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Integrated assessment and environmental policy making

In pursuit of usefulness

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Current integrated assessment projects primarily seek end to end integration through formal models at a national to global scale, and show three significant representational weaknesses: determinants of decadal-scale emissions trends; valuing impacts and adaptive response; and the formation and effects of policies. Meeting the needs of policy audiences may require other forms of integration; may require integration by formal modeling or by other means; and may require representing decisions of other actors through political and negotiating processes. While rational global environmental policy making requires integrated assessment, current practice admits no single vision of how to do it, so understanding will be best advanced by a diverse collection of projects pursuing distinct methods and approaches. Further practice may yield some consensus on best practice, possibly including generic assessment skills generalizable across issues.

Keywords: *Integrated assessment; Environmental policy; Modeling*

While there have been examples of integrated assessment of important environmental issues for 20 years or more, the last three years have seen a rapid increase in work on, and interest in, integrated assessment of climatic change. The papers presented in this volume are indicative of the amount of energy, and the breadth of interest, going into this field.

Substantial confusion and fruitless definitional debate has surrounded the concept of integrated assessment, perhaps because the term embeds two distinct opportunities for obscurity: what is assessment, and what does it mean for assessment to be integrated? I propose to separate these two concepts as follows. Assessment, in contrast to pure research, is the presentation of knowledge derived from research to help someone with responsibilities evaluate possible actions or think about a problem. Assessment is recognized by its purposes.

Assessment normally does not mean doing new science, but rather assembling, summarizing, organizing, interpreting, and possibly reconciling pieces of existing knowledge, and communicating them so that they are relevant and helpful for the deliberations of an intelligent but inexpert policy maker. What this requires depends strongly on the specific decision context or issue to be informed. It may be a simple exercise in the clear communication of information that is well known and accepted by a specific research community. More often, however, it is synthetic. It may require expressing results in different forms or at different resolutions; drawing causal inferences from knowledge or data that lie outside the scope of the discipline that generated them (if you do X, then Y will (probably) happen); or combining propositions from different disciplines, of different degrees of confidence and verification. Because assessment is driven by the need to inform important decisions, it may require statements of

probability, or of the degree of confidence with which a certain contention can be held, that would be unacceptable within a disciplinary debate, either because they would breach norms of propriety or because the discipline lacks authoritative means to agree on them.

What, then, does it mean for assessment to be integrated? Again, the answer is highly context dependent. In general, to be integrated means to assemble, and to make coherent, information from a broader set of domains than would typically be provided by good research from a single discipline. There can be many dimensions of integration, and many possible degrees or forms of integration on each dimension. There is some redundancy between 'assessment' and 'integration', since most assessment will require some integration. It is possible in principle, but likely to arise only infrequently, that an issue of importance that a responsible person faces can be well understood, or a significant choice well advised, with reference only to the research output of a single field.

On matters related to global climate change, many actors will face many decisions that could, and should, be informed by careful integrated assessment activity. As I will argue in subsequent sections, the distinct characteristics of these actors and the issues and decisions they face may require different ways of doing and managing assessment. Different dimensions and degrees of integration may be appropriate for different applications. Maximal integration is not always an appropriate goal. Moreover, some important questions about appropriate organization, support, and oversight of the assessment activity are not yet well understood.

The paper proceeds as follows. The next section presents a brief summary of common characteristics of current projects in integrated assessment of climatic change, and outlines three of the most serious weaknesses in their present representations of the human–climate system. The following sections discuss a set of issues concerned with the relationship between assessment and the decision or political process it seeks to inform, in two classes. First I discuss questions of design and implementation of a single integrated assessment project, while the following section considers goals and direction for an integrated assessment capability or system that may comprise multiple projects. Substantial parts of the argument are drawn from an earlier paper (Parson, 1994), which includes summaries of the approaches and methods of several integrated assessment projects now underway.

Current integrated assessment projects: characteristics and challenges

While the level of current activity in integrated assessment of climate change is unprecedented, earlier integrated assessments of major environmental issues have been conducted, usually under a specific charge from policy makers, since the early 1970s. Earlier assessments have included major projects on stratospheric ozone depletion (Grobecker *et al*, 1974) on acid rain in Europe and North America,[1] and one program on global climate change terminated early in its promising life.[2]

In contrast to these earlier efforts, current integrated assessment projects have emerged principally from the research and modeling communities, seeking to develop assessment tools to advance their understanding of the human–climate system, and to be of use to policy makers if and when they should ask for them. At risk of oversimplification in seeking to characterize a rapidly developing research program with many individual projects, current endeavors in integrated assessment of climatic change by and large have the following characteristics in common. First, they employ a spatial scale that lies between the national and the global, typically dividing the world into a set of regional groupings, some of which may be single large nations (world regions number from 2 to 15). The time-scales represented range from a few decades to somewhat longer than a century.[3]

With so few regions in the world, all these projects have rather coarse spatial resolution, and employ a variety of devices for interpolation, parameterization, and approximation to represent environmental (and other) processes that take place at finer spatial scale, or faster time scale, than their dominant resolution. Their sectoral resolution – that is, their representation of the specific economic activities generating emissions, and of the specific activities, resources, and people bearing the consequences of climatic impacts – is also coarse, posing difficulties for the representation of policies or the valuation of impacts.

