A Minimal Framework with Precautionary Mitigation

Thomas F. Rutherford
University of Wisconsin, Madison

(with Geoff Blanford, Rich Richels, Steve Rose and the MERGE team)

EMF Workshop:
Climate Change Impacts and Integrated Assessment
Snowmasss Village, Colorado, USA
25 July, 2013

Objectives of this Talk

1. Suggest a new approach to the representation of catastrophic risk in integrated assessment models.

Objectives of this Talk

1. Suggest a new approach to the representation of catastrophic risk in integrated assessment models.
2. Introduce some of the ideas behind decision theoretic reasoning.

Objectives of this Talk

1. Suggest a new approach to the representation of catastrophic risk in integrated assessment models.
2. Introduce some of the ideas behind decision theoretic reasoning.
3. Measure the sensitivity with respect to “time consistency”

Objectives of this Talk

1. Suggest a new approach to the representation of catastrophic risk in integrated assessment models.
2. Introduce some of the ideas behind decision theoretic reasoning.
3. Measure the sensitivity with respect to “time consistency”
4. Illustrate the integration of stochastic control elements in an “off the shelf” integrated assessment model *with solution times on the order of a few minutes*.

Key Ideas

1. Most integrated assessment models focus on the avoidance of market and non-market damages as an incentive for short-run mitigation.

Key Ideas

1. Most integrated assessment models focus on the avoidance of market and non-market damages as an incentive for short-run mitigation.
2. Some more recent work (e.g., Lemoine and Traeger (2011) or Cai, Judd and Lontzek (2013)) have introduced a *precautionary motive* for mitigation. Mitigation in the short run is desireable because it reduces the rate of temperature change and thereby reduces the likelihood of catastrophic impacts.

Key Ideas

1. Most integrated assessment models focus on the avoidance of market and non-market damages as an incentive for short-run mitigation.
2. Some more recent work (e.g., Lemoine and Traeger (2011) or Cai, Judd and Lontzek (2013)) have introduced a *precautionary motive* for mitigation. Mitigation in the short run is desireable because it reduces the rate of temperature change and thereby reduces the likelihood of catastrophic impacts.
3. Unlike most decision-theory integrated assessment models, the introduction of uncertain catastrophic damages demands a *stochastic control* rather than a *stochastic programming* format.

Key Ideas

1. Most integrated assessment models focus on the avoidance of market and non-market damages as an incentive for short-run mitigation.
2. Some more recent work (e.g., Lemoine and Traeger (2011) or Cai, Judd and Lontzek (2013)) have introduced a *precautionary motive* for mitigation. Mitigation in the short run is desireable because it reduces the rate of temperature change and thereby reduces the likelihood of catastrophic impacts.
3. Unlike most decision-theory integrated assessment models, the introduction of uncertain catastrophic damages demands a *stochastic control* rather than a *stochastic programming* format.
4. The purpose of this model is to illustrate a minimalist framework for investigating the impact of uncertain catastrophic loss on near term mitigation.

