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A Conceptual Tool for Climate Change Risk Assessment

Paul A. T. Higgins* and **Jonah V. Steinbuck**

Policy Program, American Meteorological Society, Washington, D.C.

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ABSTRACT: This study develops a new conceptual tool to explore the potential societal consequences of climate change. The conceptual tool delineates three quasi-independent factors that contribute to the societal consequences of climate change: how climate changes; the sensitivity of physical systems, biological resources, and social institutions to climate change; and the degree of human dependence on those systems, resources, and institutions. This conceptual tool, as currently developed, is not predictive, but it enables the exploration of the dependence of climate change risks on key contributing factors. In exploring a range of plausible behaviors for these factors and methods for their synthesis, the authors show that plausible assumptions lead to a wide range in potential societal consequences of climate change. This illustrates that the societal consequences of climate change are currently difficult to constrain and that high-consequence climate change outcomes are not necessarily low probability, as suggested by leading economic analyses. With careful implementation, this new conceptual tool has potential to increase public understanding of climate change risks, to support risk management

* Corresponding author address: Paul Higgins, Policy Program, American Meteorological Society, 1200 New York Avenue NW, Suite 450, Washington, DC 20005.

E-mail address: phiggins@ametsoc.org

decision making, or to facilitate communication of climate risks across disciplinary boundaries.

KEYWORDS: Communications/decision making; Education; Policy; Risk assessment; Societal impacts

1. Introduction

Understanding the potential consequences of climate change to society is extremely challenging because climate impacts will depend on a multitude of contributing factors that interact in complicated ways and that are characterized by varying degrees of uncertainty (Moss 2011). For example, the risk assessment process must synthesize information from numerous disciplines that span the physical sciences (e.g., how much and how fast climate changes), natural sciences (e.g., how biological systems respond), and social sciences (e.g., how effectively humanity can adapt to and cope with impacts). Furthermore, subjective views and value judgments heavily influence how individuals perceive both the risks of climate change and the potential benefits and costs of risk management options (Leiserowitz et al. 2011a,b).

A wide range of modeling approaches is currently used to explore the societal consequences of climate change, each of which contributes significantly to our assessment capabilities. For example, reduced form economic models are used to evaluate the economic implications of a change in climate using relatively simple climate damage functions—usually a linear or quadratic mathematical function that relates changes in temperature with economic impacts (Hope 2006; Nordhaus 2008). The approach is powerful because it provides an analytical framework to explore the aggregated consequences of climate change to society at the broadest levels. It also provides model developers with a tool to integrate the existing knowledge base through the use of expert judgment (either by the model developer directly or through a more systematic synthesis of the expert community). However, climate damage functions will inevitably have a high degree of uncertainty because of the very wide range of impacts and potential responses and adjustments that are possible and because of interconnections of impacts across space and time (DeCanio 2003; Ackerman et al. 2009; Higgins 2013). This uncertainty is further exacerbated by the fact that human civilization has never before experienced the types of climate change expected over the next several decades. This limits the capability of empirical studies to constrain the range of possible societal outcomes. As a result, climate damage functions are (and will remain) difficult to constrain.

More comprehensive integrated assessment models (IAMs) (Edmonds et al. 1997; Hulme et al. 2000; Sokolov et al. 2005; Sterman 2012) and climate assessments (McGuire Elsner et al. 2009; Karl et al. 2009; America's Climate Choices 2010) incorporate considerable detail relating to climate impacts and thereby overcome many of the challenges associated with reduced form economic models and contribute greatly to our understanding of climate change risks. A great advantage of these approaches is that they often incorporate mechanistic understanding of the climate system and capture key relationships between the climate system and social or economic well-being. More comprehensive IAMs can also incorporate experimental results directly and be used to explore a wide range of plausible assumptions relating to those relationships, which makes it possible to

develop a range of plausible scenarios or produce unique outcomes (or projections) based on the best available knowledge and understanding.

However, the level of detail included in comprehensive IAMs creates a potential barrier to engagement for some users and an obstacle to communication among experts who are not familiar with the model details. Similarly, some built-in model assumptions characteristic of existing approaches may restrict the range of potential outcomes obtained by model users (though several notable efforts do allow model users to specify at least some key model parameters and explore the implications of plausible assumptions; [Hulme et al. 2000](#); [Sterman et al. 2012](#)).