The predominant interpretation current studies make of the meaning of integrated assessment is 'end to end'

[1]Extensive, highly influential assessment was conducted in Europe, clustered around the development of the RAINS model of acidification: see Alcamo *et al* (1990) and Hordijk (1991). In the USA a much larger 10-year assessment effort, culminating in a harshly criticized integrated assessment report in 1990, was undertaken by the National Acid Precipitation Assessment Program, see NAPAP (1991); NAPAP ORB (1991); Rubin (1991); and Rubin *et al* (1992).

[2]Carbon Dioxide Effects Research and Assessment Program (1980). Part of the story of this 1970s US Department of Energy program's demise is told in Schneider (1989).

[3]Descriptions of a selection of current and recent projects in integrated assessment of climate change can be found in Alcamo (1994); Hammitt *et al* 1992; Hope *et al* (1993); Dowlatabadi and Morgan (1993a); Dowlatabadi and Morgan (1993b); Edmonds *et al* (1993); Fisher-Vanden *et al* (1993); Manne *et al* (1994); MIT (1993); Nordhaus (1992); Peck and Teisberg (1992); Peck and Teisberg (1993); and Rotmans (1989). Houghton, J T, Jenkins, G J, and Ephraums, J J (eds) *Climate Change: The IPCC Scientific Assessment* Cambridge University Press, Cambridge, London

assessment – representing emissions, concentrations, global and regional climatic change, ecosystem change, and changes in environmental components or economic activities that people value, all in the context of a single causal chain from emissions to impacts.[4] The predominant means of accomplishing this end to end integration is through integrated computer models – created either by coupling existing sectoral models that each deal with one link of the causal chain, or by constructing new, simpler and more consistent, models that represent the chain from beginning to end (and possibly close the loop back to the beginning). In some cases, these models are embedded in larger research projects that undertake more in-depth investigations of particular aspects of the system than can necessarily or immediately be brought into a single integrated model.

Current assessment projects, in their attempts to represent the human-climate system from end to end, show three particularly important weaknesses. Perhaps surprisingly in view of the prominence of public debate about uncertainty and disagreement in climate models, representation of atmospheric systems is not among these fundamental weaknesses. While the atmospheric components of integrated assessment models naturally have limitations and uncertainties, and while their computational demands make them the most limiting components for such meta-modeling activities as sensitivity and scenario analysis and propagation of uncertainty, other assessment components pose more fundamental conceptual problems.

The first weak area is the projection of future emissions over decade to century time scales. Over these periods, population growth and technological change are likely to be the most important determinants of emissions paths, but these factors are also likely to be endogenously determined by economic and environmental changes, and policy choices. At present, though, we do not understand the fundamental determinants of these drivers – of changes in fertility and migration, or of the rate and character of technological innovation. For example, it is not known whether the aggregate effect of technical change will be to increase the emissions intensity of consumption, thereby exacerbating climate change, or to reduce emissions intensity and hence mitigate climate change. Present integrated assessment projects typically represent both population growth and technological change through sets of exogenous scenarios. Work now underway on improving understanding of the endogenous determinants of technological change could substantially advance this component, but there is a long way to go to practical understanding.

The second weak area is the description and valuation of impacts of climate change. Current projects take a wide variety of approaches to impacts. Some use highly aggregated methods that are acknowledged to be merely illustrative, such as drawing simple global aggregate-damage curves or response surfaces as functions of global change in radiative forcing or delta-T, or their time derivatives.[5] Others provide a first-order disaggregation of impacts in market and non-market sectors, (thereby distinguishing, eg changes in agricultural production from changes in health and in the pleasure people derive from climate and resultant ecosystem patterns), allowing different dependence of each on climatic change, and its timing and rate. Others employ detailed ecological process models to project shifts in species mix, productivity, and element cycling of plant communities.[6] This third approach, while presently in its early stages, could eventually permit detailed, high-resolution estimates of changes in agricultural yields and in the characteristics of valued but unmanaged ecosystems. However, all these approaches rely on some means of describing human adaptive response to changes in climate and ecosystems, and of valuing the changes. Both of these are highly problematic. For adaptation, careful observation and modeling of local and regional-scale adaptive responses may help.[7] For valuing, contingent valuation estimates, while particularly problematic over long time horizons, may help (NOAA, 1993). So may multi-attribute measures of valued environmental amenities, used either to define multi-attribute utility functions of representative actors, or to identify multi-dimensional costs of particular environmental constraints. But all this work is still in its early stages.

These two weaknesses are widely discussed among practitioners of integrated assessment. The third, the representation of policy, is less so. If an assessment is intended to be of direct assistance to some responsible actor, it is helpful if it includes a representation (at least

[4]In addition, two substantial contributions to understanding potential impacts of climate change have been made by studies that examined only impacts, imposing hypothesized climatic change on a region and performing highly local, disaggregated analysis of resultant impacts and adaptations. One such study has been completed, see Rosenberg (1993), while another is underway, see Cohen (1993).

[5]Though analysts using this approach claim no more than illustrative significance for their damage estimates, most calibrate their functions to pass through one of Nordhaus's estimates of equilibrium 3° losses for the USA, which are in fact founded on a detailed sectoral estimates of sectoral climate sensitivity in the US economy: see Nordhaus (1990). Hence, even these highly aggregated estimates are not completely without empirical content. See for example, Hammitt *et al* (1992) and Peck and Teisberg (1992, 1993).

[6]For example, some integrated assessment projects are working with the ecosystem modeling approaches presented in Melillo *et al* (1993) and Prentice *et al* (1992).

