Policy tradeoffs under risk of abrupt climate change

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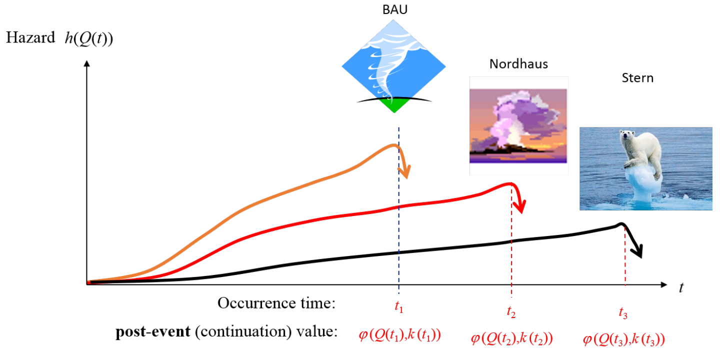
MOTIVATION

- The more serious outcomes of climate change are associated with abrupt catastrophic events;
- Occurrence conditions are stochastic or not well-understood $\Rightarrow$
- Uncertain occurrence time; occurrence probability depends on policy: endogenous hazard

Climate change context



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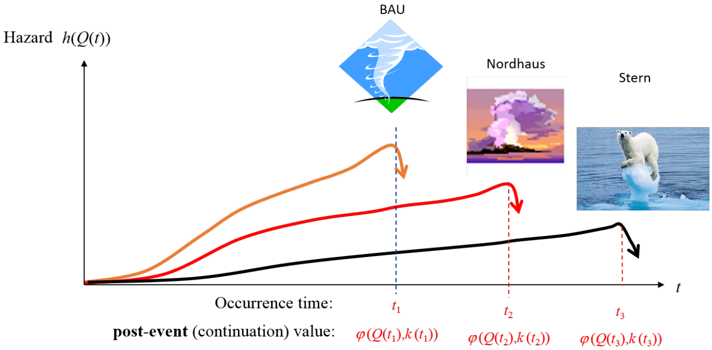

- $Q(t)$ =GHG stock – affects the hazard rate (occurrence probability)
- $k(t)$ =adaptation capital (levees, vaccines, crop varieties) – affects the scale of damage upon occurrence

CLIMATE POLICY: MITIGATION & ADAPTATION

Mitigation efforts (emission abatement, carbon capture) affect the GHG stock $Q(t)$

Adaptation investment determines the adaptation capital $k(t)$

Both activities reduce the welfare of present generation but contribute to the welfare of future generations

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Purpose

Characterize optimal long-run **Mitigation-Adaptation** mix (steady state properties)

CONTRIBUTION

- Tsur and Zemel (2014) developed a general method to identify optimal steady states in multi-dimensional dynamic economic models (extends the single-state case of Tsur & Zemel, 2001, 2014a)
- Apply this methodology to (2-dimensional) mitigation-adaptation, climate change policies
- Relaxes the linearity assumption of Zemel (2015)

EXAMPLES

- Unknown stock (Kemp 1973)
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- Forest and rangeland fire (Reed 1984, Yin and Newman 1996, Perrings and Walker 1997)
- Disease outburst, pollution control (Clark and Reed 1994; Tsur and Zemel 1998)
- Ecological regime shift (Mäler 2000, Dasgupta and Mäler 2003, Mäler et al. 2003, Polasky et al. 2011; de Zeeuw and Zemel 2012)

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- Climate change (Tsur & Zemel 1996, 2008,2009; Gjerde et al (1999); Mastrandrea & Schneider 2001, 2004; Naevdal 2006)
- Climate change - IAMs (Traeger & Lemoin 2014; van der Ploeg & de Zeeuw 2014; Lontzek, Cai, Judd & Lenton 2015)

RECURRENT EVENT

A damage $\psi(k)$ is inflicted each time the event occurs (Tsur and Zemel 1998) and the problem continues under risk of future occurrences