Here we develop a straightforward, user-driven framework designed to enable both experts and nonexperts to explore the potential consequences of climate change. This new conceptual tool is designed to 1) be sufficiently intuitive to enable virtually anyone to understand, evaluate, and use; 2) make necessary assumptions and choices explicit; 3) minimize the use of weakly supported assumptions whenever possible; and 4) be easy to update and refine as new information becomes available (either with increasing learning by the tool user or through scientific advances).

Based on these four characteristics, the conceptual tool enables users to conduct easy to implement and transparent thought experiments. It can be used to consider the plausibility of assumptions and their implications, to assess and refine one's views, to search for general conclusions, and to identify key opportunities for improved risk assessment by expanding the underlying knowledge base.

This approach complements reduced form economic models by allowing users of the tool to explore broadly the factors that could affect the relationship between climate change and societal well-being (i.e., the factors that determine a climate damage function). It complements more detailed IAMs, by creating a relatively straightforward point of entry for exploring the societal consequences of climate change. The results from the conceptual tool might also help reveal potential limitations to (or reinforce) conclusions based on the results of the economic models and more detailed IAMs. The results from the more detailed impact assessment studies and IAM experiments can also help refine and constrain the assumptions for (and results from) the conceptual tool.

We envision three potential broad applications for the tool. It could be used to facilitate communication across disciplinary boundaries; to help increase public understanding of climate change risks; and to support risk management decision making. Notably, all three applications would likely require expert facilitation and additional development of the framework.

This initial study uses the conceptual tool approach to examine how plausible assumptions can lead to a wide range of potential outcomes that span modest to severe consequences. However, the conceptual tool, as currently developed, is not predictive. Instead it enables the exploration of the dependence of climate change risks on key contributing factors and the search for general conclusions. Key insights from the tool most likely must then be further investigated and evaluated by using more comprehensive models that treat interactions and couplings through more rigorous and quantitative approaches in order to reach more specific conclusions about climate change risks.

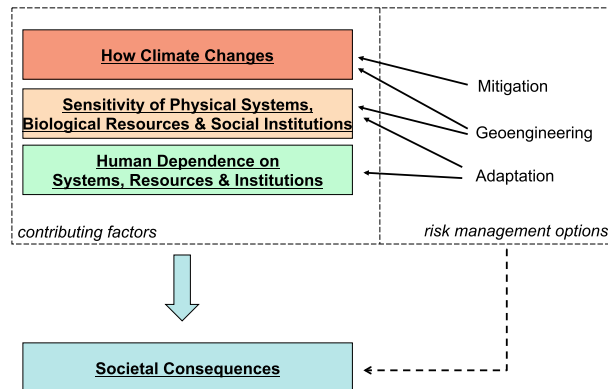


Figure 1. Schematic showing three quasi-independent factors that contribute to the societal consequences of climate change: how climate changes; the sensitivity of physical systems, biological resources, and social institutions to climate change; and the degree of human dependence on those systems, resources, and institutions. Risk management strategies (mitigation, adaptation, and geoengineering) can influence the contributing factors and thereby alter societal consequences (solid arrows). Each risk management option could also create ancillary benefits or new societal risks unrelated to climate change (dashed arrow).

2. A tool for climate change risk assessment

In broad terms, the societal consequence of climate change will depend on three quasi-independent contributing factors: 1) how climate changes (i.e., how much and how fast) (“climate”); 2) the sensitivity of physical systems, biological resources, and social institutions to changes in climate (“pbs sensitivity”); and 3) societal dependence on those physical systems, biological resources, and social institutions (“human dependence”) (Figure 1). Each of these three contributing factors includes more detailed components (e.g., *climate* will depend on numerous forcings and feedbacks) and links with the other factors (e.g., *pbs sensitivity* affects *climate* because some physical and biological system responses involve components of the climate system itself; Betts et al. 1997; Sellers et al. 1997; Field and Avissar 1998; Feddema et al. 2005; Higgins and Harte 2006; Randall et al. 2007; Higgins and Harte 2012). The goal in separating these three quasi-independent factors is to focus on the salient and tractable contributions to societal consequences that are both cumulatively comprehensive and broadly intuitive individually.

