Climate Change and Its Interaction with Natural, Economic and Social Processes

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Abstract: *Human-made GHGs work against us when they trap too much sunlight and block outward radiation. Scientists worry that the accumulation of these gases in the atmosphere has changed and will continue to change the climate. Potential climate risks include more severe weather patterns; hobbled ecosystems, with less biodiversity; changes in patterns of drought and flood, with less potable water; inundation of coastal areas from rising sea levels; and a greater spread of infectious diseases such as malaria, yellow fever, and cholera. On the plus side, climate change might benefit agriculture and forestry in certain locations by increasing productivity as a result of longer growing seasons and increased fertilization. Although climate change is not the same as day-to-day or even year-to-year fluctuations in the weather, the nature of these fluctuations could be altered by climate change.*

Keywords*: climate risks, weather patterns, benefit, climate change, fluctuations.*

1. Potential physical and socioeconomic consequences

The risk of climate change depends on the physical and socioeconomic implications of a changing climate. Climate change might have several effects:

- Reduced productivity of natural resources that humans use or extract from the natural environment (for example, lower agricultural yields, smaller timber harvests, and scarcer
- water resources).
- Damage to human-built environments (for example, coastal flooding from rising sea levels, incursion of salt water into drinking water systems, and damages from increased storms and floods).
- Risks to life and limb (for example, more deaths from heat waves, storms, and contaminated water, and increased incidence of tropical diseases).
- Damage to less managed resources such as the natural conditions conducive to different landscapes, wilderness areas, natural habitats for scarce species, and biodiversity.

All of these damages are posited to result from changes in long-term GHG concentrations in the atmosphere. Very rapid rates of climate change could exacerbate the damage. The adverse effects of climate change most likely will take decades or longer to materialize, however. Moreover, the odds that these events will come to pass are uncertain and not well understood. Numerical estimates of physical impacts are few, and confidence intervals are even harder to come by. The rise in sea level as a result of polar ice melting, for instance, is perhaps the best understood, and the current predicted range of change is still broad.

Unknown physical risks are compounded by uncertain socioeconomic consequences. Cost

estimates of potential impacts on market goods and services such as agricultural outputs can be made with some confidence, at least in developed countries. But cost estimates for nonmarket goods such as human and ecosystem health give rise to serious debate.

In constructing a viable and effective risk-reducing climate policy, policymakers must address hazy estimates of the risks, the benefits from taking action, and the potential for adaptation against the uncertain but also consequential cost of reducing GHGs. Costs of mitigation matter, as do costs of climate change itself. One must consider the consequences of committing resources to reducing climate change risks that could otherwise be used to meet other human interests, just as one must weigh the consequences of different climatic changes.

Global change can exert severe impacts on the ecology of aquatic and wetland ecosystems, on the filter and transport functions of soils and on water quality. Assessments of these changes require a better understanding of the consequences of major hydrological changes, to identify and quantify the key bio-geochemical processes and to predict the consequences of global change at different scales. The integrated management of soil-water systems requires a detailed understanding of the properties, and the functional role of soils and the behaviour and fate of pollutants, in order to allow the development of risk-based management approaches. Research will focus on the impacts of global change on the ecology of surface water bodies, on how to improve floodplain functioning and management, and on water-soil system functioning and management.

2. The importance of evaluating of climate change risk

Although uncertain, climate change risks are real and need to be better understood so as to avoid unwanted consequences. Many observers characterize responding to the risks of climate change as taking out insurance; nations try to reduce the odds of adverse events occurring through mitigation, and to reduce the severity of negative consequences by increasing the capacity for adaptation once climate change occurs. The insurance analogy underscores both the uncertainty that permeates how society and policymakers evaluate the issue and the need to respond to the risks in a timely way.

Responding effectively to climate change risks requires society to consider the potential costs and benefits of various actions as well as inaction. By costs we mean the opportunity costs of

GHG mitigation or adaptation – what society must forgo to pursue climate policy. Benefits are the gains from reducing climate change risks by lowering emissions or by enhancing the capacity for adaptation. An assessment of benefits and costs gives policymakers information they need to make educated decisions in setting the stringency of a mitigation policy (for example, how much GHG abatement to undertake, and when do it) and deciding how much adaptation infrastructure to create.