[7]Improving understanding of such responses is one of the most significant potential contributions of the highly disaggregated impacts-study approach in the projects presented in Rosenberg (1993) and Cohen (1993).

vaguely recognizable) of decisions they might take and consequences they might care about. The coarse spatial and sectoral resolution of most current assessments makes this goal difficult, for the kinds of decisions or responsibilities most particular actors have under their authority, and the kinds of consequence measures they are concerned with, are typically either of finer scale than those used in assessments, or are characterized by much more complex implementation limits and constraints, or do not appear in assessments at all. For example, assessments that treat the EC as a single region neither help European officials with their decisions allocating taxes or targets to member states, nor help national officials understand likely impacts of climate change in their countries. While aggregating fine-resolution results to coarser resolution typically poses no technical problems, going the other way can be contentious and difficult. Because the USA is often treated as a single assessment region (though also often aggregated with Canada) consideration of US policies less often suffers from inappropriate spatial resolution, but still suffers from coarse sectoral resolution and insufficiently detailed specification of policies.

Increasing sectoral resolution of both technologies and the economy would facilitate more useful representation of the cost and effectiveness of particular abatement policies. With enough technological detail, policies could be specified that regulate particular technologies, or impose technical goals (eg a 35 mpg automobile fleet, or a specified efficiency of combined cycle gas turbine generators), and their aggregate emission impact estimated. With enough economic detail, tax or subsidy policies could be imposed on the baseline, and their effect on emissions observed after the consequent economy-wide adjustments. However, the measures necessary to achieve a specific sectoral technical goal, or the effect of non-ideal economic policies as actually implemented in an economy (or a collection of economies) with pre-existing distortions, can be difficult to represent. For example, most integrated assessment models assume an international system of tradable emission permits results in equalization of marginal abatement costs in all participating nations, making the policy equivalent to a common carbon tax with lump-sum transfers. If an international system of tradable emission permits could be negotiated and implemented, it is unlikely that it would be this simple.

Representing adaptation policies poses even more severe difficulties, because of their close and complex links to climate impacts, and to the poorly understood adaptive responses that would occur in the absence of policies. They also pose difficulties of spatial and sectoral resolution, because adaptation measures will be taken by many actors from individual to international levels, often for reasons and through policy channels not explicitly related to climate or environment: zoning, infrastructure investment, insurance, labor mobility, and many others. Present assessment approaches to adaptation measures, which either represent them endogenously within impact functions, or study particular adaptive measures at micro or macro scale (eg changes in planting time and crop rotation by representative farmers, or national investment in coastal defense), are promising but preliminary. Geo-engineering policy, while in some respects simpler to represent in an assessment than either abatement or adaptation, is included in simplified form in only one or two present assessment projects.

Non-representational issues: designing a single assessment

The representational weaknesses discussed above are recognized to varying degrees, and work now underway is likely to bring continued progress on all of them. But performing useful assessment also poses challenges that are not representational, but are rather concerned with the conception and organization of the endeavor, and with its relationship to the intended audience or audiences. This section considers some of these broader challenges in assessment design from the perspective of a single assessment project, while the next section considers the same questions from the perspective of a system of assessment projects, or an assessment capability, serving to inform policy and decisions of a wide variety of actors in a nation or government

Audience, purpose, and degree and form of integration

If the purpose of an integrated assessment is to help inform an identified decision maker or decision, then there are several ways in which the audience and their responsibilities impose requirements on the assessment. Some of these are obvious issues of professional responsibility and clear, appropriate communication. Obviously, if the audience has a specific decision to make by a deadline, the assessment should address the decision and be done on time, while taking what opportunities are appropriate for broader education on the issue. Other dimensions of the audience that matter include the time and expertise they have to interact with the assessment, their interest in engaging its details, the extent of substantive disagreement or partisan conflict in which they are involved, and their goals for the assessment. Their goals might match, or conflict with, those of the assessors, including, eg increasing understanding of the issue; resolving disagreement; deflecting responsibility; or seeking support for a particular decision or

policy. For the assessors, there is a clear trade-off between speed of response and depth of analysis. When there are multiple audiences, it may be appropriate (or necessary) to communicate the same results in different ways for different audiences: short briefings or long conferences, thin pamphlets or fat reports. While it is often asserted that a client must be centrally involved in developing the basic structure and questions of an assessment, this involvement is more often advocated than realized.

The most important audience characteristic for shaping an assessment, though, is the extent and kind of their authority and concerns. A useful assessment should help some actors make decisions she/he is responsible for, or help them understand important characteristics of an issue they are concerned with. In order to realize this, an assessment should aspire to represent the kinds of policies and decisions that the audience is concerned with – eg consideration of abatement measures, adaptation measures, or allocation of resources for research would all imply distinct *foci* for assessment – and to represent both policies and valued impacts at a resolution, and with a level of detail, that corresponds to the responsibilities and concerns of the audience.

Most present integrated assessment projects, in their national to global spatial scale and in their focus on end to end integration that combines assessment of emissions and abatement measures with impacts and adaptation measures, implicitly pose the question they are addressing in a particular way: to provide a cost–benefit framing of the climate issue at national or global scale, so as to inform a decision on an optimal emissions abatement level and an efficient means of carrying it out. The implied audience is some unitary national (or global) decision maker, whose authority embraces both deciding the extent and form of abatement measures, and balancing these with other forms of measures.