Climate sticker shock: Arctic thaw could cost $60 trillion

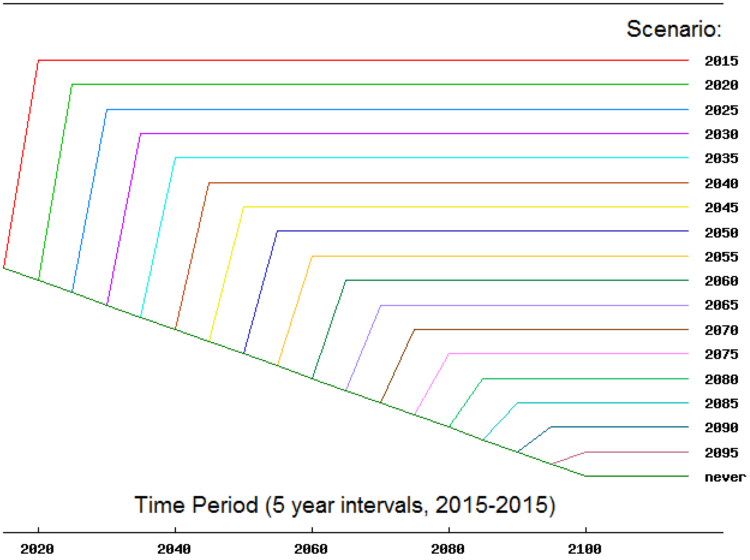
By **Matt Smith**, CNN

updated 3:31 PM EDT, Wed July 24, 2013

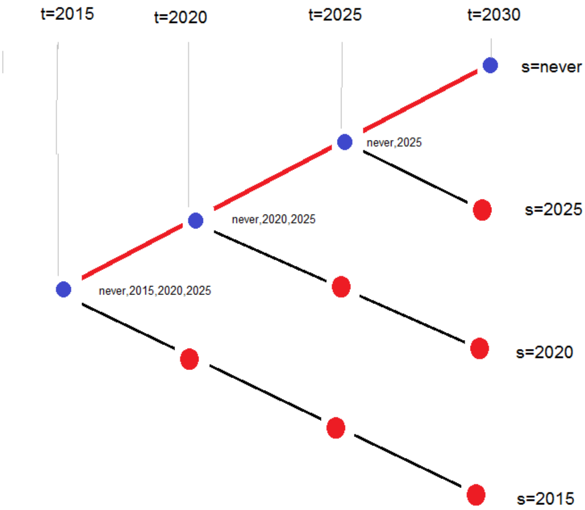
Model Features

1. DICE 2013 (one world, market and non-market damages, costly mitigation, Ramsey growth model, simple climate model driven by carbon emissions)
2. t_E time periods of economic activity (2015,2020,. . . ,2115)
3. $t_C > t_E$ time periods of climate evolution and damages (2015,2020,. . . ,2300)
4. s states of world (*scenarios*) each associated with the year in which catastrophic damage is realized or "*never*"

Scenario Structure



Scenario Indexing



Bayesian Learning

Following Lemoine and Traeger we adopt a simple uniform prior: the probability of a catastrophe *at a temperature* $T > T_{2015}$ is ex-ante assumed to be:

$$p_T = \frac{T - T_{2015}}{\bar{T} - T_{2015}}$$

Let h_t denote the *hazard rate*, the contitional probability of a disaster during period t assuming there has been no catastrophe to that point. If no catastrophe has yet occured in period t when the temperature is T_t, the Bayesian *hazard rate* of catastrophe during period t if the temperature in $t+1$ is T_{t+1} is:

$$h_t = \frac{T_{t+1} - T_t}{\bar{T} - T_t}$$

Probabilities

1. Let ξ_t denote the probability that no catastrophic loss has occured to the start of period t.
2. With a base year of 2015, $\xi_{2015} = 1$
3. Probability that catastrophic loss has not taken place at the start of period $t + 1$ is then:

$$\xi_{t+1} = (1 - h_t)\xi_t$$

4. Probability the scenario s is realized is then:

$$\pi_s = \begin{cases} h_t \xi_t & s = t \\ \\ \xi_{2115} & s = \text{never} \end{cases}$$

5. By definition, $\pi_s \geq 0$ and $\sum_s \pi_s = 1$.

A Couple Equations

1. Aggregate output (Y) is allocated to consumption (C), investment (I), climate damages (D) and mitigation cost (A):

$$Y_{st} = C_{st} + I_{st} + D_{st} + A_{st}$$

2. Damage costs are determined as a fraction of gross output, depending on temperature change and whether the catastrophic temperature threeshold has been exceeded:

$$D_{st} = Y_{st} \left(\alpha_1 T_{st} + \alpha_2 T_{st}^{\alpha_3} + \delta_{st} \left(\Delta \left(\frac{T_{st}}{\tilde{T}_s} \right)^{\phi} \right) \right)$$

in which $\tilde{T}_s$ is the catastrophic temperature threshold for scenario s (i.e., $\tilde{T}_s = T_{never,t}$ when $s = t$), and δ_{st} is an indicator function which is equal to unity if $t > s$ (catastrophe has occured) and zero otherwise. Code:

```
DAMAGE(s,t) =E= Y(s,t) * (aa1*TATM(s,t) + aa2*TATM(s,t)**a3 +

 ifcat(s,t) * damcat * (TATM(s,t)/THRESH(s))**asl3);
```

