Integrated Environmental Assessment: An Overview and Assessment

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INTRODUCTION

This paper attempts to give the reader an appreciation for the past contributions and potential future contributions of modeling and analysis to the development of energy and environmental policies. The focus here is on breadth of coverage rather than depth in any one particular area. Analyses of the costs of policies, the benefits of policies, attempts to integrate costs and benefits, as well as attempts to incorporate consideration of important uncertainties, sustainable development, and technological change are all discussed. The use and usefulness of the analyses are discussed relative to the great complexity and uncertainty that is inherent in most energy and environmental policy issues.

The paper starts with a quick overview of some types of contributions that modeling and analysis have made to the understanding of – and formulation of - policies designed to deal with energy and environmental policy problems. This is followed by an overview of the literature on integrated assessments of climate change, including a description of the elements of integrated assessment models, as well as of the two main types of integrated assessment models and the kinds of information each can provide the policy development process. Next, cost and benefit analyses are discussed in more detail, which sets the stage for a discussion of valuing the benefits of policies and comparing them with their costs. This is followed by further discussion of approaches to incorporating uncertainty in policy analyses. The paper concludes with a state of the art assessment of energy-environmental policy analyses, including both technical issues – like modeling technological change – and model construction and use issues – like possible mismatches between the model being used and the problem being studied.

CONTRIBUTIONS OF MODELING

The process of building and using a model can make many contributions to the understanding of a problem and potential solutions to it. The least common contributions of modeling are those that come directly from the precise set of numerical results a model produces for a particular policy under a particular set of scenario assumptions. Much more common are the insights about the nature of the problem and possible solutions to it that are obtained from the process of constructing and exercising the model. This process can also lead to the identification of ambiguities in polices that are proposed. Running a model can also help give an idea of the direction of change of key outputs as inputs and model structure are varied and possibly an order of magnitude (or occasionally a factor of two estimate) for those sensitivities. In some cases thoughtful analysis can identify non-linearities in the response of costs or benefits to variations in policy parameters. Other contributions of policy modeling have included identifying inefficiencies in existing markets or policies, exploring alternative policy architectures, identifying data requirements and identifying areas for additional model development.

ELEMENTS OF INTEGRATED ASSESSMENT

There are a large number of Integrated Assessment Models (IAM) used to examine the issue of climate change with a wide variety of differing goals and objectives motivating their construction. They vary greatly in their scope and detail, but all share the defining trait that they incorporate knowledge from more than one field of study. Thus, a great deal of work in the area of climate change therefore falls within the bounds of this definition. This also means that integrated assessment models will vary greatly with regard to their scope. It is therefore important to distinguish models in this dimension as well as their level of detail. Models which attempt to grapple with the full range of issues raised by the climate issue are referred to as "full scale" IAMs.

"Full scale" IAMs must grapple with all of the complexity of an IPCC assessment. This is of course, an intimidating array of concerns. But while an IAM for climate change must consider a wide variety of issues, the venue is bounded. For the purpose of exposition, we group considerations into four general categories, depicted in Figure 1:

Human Activities,
Atmospheric Composition,
Climate and Sea Level, and
Ecosystems.

Figure 1 is not a unique depiction of the climate change system. An infinite number of aggregations are possible and a great many "wiring diagrams" already exist. This particular "wiring diagram" has the virtue of including both human and natural system components. Human systems interact with natural systems in two ways. It is human activities which are responsible for the emissions of greenhouse related gases which are the center of concern in the

climate change issue. Human activities are also affected by climate change, either directly as for example through changes in temperature which affect demands for space heating and cooling, or indirectly as for example through changes in sea level, crop productivity, or biodiversity.

Full scale IAMs must consider the issue of emissions of greenhouse related gases. The array of gases that matter from the perspective of emissions differs slightly from the array of gases that matter from the perspective of climate. From the perspective of climate change only, gases which have the capacity to change the radiative balance of the planet need be considered. At present the set consists principally of the following set of gasses: Water vapor (H_2O), Ozone (O_3), Carbon dioxide (CO_2), Methane (CH_4), Nitrous oxide (N_2O), Sulfur aerosols. and the Chlouroflurocarbons and their substitutes.

The set of gases that must be considered from the perspective of emissions is strongly overlapping, but includes some important differences. Water vapor and O_3 are not emitted in sufficient quantities by human activities to matter. Their concentrations are, however affected by the emissions of other greenhouse related gases such as carbon monoxide (CO), odd-nitrogen (NO_x), and non-methane hydrocarbons (NMHC).

With regard to the emissions of greenhouse related gases the following human activities figure prominently:

Energy systems
Agriculture, Livestock, & Forest systems, and
Industrial systems.

The role of energy systems is the single most critical component determining emissions in IAMs. Not only are energy systems associated with the greatest anthropogenic release of carbon to the atmosphere, but they are also associated with the largest anthropogenic release of sulfur compounds as well.

Systems which determine rates of land-use change figure importantly, though the relationship between specific human actions and land-use change is less well defined than the relationship between energy production and use and the release of greenhouse related gases. Agriculture, livestock, and forestry practices are generally linked to land-use as they represent the most extensive anthropogenic uses of land. In addition agriculture and livestock are important determinants of CH_4 and N_2O releases.

Finally, full scale IAMs must consider the array of other greenhouse related emissions that are being released into the atmosphere. Most prominent among these are the chlouroflourocarbons (CFCs) and their substitutes, although there are others.

From the perspective of the consequences of climate change an overlapping but somewhat different list of issues must be dealt with by IAMs. The problem of climate change impacts is more difficult to deal with in IAMs because impacts are anticipated to affect a wide array of human activities with no single activity though to be substantially more vulnerable than others. IAMs thus frequently confront the impacts issue abstractly, using “damage functions,” rather

than explicitly. Nevertheless, underlying any treatment of impacts within an IAM are at a minimum the following human activities:

agriculture, livestock, & forest systems,
energy systems,
coastal zones,
water systems,
human health,
the value of local air quality, and
the values of unmanaged ecosystems[1].

The second information set that a full scale IAM must generate is the concentrations of greenhouse gases. IAMs deal with the problem of translating the emissions flows generated by human activities into concentrations of greenhouse gases in the atmosphere. This requires dealing with the fact that emissions are the sum of those from natural and anthropogenic sources. In general greenhouse gases can be segregated into CO_2 and other gases. The non-CO_2 greenhouse related gases are controlled by atmospheric processes. Their sinks are predominantly in the atmosphere. CO_2 on the other hand is governed by the processes of the carbon cycle. The concentration of CO_2 in the atmosphere is determined predominately by interactions between atmospheric concentrations and the oceans and terrestrial systems.