Assessment of this kind is bound to help inform general understanding of appropriate responses to the climate-change issue. But for many of the potential audiences whose actual decisions will determine aggregate responses to global climate change, it may not be particularly useful. There are both respects in which end to end integration may be unnecessary for informing anybody's specific decision responsibility, and respects in which it may be insufficient for informing consideration of the climate-change issue at full breadth.

End to end integration may not be necessary, because all policy makers with relevant responsibilities may need studies that integrate along other, more limited dimensions. Nobody is likely to have the responsibility to decide optimal allocation of resources between abatement and adaptation (or geo-engineering), for two reasons. First, in many cases, a political consensus that certain action is needed may truncate the problem, making a cost-effectiveness framing more appropriate than a cost–benefit framing. Particularly in international settings, environmental targets have often been set according to simple heuristic principles like the precautionary principle or arbitrary, seemingly achievable round numbers (NOAA, 1993). If for any reason abatement decisions are driven along this path, the most crucial dimension of integration for a useful assessment will be across emission types, sources, gases, and regions, to determine feasible, low-cost ways to meet a predetermined abatement goal. Finding a more valid and widely accepted means of comparing emissions of different gases (solving the problem of global warming potentials) would be a particularly valuable contribution to integration on this dimension.

Alternatively, in many cases an assessment's potential audience may be responsible for managing resources that suffer climate impacts but have little or no influence over global emissions, as is the case for any small country or region. For such an actor, the crucial dimension of integration will be across possible dimensions of impact: sector, location, group, and time. Effective integrated assessment of impacts across these dimensions under an illustrative set of climate-change scenarios could inform the decisions of long-term climate-dependent investment, emergency response measures, zoning, and insurance and compensation schemes, that would form the bulk of the adaptation response.

There are strong reasons to expect that the most effective conduct and use of assessments will be done at such lower levels of integration, to inform specific decisions of actors responsible for the welfare of particular industries, activities, sectors, or regions. Such groups command the relevant expertise and bear the consequences, so have the incentive and ability to do high-quality, practical assessment. Moreover, they may be more homogeneous in interests and worldview than national or international bodies, so more likely able to conduct assessment whose technical analysis is premised on a single, acknowledged and shared set of political and value assumptions. A recent empirical study of assessment activity in several nations for climate, ozone depletion, and acid rain has suggested that the evidence supports this claim: the most effective assessments of response options, and those most widely regarded as effective, have tended to be done at rather small scale, by particular industries or other groups directly responsible for implementing proposed responses or directly bearing the costs of potential impacts (Clark, 1994).

But does this argument not imply an excessively circumscribed scope for assessment? The highest level of decisions balancing responses and impacts will be made,

whether explicitly or implicitly, and it is clearly preferable that those whose decisions contribute to the collective outcomes have some big-picture understanding of potential impacts, and characteristics of potential responses. While prior delimitation of debate may be politically necessary to restrict agendas and achieve consensus for action, it is still plausible that maintaining a broader agenda could result in a better option being available. Integrated assessment that seeks to engage the highest level of policy making, as so many assessments do, thus faces a serious challenge. This is the only decision level with the authority to make aggregate decisions balancing risk and response (if such authority exists anywhere). But it is also the decision level where participants are most removed from the direct consequences of such decisions, most disparate in expertise, most heterogeneous in worldview and interests, and most engaged in a broad set of other, more or less related, highly contentious political issues. Consequently, assessments directed to this decision making level are most liable to be created, used, and regarded as partisan tools – or sincerely misunderstood, or ignored. That a few examples exist of highly effective use of assessments in international policy making suggests that this view may be too pessimistic; nevertheless, the failures outnumber the successes, and little is known about what conditions contributed to the successes.

Moreover, even suspending judgment about the potential for destructive or ill-informed use of assessments at international levels – if, for example, we imagine that the audience for integrated assessments could be either a benevolent global despot, or the leaders of the world harmoniously assembled in deliberation, end to end integration as currently practiced and advocated may still not be the appropriate form of integration, because it may not be broad enough. Greenhouse emissions, and measures to change them, will affect other environmental problems, for good or ill. An assessment directed to global understanding of the entire climate issue should integrate over linkages to other environmental issues. Ultimately, the most useful form of integrated assessment may involve abstracting away from particular environmental issues entirely, to examine fundamental policy choices that shape activities contributing to a variety of dimensions of global well-being, environmental and other. Examples could include assessments examining broad directions in agricultural policy, or energy investment and policy, examining questions such as how the world should meet its energy needs in the middle of the next century, and what current decisions are likely to promote movement toward the desirable endpoint. In such a broadly integrated assessment, the dimensions of consequence should not even be limited to environmental ones. The most basic question about climate change is, how important is it? Helping senior policy makers with this question would require integrating not just across environmental issues, but across the aggregate of other impacts on human well-being liable to occur over the same time-horizon. Expressing projected consequences in universal metrics like economic losses or lives at risk is an attempt to achieve such universal comparability, but is only partly successful. The most salient difficulty with conducting and applying assessments at this level of integration and generality, is that the resultant decisions are nobody's job, so no one is likely to request them, or to be able to use them if provided. There does not even exist international negotiating bodies structured along these lines, unless we regard senior political fora such as G7 as directed to integrating issues at this level.

Integrated assessment and integrated models

Integrated assessment is not the same as integrated modeling, though the two are sometimes confused or used interchangeably. Most assessment projects now underway are developing an integrated model, and some are putting the greater part of their intellectual effort into it, while most commentators on integrated assessment are careful to assert that developing a model does not by itself make an assessment. There are several possible relationships between assessment and modeling. In past projects, there has been little correlation, positive or negative, between how strongly modeled a project was, and its effectiveness.