For illustrative purposes, consider the potential societal consequence of climate change as mediated by impacts to agriculture, one potentially sensitive social institution of many. First, large (small) changes in climate create larger (smaller) risks to agricultural productivity because they require greater (lesser) resilience or adjustment. Second, it could prove easy (hard) to shift the location of agricultural operations, to switch to new crop varieties, or to alter practices (e.g., irrigation and pest management) in response to climate changes, making agricultural production relatively immune (highly sensitive) to disruption as a result of changes in climate. Finally, the human dependence on agriculture could be small (large) based on the

extent to which humanity can substitute for agricultural goods and services (e.g., via fishing, hunting, or manufacturing food). Thus, the societal consequence of climate change as mediated by agricultural impacts will depend on how climate changes, the sensitivity of agricultural systems to climate change, and human dependence on agriculture. Similarly, the three broad contributing factors identified above are relevant for physical systems such as snowpack (and related water resources) and for biological resources such as forests (and their related ecosystem services).

Implementation of the conceptual tool involves two steps: 1) estimating the potential behavior of each of the three contributing factors (*climate*, *pbs sensitivity*, and *human dependence*) and 2) synthesizing the contributing factors to determine the potential societal consequence of climate change.

2.1. Step 1: Estimating the potential behavior of the three contributing factors

Each factor could have a range of potential characteristics or behaviors. In principle, *climate* driven by greenhouse gas (GHG) emissions could range from little future change (e.g., assuming future GHG emissions are low, carbon removal from the atmosphere proves successful at scale, compensatory negative climate forcings occur, and/or negative climate feedbacks dominate) to massive change (e.g., assuming GHG emissions are high and/or positive feedbacks dominate). Similarly, *pbs sensitivity* could range from no sensitivity (physical, biological, and social systems immune to climate changes) to high sensitivity (systems heavily disrupted), and *human dependence* could range from no dependence (substitutes for disrupted systems readily available) to complete dependence (no substitutes available).

For tractability and clarity, we create an illustrative implementation of the conceptual tool here by allowing each factor to take on only one of three possible discrete values that capture the range of possible behaviors: low (L), moderate (M), and high (H). We then test four plausible distributions for the contributing factors: uniform, centered, leftward, and rightward. In a uniform distribution, the three potential values are equally likely. In a centered distribution, moderate values are most likely with low and high values less likely. In a leftward distribution, low values are most likely and moderate and high values are less and least likely, respectively. Finally, in a rightward distribution, high values are most likely and moderate and low values are less and least likely, respectively. Other distributions (e.g., bimodal) are possible, as are variations on the distributions considered here (e.g., changes in the mean, standard deviation, skewness). However, the four distributions we include here span a broad range of plausible assumptions for the potential behavior of the contributing factors.

2.2. Step 2: Synthesizing the contributing factors to determine societal consequence

Synthesizing *climate*, *pbs sensitivity*, and *human dependence* to assess societal consequence is challenging because of the deep uncertainties that characterize potential climate impacts (Dessai et al. 2009; Moss 2011) and the scarcity of conclusive empirical evidence for how the factors might interact given the unprecedented

Table 1. Four illustrative distributions for the contributing factors: uniform, leftward, centered, and rightward. Each distribution shows the probability of low, moderate, and high values for an individual factor.

Contributing factor distribution	Probabilities		
	Low	Moderate	High
Uniform	3/9	3/9	3/9
Leftward	6/9	2/9	1/9
Centered	2/9	5/9	2/9
Rightward	1/9	2/9	6/9

nature of climate changes and the scale on which change is occurring. This leads, not surprisingly, to differing judgments among experts about the seriousness of climate change risks (Nordhaus 1994; Schneider et al. 2007; Rockström et al. 2009; Smith et al. 2009; Tol 2009; Weitzman 2009; Barnosky et al. 2012; Hansen et al. 2012) (see section 4). As a result, the appropriate method of synthesizing the contributing factors is also difficult to constrain at present.

Even a working definition for societal consequence poses potential challenges because it could be based on numerous specific metrics such as socioeconomic well-being (GDP, poverty, etc.), environmental quality (air and water quality, species richness, etc.), and human health and safety (mortality, morbidity, etc.). For the purposes of this exercise we consider societal consequence in its broadest form (i.e., integrating all potential climate impacts whether deemed harmful or beneficial) and consider three schematic approaches for the synthesis that illustrate a broad range of possible alternatives.

