Biodiversity, Biosphere & Climate

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Big issues in ERE …

- I used to think that there were 2 “big issues” in our field
  - Climate change and
  - Biodiversity loss
- Now I think there’s just 1
  - Managing human interaction with the biosphere

What is the biosphere?

- A layer about 10km thick around Earth
- This layer supports all life: all plants and animals depend on it totally
- We evolved in and because of the biosphere and are still dependent on it
- Earth's diameter is 12,500km so biosphere's thickness is < 1/1000 of earth's diameter
  - If I drew Earth as a sphere 1.25m diameter, Biosphere would be a 1mm thick line around it
  - This very fragile habitat is what we depend on
  - Has changes radically over geological time – from hostile to supportive


Biosphere 2

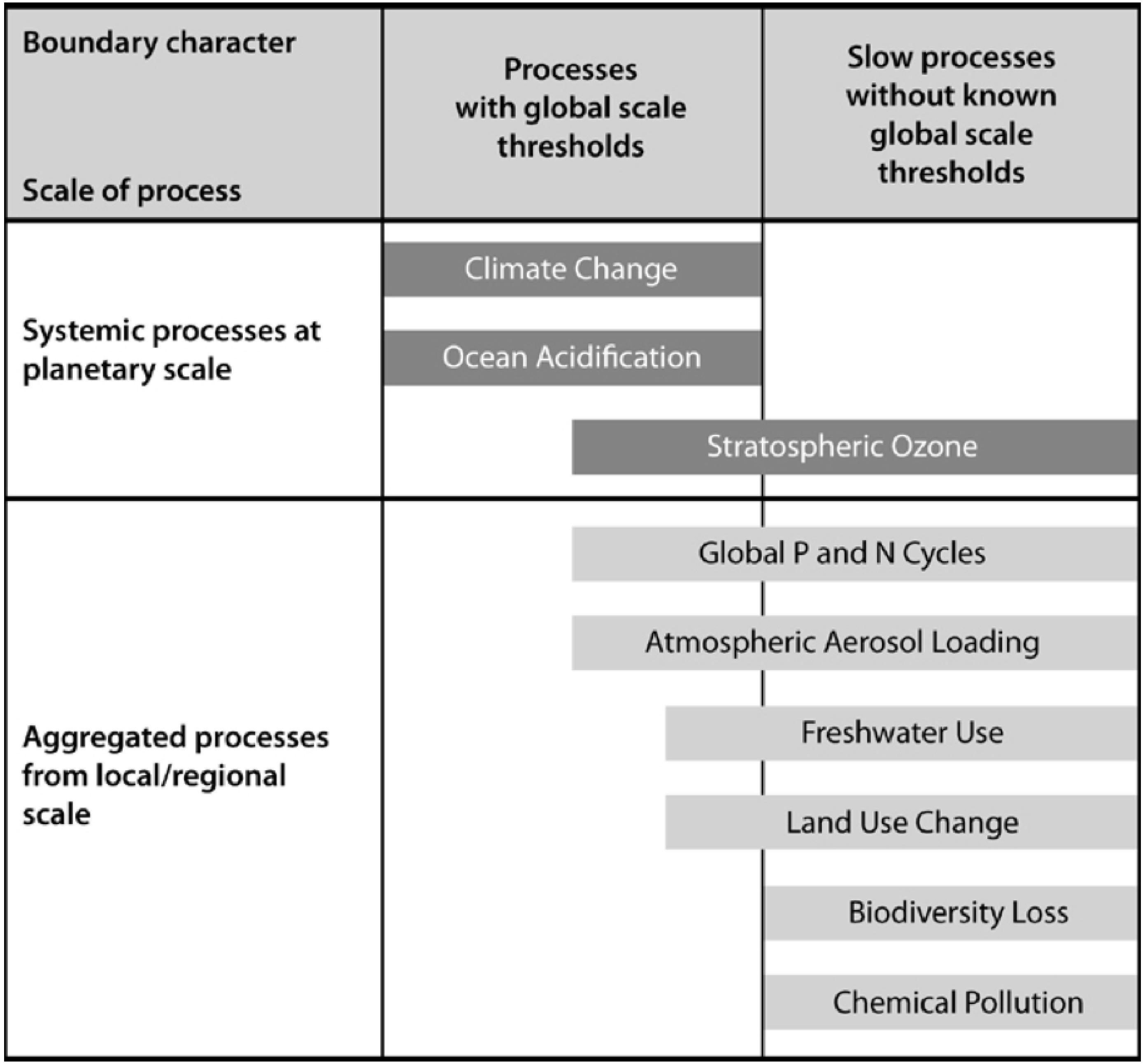
Biosphere’s importance

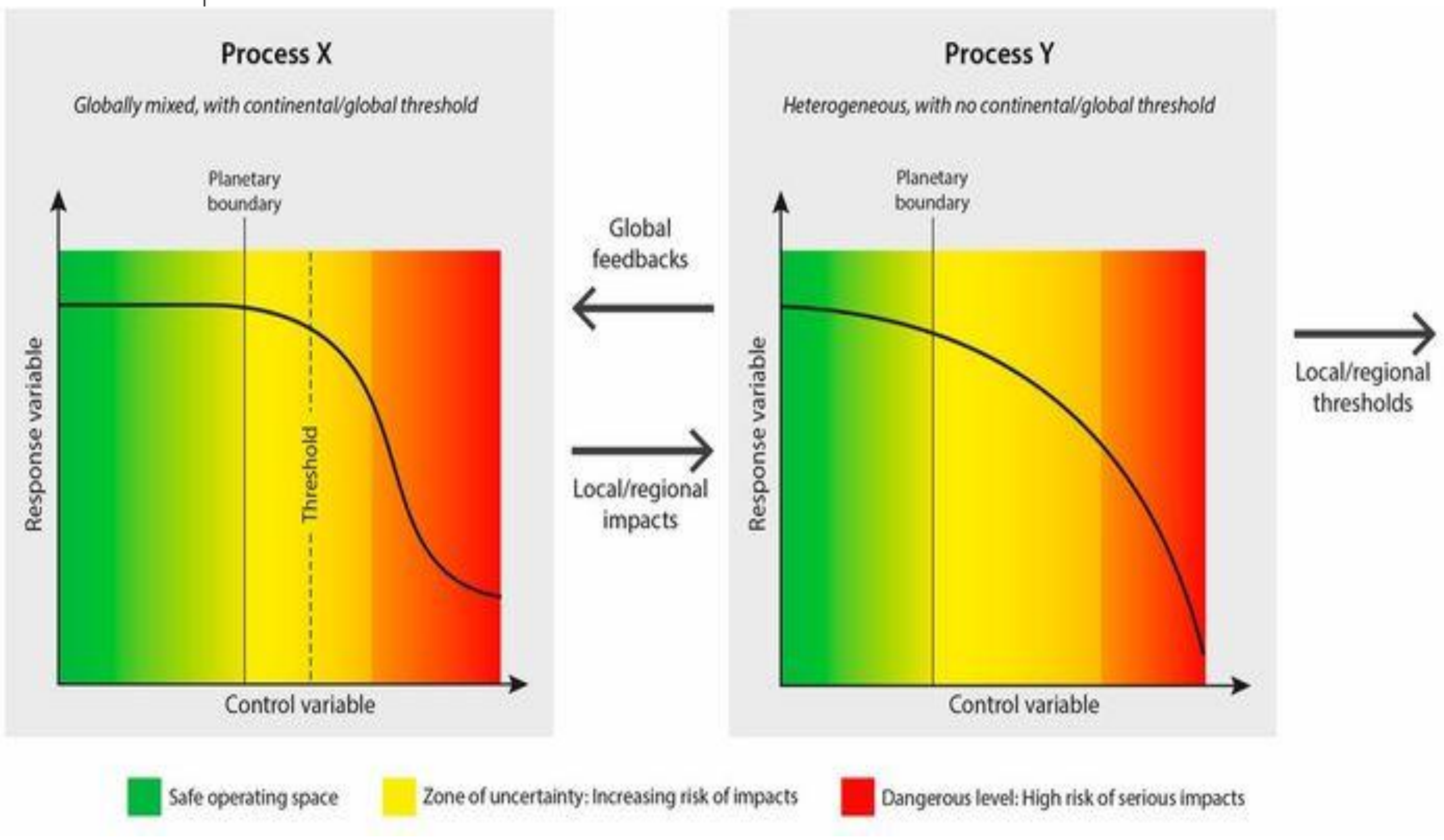
- Think of solar system – Venus & Mars are our planetary neighbors, similar in size, composition and distance from sun.
- If we saw a distant star with two such planets, we would immediately be excited about the possibility of life there
- But both are dead: Venus’s biosphere is poisonous and makes it far too hot for life, Mars has no biosphere – once have had one but it was somehow destroyed, so there can be no life on Mars – no oxygen, far too cold
- Earth’s biosphere keeps temperature ”just right,” provides oxygen, etc

What is the Biosphere

- Biodiversity & climate system are two components of the **biosphere**
- All life – plant, animal - is part of the biosphere, as are the geochemical systems that underpin life
- The biosphere is our “home,” and in big picture terms it’s what we should focus on
- Relevant literature – *planetary boundaries* and *climate tipping points*
    - *Planetary boundaries: exploring the safe operating space for humanity,* Ecology & Society Dec 2009, Rockström et al. *Economic impacts of tipping points in the climate system*, PNAS Aug 2021, Dietz, Rising, Stoerk & Wagner. Lemoine & Träger, *Watch your step: optimal policy in a tipping climate*, AEJ policy 2014

Planetary boundaries from Rockström et al.