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Mitigation efforts $m(t)$ drive GHG stock $Q(t)$ according to

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GHG stock $Q(t)$ and occurrence probability:

$T =$ next occurrence time

$S(t) = Pr\{T > t\}$ (survival probability)

$f(t) = -dS(t)/dt$ (density of T)

$h(Q(t))$ (hazard rate): $h(Q(t))\Delta = Pr\{T \in (t, t+\Delta] | T > t\} = f(t)\Delta/S(t)$

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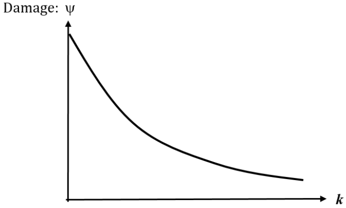
$$S(t) = \exp\left(-\int_0^t h(Q(s))ds\right), \quad f(t) = h(Q(t))S(t)$$

ADAPTATION CAPITAL & OCCURRENCE DAMAGE

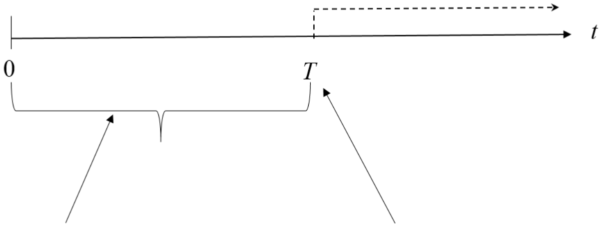
Adaptation capital evolves with investment $a(t)$ according to

$$\dot{k}(t) = a(t) - \delta k(t)$$

and affects occurrence damage $\psi(k)$:



PAYOFF



$$\int_0^T u(m(t), a(t))e^{-\rho t}dt \quad + \quad e^{-\rho T}[v(Q(T), k(T)) - \psi(k(T))]$$

EXPECTED PAYOFF

$$\int_0^\infty \left[u(m(t), a(t)) + h(Q(t))\varphi(Q(t), k(t))\right] e^{-\int_0^t [\rho + h(Q(s))]ds} dt$$

where

$$\varphi(Q, k) = v(Q, k) - \psi(k)$$

is the continuation value

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Seek the feasible mitigation-adaptation policy that maximizes the expected payoff

Notice the discount rate endogeneity (Tsur and Zemel 2009, 2014b)

LONG RUN PROPERTIES: DEFINITIONS

States: $X = (Q, k)'$

Actions: $C = (m, a)'$

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Jacobian of G wrt $C = (m, a)'$: $J_C^G = \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}$

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Instantaneous utility: $f(X, C) \equiv u(m, a) + h(Q)\varphi(X)$

Gradient of f wrt $C = (m, a)'$: $f_C = \begin{pmatrix} u_m \\ u_a \end{pmatrix}$

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$$W(X) = \int_0^\infty \left[u(\hat{C}(X)) + h(Q)[W(X) - \psi(k)] \right] e^{-\int_0^t [\rho + h(Q)] ds} dt$$

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from which $W(X)$ is solved:

$$W(X) = \frac{u(\gamma Q, \delta k) - h(Q)\psi(k)}{\rho}$$

THE L(X) FUNCTION

$$L(X) \equiv \begin{pmatrix} l_1(X) \\ l_2(X) \end{pmatrix} = (\rho + h(Q)) \left([J_C^{G\prime}]^{-1} f_C + W_X(X) \right)$$

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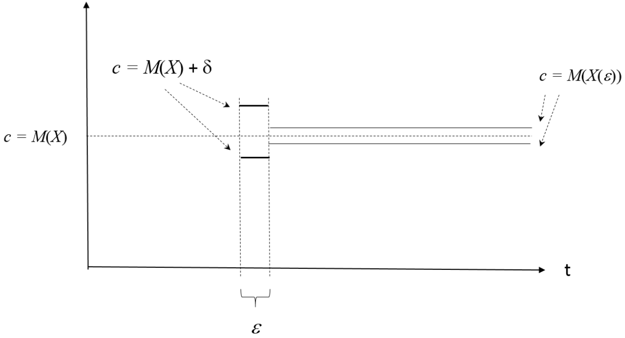
In the present setting, $L(X)$ specializes to

$$L(X) = \frac{\rho + h(Q)}{\rho} \begin{pmatrix} (\rho+\gamma)u_m(\gamma Q, \delta k) - h'(Q)\psi(k) \\ (\rho+\delta)u_a(\gamma Q, \delta k) - h(Q)\psi'(k) \end{pmatrix}$$