It is important to consider the costs and the benefits of climate change policies because all resources – human, physical, and natural – are scarce. Policymakers must consider the benefits not obtained when resources are devoted to reducing climate change risks, just as they must consider the climate change risks incurred or avoided from different kinds and degrees of policy response. Marginal benefits and costs reveal the gain from an incremental investment of time, talent, and other resources into mitigating climate risks, and the other opportunities forgone by using these resources for climate change risk mitigation. It is not a question of whether to address climate change but how much to address it.

Critics object to a benefit-cost approach to climate change policy assessment on several grounds. Their arguments include the following:

- The damages due to climate change, and thus the benefits of climate policies to mitigate these damages, are uncertain and thus inherently difficult to quantify given the current state of knowledge. Climate change also could cause large-scale, irreversible effects that are hard to address in a simple benefit-cost framework. Therefore, the estimated benefits of action are biased downward.
- Climate mitigation costs are uncertain and could escalate rapidly from too-aggressive emission control policies. Proponents of this view are indicating a concern about the risk of underestimating mitigation costs.
- Climate change involves substantial equity issues – both among current societies and between current and future generations – that are questions of morality, not economic

efficiency. Policymakers should be concerned with more than benefit-cost analysis in judging the merits of climate policies.

As these arguments indicate, some critics worry that economic benefit–cost analysis gives short shrift to the need for climate protection, whereas others are concerned that the results of the analysis will call for unwarranted expensive mitigation.

Supporters of the conventional approach to discounting on grounds of economic efficiency argue just as vehemently that any evaluation of costs and benefits over time that understates the opportunity cost of forgone investment is a bad bargain for future generations because it distorts the distribution of investment resources over time. These supporters of standard discounting also argue that future generations are likely in any event to be better off than the present generation is, casting doubt on the basic premise of the critics' concerns [5].

Analyzing the benefits and costs of climate change mitigation requires understanding biophysical and economic systems as well as the interactions between them. Integrated assessment (IA) modeling combines the key elements of biophysical and economic systems into one integrated system (Figure 1). IA models strip down the laws of nature and human behavior to their essentials to depict how more GHGs in the atmosphere raises temperature and how temperature increase induces economic losses. The models also contain enough detail about the drivers of energy use and interactions between energy and economy that one can determine the economic costs of different constraints on CO2 emissions [3].

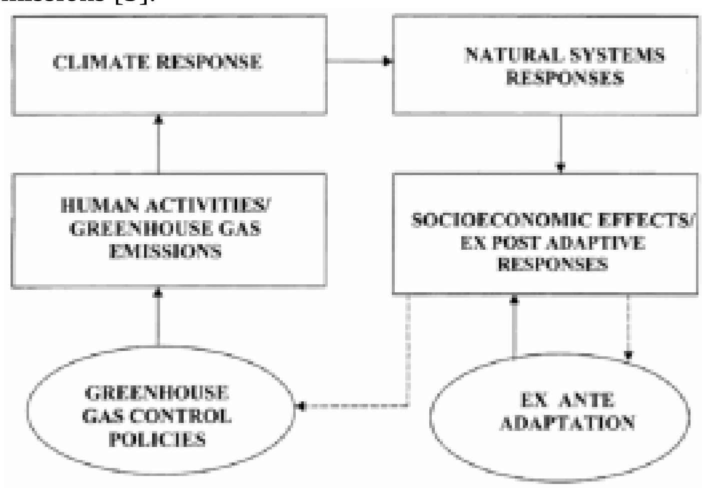

Fig. 1 Climate change and its interaction [1]

Researchers use IA models to simulate a path of carbon reductions over time that would maximize the present value of avoided damages (that is, the benefits of a particular climate policy) less mitigation costs. As noted above, considerable controversy surrounds this procedure.

A striking finding of many IA models is the apparent desirability of imposing only limited

GHG controls over the next 20 or 30 years. According to the estimates in most IA models, the costs of sharply reducing GHG concentrations today are too high relative to the modest benefits the reductions are projected to bring.

Irreversibility of GHG emissions is yet another factor influencing the benefits of GHG abatement. Because GHG emissions persist in the atmosphere for decades, even centuries, the resulting long-term damages strengthen the rationale for early and aggressive GHG control. Moreover, given that some damage costs from adjusting to a changed climate depend on the rate of climate change, immediate action also might be valuable. To date, however, the importance of this factor has not been conclusively demonstrated; the gradual abatement policies implied by the IA models do not seem likely to increase the speed of further climate change that much.