Why is model building so compelling in assessments? The essence of integrated assessment is providing a systematic way of integrating knowledge across disciplines, thought styles, resolutions, and degrees of certainty. The pursuit of coherent means of defining and meeting information needs across these borders, in useful form and in time, is challenging for the domains being coupled. Linking knowledge across fields can require thinking differently within the fields. While the bulk of the intellectual contribution of integrated assessment will be made at the joints, through these processes of linking, sharing, and reconciling knowledge, the joints are also where friction occurs. Since researchers working within their fields do not normally attend to borders of other fields, achieving this attention shift requires some form of authority in an assessment project, at least a coordination mechanism and a common language for communicating across boundaries. One of modeling's great advantages is that it can transparently and effectively impose this discipline of consistency and mutual intelligibility across subdomains of the problem.

Another potential benefit of integration through modeling is that it can facilitate making an assessment

flexibly able to incorporate new, changed information – which, since knowledge is sure to change, may be among the most important criteria for a useful assessment. Whether a particular integrated model is in fact robust to new knowledge depends on how it is designed. Changed parameter estimates or distributions are normally easy to incorporate, while more fundamental changes in understanding can be more easily assimilated if basic design is modular, permitting relatively easy redesign, addition, or deletion of submodels. Similarly, incorporating changed knowledge that requires some phenomenon be treated at different resolution or dimensionality can most easily be incorporated in a model that incorporates array abstraction.

Other modes of integration than modeling are possible, though at the cost of sacrificing some of this discipline and precision. Assessments can be developed by judgmental integration of expert knowledge across relevant fields even with no formal modeling, as in many OTA and NAS studies.[8] Alternatively, assessments can use formal models of sub-components of a problem, linked through external, judgmental combination of their results rather than through a formal integrating model.[9]

Other incentives than clarity and coherence also favor integration through integrated modeling, though, and the beneficial discipline of a single integrating model can come with attendant costs. Because a model is an identifiable product, making one may be an easier activity to promote to funders than other kinds of assessment. Because the challenges of model building are more specific, more technical, more readily bounded and easier to talk about, more strongly modeled assessments may also be attractive to researchers. On the other hand, the rigor of forcing knowledge from disparate domains into a single formal model can become Procrustean, involving falsifying sectoral information, imposing inappropriate restrictions, and yielding aggregate results that say as much about algorithmic artifacts as they do about understanding of the components.

If an assessment project does choose to construct an integrated model, it can be used in many ways in the overall assessment. Building the model may be the central task of the project and command essentially all resources. Alternatively, areas of the problem may be studied on parallel tracks, with one track developing a representation for the model and others examining the area in greater depth. Even a project centered on a model may decide to study some areas that are unlikely to be representable in the model, simply because they are deemed important enough. The problem of how loosely or tightly coupled the components of an integrated assessment project should be, and the closely related question of the centrality of a single integrating model, have no evident dominant solution. Each study must make a design choice, somehow balancing appropriate internal pressure for consistency, economy, and thorough integration with respect for the outrage of sub-domain experts when their tolerance is stretched beyond the bounds of intellectual honesty.

Treatment of uncertainty

The most basic jobs of integrated assessment, even more fundamental than evaluating specific response options, is characterizing present, policy-relevant knowledge. Representing uncertainty is central to this task. Some assessments have used heuristic schemes to communicate uncertainties by assigning judgmental degrees of confidence to their main concluding statements.[10] This approach can be used in any assessment, whether integrated by modeling or by less formal means. But in a model-based assessment, more systematic forms of analysis and communication of uncertainty are also available. Since component models in assessments are deterministic, uncertainty must normally be treated through some form of meta-model analysis.

Several approaches are possible. Since uncertainty in a model is normally analyzed through repeated runs with variation, there is a trade-off between the size and complexity of the basic model and how much uncertainty analysis is feasible. Specifying a set of future scenarios is one simple way of presenting uncertainty, with the scenarios selected to span a judgmentally determined range of plausible, representative futures. The difficulties of scenario analysis are that the origin and meaning of the range bounded by the scenarios cannot normally be explored precisely. Sensitivity analysis is a more systematic method of studying uncertainty, through which the sensitivity of outputs to variation in key input parameters, or to discrete changes in assumed models or policies, can be examined. The difficulty of a sensitivity-analysis approach is that one cannot examine sensitivity to every input, and determining which key ones to select

[8]Both OTA and NAS have conducted assessments of climate change, integrated in this judgmental manner: see OTA (1991); NAS (1991).

[9]This was the approach of the first major integrated assessment of an atmospheric issue, which examined environmental implications of the proposed American supersonic transport (SST) project in the early 1970s: see Grobecker *et al* (1974) as well as the recent 'MINK' study of climate impacts in a four-state region of the central United States (Rosenberg, 1993).

[10]For example, the 1990 IPCC Scientific Assessment presented its main conclusions in groups prefaced by statements such as 'We are certain of the following', 'We calculate with confidence that', and 'Our judgement is that': see Houghton *et al* (1990). The NAPAP integrated assessment used a system of assigning different numbers of stars to conclusions denoting different degrees of confidence (NAPAP, 1991).

for analysis inevitably involves some arbitrariness. The most comprehensive approach to uncertainty involves specifying large numbers of inputs as probability distributions and running models many times sampling over input values in some efficient way. The strength of this approach is that it allows simultaneous consideration of how uncertain an input value is, and how sensitive important outputs are to it. The difficulties of this method are two: its requirement for vast quantities of data, as many inputs must be specified not just as point estimates but as distributions, and the number of repeated model runs required to sample over all inputs, inevitably limiting the feasible complexity of the basic models. None of these approaches is strong at handling the extremes of uncertainty, low-probability, potentially catastrophic events such as major shifts in ocean circulation or large releases of methane from clathrates. Methods to accommodate such events appropriately in models or assessments are largely undeveloped.