Planetary boundaries: Guiding human development on a changing planet, Volume: 347, Issue: 6223, DOI: (10.1126/science.1259855)

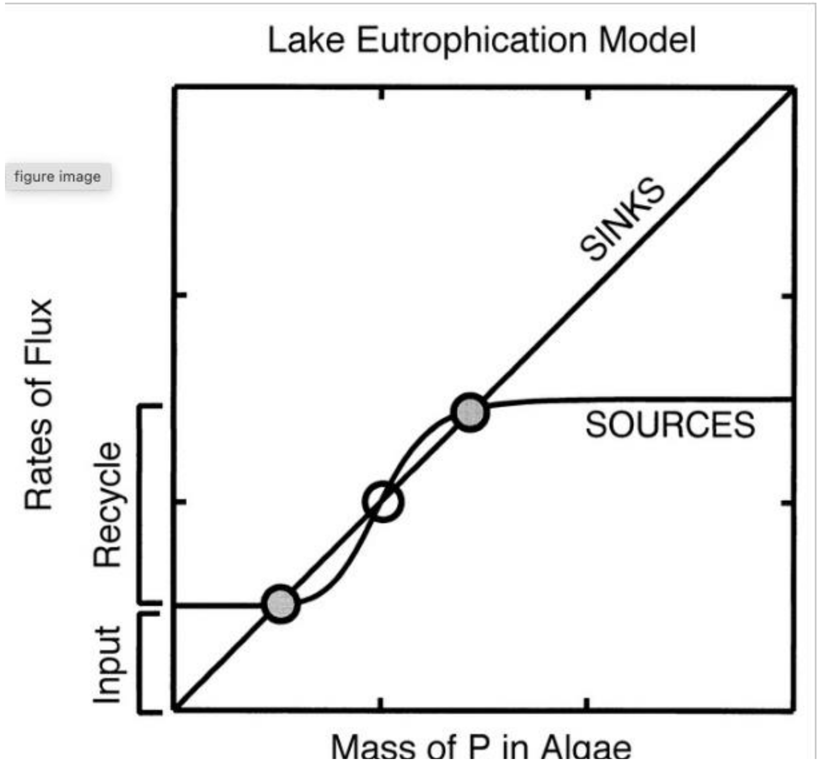
Modeling the biosphere

- Key variables:
  - atmospheric composition, aerosol loading, stratospheric ozone
  - ocean acidity
  - nitrogen concentration
  - freshwater availability
  - vegetation cover
  - Ice sheets
- A complex non-linear dynamical system in $\mathbb{R}^8$ (or more)

What do we expect?

- System with multiple attractors, some complex (cycles or spirals), shifting between them in response to perturbations in e.g. climate
- Example – eutrophication of shallow lakes

Carpenter Ludwig & Brock



Rates of P flux vs. P mass in the water, according to Eq. 1. The diagonal line is the rate of P loss. The sigmoid line represents the P sources (inputs + recycling). Intersections of these lines are the steady states. The open circle denotes the unstable steady state. Shaded circles denote stable steady states.

- Concentration of P in lake water has 2 stable 1 unstable equilibria
- S-curve shifts with temp, rainfall

$$\frac{dP}{dt} = l - sP + \frac{rP^q}{m^q + P^q}. \quad (1)$$

Modeling biosphere

- No good biosphere models
- Most climate models heavily linearized
- We know Biosphere has oscillatory attractors & tipping points –
  - El Niño – Southern Oscillator ENSO
  - North Atlantic Oscillator NAO
  - Atlantic Meridional Overturning Circulation AMOC
  - Asian Monsoon
  - Methane in permafrost, methane clathrates
- All exemplify what we would expect from complex high-dimensional systems – complex attractors and regime changes

Recall key biosphere variables

1. atmospheric composition, aerosol loading, stratospheric ozone
2. ocean acidity
3. nitrogen concentration
4. freshwater availability
5. vegetation cover
6. Ice sheets

- Carpenter et al.is about 4.
- AMOC, El Niño, NAO are about 1
- These interact

Interactions

- Clearly AMOC is affected by climate change and has been flipped to another state within 10-20,000 years
- ENSO appears to be impacted by climate change
- N concentration affects economic activity
- Vegetation cover and climate interact