3. Uncertainty in the social cost of carbon

The social cost of carbon (SCC) is the estimate of the cost of climate change damages.the net effects of impacts on economies and societies of long term trends in climate conditions, including extreme events, related to anthropogenic emission of greenhouse gases. Such estimates have been compiled in order to aid consideration of greenhouse gas emission policies and to prioritise adaptation strategies according to their potential effectiveness.

The term, social cost of carbon (SCC), generally refers to the marginal cost of climate change impacts. The SCC is usually estimated as the net present value of the impact over the next 100 years (or longer) of one additional ton of carbon emitted to the atmosphere today. This should not be confused with the total impact of climate change or the average impact (the total divided by the total emissions of carbon). The SCC is expressed as the economic value (in US$, € or GB£) per ton of carbon (tC). In this assessment, the baseline is the year 2000 for the emissions as well as for the net present value. In some literature, but not in this report, marginal damages are related to 1 ton of carbon dioxide.

This review of uncertainty in estimates of the social cost of carbon is summarised in key messages:

Understanding of the social cost of carbon:

- Our understanding of future climatic risks, spanning trends and surprises in the climate system, exposure to impacts, and adaptive capacity, is improving, but knowledge of the costs of climate change impacts is still poor.
- The lack of adequate sectoral studies and understanding of local to regional interactions precludes establishing a central estimate of the social cost of carbon with any confidence.
- The balance of benefits and damages in the social cost of carbon shifts markedly over time, with net damages increasing in later time periods. Estimates of the SCC are particularly sensitive to the choice of discount rates and the temporal profile of net damages.
- Vulnerability and adaptation to climate change impacts are dynamic processes responding to climatic signals, multiple stresses, and interactions among actors. Large scale impacts, such as migration, can be triggered by relatively modest climate changes in vulnerable regions.

Uncertainty and risk:

- Climate uncertainties and the climate sensitivity are key factors in larger estimates of the social cost of carbon.
- Uncertainties in coverage, sectoral assessments and regional processes are likely to be significant, but are difficult to judge without further model development and inter-model comparison.
- Decision variables such as the discount rate equity weighting also are extremely important.

The range of estimates of the social cost of carbon:

- Estimates of the social cost of carbon reflected uncertainties in climate and impacts, coverage of sectors and extremes, and choices of decision variables.
- An upper benchmark of the SCC for global policy contexts is more difficult to deduce from the present state-of-the-art, but the risk of higher values for the social cost of carbon is significant.

Significant improvement in estimates of the SCC will require well validated assessments at the regional scale of the dynamic processes of vulnerability and adaptation. Partnerships among researchers and stakeholders in developing countries are essential.

The arrows on the three axes imply increasing uncertainty, although not necessarily larger estimates of the SCC.

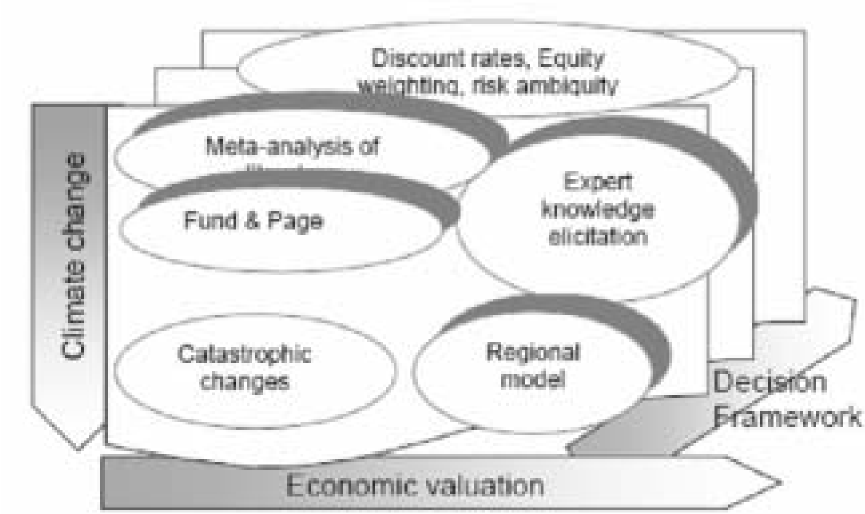

Fig. 2 Schematic mapping of multiple lines of evidence in understanding uncertainty in the social cost of carbon

Framing of estimates of the SCC is organised as a matrix of confidence in projections of future climate change and understanding of economic valuation (Figure 3). The climate axis ranges from projections of global and regional temperature, to bounded scenarios of changes in precipitation and risk of storms, to systemic, large scale changes such as collapse of the West Antarctic Ice Sheet, shift in ocean circulations, or reversal of the biosphere carbon sink.