The crucial questions in the treatment of uncertainty bear on the communication of results, which in turn depend on how the assessment is intended to be used, and by whom. Propagating point estimates through cascaded sets of large, deterministic models can provide great value in advancing the understanding of modelers, and forcing disciplinary experts to address the exchange of information with other parts of the system. For informing policy or decisions, though, such an approach suffers, probably fatally, from excessive and misleading precision. If knowledge of crucial parameters or relationships is limited, the point estimates that emerge from such a process may have little meaning. If a major purpose of the assessment is to identify what gaps in knowledge are of most importance for decision making, then there is no substitute for full propagation of uncertainty through an assessment.

Incorporating political processes and negotiation

An integrated assessment is directed at an audience with some responsibility for managing the risk of climate change. But no single person, organization, or government has the authority or power to manage the issue unilaterally. Above, I discussed the importance of assessments' engaging the more narrow and focused decisions that are actually under the authority of the intended audience, rather than futilely attempting to embrace the issue at full global scale. But another consequence of the delimited character of any actor's decision authority is that other actors' decisions also matter in determining outcomes. An issue not yet addressed by any integrated assessment project is how to represent the decisions and behavior of important actors other than the assessment's audience.

Of course, any economic modeling incorporated in an integrated assessment represents other actors' decisions, when those actors are numerous, small, and act through markets. But in international negotiations and policy making on climate change (and indeed in many instances in domestic politics) decisions of a small number of large, discrete actors jointly determine outcomes. Most assessment projects represent these other actors' decisions simply by jointly specifying policies adopted by all major actors, for example by stipulating that OECD nations all enact a US$10 per tonne carbon tax while the rest of the world does nothing. More sophisticated approaches to representing endogenously the decision making of other agents are of great importance for a useful assessment methodology, but are not yet well developed. A minimal approach would be to enrich the specification of other actors' decisions to include sets of plausible outcomes of international negotiating processes, including varying degrees of national implementation of negotiated commitments. Alternatively and more ambitiously, one could seek to incorporate models of interactive decision making and bargaining into integrated assessments. One promising approach involves embedding integrated assessment models within simulation-gaming exercises, in which teams playing the roles of major agents pursue negotiations, policy and implementation choices, in a simulated world described by the integrated models. For most integrated assessments, the consequences of the choices they are intended to inform depend crucially on politics and negotiations; consequently, in these instances it is particularly valuable that politics and negotiations be inside the assessment. Though methods to do so are at present crude and little developed, advancing practice in this area is a high priority for advancing the overall endeavor of integrated assessment.

A capacity for assessment: requirements and major questions

Provisional knowledge

In addition to design questions in undertaking a single integrated assessment project, a second set of questions, at a higher level of aggregation, are equally important. These concern the purposes and desirable characteristics of a systemic capability to do integrated assessment, as distinct from any particular project. This section summarizes a set of provisional claims about these questions.

To the most basic question, whether we need integrated assessment, I believe the answer is yes. To make rational, informed social decisions on such complex, long-term, uncertain issues as global climate change, the capacity to integrate, reconcile, organize, and communicate knowledge across domains – to do integrated assessment – is essential. Though there is much to criti-

cize in present integrated assessment endeavors, the activity is of the highest priority and is advancing, and seeking to advance and better employ the craft is markedly preferable to the conceivable alternatives – ie either not doing assessment at all, or doing assessment without striving to integrate knowledge from all relevant domains.

The contributions integrated assessment can make to understanding such issues and decisions are of several kinds. Some of these are highly promising, some more problematic, and present projects in integrated assessment for climate change realize them to varying degrees. First, integrated assessment can in principle help (and indeed is the only approach that conceivably can help) to answer the broadest bounding question, how important is climate change. Answering this requires comparing the aggregate social effect of climate change with the aggregate social effect of other changes and risks over the same period. This in turn requires assessing plausible future paths of impacts of climate change, and response measures, and expressing these in some form that permits comparison with other social concerns.

Second, integrated assessment can help assess potential responses to climate change, either with a cost–benefit framing (comparing costs of responses to the impacts they prevent) or a cost-effectiveness framing (comparing relative effectiveness and cost of different responses to meet a specified target). Framed in either way, integrated assessment performs this function by making consistent, appropriately qualified predictive statements of the likely cost and effect of specified response measures. While assessment practitioners responsibly warn that their scenarios or results are not to be taken as predictions, performing this function necessarily does require prediction: contingent, appropriately qualified prediction, responsibly reflecting current uncertainties, addressed to decisions of concern to the intended audience. Not all assessment of responses requires the same level of understanding of the system; some assessment of some proposed responses can be offered earlier, some not until understanding is far advanced.