Models deal with CO_2 in a variety of ways which range from simple airborne fraction models, which use a proportional approximation method to determine atmospheric concentrations, to interactive processes models of the atmosphere and biosphere. The present understanding of both the carbon cycle and atmospheric chemistry have been surveyed by IPCC Working Group I.

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(1)The following types of values of unmanaged eco-systems are identified in Chapter 6 of this report: (1) direct and indirect use values (e.g., plant inputs into medicine and the role of mangrove forests in coastal protection, respectively, (2) option value (preserving a species to retain the possibility that it may be of economic use in the future), and (3) existence value (i.e., the value of knowing that there are still blue whales).

Full scale IAMs should ultimately also consider the problem of local air quality as the removal rates for local air pollutants depend on weather conditions. This in turn interacts with the economic value of changes in health conditions. The third information set that a full scale IAM must generate is the state of climate and sea level. These two information sets are interdependent. That is climate cannot be derived without dealing in one way or another with oceans. Oceans are an important determinant of the timing of climate change, as they represent an enormous heat sink. They thus also determine the rate of sea level rise. In addition, interactions between the atmosphere and cryosphere affect climate change and sea level. Sea level calculations must grapple in some way with the major land based ice sheets.

It should also be noted that the ocean which interacts with atmospheric processes in determining climate change and sea level is the same ocean which is absorbing carbon in the atmospheric composition model. Thus, while Figure 1 treats them as if they were separable features, they are not, and more process oriented IAMs will have a single ocean model which determines carbon uptake, sea level rise, and thermal lag in climate change.

In Figure 1, the fourth category of IAM information is ecosystems. This category includes information associated with the natural system emissions of greenhouse related gases, the terrestrial carbon cycle, the effect of climate change, sea level rise, and CO_2 on crops, pastures, grazing lands, forests, hydrology, and unmanaged ecosystems.

These systems are strongly interactive. Some models handle them in a holistic manner, explicitly considering the interactions of natural system emissions, the status of unmanaged ecosystems, hydrology, ground cover, crop and forest productivity. Other models treat them as if

they were independent. The managed biosphere interacts strongly with human systems, which determine the selection of crop and managed forest species, and the allocation of water resources among competing ends. Interactions between ecosystems and the climate and sea level functions are presently thought to be of second order importance and are not dealt with in a majority of IAMs.

In addition to the degree of complexity (including disaggregation) considered within and between modules, another major design consideration in an integrated assessment model is the treatment of the considerable uncertainties about virtually every major relationship in the climate change assessment system. Future population and economic growth are uncertain, future greenhouse gas emissions given population and economic activity are uncertain, future greenhouse gas concentrations given emissions are uncertain, future climate given atmospheric concentrations of greenhouse gases are uncertain, future physical impacts of climate change are uncertain, and the future valuation of the physical impacts attributable to climate change are uncertain.

Uncertainty can be handled in a number of ways in integrated assessment modeling. Extensive sensitivity analysis can be performed on key model inputs and parameters, or explicit subjective probabilities can be assessed for these inputs and parameters and input into a formal risk or decision analysis framework. If a formal risk or decision analysis approach is pursued, it is generally possible to calculate the value of information with respect to wholly or partially resolving the uncertainty associated with each key input or parameter. Such calculations can provide a useful screening of uncertainties to determine where research expenditures may or may not have large net expected benefits. Combined with estimates of research costs and success probabilities, they can help set research probabilities in a rationale way. Of course, these

priorities can be expected to change over time as research itself changes perceptions of research costs and benefits.

Overview of Existing Integrated Assessment Models

Prior to 1992, only two integrated assessment of climate change models had appeared in the literature (Nordhaus, 1989, 1991); Rotmans (1990). Since 1992 a host of new models have emerged.

State of the Art in Integrated Assessment Modeling

It is difficult to characterize the state of the art in integrated assessment modeling of climate change simply - a great deal of model development is underway at present, involving a large number of research teams, with members drawn from a myriad of relevant disciplines, focusing on different dimensions of the problem, using different types of methodologies. Nonetheless, a focus on the tradeoffs between natural systems model complexity, economic model complexity, and effort devoted to the explicit incorporation of uncertainty can help us understand the model development that has been completed, that is occurring today, and that is planned or anticipated for the future.

There are two broad classes of integrated assessment models (Weyant, et al., 1996): (A) models that project the physical, ecological, economic and social consequences of policies - these are referred to as policy evaluation models here; and (B) models that optimize over key policy control variables (e.g., carbon emission control rates, carbon taxes) given formulated policy goals (e.g., maximize welfare, minimize the cost of meeting a carbon emission or concentration target) - these are referred to as policy optimization models here. There are two general types of policy evaluation models: (A1) deterministic projection models in which each input and output

takes on a single value, and (A2) stochastic projection models, in which at least some inputs and outputs are treated stochastically. There are three general type of optimizing integrated assessment models: (B1) models that optimize responses given targets for emissions or climate change impacts, (B2) models that seek to balance the costs and benefits of climate policies, and (B3) models of sequential climate decision making under uncertainty. Each approach has strengths and weaknesses, and produces particular insights regarding climate change and potential policy responses to it. Some of the more advanced models can be used for several of the above purposes. Each approach has strengths and weaknesses, and produces particular types of insights regarding climate change and potential policy responses to it.

The policy optimization integrated assessment models focus on equilibrating the marginal costs of controlling greenhouse gas emissions and adapting to any climate change impacts that may occur with the damages that results after implementation of the mitigation and adaptation policies.

These models reflect the cost/benefit paradigm shown in Figure 2. In this approach any constraint on human activities is explicitly represented and costed out. At present, models of this type include very aggregate representation of climate damages, generally representing economic losses as a function of mean aggregate surface temperatures, but sometimes disaggregated into market and non-market damage components.[1] Thus, as additional research on climate change impacts proceeds, it may be determined that these measurements are inaccurate. Moreover, it may be difficult to get policy makers to implement policies based on aggregate damages, as they are more likely to be able to relate to impacts on particular regions/countries and sectors (e.g.,

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(2)An exception is the FUND model (Tol, et al., 1994) which has separate damage functions for each of the damage categories discussed in Chapter 6.

agriculture, biodiversity in tropical rain forests) which are not explicitly represented in the current set of cost/benefit type integrated assessment models. Early models of this type were also complicated enough that it was difficult to incorporate explicit representation of uncertainty (and risk aversion) within the model structures. As discussed below, this situation has improved somewhat over the last couple of years.