Uncertainty in Climate Change \ Uncertainty in valuation	A. Market	B. Non-market	C. Socially contingent
1. Projection			
2. Bounded risks			
3. System change and surprise			

Fig. 3 A risk assessment framework

The corresponding economic axis begins with market sectors, with uncertainty expanding to the valuation of non-market sectors such as coral reefs, and socially contingent feedbacks, such as conflict over water, that exacerbate sectoral impacts or present non-marginal impacts at the local to regional level. Note that socially contingent effects are a class of non-market impacts, where B might be considered micro-economic effects and C includes macro-economic effects.

The gradient across the matrix, from top-left to bottom-right suggests an increase in uncertainty. The larger scale climate changes are still speculative and often described as surprises outside the realm of current global model predictions. The relative lack of studies of non-market and socially contingent effects increases uncertainty in estimates of the SCC.

The gradient also reflects different timings of impacts.systemic changes in the global climate are posited on a century time scale (e.g., collapse of the West Antarctic Ice Sheet); collapse of regional societies and economies is not forecast in the next few decades (if at all). Some of the largest uncertainties.such as release of methane hydrates.are events that are not fixed to a particular time frame.

At present, the most commonly held assertion is that the net non-market and socially contingent costs will be adverse (rather than benefits). However, there is insufficient evidence to suggest that the gradient from upper-left to lower-right is necessarily a substantial increase in the total social cost of carbon.

The typical situations with each cell may help to illustrate both the range of issues inherent in estimating the SCC as well as the role of the risk matrix.

For the column of impacts related to markets (A):

- A1: Global and regional temperatures are projected to increase with relatively high confidence. To the extent that warmer conditions would expand the area suitable for agriculture, leading to climate impacts (in this case benefits) that are readily valued through market exchanges (such as the price of major commodities, value of agricultural land, net profit to producers or net benefit to consumers). Sea level rise is the other major climatic element with high confidence, leading to impacts on coastal communities, loss of dryland and wetland, forced migration, and the costs of coastal protection.
- A2: Most climate elements are uncertain at the regional level, but current climate models project changes within a reasonable range. Such bounded risks include increases or decreases in precipitation, intensity and tracks of storms, and the frequency and magnitude of other climatic extreme events (e.g., floods, droughts, lightning). The market impacts, for example of drought on agriculture, can be estimated in principle although it is difficult to differentiate between the effect of climate change and other stresses and responses that shape economic outcomes. Current scenarios of climate change may underestimate drought risks, leading to a possible bias toward short-term benefits of climate change for agriculture.
- A3: System change and surprises are plausible climate outcomes that are not readily evaluated in a probabilistic framework, such as a weakening of the thermohaline circulation, changes to the phases of the major ocean-atmosphere modes (such as ENSO), the more extreme scenarios of collapse of the West Antarctic Ice Sheet, large releases of methane hydrates or reversals of the terrestrial carbon uptake. While the market effects can be described, the impacts over large areas and time scales are not linear and therefore difficult to value in a micro-economic framework. For example, what would be the (net) value of displacement of all of the major world coastal cities due to a 3-5m sea level rise [4, 6]?

Effects on non-market sectors (B) are more difficult to value in that there are little empirical data on how people in different countries and economic classes value amenities, species, landscapes and other qualities of livelihoods. Contingent valuation based on willingness to pay or willingness to accept principles give some guidance, but such values are often contentious and may not scale up from local issues to the widespread effects of climate change. Examples of the sectors and issues in this column are:

- B1: Warmer temperatures and higher humidity.both projected to increase with some confidence.will alter the amenity value of climates. In northern Europe, for instance, longer and warmer summers will encourage more people to enjoy the outdoors and visit local tourist destinations. On the other hand, a greater incidence of heat waves in southern Europe may be problematic and losses in boreal and mountain ecosystems and winter tourism are likely.
- B2: The bounded risks of changes in major cyclones, for instance, would affect coastal ecosystems and agricultural land subject to increasing frequency and severity of coastal

flooding and salt water inundation. The value of species lost in local environments is difficult to estimate.