Third, integrated assessment can provide a framework in which to structure present knowledge, thereby providing several benefits. This structuring can promote keeping the whole problem in view, facilitating systematic searching through the space of possible responses, and resisting premature closure on a few responses. It can also provide a comprehensive (and comprehensible) structure for assembling, organizing, and communicating advances in knowledge as they occur. Perhaps the most important contribution is structuring of uncertainty and sensitivity: how well quantities and relationships are known, and how strongly valued consequences depend on them. This permits identification and ranking of the most practically important uncertainties: those that most must be reduced to tell how serious climate change is, or what to do about it. These will not necessarily be the same uncertainties as are most important from standpoint of intellectual curiosity about the climate system, so the role of integrated assessment in guiding allocation of research resources directed to policy-relevant questions can be of the highest importance.

Finally, integrated assessment can serve the longer-term goal of building capacity. For better management of environmental risks, several kinds of capacity are important: a community of researchers skilled in craft of integrated assessment itself; communities of disciplinary researchers knowledgeable in the challenges of integrating the work of their field with others; and an increasingly sophisticated policy making community. Increasing these pools is liable to promote a general elevation of the quality of debate on the issue, independent of the direct contribution to policy making of any particular assessment.

Integrated assessment can in principle do all these things, which disciplinary research cannot do. Disciplinary research, whether in the natural or social sciences, is unlikely to do the jobs of attending to intersections across domains, or prioritizing decision-relevant uncertainties and research needs. Even if a research program includes support for the entire set of relevant disciplines, from natural and social sciences, this breadth alone does not make for integration. Nor is the required integrating activity likely to emerge spontaneously from a broad, disciplinary-oriented program; it requires serious, intentional direction and resources.

But integrated assessment does not replace disciplinary research; it supplements it. While integrated assessment is needed to identify and prioritize decision-relevant gaps in knowledge, it cannot normally fill the gaps. Filling them requires disciplinary research, whether in the natural or social sciences.

This integrating activity is difficult, for reasons both obvious and subtle. It is costly, because it requires redirecting substantial intellectual resources from their normal pursuits. The field is relatively immature, and lacks a well-established research community and established vehicles for practitioners to review each other's work. Moreover, because the main contribution of integrated assessment is not to advance understanding of component parts, tension can arise between project goals and the incentives of participating researchers seeking to advance in their fields. Possible related pathologies include re-labelling of research, and grudging participation by researchers who regard the integration activity as a disagreeable necessity to secure funding.

Perhaps the most serious consequence of the immatu-

rity of the field is that there is no shared body of knowledge and standards of 'best practice' for integrated assessment. Such knowledge is likely to develop with more thought and practice, but its present absence makes it ill advised to pursue a single, authoritative vision of integrated assessment. On both intellectual and managerial dimensions, there are many plausible ways of addressing the most basic challenges of integrated assessment. There is no single way to do it right.

In the absence of an authoritative vision of how to do integrated assessment, on climate change or in general, there is great value in having a diverse portfolio of several parallel efforts pursuing it. The problem is too complex, difficult, and multifarious for any single project to cover all important aspects of it. Moreover, pursuing different visions of how to do integrated assessment, through designing and structuring projects in different ways, is liable to advance the craft most rapidly. A diversity of project approaches will allow people to think differently, and individual projects will benefit from both the pressure of competition, and the opportunity for mutual learning.

Pursuing a diverse portfolio of assessment projects would have two implications. First, it suggests that there is great value in vehicles bringing together the approaches and results of different projects, perhaps through structured comparisons analogous to the Energy Modeling Forum.[11] Second, it suggests that some projects will be unsuccessful, and that projects and sponsors must somehow combine high intellectual standards with enough error tolerance to permit exploration of novel methods that may carry high risks.

The knowledge and capacity to do good integrated assessments can be built up, but will require continuity of support and can be lost, as it has before. Even on a particular issue such as climate, assessment is not a one-time activity that culminates with delivery of one report, but must be revisited, continuously or episodically, as policy questions and relevant knowledge advance. To the extent that assessment skills may generalize across issues, there would also be benefit to building capacity in a way that can be applied to different issues. The argument that generalized assessment capacity can be built does make assumptions about the gaming between researchers and sponsors, presuming that enough researchers pursue problems of integrated assessment sincerely and enthusiastically that a body of knowledge, and a community with its own standards and incentives, can develop.

Major unresolved questions

Developing a capability to do integrated assessment is largely unexplored territory, and a number of fundamental questions about how such a capability is likely to develop, or should be developed, remain open.

First is the question of tailored assessments, as opposed to the possibility of developing generic assessment tools (or skills). I argued above that useful assessments must be consciously tailored to the decision authority and knowledge needs of a specific audience. But since assessment skills consist to a substantial extent of methods for integrating knowledge across domains, rather than knowledge of the domains *per se*, it is possible that some of the basic intellectual activity could be abstracted from the substantive issue assessed. This in turn suggests the possibility of developing generic assessment tools or skills.

Tasks for which such generic skills or tools might be developed could include the following: matching resolutions of information across fields through aggregation, parameterization, and downscaling; representing and propagating uncertainty, including both structural and parameter uncertainty; blending information available with different degrees of confidence; eliciting and employing expert judgment within models; developing tools to involve decision makers in assessment and modeling processes; and representing different sets of valued consequences, and defining different bases for valuing and comparing them. While these are all expressed in modeling terms, parallel questions could be posed about corresponding generalizable skills in the integration of knowledge through less modeled assessments; are there generic skills in this realm too, or only the mysteries of expert judgment and non-articulable craft knowledge? The argument above, that assessment capacity can and should be built, implies the existence of at least some body of general 'assessment' skills that generalize across individual issues, for otherwise nothing would be lost by running assessments as a discrete set of stand-alone projects.

