1st Teaching Workshop on Environmental Economics

for the Middle East and North Africa

December 5-16, 2005 - ICTP, Trieste, Italy

Water and the Environment: Water management under threats of catastrophic events

Lecture II.2

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Environmental events are ubiquitous -- related to

non-convex behavior, positive feedbacks, system collapse and thresholds that underlie many environmental processes

(Mäler 2000; Dasgupta & Mäler 2003; Arrow, Dasgupta & Mäler 2003)

Examples:

- Global warming induced events
  (IPCC 1996, 2001, Tsur & Zemel 1996, Hayhoe et al. 2004)
- Pollution related events
  (Clarke & Reed 1994, Tsur & Zemel 1998)
- Biodiversity loss and species extinction
  (Tsur & Zemel 1994, 2005, Limburg et al. 2002)
- Nuclear accidents
  (Cropper 1976, Aronsson et al. 1998)

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Dust storm (looks much worse that actual damage)

Wildfire in Yosemite

Event classification (1)

The Damage is:

- Reversible - Restoration is possible at a cost
- Irreversible - Restoration is impossible (or too costly)

Different penalty functions.

Environmental Events

Characteristic features:

- Sudden ("discrete" in time)
- Catastrophic damage (modifies the economics of the resource)
- Uncertain occurrence conditions

Groundwater managements:

Tradeoffs:

- Diminishing marginal benefit vs. Increasing pumping cost
  ("economic depletion" – static optimization)
- Present benefit vs. Future scarcity
  (physical depletion – dynamic optimization)
- Exploitation benefit under risk of Catastrophic Events
  (seawater intrusion)

Event classification (2)

Uncertainty is:

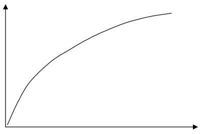
- Exogenous – Events are triggered by genuinely random conditions. The manager affects the hazard.
- Endogenous – Occurrence determined only by exploitation. Uncertainty relates to (partial) ignorance concerning the threshold stock level that triggers the event.

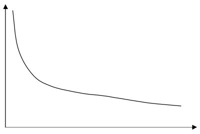
Profound effect on exploitation policy (equilibrium structure)

The instantaneous benefit

$B(S,x) = Y(x) - C(S)x$

gross benefit — extraction cost

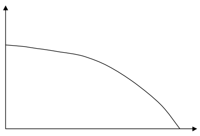




Water stock dynamics:

$dS/dt = R(S) - x(t)$

natural recharge — extraction

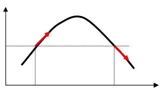


Steady-state policy: $x = R(S)$

Properties of the solution under certainty :

Monotonic stock evolution:

Same decision problem – Conflicting actions!



The stock process must approach a steady-state $\hat{S}$.

$\hat{S}$ is found by solving the algebraic equation $\boldsymbol{L(S) = 0}$.

The stock process converges to the steady state from any initial stock.

Groundwater management under certainty

Set extraction policy $\{x_t, t \geq 0\}$ in order to:

$$V^{ne}(S_0) = Max_{\{x_t\}}\{\int_0^\infty [Y(x_t) - C(S_t)x_t]e^{-rt}dt\}$$

subject to:

$dS/dt = R(S_t) - x_t$

$S_t \geq 0$; $x_t \geq 0$; S_0 given.

No event. Standard Dynamic Optimization problem.

Catastrophic events under certainty:

Event occurs at the known state S_c and imply the post-event value ϕ.

Set extraction rate x_t and the time T in order to find

$$V^c(S_0) = Max_{\{x_t,T\}}\{\int_0^T [Y(x_t) - C(S_t)x_t]e^{-rt}dt + e^{-rT}\phi\}$$

subject to:

$dS/dt = R(S_t) - x_t$

$S_t \geq 0$; $x_t \geq 0$; $S_T = S_c$; S_0 given.

The evolution function

A simple algebraic method to identify optimal steady states (T&Z, 2001):

Only roots of $L(S)$ (or corner states) qualify.

$$L(S) = (r - R'(s))\left\{\frac{-C'(S)R(S)}{r - R'(S)} - [Y'(R(S)) - C(S)]\right\}$$

At the root of $L(S)$: marginal increase in pumping cost equals marginal increase in net benefit due to a small variation from the steady state policy $x = R(S)$.

Uncertain endogenous events I

Occur at the unknown state S_c with the post-event value $\phi(S_c)$.