Expected Utility

- Nested Constant Elasticity of Substitution

$$EU = \left(\sum_s \pi_s \left(\sum_t \beta_t C_{st}^{1-\theta} \right)^{(1-\gamma)/(1-\theta)} \right)^{1/(1-\gamma)}$$

EU	Expected utility
β_t	The utility discount factor (accounting for both population and impatience)
$\theta = 1.45$	Elasticity of marginal utility of consumption (the inverse of the intertemporal elasticity of substitution)
$\gamma = 2$	The coefficient of relative risk aversion

- Cobb-Douglas assumes $\gamma = \theta = 1$:

$$EU = \sum_{st} \pi_s \beta_t \log(C_{st})$$

Limitations

- Problem with Cobb-Douglas model: no distinction between attitudes toward time and uncertainty.
- Problem with constant elasticity model: time consistency.

Thanks to Svenn Jensen for helping me understand these issues and the usefulness of the Epstein-Zin model.

Dynamic Inconsistency

In economics, dynamic inconsistency, or time inconsistency, describes the situation: A decision-maker's preferences change over time, in such a way that a preference, at one point in time, is inconsistent with a preference at another point in time. It is often easiest to think about preferences over time in this context by thinking of decision-makers as being made up of many different "selves", with each self representing the decision-maker at a different point in time.
Wikipedia

- A concrete example: a government climate policy commission produces a full schedule of state-contingent policies. Ten years later, policy is revised, *even though there has be no change in the likelihoods of different states of world*.
- An more mundane example: the third or fourth beer may be regretted in the morning.

Epstein-Zin Preferences

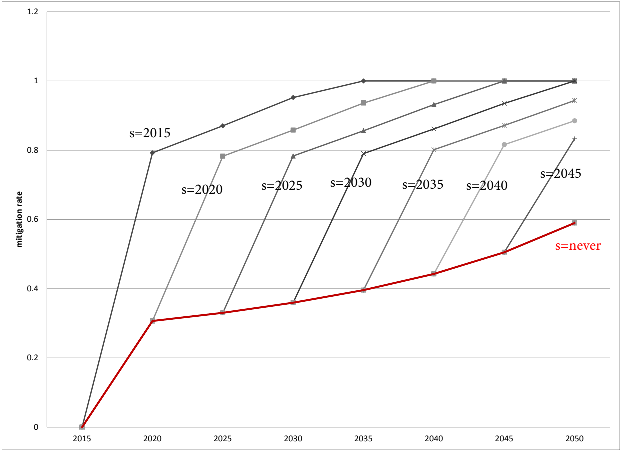
A recursive utility function can be constructed from two components: a time aggregator that characterizes preferences in the absence of uncertainty and a risk aggregator that defines the certainty equivalent function that characterizes preferences over static gambles and is used to aggregate the risk associated with future utility.

$$U_t = \left\{ C_t^{(1-\gamma)/(1-\theta)} + \tilde{\beta}_t E_t \left[U_{t+1}^{1-\gamma} \right]^{1/(1-\theta)} \right\}^{(1-\theta)/(1-\gamma)}$$

The time discount parameter $\tilde{\beta}_t$ is a parameter reflecting pure time preference, growth and concavity of utility which is related but not equal to β_t in the CES model.

Mitigation Before and After Catastrophe

Damage rates jump following realization of a catastrophe and mitigation becomes more profitable:



Diagnostic Simulations

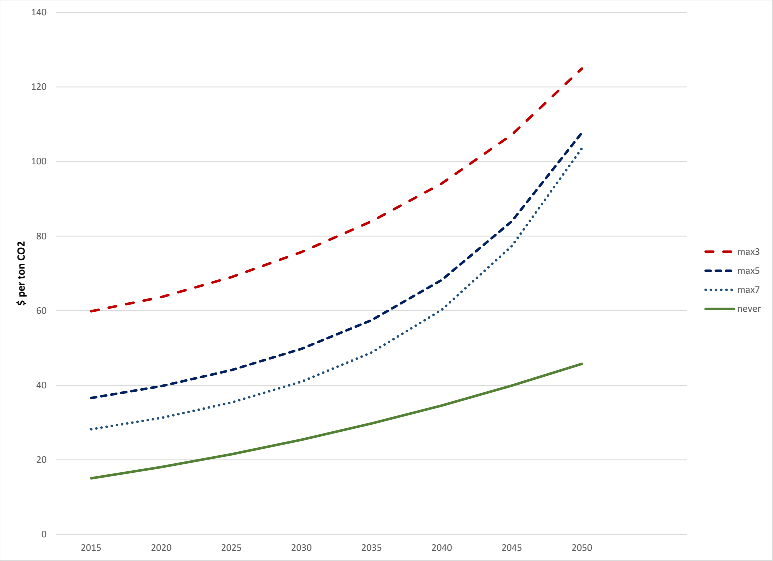
- Stochastic simulations with a uniform Bayesian prior

max3	Catastrope is certain with a $3\,^{\circ}\mathrm{C}$ temperature change
max5	Catastrope is certain with a $5\,^{\circ}\mathrm{C}$ temperature change
max7	Catastrope is certain with a $7\,^{\circ}\mathrm{C}$ temperature change

- Deterministic simulation

never	Catastrophe is ignored and unrealized.

Catastrophe and the Shadow Price of Carbon



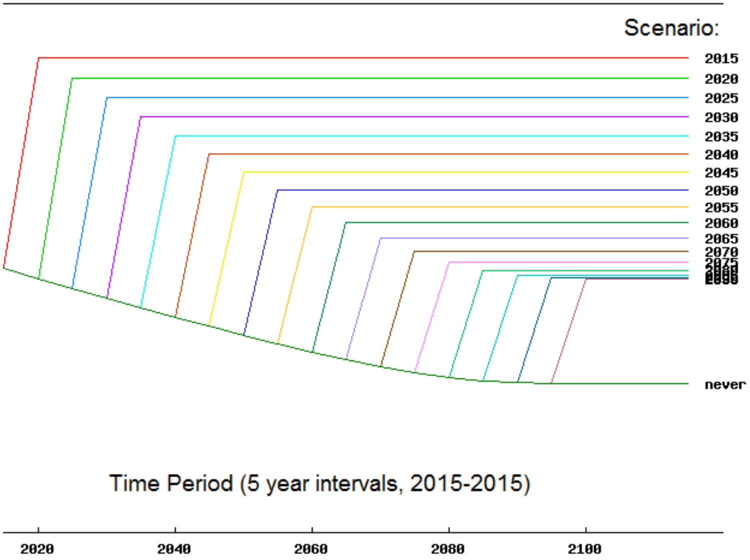
Decomposing the Precautionary Motive

We run the Bayesian stochastic control model with endogenous hazard rates. Let h_t^* denote the resulting hazard rates. We can solve a *stochastic program* to decompose the *precautionary motive*. We do this by dropping the Bayesian update expression and assigning:

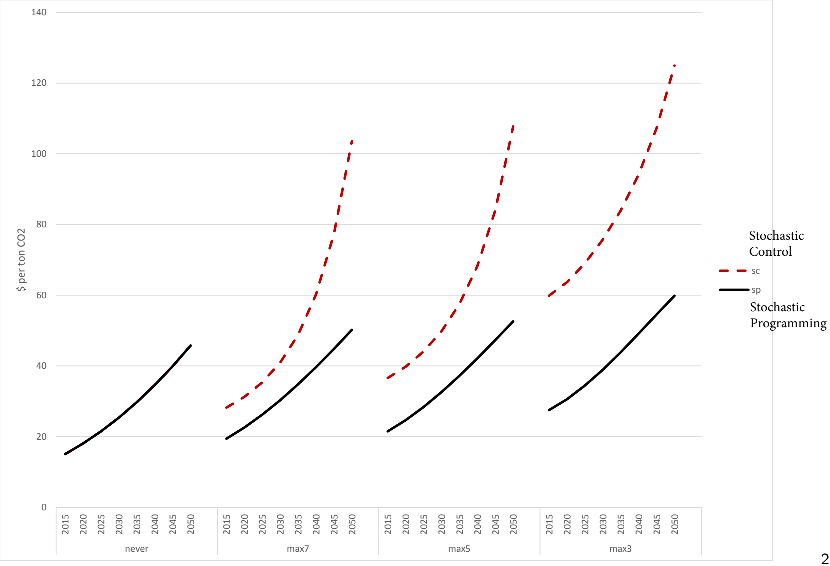
$$h_t = h_t^*$$

The hazard rate in each period remains unchanged, but the optimal program then undertakes less aggressive abatement because the transition probabilities are fixed.

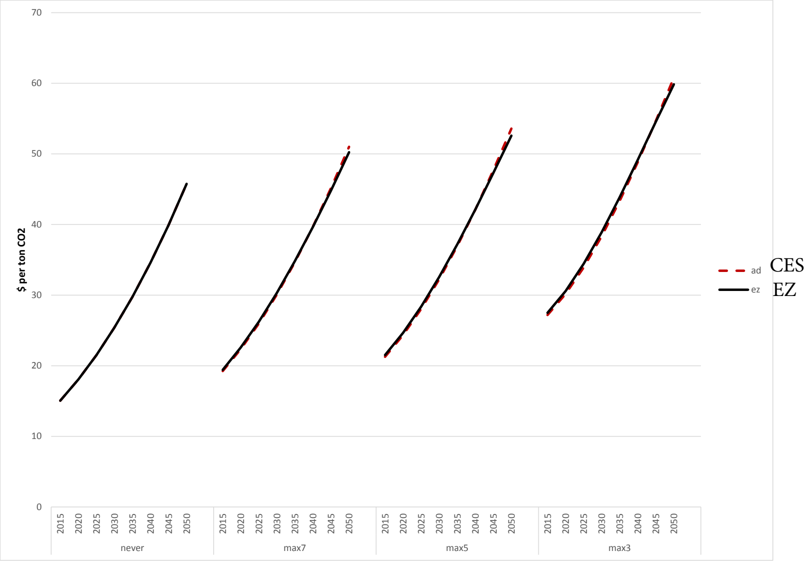
Illustrated Scenario Probabilities π^*



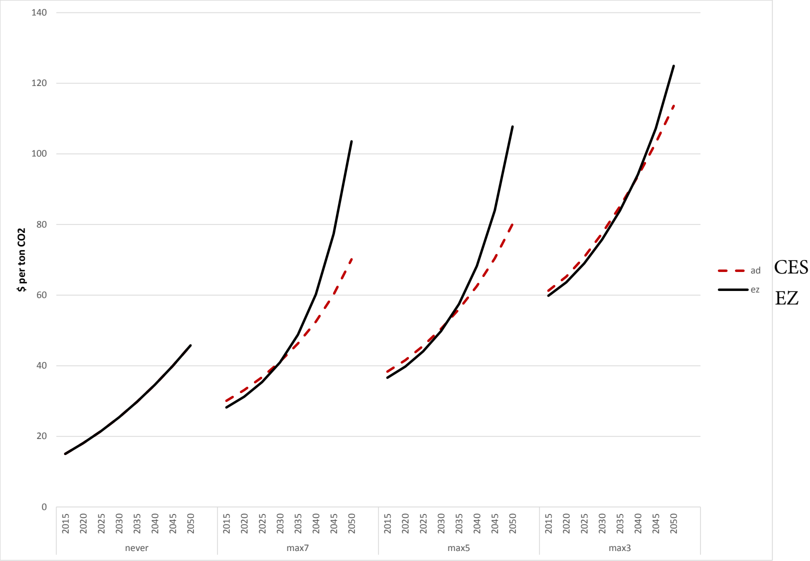
Decomposing Precautionary Abatement



Time Consistency with Stochastic Programming



Lack of Time Consistency with Stochastic Control?



Research Agenda going Forward

- Evaluate the *expected value of perfect (or imperfect) information*.
- Assess the qualitative importance of the prior distribution.
- Incorporate precautionary adaptation investments.
- Investigate the scientific basis for tipping points and catastrophes.