The policy evaluation IAMs add detail on the physical impacts of climate change on countries/regions in various market and non-market sectors based in part on the impacts and mitigation areas addressed in IPCC Working Group II. Economic values have not generally yet been put on these impacts, reflecting both the paucity of valuation studies in some sectors, and the modelers perception that policy makers feel more comfortable trading off natural and physical impacts than dollars. In addition, the targets can be set to avoid certain types of risks, perhaps according to the "precautionary principle." On the other hand, there is no guarantee that the marginal cost of implementing the mitigation and adoption measures resulting from the individual targets will equal the marginal benefit (if they can be assessed) of the impacts avoided. In addition, like the early cost/benefit models these models have also been large enough that limited amounts of sensitivity analysis can be performed, but more explicit representations of uncertainty (and risk aversion) have not been included (although preliminary uncertainty analyses have been performed with the TARGETS model, van Asselt, et al., 1995).

Reflecting the high level of uncertainty about the future evolution of socio-economic and natural systems, some analysts have put the analysis of climate change into explicit decision making under uncertainty frameworks, of the kind discussed below. These models have generally either been the results of a relatively complete uncertainty representation of all key parameters within simplified models of the types discussed above, or the result of adding a limited number of alternative states to the policy evaluation and policy optimization models discussed above. In addition, many of these models allow policies to be changed as uncertainties are resolved through time, although the process by which uncertainties will be resolved is usually represented quite simplistically. Stochastic models can generate multiple scenarios that in some cases have probabilities associated with them . Then, the (usually more complex) deterministic models can be run to investigate specific scenarios further.

Uses of Integrated Assessment Models

Each of the main types of integrated assessment models can be used to provide information that can be useful to policy makers, but the information provided differs significantly according to the type of model employed. Deterministic policy optimization models can be used to compute optimal carbon taxes and emissions control rates for a particular set of model inputs and parameters. They can also be used to calculate the costs of meeting emission, concentration, climate variable, or impact sector targets. Stochastic policy optimization models can be used to assess optimal carbon taxes and emissions levels under uncertainty (see below for a specific example) and to compute the value of better information about model inputs or parameters.

Deterministic policy evaluation models can be used to project a wide range of climate impacts, to insure consistency in assumptions, to assess interactions and feedbacks in key systems, and to identify critical gaps in research. Stochastic policy evaluation models can be used to compute probabilities distributions of the costs and benefits of climate policies and of meeting climate change or climate change impact targets.

COST ANALYSES

Analyses of the cost of energy-environmental policies are discussed in a little more depth in this section. After a brief overview of the different types of costing models that have been used, the major determinants of cost projections are identified, and results from a large number of studies of the cost of reducing carbon emissions are synthesized.

Cost Models

Although each model has characteristics that are unique to it and have proven to be extremely valuable for studying certain types of issues, the structures of the models can be put in the three basic categories with a small number of sub categories. Many of the models now employing combinations of the traditional modeling paradigms.

One category of models focuses heavily on the energy sector of the economy. These models consider the consumption and supplies of fossil fuels, renewable energy sources, and electric power generation technologies, as well as energy prices, and transitions to future energy technologies. In general, they explicitly represent capital stock turnover and new technology introduction rate constraints in the energy industries, but take a more aggregated approach in

representing the rest of the economy. In these models, all industries are aggregated together, and GDP is determined by an aggregate production function with capital, labor, and energy inputs. These models generally omit inter-industry interactions and assume full employment of capital and labor. The MERGE3, CETA, and GRAPE models are examples of this category of models. MERGE3 and CETA have the same basic structure, but nine and up to four regions, respectively. GRAPE includes a somewhat broader set of technology options, including especially carbon sequestration technologies.

A second category of models are those that include multiple economic sectors within a general equilibrium framework, focusing on the interactions of the firms and consumers in various sectors and industries, allowing for inter-industry interactions and international trade in non-energy goods. In these models, adjustments in energy use result from changes in the prices of energy fuels produced by the energy industries included in the inter-industry structure of the model (e.g., coal, oil, gas, electricity), and explicit energy sector capital stock dynamics are generally omitted. These multi-sector general equilibrium models tend to ignore unemployment and financial market effects. The MIT-EPPA, and WorldScan models are examples of this type of model. G-Cubed does consider some unemployment and financial effects and is, therefore, a hybrid general equilibrium/macro-econometric model. G-Cubed, MIT-EPPA, and WorldScan all include trade in non-energy goods.

A third basic class of models combines elements of the first two categories. That is, they are multi-sector, multi-region economic models with explicit energy sector detail on capital stock turnover, energy efficiency, and fuel switching possibilities. Examples of this type of hybrid model are the AIM, ABARE-GTEM, SGM and MS-MRT models. These models include trade in non-energy goods, with AIM including energy end-use detail, GTEM and MS-MRT including

some energy supply detail, and the SGM considering five separate supply sub-sectors to the electric power industry.

A variant of the multi-sector modeling category is one which includes macro-economic dimensions. By including unemployment, financial markets, international capital flows, unemployment, and monetary policy, the Oxford model is the only model included here that is fundamentally macro-economic in orientation. The G-Cubed model does consider some unemployment and financial effects, as well as international capital flows.

In many models, technologies are represented with "production functions" that specify what combinations of inputs are needed to produce particular outputs. The production function specifies the rates at which inputs can be substituted for one another in response to shifts in input prices. As new capital investment occurs and older capital is retired, the technology mix within the model will change.

Two basic types of production functions may be specified. Some models (e.g., G-Cubed, SGM, and EPPA – see box for information on models cited in the text) use smooth and continuous aggregate production functions that allow incremental input substitutions as prices change, even if the resulting input configuration does not correspond to a known technology. These models do not represent individual technologies. Such models often assume 'nested' production functions: For example, at one level, substitutions are possible between energy, capital, and labor in producing final commodities; at a second level, substitutions are possible between electricity and fuel oil in producing energy; and, at a third level, substitutions are possible between coal and natural gas in producing electricity.

In contrast, other models (e.g. Markal-Macro and NEMS) draw from a 'menu' of discrete technologies, each requiring fixed input combinations—i.e., each technology is essentially

represented with its own production function. This approach is often referred to as "process analysis." These combinations correspond to those employed in actual, or anticipated, technologies that the modeler specifies. The technology-rich Markal-Macro model specifies over 200 separate technologies. For discrete technology models, different technologies become cost effective as input prices change. Modelers then assume that these technologies are selected and used to produce outputs. A number of models use a process analysis approach within the energy sector and an aggregate production approach for the remainder of the economy (e.g., MERGE, MARKAL-Macro). When using either approach, it is important to be able to distinguish between the causes of changes in the selections the models make among the existing technologies. Sometimes the technology choice changes because of changing prices, and sometimes it changes because of new technologies becoming available.

Some models represent both individual energy supply technologies and individual energy consumption technologies, and do not represent the remainder of the economy explicitly. With these models, however, the analyst must either: (1) assume that "end-use" energy demands (such as the demand for home heating and automotive transport) do not respond to changes in the prices of those services, or (2) employ a complex statistical estimation technique (that requires some historical data on the cost of end-use energy equipment) to estimate the price responsiveness.