For each approach, the values for the contributing factors (L, M, or H) map to the societal consequence domain as low, moderate, or high climate impacts as follows: Societal consequence could be represented by Equation (1), in which the lowest value among the three contributing factors determines societal consequence,

$$SC = \min(CF_{clm}, CF_{pbs}, CF_{hd}), \tag{1}$$

where SC is societal consequence, CF_{clm} is *climate*, CF_{pbs} is *pbs sensitivity*, and CF_{hd} is *human dependence*. As described above, the contributing factors take on one of three possible values (low, moderate, and high) with probabilities determined based on distributions given in Table 1 and assuming that the factors assort independently. Alternatively, societal consequence could be represented by Equation (2), in which the highest value among the contributing factors determines societal consequences,

$$SC = \max(CF_{clm}, CF_{pbs}, CF_{hd}). \tag{2}$$

Finally, societal consequences could be represented by Equation (3), which assumes an equal weight average of the contributing factors,

$$SC = (1/3)CF_{clm} + (1/3)CF_{pbs} + (1/3)CF_{hd}. \tag{3}$$

Using the lowest value of the contributing factors [Equation (1)] is a single-point safety system in which any of the three factors confers protection to society from the other two. Hypothetically, if there were no climate change at all, then it would

not matter how sensitive physical systems, biological resources, and social institutions are to climate changes. Using the highest value of the contributing factors [Equation (2)] is a single-point failure system in which any of the three factors determines the societal consequence no matter how little the other factors contribute. For example, if human society were highly dependent on existing physical systems, biological resources, and social institutions, then even small climate changes could result in high-consequence outcomes. The equal weight average approach [Equation (3)] implies that each factor contributes equally to societal consequence. Other approaches for synthesizing the factors are also possible, but these three options span a very broad range of plausible assumptions.

Managing the uncertainties that underlie the assumptions in this way (i.e., identifying and testing a very broad range of plausible assumptions for contributing factors and approaches to their synthesis) allows us to search for general conclusions—those that hold across a wide range of possible assumptions. However, this approach comes at the expense of precision and specificity in those results. In principle, the tool could be implemented to provide more specific results, but this would require more narrowly constrained assumptions and the results would only be as good as the underlying assumptions. For this analysis, we maximize the range of possible assumptions that we explore (considering the range of distributions and synthesis approaches without respect to whether any set of assumptions is more or less likely) and thereby minimize the potential of relying on weakly supported assumptions.

3. Results

This implementation of the conceptual tool uses three contributing factors (*climate*, *pbs sensitivity*, and *human dependence*), each of which has three values (low, moderate, or high) that assort independently. Thus, there are 27 unique raw combinations or potential outcomes (Table 2). These raw outcomes express differently based on the method of synthesis. For example, the raw value in which the change in *climate* is high, *pbs sensitivity* is moderate, and *human dependence* is low (the “HML” raw outcome in Table 2) could express as a low, moderate, or high societal consequence if the synthesis uses a single-point safety system, an equal weight average, or a single-point failure system, respectively.

As a result, the choice of the synthesis method leads to considerably different assessments of societal consequence. In the case of uniformly distributed contributing factors (Table 1), the single-point safety synthesis suggests that the consequences of climate change are most likely to be low (70.4% of potential outcomes), with a substantial chance for moderate-consequence outcomes (25.9%), and a small chance of high-consequence outcomes (3.7%) (Figure 2). In contrast, the single-point failure synthesis assumption suggests the consequences of climate change are most likely to be high (70.4% of potential outcomes), with a substantial chance of moderate outcomes (25.9%) and a small chance of low-consequence outcomes (3.7%). The equal weight average synthesis assumption suggests the consequences of climate change are most likely to be moderate (70.4% of potential outcomes), with more modest chances for high and low-consequence outcomes (14.3% each).

Including different potential distributions for each contributing factor (Table 1) further influences the assessment of the potential consequences of climate change

Table 2. The expected societal consequence of climate change derived from the conceptual tool. The three-factor tool generates 27 raw combinations that map to different expected societal consequences, depending on the method of synthesis (equal weight average, single-point safety, and single-point failure).

