AGU PUBLICATIONS

Tipping elements and climate-economic shocks: Pathways toward integrated assessment

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Key Points:

- Potential state shifts in climatic and social systems play an important role in estimates of climate damages.
- 'Tipping points' as broadly understood involve positive feedbacks and abrupt change, but not all climatic thresholds cause abrupt change.
- Some possible climate–economic shocks, whether or not they can be called 'catastrophes', involve tipping points; not all do.

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Abstract:

The literature on the costs of climate change often draws a link between climatic "tipping points" and large economic shocks, frequently called "catastrophes." The phrase "tipping points" in this context can be misleading. In popular and social scientific discourse, "tipping points" involve abrupt state changes. For some climatic "tipping points," the commitment to a state change may occur abruptly, but the change itself may be rate-limited and take centuries or longer to realize. Additionally, the connection between climatic "tipping points" and economic losses is tenuous, although emerging empirical and process-model-based tools provide pathways for investigating it.

We propose terminology to clarify the distinction between "tipping points" in the popular sense, the critical thresholds exhibited by climatic and social "tipping elements," and "economic shocks." The last may be associated with tipping elements, gradual climate change, or nonclimatic triggers. We illustrate our proposed distinctions by surveying the literature on climatic tipping elements, climatically sensitive social tipping elements, and climate–economic shocks, and we propose a research agenda to advance the integrated assessment of all three.

Often only *ad hoc* inclusion in climate-economic models of "high-consequence" events

Climate economists often link the economic consequences of tipping thresholds to sometimes elusively defined "economic catastrophes." For example, in *Nordhaus and Boyer* [2000]'s DICE-99 integrated assessment model (IAM), an estimated willingness to pay to avoid such catastrophes—1.0% of output-weighted global GDP at 2.5∘C and 6.9% of output-weighted global GDP at 6∘C—constituted about two-thirds of the total estimated economic damage caused by climate change.

Nordhaus and Boyer [2000]'s numbers were derived from an earlier survey of a group of economists and scientists [*Nordhaus*, 1994], which asked respondents to evaluate the probability that different climate pathways would cause a Great Depression-scale "high-consequence [economic] outcome," defined as a 25% loss of global income [*Nordhaus*, 1994]. For a 3∘C rise in global mean temperature in 2090, the estimated probabilities ranged from 0% to 30%, with a mean probability of 0.6% and a median probability of 5%. Natural scientists averaged 12%, while non-environmental economists averaged 0.4%. Noting growing concern about the possibility of what they now called "catastrophic" impacts, *Nordhaus and Boyer* [2000] doubled the mean estimates of *Nordhaus* [1994] without further explanation and remapped the 3∘C probability to 2.5∘C. They estimated that, due to risk aversion, the willingness to pay to avoid such "catastrophic" losses would be ~2–3 times the expected loss.

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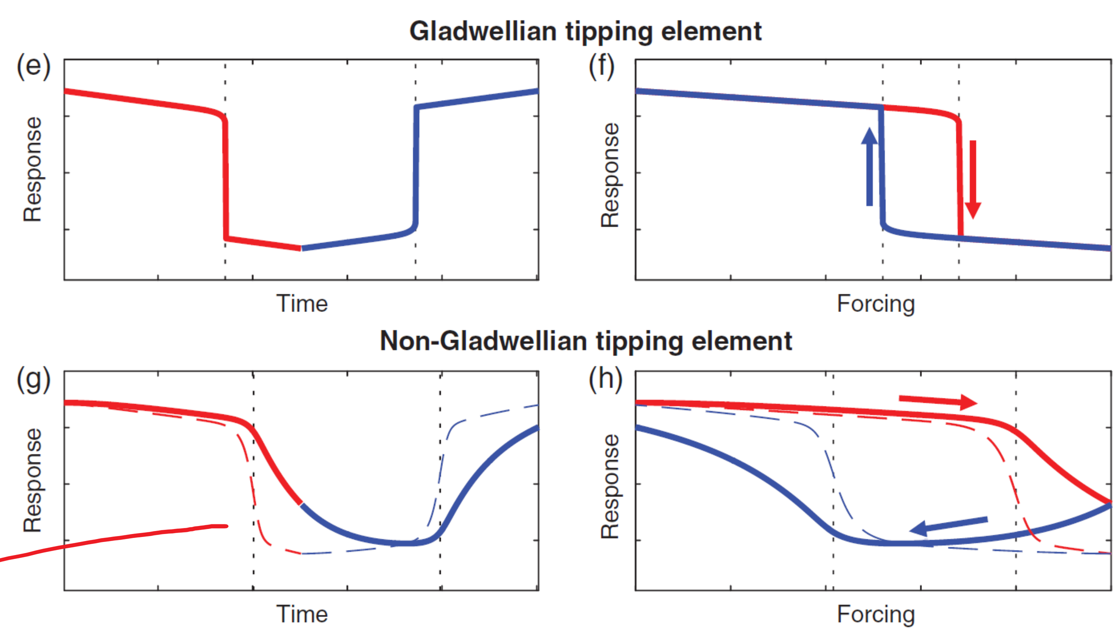
Large costs!?

Distinguish between 'Gladwellian tipping elements' and 'non-Gladwellian tipping elements'



Role for climate/solar geoengineering?