Determinants of Cost Projections

What are the potential costs of cutting greenhouse gas (GHG) emissions? Can such reductions be achieved without sacrificing economic growth? Interest groups active in the climate change debate believe the stakes are high. Some fear the environmental and socioeconomic costs of climate change itself. Others are more fearful of the economic consequences of trying to avoid climate change. This debate is, to a large extent, played out through economic analysis of climate

change policy. Hundreds of these analyses have been published over the past decade, and this pace is likely to continue. Large computer models are used to perform economic analyses.

These analyses are rich and extensive, but widely divergent in their results. Many predict the domestic costs of complying with the Kyoto Protocol. Numerous groups have concluded that the United States can reduce its carbon emissions to significantly below its Kyoto target, with net economic savings. Others have predicted rather significant costs to the U.S. economy.

Through these economic analyses, people translate their expectations into concrete assumptions about the future. The set of assumptions that describe what happens in the future if nothing is done to control GHG emissions is known as the "base case" (or as the "baseline" or "business-as-usual" case). The base case may embody optimism or pessimism about the economy, about GHG emissions, about the changes in climate that will occur as a result of these emissions, and about what will happen to the environment as a result of this climate change. The higher the base case emissions, the more emissions must be reduced to achieve a particular target, and therefore the higher the control costs. The greater the base case climate impacts, the greater the benefits of controlling emissions.

Two other assumptions drive projections of what will happen if society does control GHGs. Will new, low-cost, low-emitting technologies become available? Will consumers and producers respond cleverly, meeting their needs differently but equally well through lower-emitting products and services? Economic analyses may embody optimism or pessimism on either of these fronts.

A fourth assumption is related to how society goes about requiring GHG control, i.e., what policies the government will put in place. Will the policies be flexible, allowing targets to be met

at significantly lower costs? For example, one key aspect of the policy regime is the extent to which emissions trading is allowed. Another key aspect is the inclusiveness of the policy. Will carbon-absorbing activities, such as tree-planting, count as an offset to carbon emissions? Will all GHG emissions count, and will inter-gas trading be permitted?

Finally, most quantitative analyses make assumptions about the degree of foresight consumers and corporations employ in assessing investment decisions, and about the proper rate of discount to be used in comparing costs and benefits that occur at different points in time.

Three or the six key assumptions–substitution, innovation, and foresight --are structural features of the economic models used to make emissions projections. The other three are external factors or assumptions. The results summarized in this Weyant, 2000, 2002) illustrate the importance of these six determinants and the large role played by the external factors or assumptions. Cost projections for a given set of assumptions can vary by a factor of two or four across models because of differences in the models' representation of substitution and innovation processes. However, for an individual model, differences in assumptions about the baseline, policy regime and emissions reduction benefits can easily lead to cost estimates that differ by a factor of 10 or more. In understanding how these five determinants influence cost projections, decision-makers will be better equipped to evaluate the likely economic impacts of climate change mitigation. For example, among the twelve models and dozens of model runs reviewed, the base case forecasts range from a 20 percent to a 75 percent increase in carbon emissions by 2010.

BENEFIT ANALYSES

The benefits of environmental polices result from the reductions in the impacts of the emissions of environmental pollutants that are expected to result from their implementation. Here, again climate change is used as an example application area. The impacts of climate change are expected to result from changes in the climate system resulting from changes in the rate at which

greenhouse gases are emitted. The impacts can usefully be disaggregated into three categories: (1) impacts on sectors whose products are sold in formal markets, (2) impacts on sectors whose products are not sold in formal markets, and (3) impacts on sectors where some outputs are sols I markets and other are not.

Market impact sectors include:

Agriculture
Forestry
Coastal Zone Infrastucture
Water Supply
Energy Consumption
Fisheries

Non-Market impact sectors include:

Unmanaged eco-systems (both terrestrial and marine)
Wildlife
Amenities (e.g., sunshine and beautiful surroundings)

Sectors that can include both market and non-market impacts include:
Human Health
Bio-Diversity
Recreation

Benefits Models

Four basic types of models have been used to assess the impacts of climate change and benefits of policies designed to reduce the extent of climate change. The first type of model represents the output of a sector - in terms of either market value or physical measures – as a function of the inputs to the sector. For example, the output of the agricultural sector – in terms of either value or bushels of products – are frequently represented as a function of inputs of like fertilizer, different technologies for growing crops, irrigation, and various climate variables like the length of the growing systems and the minimum and maximum daily temperatures. For a non-market sector like eco-systems output is typically measured in terms of eco-systems services and inputs

in terms of current land cover, soil conditions and various climate variables. This approach is generally very data and estimation methodology intensive.

Where sufficient data is unavailable to do a structural model of impacts, a reduced-form aggregate statistical analysis approach is sometimes used. In this approach limited data on the inputs to - and outputs from – a sector are pooled across regions and then used to estimate a general relationship between inputs and outputs that assumes technologies are the same every where. Although useful insights continue to be developed using this approach, it is important to realize that the transferability of results from one region to another may be questionable in cases where there are large differences in conditions including the technological sophistication of the work force in the areas being considered.

A third approach that has been used in assessing the value of recreational activities for many years is the so-called "travel cost model" approach in which the minimum value an individual places on a recreational activity by adding up the wages lost by that individual to engage in that activity, the cost of getting to the site and any direct fees and licenses required.

The final approach to estimating benefits is the so-called "contingent valuation" survey approach, which is used in situations where no market data that can be used to assess consumer preferences is available. In this approach individuals are asked to specify the amount they would be willing to pay for something that is not sold in formal markets. For example, people might be asked to specify how much they might be willing to pay to avoid the loss of large numbers of animal and plant species from the earth. Although there are many possible biases – e.g., people will generally say they will pay more for something they currently get for free if they know they will not then be required to pay what they specify. Despite these potential problems these techniques

can provide valuable inputs to the policy process in part because such impacts might otherwise be implicitly or explicitly assigned no value at all.

Determinants of the Costs of Climate Change

Looking across impact sectors several factors seem to influence the impact/benefit projection. The baseline level of activity in the sector is important and the sensitivity of that level of activity to changes in climate are positively correlated with the magnitude of the impact. The ability of the sector to adapt to changes in climate and technological change are generally negatively correlated with the impact estimate. Although it is commonly believed that climate change will increase climate variability there is so far not much direct evidence of this relationship. In addition, it is felt that increases in climate variability will, holding everything else constant, lead to higher climate damages, but again the evidence on this is just starting to accumulate.