Climate	Contributing factors			Societal consequence		
	pbs sensitivity	Human dependence	Raw combination	Equal weight average	Single-point safety	Single-point failure
L	L	L	LLL	L	L	L
L	L	M	LLM	L	L	M
L	L	H	LLH	M	L	H
L	M	L	LML	L	L	M
L	M	M	LMM	M	L	M
L	M	H	LMH	M	L	H
L	H	L	LHL	M	L	H
L	H	M	LHM	M	L	H
L	H	H	LHH	M	L	H
M	L	L	MLL	L	L	M
M	L	M	MLM	M	L	M
M	L	H	MLH	M	L	H
M	M	L	MML	M	L	M
M	M	M	MMM	M	M	M
M	M	H	MMH	M	M	H
M	H	L	MHL	M	L	H
M	H	M	MHM	M	M	H
M	H	H	MHH	H	M	H
H	L	L	HLL	M	L	H
H	L	M	HLM	M	L	H
H	L	H	HLH	M	L	H
H	M	L	HML	M	L	H
H	M	M	HMM	M	M	H
H	M	H	HMH	H	M	H
H	H	L	HHL	M	L	H
H	H	M	HHM	H	M	H
H	H	H	HHH	H	H	H

(Figure 3). Relative to the uniform distribution, if distributions are leftward for each factor, then low-consequence outcomes of climate change become more likely and high-consequence outcomes become less likely. If distributions are rightward, then high-consequence outcomes from climate change become more likely and low-consequence outcomes become less likely. If distributions are centered for each factor, then moderate-consequence outcomes become more likely.

4. Discussion

The societal consequences of climate change will depend on the magnitude that climate changes together with those factors that determine the capacity of society to absorb changes in climate (i.e., the sensitivity of physical, biological, and social systems to climate changes and human dependence on those physical, biological, and social systems). Therefore, even a small change in climate could lead to high-consequence outcomes if society’s adaptive capacity is relatively weak and even

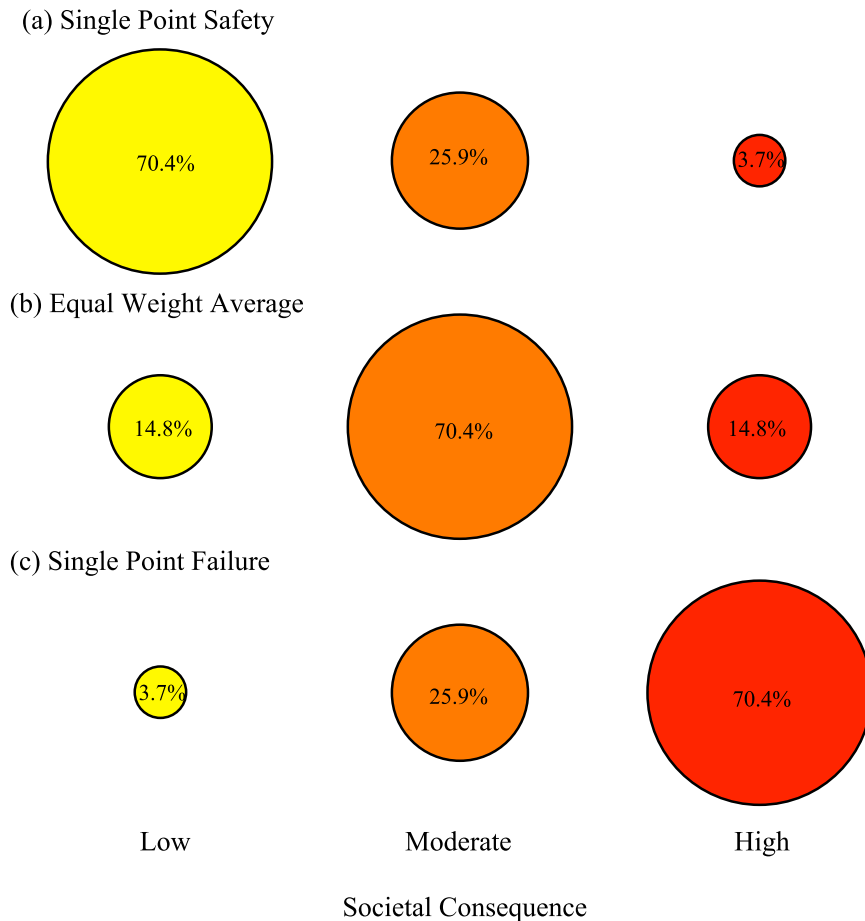


Figure 2. Bubble histograms of the societal consequence of climate change for three uniformly distributed contributing factors organized according to synthesis method: (a) single-point safety, (b) equal weight average, and (c) single-point failure. The results are derived from the 27 possible outcomes of the three-factor conceptual tool (Table 2), assuming all three contributing factors have uniform distributions (Table 1) that assort independently.

large climate changes could translate into low-consequence outcomes if society is sufficiently resilient to climate disruptions.