L(X) MOTIVATION (SINGLE STATE)



$$W^{\epsilon\delta}(X) - W(X) \approx L(X)(\epsilon\delta) + o(\epsilon\delta)$$

Extension to multi-state is straightforward

Steady state properties (Tsur and Zemel 2014)

Necessary conditions for the location of an optimal steady state:

(i) If $\hat{Q} \in (0, \bar{Q})$ and $\hat{k} \in (0, \bar{k})$ then $L(\hat{X}) = 0$.

(ii) If $\hat{Q} = \bar{Q}$, then $l_1(\hat{X}) \geq 0$; if $\hat{k} = \bar{k}$, then $l_2(\hat{X}) \geq 0$.

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Necessary condition for stability:

If a steady state $\hat{X}$ at which $L(\hat{X}) = 0$ is locally stable, then $\det(J_X^L(\hat{X})) > 0$.

APPLICATION TO CLIMATE POLICY

Functions:

Utility: $u(m, a) = \alpha m - m^2/2 - a^2$

Hazard: $h(Q) = \beta Q$

Damage: $\psi(k) = \psi_0 k_m/(k + k_m)$

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Parameters:

$\alpha = 1$ (utility parameter);

$\rho = 0.03$ (discount rate);

$\gamma = 0.01$ (GHG rate of decay);

$\delta = 0.03$ (adaptation capital depreciation rate);

$\beta = 0.005$ (hazard sensitivity)

$\psi_0 = 10,\ k_m = 50$ (damage parameters)

$\bar{Q} = 200$; $\bar{k} = 33.33$

Internal steady state

A unique internal steady state (with $L(X) = 0$):

$$\hat{X} \equiv (\hat{Q}, \hat{k}) = (106.178,\ 16.616)$$

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The Jacobian $J_X^L(\hat{X}) = \frac{\rho + h(\hat{Q})}{\rho} \begin{pmatrix} -0.0004 & 0.000563 \\ 0.000563 & -0.0054 \end{pmatrix}$ has a positive determinant, as required by the Stability Property .

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$\hat{X} \equiv (\hat{Q}, \hat{k}) = (106.178,\ 16.616)$ is the unique optimal steady state to which the system converges from any initial state $X_0 \equiv (Q_0, k_0)$.

Corner steady state

Doubling the hazard sensitivity (from $\beta = 0.005$ to $\beta = 0.01$):

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Second:

Only the corner $\hat{X} \equiv (\hat{Q}, \hat{k}) = (0, 0)$ satisfies the necessary conditions for an optimal steady state $\Longrightarrow (\hat{Q}, \hat{k}) = (0, 0)$ is the unique optimal steady state.

Corner steady state (cont.)

- The strong dependence of the hazard rate on the GHG stock provides a strong incentive to reduce emissions and bring the occurrence probability down to zero.

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- Eliminating the catastrophic risk removes the motivation to invest in adaptation, hence the adaptation capital stock k is also driven down to its lowest feasible level.

SUMMARY

- Identify optimal mitigation-adaptation (two-dimensional) steady states by means of a simple (algebraic) function $L(X)$, both for interior and for corner steady states.
- In either case, the optimal steady state reflects the tradeoffs between the adaptation and mitigation responses to the catastrophic risk.
- The method can be applied in other multi-dimensional resource situations involving uncertain abrupt changes, such as regime shifts in the dynamics of ecosystems and other regenerating resources.