$F(S) = \Pr\{S_c \leq S\}$ with the density $f(S)$

$h(S) = f(S)/F(S)$ – the hazard

T is the event occurrence time (i.e., $S_T = S_c$). The distribution of S_c induces a distribution on T that depends on the extraction plan

Solution for certain events:

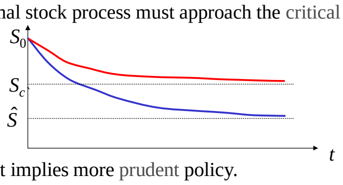
It is never optimal to trigger the event.

If $S_c < \hat{S}$, the event has no effect :

No reason to go below the steady state.

If $S_c > \hat{S}$, the root of $L(S)$ is not feasible :

The optimal stock process must approach the critical state.



The event implies more prudent policy.

Insensitivity to the exact penalty.

Improper formulation?

The lowest stock so far is safe. The value depends on all history!

But:

The optimal stock process is monotonic (non trivial! T&Z '94).

The problem splits into two distinct sub-problems:

Increasing processes – back to the certainty problem.

Decreasing processes – only the current stock matters.

Well-posed auxiliary problem with

$L^{aux}(S) = [L(S) + h(S)r\psi]F(S)/F(S_0)$.

$h(S)$ – hazard rate $F(S)$ – distribution function ψ – penalty

Uncertain endogenous events

The management problem:

$$V^{en}(S_0) = Max_{\{x_t\}} \underline{\underline{E_T}}\{\int_0^T [Y(x_t) - C(S_t)x_t]e^{-rt}dt + e^{-rT}\phi(S_T)\}$$

subject to:

$dS/dt = R(S_t) - x_t$

$S_t \geq 0$; $x_t \geq 0$; S_0 given.

E_T is the expectation with respect to the distribution of T.

Uncertain exogenous events

Occur randomly at some state S_t and imply the post-event value $\phi(S_t)$.

Set extraction rate x_t in order to find

$$V^{ex}(S_0) = Max_{\{x_t\}} \underline{\underline{E_T}}\{\int_0^T [Y(x_t) - C(S_t)x_t]e^{-rt}dt + e^{-rT}\phi(S_T)\}$$

subject to…

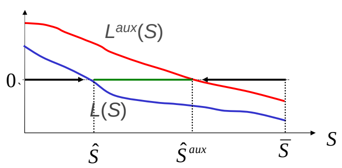
E_T is the expectation with respect to the distribution of T.

Stock-dependent hazard-rate: $f(t)/[1-F(t)] = h(S_t)$.

$F(t) = Pr\{T \leq t\} = 1 - exp\{-\int_0^t h(s_\tau)d\tau\}$

No state is safe. History does not matter.

Characterization of the endogenous process.



Below $\hat{S}$, the endogenous process increases

Above $\hat{S}^{aux}$, the endogenous process decreases

$[\hat{S}, \hat{S}^{aux}]$ is an equilibrium interval depending on $h(S)$ and ψ

The event implies more prudent and penalty-sensitive policy.

Non standard equilibrium structure

Effect of exogenous uncertainty

$L^{ex}(S) = L(S) - d[h(S)\psi(S)] / dS.$

A wide range of possible behavior:

- $h(S)$ and $\psi(S)$ decrease with stock: $\hat{S}^{ex} > \hat{S}$
  Uncertainty implies more conservative extraction. (T&Z 98)
- $h(S)$ and $\psi(S)$ independent of stock: $\hat{S}^{ex} = \hat{S}$
  Uncertainty does not affect extraction.
  (penalty plays no role in policy tradeoffs).
- $h(S)$ independent of stock, irreversible events: $\hat{S}^{ex} < \hat{S}$
  Uncertainty implies more vigorous extraction! (C&R 94)
  (maximum exploitation prior to occurrence).

Proper formulation!

The expectation can be evaluated regardless of trend.

Only the current stock matters.

A unique, well-posed exogenous problem with

$L^{ex}(S) = L(S) - d[h(S)\psi(S)] / dS.$

$h(S)$ – hazard rate $\psi(S)$ – penalty.

•No equilibrium interval.

•Uncertainty shifts the steady state.

Summary:

- A unified framework to analyze resource management under event uncertainty.
- Uncertainty is resolved only upon occurrence, and must be accounted for in advance. No need to adjust policy along the way.
- The details of the occurrence conditions are important, with significant effects on the optimal extraction policies.
- Equilibrium intervals for endogenous events - hysteresis behavior
- Uncertainty typically induces prudence - but not always!
- Application to seawater intrusion into coastal aquifer - extends to a variety of renewable resource situations involving event uncertainty.