The conceptual tool developed here suggests that plausible assumptions about the behaviors and synthesis of the relevant contributing factors can lead to very different assessments of the societal consequences of climate change. Critically, each of the assumptions explored with the tool appears plausibly justifiable given current knowledge and understanding.

For example, consider the distribution of values for *human dependence*. Relatively small changes in climate have, at times, had large consequences on societies locally or regionally (Diamond 2005), potentially suggesting a rightward distribution for *human dependence* on physical, biological, and social systems (i.e., one

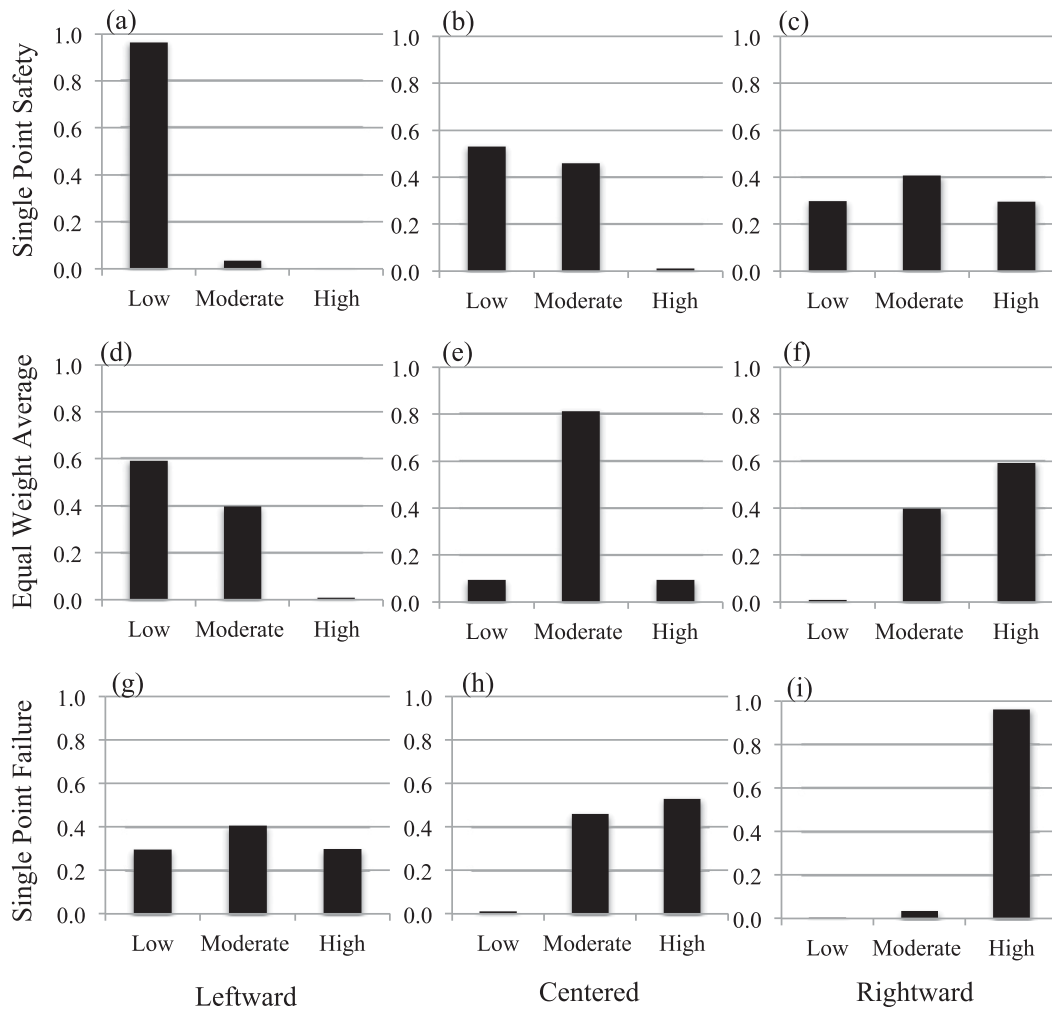


Figure 3. Histograms of the societal consequence of climate change derived from Tables 1 and 2 for various contributing factor distributions (leftward, centered, and rightward; shown in Table 1), which are taken to be the same for all three factors, and for three approaches to synthesis (single-point safety, equal weight average, and single-point failure; shown in Table 2). The societal outcomes are expressed as low, moderate, and high consequences.

in which high dependence is most likely). On the other hand, humanity’s scientific understanding and technological capabilities are considerably more advanced than at any previous time in human civilization and could greatly enhance society’s capacity to cope with climate change. This provides a possible rationale for a leftward distribution for *human dependence* (i.e., one in which low dependence on physical, biological, and social systems is most likely).

