acceptable solution is found.

Consider the foregoing example of changing precipitation pattern induced by climate change and resulting high-water conditions. In many countries, legally binding criteria exist regarding the level of flood protection (e.g., protection against a 50- or 100-year return flood). CEAwould take these or other socially agreed flood protection targets and seek the mix of dams, reservoirs, and other river basin management options that would minimize the costs of achieving the specified target.

2.7.2.4. Policy Exercise Approach

The policy exercise (PE) approach involves a flexibly structured process that is designed as an interface between academics and policymakers. Its function is to synthesize and assess knowledge accumulated in several relevant fields of science for policy purposes in light of complex practical management problems. At the heart of the process are scenario writing ("future histories," emphasizing nonconventional, surprise-rich, but still plausible futures) and scenario analyses via interactive formulation and testing of alternative policies that respond to challenges in the scenario. These scenario-based activities take place in an organizational setting that reflects the institutional features of the issues addressed. Throughout the exercise, a wide variety of hard (mathematical and computer models) and soft methods are used (Brewer, 1986; Toth, 1988a,b; Parson, 1997).

The product of a PE is not necessarily new scientific knowledge or a series of explicit policy recommendations but a new, better structured view of the problem in the minds of participants. The exercise also produces statements concerning priorities for research to fill gaps of knowledge, institutional changes that are needed to cope more effectively with the problems, technological initiatives that are necessary, and monitoring and early warning systems that could ease some of the problems in the future. In recent years we have witnessed increasing use of the PE approach to address climate change at the national scale (see Klabbers *et al.*, 1995, 1996) and at the global level.

2.7.3. Relevance and Use of DAFs in Sectoral Adaptation Decisions—Selected Examples

Working Group II has reviewed a huge volume of climate impact assessment studies conducted to date. Most of these studies investigate possible implications of climate change for a single economic sector or environmental component. An increasing, yet still small, fraction of these studies lists options to alleviate impacts, but few take even the next step of exploring direct and indirect costs of those adaptation options. Even fewer studies provide comprehensive assessments of direct and indirect benefits.

Although these studies qualitatively indicate that many policy options proposed as adaptation measures to reduce negative impacts of climate change would be justified even in the absence of climate change (dubbed "no regret" measures on the impacts adaptation side), to date very few have been developed to the point at which comprehensive and quantitative assessment of adaptation options would be possible. Nevertheless, they are a prerequisite for establishing appropriate applications of the more quantitative DAFs reviewed in Section 2.7.2. The main reason is that, despite uncertainties of regional climate change patterns and resulting impacts, some information is generated about possible biophysical impacts. However, little is known about future socioeconomic sensitivity and even less about future adaptive capacity. Resolving this would require fairly detailed regional development scenarios to provide the broader context for sectoral assessments. All these factors together make rigorous applications of quantitative DAFs difficult.

A simple ranking of climate impact and adaptation studies according to how far they get in using DA tools would start with those that are preoccupied almost exclusively with impacts and casually mention some obvious adaptation options. The next category would be studies that attempt to produce a comprehensive list of possible adaptive measures. More advanced studies would explore positive and, if they exist, negative effects of listed options and try to establish at least a qualitative ranking. By assigning monetary values to those comprehensive effects, CBAcould help determine the optimal level of adaptation measures; CEA would select the least-cost solution to provide a predetermined level of adaptation objective.

Perhaps the most crucial area of public policy in climate change adaptation is water resource management. A set of papers arranged by Frederick *et al.* (1997a) looks at different aspects of climate change and water resources planning. Their general conclusion is that DAFs adopted in public policy procedures of water management are largely "appropriate for planning and project evaluation under the prospect of climate change, but new applications and extensions of some criteria may be warranted" (Frederick *et al.*, 1997b). The authors mention nonstationarity, interest rates, and multiple objectives as issues on which progress is required to support better assessments of climate change adaptation decisions.

Water is an important factor to consider in most other sectoral impact and adaptation assessments, even if their primary focus is on a single sector. With a view to the complexity of interactions among sectoral impacts on one hand and adaptation measures on the other, integrated regional assessments increasingly are considered to be indispensable to understand climate-related risks.

2.7.4. Relevance and Use of DAFs in Regional Adaptation Decisions—Selected Examples

Sectoral adaptation decisions must be considered in the broader regional context in which evolution in related sectors and their responses to changing climatic conditions represent additional factors to consider in planning a given sector's own adaptation strategy. This process is likely to involve a broad mix of private and public stakeholders and their interactions. From the perspectives of regional planners and policymakers who are responsible for the overall socioeconomic development of a specific region, the challenge is to create conditions under which relevant sectoral actors can formulate their own adaptive strategies efficiently and install public policies that will help adaptation in sectors that provide public services and manage public resources.