Figure 2. Illustration of the response of different types of tipping elements and nontipping elements with thresholds to forcing. The dotted vertical lines mark the time or forcing of the maximum rate of committed change; for tipping elements, this maximum rate defines the critical threshold or "tipping point." (e–f) Response of a Gladwellian tipping element, plotted as a function of (e) time and (f) forcing. (g–h) Response of a non-Gladwellian tipping element, plotted as a function of (g) time and (h) forcing. Solid lines represent realized change, and dotted lines represent committed change.

Table 1. Illustrative Candidate Tipping Elements

Candidate Tipping Element	Main Impact Pathways	Potentially Gladwellian	Key Reference
Atmosphere/ocean circulation			
Atlantic Meridional Overturning Circulation	Regional temperature and precipitation; global mean temperature; regional sea level	yes	*Rahmstorf* [2005]
Atmospheric superrotation	Climate sensitivity (cloudiness)	yes	*Caballero and Huber* [2013]
El Niño-Southern Oscillation	Regional temperature and precipitation	yes	*Latif et al.* [2015]
Regional North Atlantic convection	Regional temperature and precipitation	yes	*Drijfhout et al.* [2015]
West African Monsoon	Regional temperature and precipitation	yes	*Dong and Sutton* [2015]
Cryosphere			
Antarctic ice sheet	Sea level; albedo	no	*Schoof* [2007]
Arctic sea ice	Regional temperature and precipitation; albedo	yes	*Li et al.* [2013]
Greenland ice sheet	Sea level; albedo	no	*Robinson et al.* [2012]
Carbon cycle			
Methane hydrates	Greenhouse gas emissions	no	*Archer et al.* [2009]
Permafrost carbon	Greenhouse gas emissions	no	*Schuur et al.* [2015]
Ecosystem			
Amazon rainforest	Ecosystem services; greenhouse gas emissions	no	*Jones et al.* [2009]
Boreal forest	Ecosystem services; greenhouse gas emissions; albedo	no	*Jones et al.* [2009]
Coral reefs	Ecosystem services	yes	*Hoegh-Guldberg et al.* [2007]
Socioeconomic			
Conflict/development	Economic welfare	yes	*Hsiang et al.* [2013]
Environmental policy	Adaptation/vulnerability; greenhouse gas emissions	yes	*Baumgartner et al.* [2014]
Migration	Economic welfare	yes	*Massey and Zenteno* [1999]
Technology	Adaptation/vulnerability; greenhouse gas emissions	yes	*Rogers* [2003]

Four pathways toward integrated assessment

Climatic tipping elements, climatically sensitive social tipping elements, and climate–economic shocks may all be important contributors to the costs of climate change; indeed, it is possible that they may be the largest contributors. Their incorporation into climate change risk analyses is therefore a crucial task that requires pursuing multiple research pathways.

1. **Start with candidate climatic tipping elements** and evaluate the climate–economic shocks that they might cause. Two possible approaches: Growing body of empirical, econometric analyses of the effects of climate variability [e.g., Dell et al., 2014]; the emerging set of sectoral models of impact processes [e.g., Warszawski et al., 2014]. Experiments with empirical and process-based impact models, applied to scenarios in which the critical thresholds of different natural-system tipping elements are crossed, can help assess the economic hazards posed by state shifts and prioritize economic research.

   It is also important to examine how tipping-element state shifts may influence both one another and also climate–economic shocks triggered by other causes. These experiments may show that some tipping elements have impacts that are small relative to more gradual climatic changes and thus are not a priority for integrated assessment research. They can also reveal how the economic influence of different tipping elements differs between regions and on different timescales.

   Links across tipping elements

2. **Focus on social tipping elements.** Empirical evidence regarding policy thresholds, technology adoption, and technology costs can inform estimates of the costs of, efficacy of, and barriers to adaptation and mitigation, as well as of barriers to climate engineering. E.g. empirical data on the relationships among climate change, migration, and civil conflict may reveal costs that are larger than those associated with many climatic tipping elements.
3. **Identify known triggers causing large-scale climate-economic shocks.** Triggers with relatively clear mechanisms include meteorological disasters, civil conflict, and temperature effects on growth rates, but less obvious triggers like financial crisis and international wars should not be neglected. Both statistical and system-dynamic approaches may play important roles in tracing these mechanisms.
4. **Conduct structured expert elicitation,** in which the probability estimates of experts are combined based on calibrated assessments of the experts' reliability, can temporarily fill remaining gaps. In many cases, empirical and modeling studies may be able to identify potential state shifts or climate–economic shocks without being able to assess their likelihood, timing, or magnitude.

   (One priority for policy research should be the focus on whether and how robust decision-making frameworks should displace benefit–cost analysis within existing, real-world decision-making processes.)

Advancing the understanding of tipping elements and climate–economic shocks will require greater coordination among disciplines. By their nature, many critical thresholds involve pushing natural and/or social systems beyond the limits of behaviors to which we are accustomed and thus require deep process insight informed by a diversity of empirical observations over a wide range of timescales. However, understanding tipping points may be key to accurately assessing the societal and economic challenges posed by climate change because they may be—as *Nordhaus and Boyer* [2000] suggest—one of the primary sources of climate change risk.