The possibility that there could be developed generic assessment tools, together with the availability of increasingly accessible and powerful computer modeling tools, poses deep questions about the eventual, and appropriate, relationship between assessments, analysts, and policy makers. What is an assessment tool, who should use it, and how? These questions are posed most sharply by current developments of powerful, flexible systems for model development and analysis such as Demos (Morgan and Henrion, 1990) and Globesight (Mesarovic, 1994). These systems aspire to be not just software tools, but flexible devices for modeling and assessment, in principle usable even by decision makers who lack the normally necessary technical and modeling training. If such systems make policy makers increasingly able to represent their own understandings of the issue being assessed by manipulating and constructing

[11]Gaskins and Weyant (1993). The current study of the Energy Modeling Forum is examining integrated assessment models.

their own models, this would strongly advance the goal of making assessments responsive to policy makers' needs, but would also pose attendant risks.

I call this the question of 'embedding', or transferring the cognitive structure of models and assessments directly to policy makers. Modelers and assessors have long aspired to embed their creations deeply in the brains of senior policy people, thereby allowing them to understand the structure and dynamics of the policy issue in the same way as the analysts do. Many devices to encourage policy makers to play with models and to make models more accessible, transparent, and manipulable have been advanced to this end, while current advances in software and user interfaces seem to bring it ever closer to technical possibility. This possibility poses several key questions. How much is it possible to embed a model, or are important elements of understanding inevitably left behind? Does this pose the risk of giving policy makers a vivid, wrong understanding of an issue? Does the vision of embedding models presume a naive vision of political process, in which one person in authority makes each policy decision? Does it risk compromising the integrity of either scientific process or political accountability?

The experience of attempts to get political decision makers to use models has been frustrating and contentious.[12] An instructive recent episode occurred when John Sununu, President Bush's White House Chief of Staff, became interested in climate change and had a reduced-form version of a climate model installed on his office computer. He is reported to have used the model, and used what he learned from it in policy debates to support his view that action to reduce emissions was unwarranted (Dowd, 1990). The subsequent outrage among modelers and analysts was in part puzzling, since this story seems to realize the vision of senior policy makers becoming fully conversant with assessment models. Several legitimate bases for the outrage are plausible, though. Sununu was a busy man, using a simplified (though still fairly complex) model but no doubt unable to spend much time on it, and so probably at risk of significant misunderstanding. A model on his machine in the White House would not be open to scrutiny and technical argument, nor readily updatable to reflect advances in understanding. Finally, the model might give him a decisive advantage in political debates based on his analytical sophistication, when fights at this level should be resolved on other bases. Questions of the merit, methods, and appropriate degree of embedding also arise in the international policy setting, with additional complications posed by the pluralism of the decision making environment.

[12]With the apparent remarkable exception of the RAINS model and its use in European acid-rain negotiations, see Hordijk (1991).

Finally, there is the question of integration and authority, posed now at the systemic level of funding, conducting, evaluating, and developing a general assessment capability rather than at the level of pulling the distinct sub-elements together within a single integrated assessment project. Questions of the appropriate relationship between assessment and decision making bodies are distinct for each of the possible functions of assessment. When integrated assessment is used to inform or assess policy decisions, the assessment must integrate broadly enough across disciplinary lines to serve the policy need, while still being deeply enough informed by the relevant range of disciplinary expert knowledge and opinion to drawn on the legitimacy of science. Because assessments are introduced into contentious, pluralistic, partisan policy debates, all will be presumed biased unless they meet high standards of legitimate process. For example, policy makers will regard an assessment less suspiciously if they can consult experts from their constituency (however defined) who participated in it. The managerial dimensions of integration, such as authority, sponsorship, participation, and transparency, can thus be as essential for success and legitimacy as the conceptual or disciplinary dimensions.

Even using integrated assessment to identify research priorities poses managerial problems. Some advocates of expanded integrated assessment see its role as controlling the research endeavor; for example, an assessment board with a large budget might both perform (or oversee) integrated assessments, and act on their results by allocating resources to the research questions they identify as policy-relevant needs. This model of integrated assessment has occurred; the CIAP project, for example, did undertake new science when its preliminary assessment found that crucial pieces of researchable information were missing.

This model, while seemingly attractive, poses significant dangers. On the one hand, I have argued that a fundamental contribution of integrated assessment is to identify and prioritize key policy-relevant knowledge gaps and uncertainties. This potential contribution would surely go unrealized if no mechanism existed for the (collective) results of assessments to inform the formation of research questions and allocation of resources.

But the immaturity of the field makes the vision dangerous. If developing capacity to do integrated assessment requires multiple projects with different visions, these projects are likely to identify different research priorities as crucial, at least some of the time. No single integrated assessment project should have the potentially corrupting authority to define the vision of national research priorities. Equally clearly, policy relevance should not be the only criterion driving the global change research budget.

But if it is not a 'National Integrated Assessment Board' deciding the allocation of resources for policy-relevant research, then how should they be allocated? How can a disparate collection of integrated assessment projects themselves be integrated to inform decisions that must be made on research priorities? There is no simple answer. Clearly those bodies responsible for allocating research resources will have to watch closely the collective output of integrated assessment projects and reflect it broadly in their decisions. Sometimes, no doubt, there will be strong consensus, and sometimes none. The process of translating from a disparate collection of integrated assessment studies to research priorities will grow easier as a consensus of shared knowledge and standards for integrated assessment develops.

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