Designing and implementing regional climate change studies that incorporate full-fledged DAFs to support the development of regional climate adaptation policies has proven to be an insurmountable challenge to date. This is understandable, in view of the difficulties involved, and indicates a crucial research area for the future.

Most statements on regional adaptation policies in the literature stem from limited but logical extensions of sectoral climate impact assessment studies. Once possible biophysical changes and their direct or indirect socioeconomic consequences are established, impact assessors mention a few options that could mitigate those impacts or moderate their consequences. Seldom are these lists comprehensive, and they scarcely entail even direct cost estimates, let alone assessments of indirect costs and ancillary benefits involved in the specified adaptation options.

The study by Ringius *et al.* (1996) on climate change vulnerability and adaptation in Africa is a good example. Focusing on impacts on agriculture and water, the authors develop a typology of adaptive responses and discuss their effectiveness from the perspectives of different stakeholders. Although the study is extremely useful in pointing out that a convenient and crucial starting point for decisions on adapting to expected climate change in Africa is to reduce present vulnerability and enhance the capacity to respond to any environmental and economic perturbations (not just climate and weather), no attempt has been made to evaluate the costs and benefits of different options or to rank them in terms of their effectiveness.

An early policy-oriented impact assessment study adopted the PE approach to synthesize results of sectoral studies in a DAF in selected countries in southeast Asia (Toth, 1992a,b). The project included data collection, modeling, completion of first-order impact assessments, analysis of socioeconomic impacts on the impact assessment side, development of background scenarios, and pre-interviews with “policy” participants as preparations for PE workshops. The results of these workshops indicate that the PE approach might be a useful tool in structuring the numerous uncertain facets that are related to developing robust regional adaptation policies.

Apartially integrated regional cost-benefit assessment has been prepared for the entire coastal area of Poland (Zeidler, 1997). Scenarios of sea-level rise have been combined with different assumptions about socioeconomic development in the potentially affected coastal region to explore mainly direct and relatively easy-to-estimate costs and benefits of three specifically defined adaptation strategies: retreat (no adaptation), limited protection, and full protection. Because of its numerous merits and despite its limitations, this study has demonstrated the feasibility of using CBAto formulate climate change adaptation problems in a simple DAF and the potential usefulness of its results to policymakers.

2.7.5. Contribution of DAFs in Adaptation to Integrated Climate Change Decisions on Balancing Mitigation and Adaptation

Information generated in applying DAFs in sectoral and regional climate impact assessment studies is oriented primarily toward decisionmakers who have the mandate to initiate and implement public policies to reduce future adverse impacts of climate change. Just the attempt to integrate adaptation options into selected DAFs would force analysts to think comprehensively and achieve internal consistency, to consider broader factors beyond the influence of sectoral or regional stakeholders. Even though a comprehensive CBAor DAremains difficult to develop, the overall quality of the impact assessment improves.

Asecond, equally important use of these results is to help define GHG mitigation objectives. National and regional positions at global negotiations on long-term climate stabilization targets (with respect to anthropogenic forcing) apparently are influenced by perceived risks involved in climate change as well as net damage remaining even after plausible and affordable adaptation options have been considered.

Admittedly, it is a difficult task to formulate impact/adaptation studies properly in any DAF. This explains the modest progress in the field since the SAR. Regional and sectoral chapters in this volume review a small number of DAF applications, whereas there was hardly any application on which to report in the SAR.

2.8. Conclusion

In the decade prior to the SAR, the preponderance of studies employed methods and tools largely for the purpose of ascertaining the biophysical impacts of climate change, usually on a sectoral basis. Thus, the methods included models and other means for examining the impacts of climate change on water resources, agriculture, natural ecosystems, or coasts. Such methods have improved with regard to detection of climate change in biotic and physical systems and produced new substantive findings. In addition, since the SAR, cautious steps have been taken to expand the “toolbox” to address more effectively the human dimensions of climate as cause and consequence of change and to deal more directly with cross-sectoral issues concerning vulnerability, adaptation, and decisionmaking. In particular, more studies have begun to apply methods and tools for costing and valuing effects, treating uncertainties, integrating effects across sectors and regions, and applying DAFs to evaluate adaptive capacity. Overall, these modest methodological developments are encouraging analyses that will build a more solid foundation for understanding how decisions regarding adaptation to future climate change might be taken.

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