A similarly broad range can be justified for *climate* and *pbs sensitivity*. For example, *climate* could be low through a combination of aggressive emissions reduction efforts, the successful implementation of carbon removal projects, and low climate sensitivity (Nakicenovic and Swart 2000; Solomon et al. 2007). Alternatively,

climate could be high if climate change mitigation is weak or ineffective and climate sensitivity is high (Nakicenovic and Swart 2000; Solomon et al. 2007). Similarly, *pbs sensitivity* could be low (high) if physical characteristics, biological systems, and social institutions are resilient (easily disrupted) in the face of changes in climate (Nordhaus 1994; Schneider et al. 2007; Rockström et al. 2009; Smith et al. 2009; Tol 2009; Weitzman 2009; Barnosky et al. 2012; Hansen et al. 2012).

Therefore, it is not yet possible to conclusively invalidate assumptions that result in low-, moderate-, or high-consequence outcomes being most likely. As a result, the conceptual tool suggests that the consequences of climate change to society are currently difficult to constrain and span a range from modest to severe. This seemingly ambiguous finding has important implications for climate change risk assessment and management because it 1) suggests that studies that find that the consequences of climate change are most likely to be low are relying on assumptions that are hard to defend given current understanding and remaining uncertainties and 2) suggests that there is considerable potential for high-consequence climate impacts based on plausible assumptions. Our conceptual tool also suggests that there is considerable potential for low-consequence climate impacts based on plausible assumptions and the studies that incorporate those assumptions may be correct.

In this first implementation of the conceptual tool, we test a broad range of plausible assumptions relating to the factors that affect the relationship between climate change and societal well-being while minimizing assumptions and choices that could effectively prescribe a climate damage function. This means that we are able to represent the broad range of plausible perspectives contained within potential user communities but that the range of outcomes is similarly unconstrained (i.e., we have left many of the hard questions for subsequent analysis: how to handle heterogeneity of societal consequences across space and time, what indicators of societal consequence are most useful, etc.). This approach allows us to search for general conclusions but precludes reaching specific conclusions.

It may be possible to further constrain the plausible distributions for each contributing factor or the approach to their synthesis through research, assessment, more comprehensive IAM simulations, or expert elicitation. Notably, previous efforts to elicit expert judgment reveal divergent views among experts (particularly among experts with different disciplinary backgrounds) on the likely consequences of climate change (Nordhaus 1994). More recent scientific literature appears to continue to reflect this divergence of views, with some studies suggesting that climate impacts on society are most likely low (Tol 2009; Weitzman 2009) and others suggesting considerable potential for high-consequence outcomes (Rockström et al. 2009; Barnosky et al. 2012; Hansen et al. 2012).

The conceptual tool could be used to explore this divergence of views among experts further by considering the conditions and circumstances that would favor low, moderate, or high societal consequences. For example, a high probability of a low-consequence outcome rests on either the single-point safety approach to synthesis or one (or more) of the distributions being leftward. Either (or both) of these assumptions is certainly possible. However, it is not clear why either would be more strongly justified than the assumptions that would imply considerably higher-consequence outcomes. The conceptual tool offers a potential vehicle for

experts with differing views to communicate with one another about the basis of those differing views.

The tractable, user-driven approach of the conceptual tool makes it also potentially useful for nonexperts to examine how their own knowledge and assumptions of climate change translate to societal consequences. Most notably, the framework presented here avoids constraining risk assessment outcomes because of a model developer-imposed climate damage function, as is typical of reduced form economic models (Hope 2006; Nordhaus 2008). Instead, the relationship between climate changes and societal consequences is determined by relationships left to the tool user. Therefore, the conceptual tool may help users test and revise their assumptions and views through easy to implement thought experiments. Such a tool could be particularly valuable given that public perceptions of climate change risks are currently influenced by factors largely or wholly unrelated to the relevant contributing factors, such as recent weather and political views (Leiserowitz et al. 2011a,b).