Health Impacts of Climate Change

As an example of a climate change impact sector we will use the current study on this subject by the London School of Hygiene being done as part of the World Health Organization's Global Burden of Disease study. The objective of this study is to get rough estimates of the possible global health impacts of future changes in climate. Figure 3 shows the basic approach of the study: (1) start with a range of greenhouse gas emissions scenarios, (2) uses global climate modeling to project changes in regional climate resulting fro the GHG emission projections, (3) use health models to project the changes in the relative risk of specific health outcomes, and (4) convert those projected increase to increase in Disability Adjusted Life Years (DALYs). Included in this study are impacts on: (1) direct heat and cold related deaths, (2) the incidence of diarrhea, (3) the number of cases on vector-borne diseases like malaria and dengue fever, (4) deaths and injuries attributable to coastal and inland flooding, and (5) the risk of malnutrition.. Omitted from the study are areas where the health impacts of climate change are projected to be

relatively small like ciguatera poisoning and tick-borne encephalitis and areas where the data is poor and quantitative models lacking like impacts on: (1) other infectious diseases, (2) drought and famine, (3) population displacement, (4) destruction of health infrastructure, (5) increased urban air pollution, (6) indirect effects on plant pests and diseases on food production, and (7) conflict caused by climate change and its environmental impacts (e.g., conflict over increasingly scarce water).

INTEGRATING COSTS AND BENEFITS

Given the range and heterogeneity of sectors where climate change impacts are expected and the different ways of measuring them from physical units through various types of valuation methods it is not surprising that there is a debate about the extent to which they should be valued and aggregated that precedes any discussion of how the valuation and aggregation might be done. In its third assessment report the Intergovernmental Panel on Climate Change (IPCC) developed a way of trying to communicate the range of different types and levels of understanding of climate change impacts to policy makers. First, a number of "causes for concern" were identified. These included: (1) risk to unique and threatened systems – like coral reefs, bird populations, low-lying island nations, etc., (2) risks from extreme climate events like hurricanes and tropical cyclones, (3) distribution of impacts by region and level of income, (4) aggregate impacts as produced by highly aggregated economic models, and (5) risk from future large-scaled discontinuities like the shut down of the North Atlantic Thermo-hyaline circulation or melting of the Antarctic ice sheet. These causes for concern are then matched up with the range of temperature

changes projected for the next century as shown in Figure 4. Here the intensity of the color indicates the likely severity of the impacts in a particular area for concern and words are added to refine this scale and extend it with statements about relative numbers of people affected rather than just assets at risk.

There are a number of additional ways in which analysts can try to integrate projections of the costs and benefits of policies. One often used way is to set a target for emissions, concentrations, temperature change, or impacts and project the cost minimizing plan for respecting this target. When implemented at the impacts level this strategy is sometimes referred to as the "tolerable windows" or "safe landing" approach. A second strategy is to set targets, observe costs and adjust the targets as appropriate. Finally, the cost-benefit approach shown schematically in Figure 2 can be employed to determine the optimal levels of emissions and an optimal carbon taxes. This approach does require some aggregation and complete valuation of climate change impacts.

UNCERTAINTY ANALYSIS

The number of complexities and uncertainties that pervade the cost, benefit and integration elements of integrated environmental analysis strongly suggests the efficacy of employing some form of informal or formal uncertainty analysis At the very least extensive sensitivity analyses seems a minimum requirement for credible analysis. Beyond sensitivity analysis only a relatively small amount of formal uncertainty analysis had been applied to the climate change issue. A survey (current as of 1999) of difference approaches to dealing with uncertainty in climate change policy analyses is given in

Weyant and Kann (2001). Figure 5 shows the range of approaches reviewed in that paper. Both decision analytic and stochastic optimization approaches have been used and the published analyses vary in terms of the number of periods considered and assumptions about who learns what information when and what they are able to do with it. To give a reader a feel for how such models are formulated, Figure 6 shows a summary of an experiment described in Manne, et. al. (1996). Here there is a single uncertainty – whether of not climate damages will be what is currently expected (the 95% damages case) or whether they will be much higher – say at the upper 1 % of the probability distribution of climate damages (the 5% damages case). The figure shows the emissions trajectories that are optimal if it is known in advance whether damages will be at the expected level or at the high level, as well as for the case where there is a 5% chance of high damages with the true state of climate damages revealed in 2020. In this latter case, it is optimal to restrict emissions between those for the 95% and 5% cases until 2020 and then adjust to the actual damage state starting in 2020. This is obviously a very instructive, but very simplistic, set of calculations. The impact of more realistic assumptions about multiple decision makers, more uncertainties to be resolved, more dates at which perfect of imperfect information is expected to be acquired, who gets this information and how they use it are yet to be explored although very preliminary attempts to do so have been made in the studies reviewed by Weyant and Kann (1999).

SOME KEY CHALLENGES FOR INTEGRATED ASSESSMENT

Integrated assessment faces a number of formidable challenges. Some of these have already been mentioned and others will be noted in this concluding section of the paper.

Some of these are technical challenges, others have to do with how models are used and results from them communicated. The technical challenges include: dealing with uncertainty, comparing impacts across time and space, incorporating sustainable development into climate policy analyses, measuring and evaluating climate change impacts, integrating climate impacts with the impacts of policies designed to ameliorate them, and representing technology/technological change and linking that information to policy options. The challenges of dealing with uncertainty, valuing impacts and integrating costs and benefits have already been discussed, so they are further elaborated here only in-so-far-as necessary to discuss the other challenges.

One critical challenge faced in valuating climate change impacts at a global scale over the next century or two is comparing impacts across different regions and over generations. Some insights into the nature of these challenges are developed in Portney and Weyant (1999), but there is no consensus on how to proceed. These are fundamental challenges for economics, but become particularly relevant. For the climate change problem which plays out globally over many generations.

Complicating this technical challenge our marked differences in experiences and outlooks between the developing and developed countries. Figure 7 (purposefully overstated) shows that at times analysts in developed countries weigh the interests of people in developing countries only in terms of what they produce and sell in markets (i.e., not very heavily), while people in developing countries tend to weigh the interests of the most vulnerable (i.e., poorest) individuals (i.e., themselves) most heavily. This makes

negotiating hard and substantially enhanced and modified models will probably be necessary to facilitate more meaningful dialogue between the North and South.

Related to the comparison of benefits and costs across time and space, but from a very different perspective is the issue of how to incorporate appropriate dimensions of the quest for sustainable development into climate policy analyses. The idea here is that all countries have economic development that need to be integrated into analyses of potential environmental policies in some way. Consideration of economic development in the analysis and development of climate change policies is particularly important in the case of developing countries where people often suffer from very low income levels, poor health and poor institutions, including market that are far from perfect. Although it would be inappropriate, and probably impossible, to analyze each energy-environment issue in a comprehensive development planning framework, not including any consideration of development goals in the analyses of international environmental policy regimes would probably prevent any meaningful participation by developing countries in those regimes.