- B3: Catastrophic effects that lead to global losses of species are even more difficult to value, not least because the impacts of climate change on global ecosystems and species biodiversity is not well understood.

The socially contingent column (C) captures the secondary effects and multiple stresses of climate change across a range of sectors. For instance, it is possible that reasonably small changes in climate change could lead to significant impacts through multipliers (such as the effect of water shortages on agriculture), high vulnerabilities (such as migration triggered by increased cyclone frequencies) and behavioural responses to the risk (such as disinvestment from commercial agriculture in some regions). Such socially contingent effects are a sub-set of nonmarket impacts. The mechanisms of such responses may not be readily captured in either microeconomic valuations or macro-economic models. The range of potential values is likely to be influenced by the decision framework.for instance whether potential liability for regional damages is a motivation for a precautionary approach. Examples include:

- C1: Projected changes in mean temperatures and sea level rise, at least over the next few decades, re unlikely, on their own, to trigger significant socially contingent effects. The exception may be snow melt and glacial lake outburst floods, significant in some regions.
- C2: Changes in water cycles, along with drought and flood risks, are potential drivers of regional migration, loss of an agricultural economy and crises for mega cities without reliable water supplies. The extent of the world where such effects are most likely has not been rigorously evaluated, but the Sahel and coastal deltas such as Bangladesh are frequently mentioned. Regions of existing and exacerbated water scarcity could be subject to conflict.
- C3: The displacement of entire cities due to extreme sea level rise is a good example of a socially contingent effect with high uncertainty.in both the risks of climate change and in the means to value such impacts. A case study of the potential impacts of and adaptation to a 5 meter sea level rise illustrates the issues [4, 6].

The risk matrix is a guide to understanding uncertainties in the social cost of carbon. The risk matrix does not show explicitly three additional factors affecting uncertainty. Two are mentioned above: (i) the role of decision frameworks and choice and (ii) the time profile of climate change and its impacts.

The third factor (iii) concerns the method for aggregating estimates of the SCC in each cell to an overall value. It is not immediately apparent that decision makers would simply add up net values for each cell in the matrix. They may wish to account for those who suffer losses differently from those who gain. Such a concern might arise from awareness of political responsibilities, assessment of the risk of disruption associated with losses, or recognition of the non-substitutability of some environmental systems and cultural inheritance. Or, they may chose to weight some values differently than others. For instance market values might not be equity weighted while a high equity weight might be applied to the socially contingent values.

The risk matrix is a frame of reference, but does not imply specific values for the SCC for the less certain impacts and valuations (that is, for row 3 and columns B and C). Further studies and estimates of all of the cells are required to judge the extent to which sampling across all of the cells is required to produce a robust estimate of the SCC. However, the Intergovernmental Panel on Climate Change (IPCC) suggests that the larger impacts will become more likely as global temperatures rise particularly beyond the middle range of 2-3 °C [2]. The cascade of impacts across sectors and regions becomes an increasing concern if global warming exceeds 5 °C or so. However, this conclusion is in the nature of expert judgement, since there are few detailed studies presently available in the literature.

Integration of estimates of the SCC into stakeholder decision frameworks offers opportunities to interpret the boundaries of the SCC according to the values of different stakeholders and decision contexts. However, further research on the utility of approaches is required. The methodological implications of a hierarchy of estimates, corresponding to the scale of decision making, and similarly the use of multiple indicators of concern, should be identified at an early stage.

4. Conclusions

The rapid rise in greenhouse gas emissions has led to increasing concerns about climate change and its environmental, health and economic consequences across the world. Consequently, international efforts have gained momentum to develop policy frameworks that will control or reduce greenhouse gas emissions over a certain period of time. These policy efforts have been informed by extensive research that assesses the engineering methods and technologies to reduce greenhouse gas mitigation and determines the economic feasibility of the proposed methods. In recent years, this research has focused on investigating the costs of mitigation to achieve stabilisation targets in the presence of induced technological change, that is, additional technological changes spurred by the implementation of climate policies.

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