Lemoine and Traeger

- Increase in climate sensitivity from 3 up to 6 deg C
- Increase in CO2 atmospheric lifetime weakening sinks (decay rate) 25% to 75%
- Temperature threshold uniformly distributed between historic maximum and upper bound
- Endogenous hazard rate (i.e., probability of exceeding threshold contingent on not having crossed)

Issues: (1) Thresholds and impacts theoretical; (2) Rapid transition, and sudden yet perpetual realization seems unrealistic.

Cai, Judd, Lontzek

- Stochastic increase in GDP loss (2.5, 5, 10, 20%)
- Abrupt and gradual tipping point impact
- Tipping point probabilities from previous expert elicitations broad ranges
- Inferred hazard rates

Issues: Thresholds, impacts, and timing strike us as hypothetical.

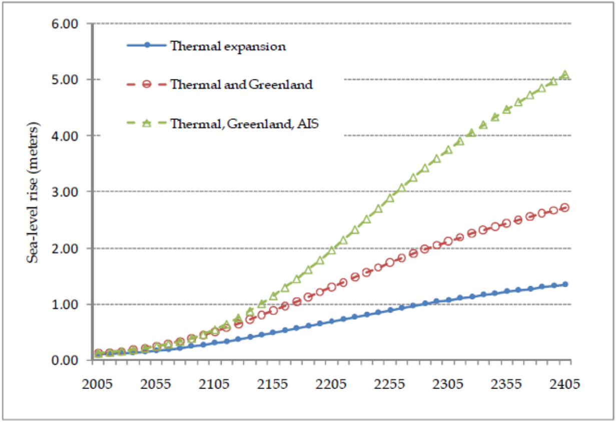
Calibrated

Sea-level rise (Nordhaus, 2010)

Equilibrium SLR temperature thresholds

Tipping points?

Reversible?

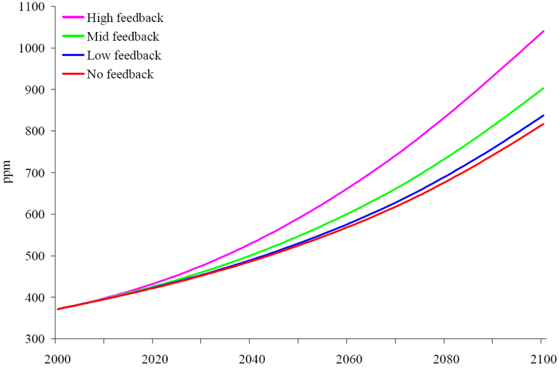


Calibrated

Terrestrial carbon feedback (Tol, 2009)

No thresholds and reversible

Tipping points?



Geophysical

Greenland ice sheet (Stone et al., 2010)

Ice sheet extent with CO2 concentrations

Collapse found between 400-560 ppmv

“Collapse?”

Today

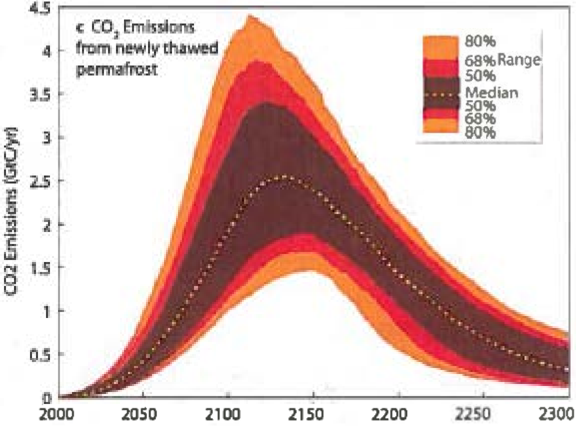
Illustrative sample of results

Geophysical

Permafrost melt (Schneider von Deimling et al., 2012)

Permafrost emissions with temperature thresholds

Abrupt or gradual?



The End

- Slides: `http://www.mpsge.org/dicesc.pdf`
- GAMS model directory: `http://www.mpsge.org/dicesc.zip`