Another major challenge for integrated assessment is projecting technological change. This area is particularly difficult because of lack of data, the complicated nature of the wide range of factors that tend to lead to innovation and the inherent uncertainty in the course and rate of technological progress (see Clarke and Weyant, 2002). For example, Figure 8 is a schematic showing a large number of factors that influence the rate of technological change that have been mentioned in the literature (although generally not or

only partially analyzed). The global climate policy models, however, either assume that technological change is totally exogenous or only focus on the influence of environmental taxes on the incentive for homogeneous firms to innovate given the existence of intrasectoral spillovers.

Challenges of Model Use

A number of common pitfalls can be identified in how integrated assessment models have been used. An immediate problem that arises is choosing a model structure without a good idea of the applications to which it will be applied or using a model designed for one purpose for a completely difference purpose. This can easily, and often unwittingly, lead to a large complicated analysis that does not produce much of the information the policy development process requires.

Another problem that can arise in the use of models that have been used and have some track record in analyzing a particular issue of set of issues, is the propensity of the model builders to tacitly assume that any relationship not in the model probably either does not exist or is decidedly second order in magnitude. This can also lead to testing the implications of alternative assumptions against what the model includes as opposed to how the world actually operates, and to convenient arguments by the modelers that limitations of the models correspond to restrictions that exist in the real world.

Finally, even if the strengths and limitations of the analytic tools are fully appreciated by the modeling community, there is the difficult task of communicating to policy makers

exactly what can be concluded from the analyses that have been done. All too often key relevant assumptions and qualifications get left out of that communication process. If these omissions are subsequently identified and communicated to the policy makers, they can often lead to a lack of faith in subsequent results from the models.

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Figure 1. Key Components of Integrated Assessment Models

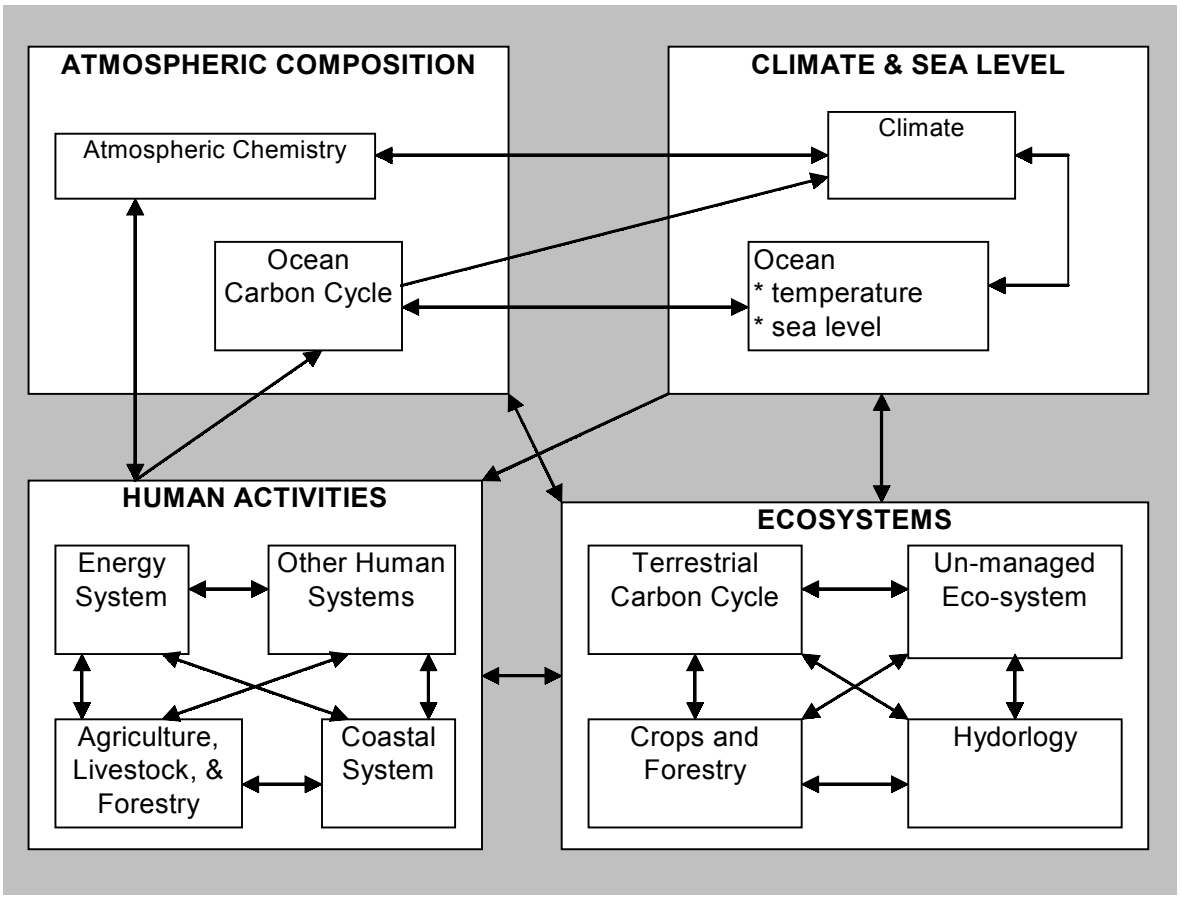


Figure 2. Cost/Benefit Modeling Approach: Balancing the Costs of Controlling Carbon Emissions Against the Costs of the Climate Impacts They Cause