The conceptual tool is also potentially valuable for decision support. For greenhouse gas-induced warming, the tool illustrates how risk management strategies (mitigation, adaptation, and geoengineering) might affect the societal consequence of climate change. For example, emissions reduction (mitigation) would reduce the amount that climate changes, thereby shifting the distribution of *climate* to the left but without directly altering the distributions of *pbs sensitivity* or *human dependence*. Efforts to increase our capacity to cope with climate change (adaptation) might decrease the sensitivity of physical systems, biological resources, and social institutions to changes in climate (*pbs sensitivity*) or reduce *human dependence* on those systems, resources, and institutions. Geoengineering could also conceivably alter how much (or how) climate changes (AMS 2009; Royal Society 2009). Each risk management strategy also has the potential to create risks or ancillary benefits that are not captured by the conceptual tool. For example, mitigation could confer cobenefits such as reductions in foreign oil dependence and improved air quality, and geoengineering could increase the risk of nonclimate environmental hazards (AMS 2009). We also note that although we have developed the conceptual tool in the context of human-caused climate change resulting from greenhouse gas emissions, it would apply equally well to risk assessment and management for climate changes caused by natural sources (e.g., because of volcanic eruptions, asteroid impacts, or changes in solar radiation) or by other human-induced causes.

Critically, all three of the potential applications of the tool we envision (expert communication, public education, and decision support) would likely require expert facilitation and further development of the framework. However, the goal of this paper is to develop the most basic version of this conceptual tool in as straightforward manner as possible. Therefore, we intentionally leave the implementation assumptions of the tool to users and future studies. In practice, this means that we have left many of the hard questions for subsequent analysis (e.g., how to handle heterogeneity of societal consequences across space and time, what indicators of societal consequence are most useful, what the distributions for the contributing factors are, and what the appropriate method of aggregating distributions is). We intend to explore the implications of several assumptions in subsequent analysis but deliberately leave these choices aside for this initial description of the tool.

We also preserve flexibility with respect to several key definitions and specifications. For example, the definition of (or metric for) *climate* is left unspecified; it could account for the mean change in global average surface temperature only or could incorporate other climate variables (e.g., precipitation, wind speed, humidity, etc.), the rate of change, potential shifts in variability and extremes, or regional and local responses. In addition, we do not explicitly define the potential values of the factors (i.e., what defines “low,” “moderate,” and “high”), the boundaries that separate those values (i.e., low from moderate and moderate from high), or the extent (range) within each value bin (e.g., whether the bin sizes are uniform).

The conceptual tool also does not currently specify a particular time horizon or spatial domain for the analysis, which would need to be set based on the specific application of the tool. The choice of temporal and spatial and scale would almost certainly have a large impact on the behavior of the contributing factors and the appropriate approach to their synthesis. For example, how climate changes will vary over time with larger changes less likely over shorter time scales. Similarly, social system sensitivity could vary over time: for example, as adaptation policies and practices are developed and adopted. The spatial scale of implementation would also influence the behaviors of contributing factors in potentially complex ways. For example, significant consequences that occur at one spatial scale may have limited impact (or even opposite impacts) at alternate spatial scales or domains (locations) of analysis. Further, the contributing factors in their most complex and complete form include spatial dependence (e.g., *pbs sensitivity* at a given location will depend on *pbs sensitivity* in connected regions). We defer such implementation choices at this stage and use the conceptual tool here for a highly generalized application that explores a range of plausible choices.

In future analysis we anticipate beginning to integrate and explore some potential assumptions explicitly. Both the synthesis step and the estimation of behaviors for the contributing factors could be refined and constrained based on scientific assessments, new research results, output from more comprehensive IAMs, or expert judgment. This would allow more specific conclusions to emerge even though the selection of any specific values for contributing factors or the synthesis approach is likely temporary and will require refinement in light of future studies of the contributing factors and their implications for societal consequence.

The power of this framework lies in its potential to leave subjective choices to the individual user (as described in this paper) or to make necessary choices explicit and transparent so that users of the tool can assess the validity of those assumptions for themselves. This makes it possible for users to consider the basis of climate risk without depending on a model developer–prescribed climate damage function. As a result, the conceptual tool enables both experts and non-experts to explore how their knowledge and assumptions of climate change translate into expectations for climate change outcomes for society. With further refinement and expert facilitation, the tool could be used for increasing public understanding, supporting risk management decision making, and facilitating communication of climate risks across disciplinary boundaries.

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