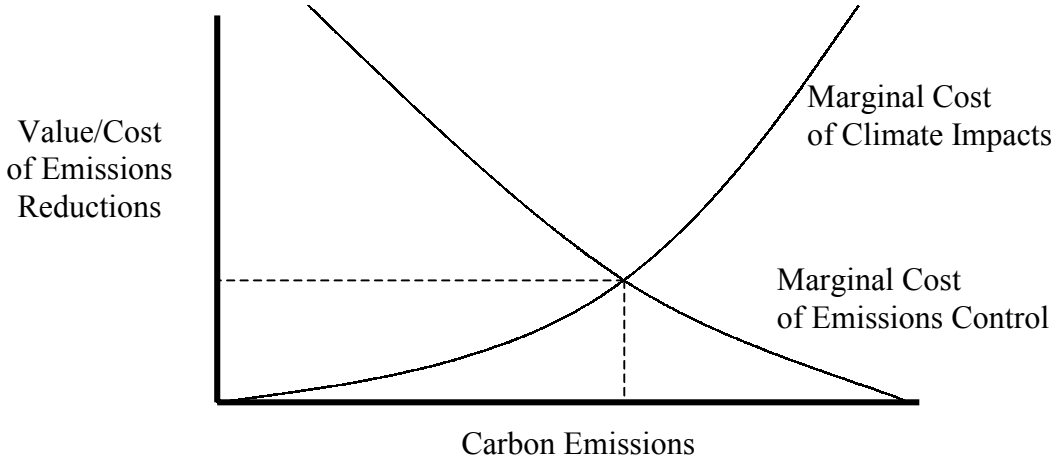


Figure 3. Overview Of CRA Process For Climate Change

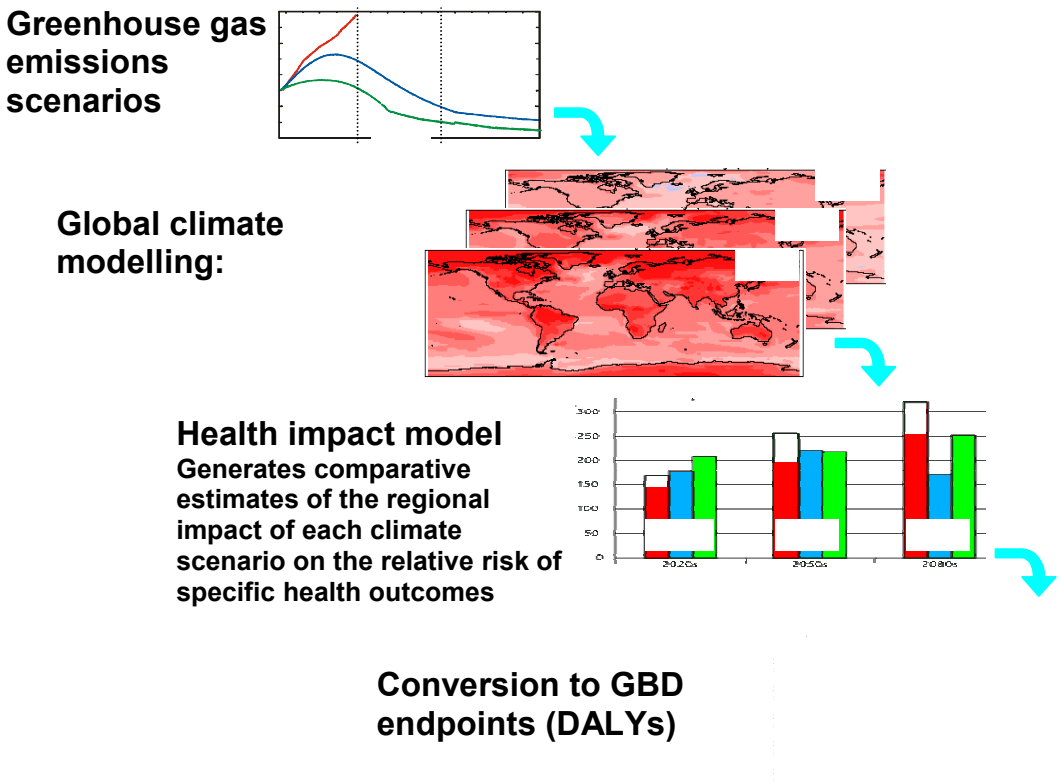


Figure 4. Causes for Concern

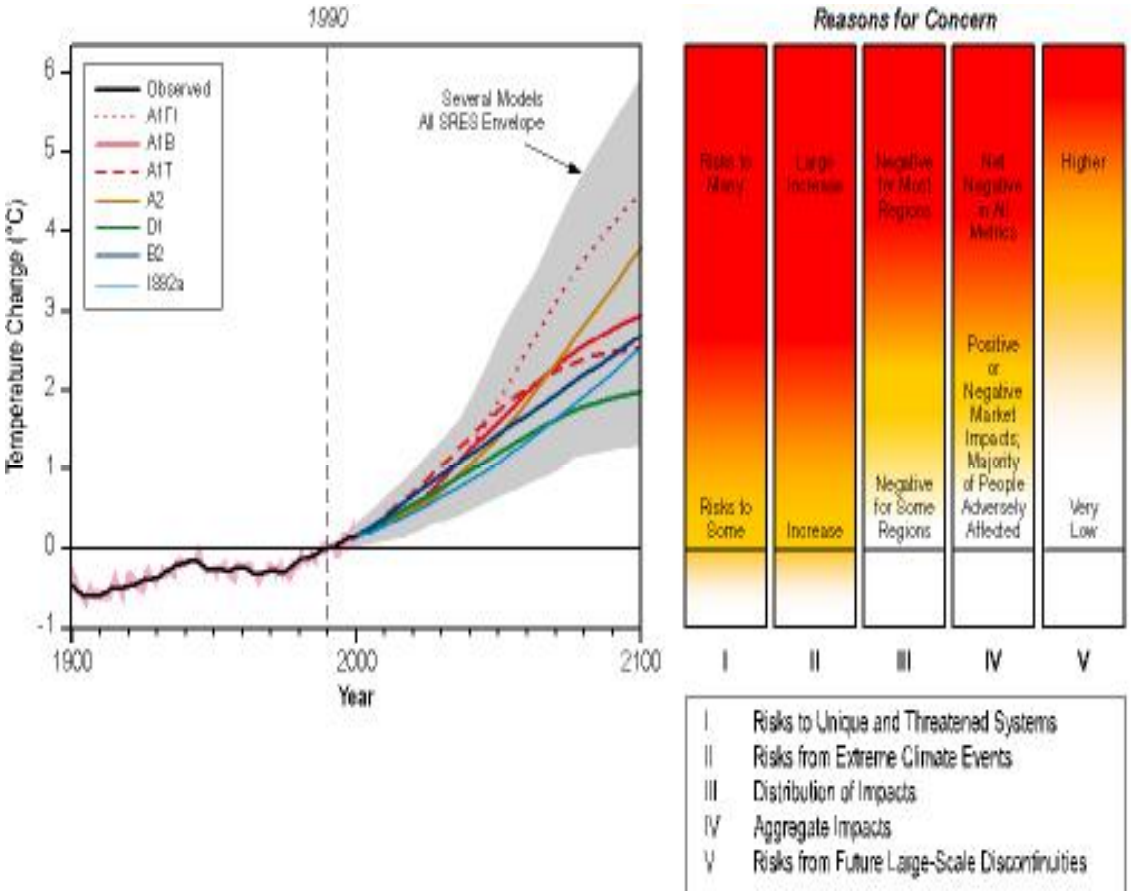


Figure 5. Range of Approaches Used to Deal With Uncertainty in Integrated Assessment

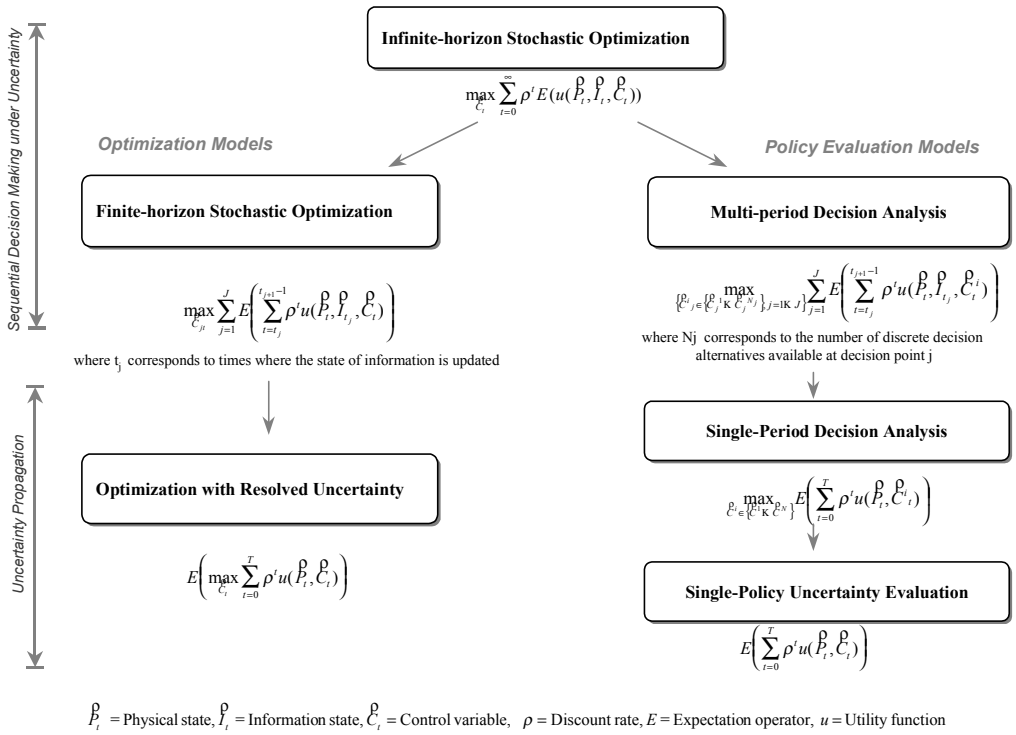


Figure 6. A Simple Example of Dealing with Uncertainty in Integrated Assessment

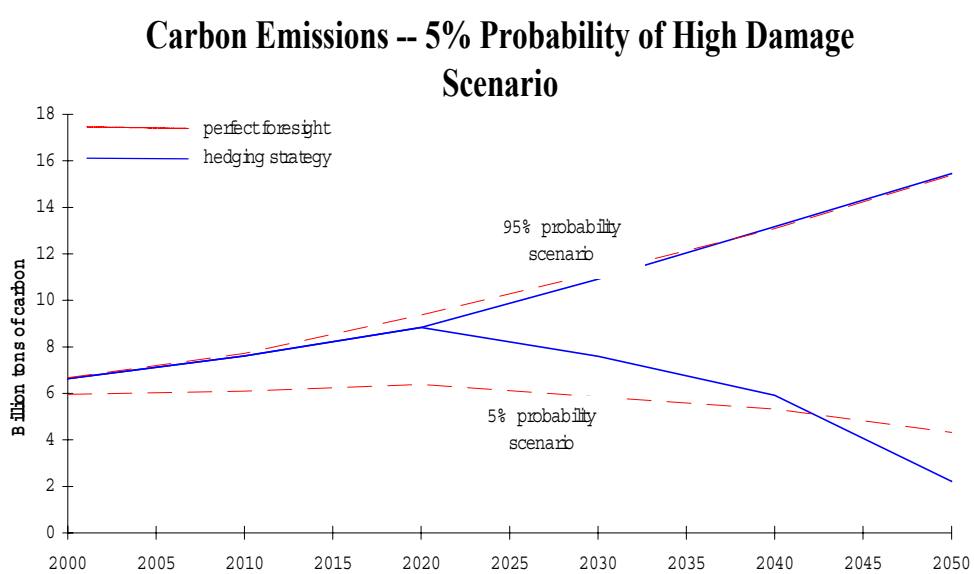
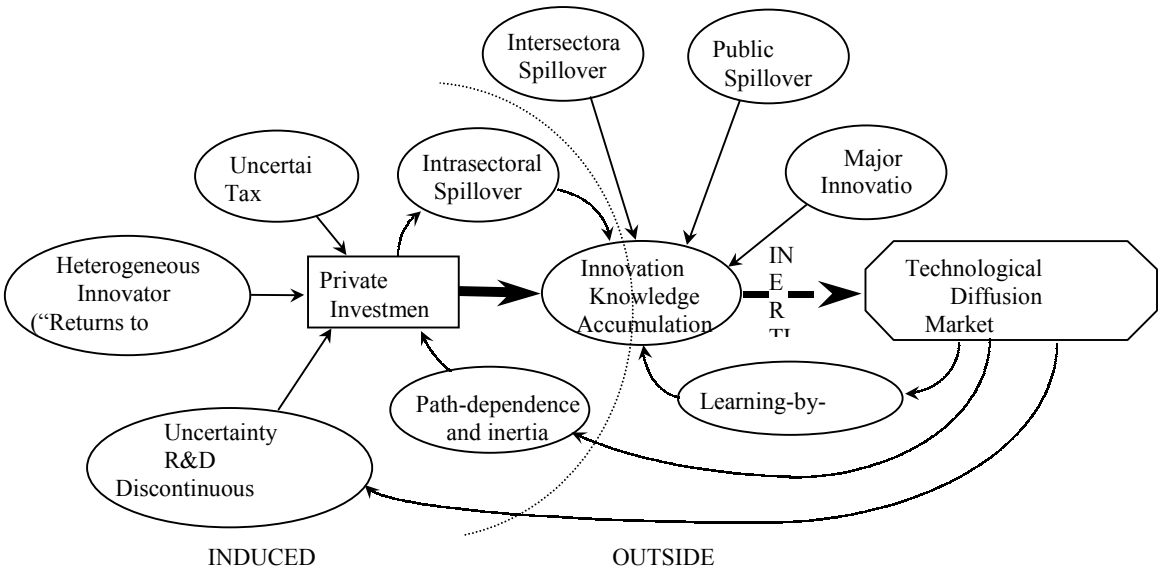


Figure 7. Contrast in World Views on Climate Change Policy Analyses

Class of World Citizen	Typical OECD (AEA Member?) Analysis	ROW Analysis
2 Billion People Without Markets	What 2 Billion People?	High Priority: Reduce Their Vulnerability
2 Billion In or Near Poverty with Fragile Markets	They Don't Count for Much!	High Priority: Reduce Their Vulnerability
2 Billion Potential Decaf Latté Drinkers	Half Are Stuck In Transition, But the Rest We Can Help	They Can Take Care of Themselves

Figure 8. Overview of Important Determinants of Technological Change

Current approaches omit important dynamics of technological change. A broader framework for analyzing ITC is needed.