Climate & BD Loss Interact: Synchronization

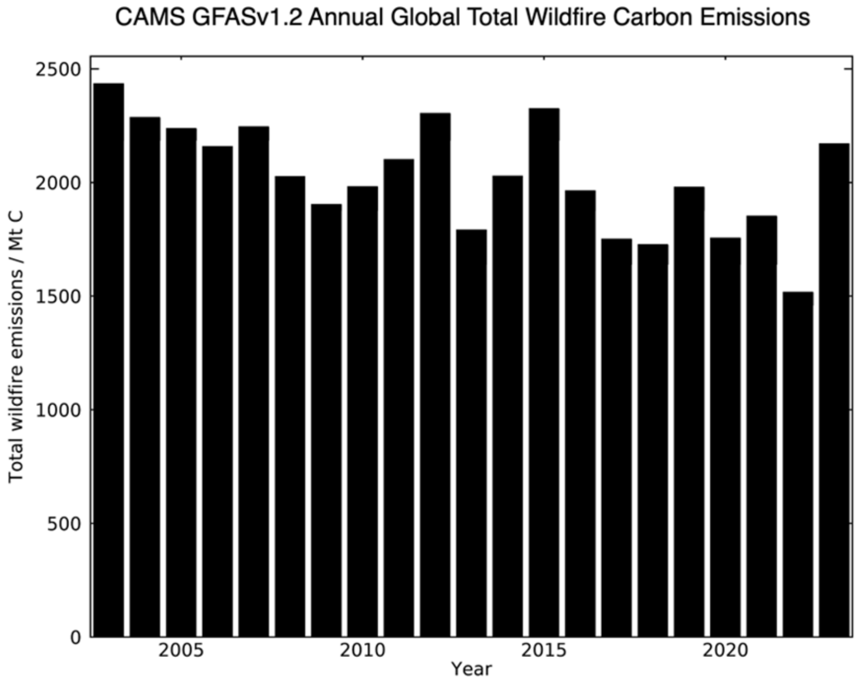
- Pied Flycatcher
- 5 inch long, migrates between N Europe & W Africa every year – crossing Sahara, Mediterranean, Alps
- Departure from W Africa triggered by length of day
- Arrival in N Europe used to coincide with emergence of insect grubs
- Emergence of grubs now occurs several weeks earlier and can't feed itself and its offspring on these – starvation
- Many similar examples of climate change disrupting ecosystem functioning
- Humming birds and flower pollination

Loss of keystone species

Can lead to radical changes in ecosystem, with impact on climate

Loss of sea otters → growth of sea urchin population → destruction of kelp beds → release of CO_2

BD → CC



Deforestation destroys biodiversity- & contributes to CC

Wildfires – caused in part by CC – contribute to CC

Wildfire emissions about 8bn tons CO2/yr

Pine bark beetles destroy BD and contribute to CC

Common Analytics to Biosphere, Biodiversity & Climate

Attributes of Climate & Natural Capital

- **Biodiversity/Natural capital & climate system can last for ever** – forests will absorb CO2 as long as they exist, Catskills watershed has managed NYC's water supply as long as the city has existed and will continue for ever – no depreciation. **Long time horizon.**
- **Destruction/Alteration is irreversible**. Generally, can't recreate biodiversity/natural capital once it's destroyed or reverse climate change. Extinction is forever!
  - Deforestation is irreversible as it leads to chemical changes in soil and also to changes in local climate
  - Destruction of US NE cod population – regulation has not allowed cod populations to rebound

Attributes

Ecosystem services & climate services are generally public goods

- Knowledge of molecular structures from bioprospecting – *knowledge a classic public good*
- Climate stability from forests and sequestration of CO2
- Pollinator services are a public good

We don’t have a good model of how policies affect outcomes

- We have reasonably widely-accepted models of the macroeconomy
- For biodiversity/climate conservation, many weak models of how policies affect human welfare

Dynamics of Climate & Biodiversity

- Highly complex
- Multiple regimes
- Tipping points – associated with irreversible changes

Implications – time horizon

- **Long time horizon** means choice of discount rate is crucial. Benefits 100+ years ahead are annihilated by conventional discount rates and so much of the value of the asset is lost
- To value conserving an extra increment of BD we need to use the consumption discount rate not the pure rate of time preference
- $\frac{dln\{U_C e^{-\delta t}\}}{dt}$ not δ. This is $\rho = \delta + \eta \frac{\dot{C}}{C}$ where $\eta = -c \frac{U_{cc}}{U_c}$
- But suppose $U = U(C, S)$ where S is state of environment or measure of biodiversity or state of biosphere

Discount rates

- Then we have two consumption discount rates, ρ_C & ρ_S given by

- $\rho_C =$ $$\frac{\partial \left(U_C\left(C_t, S_t\right) e^{-\delta t}\right) / \partial t}{U_C\left(C_t, S_t\right) e^{-\delta t}} = \delta + \eta_{CC}\frac{\dot{C}}{C} + \eta_{CS}\frac{\dot{S}}{S}$$

- $\rho_S =$ $$\frac{\partial \left(U_S\left(C_t, S_t\right) e^{-\delta t}\right) / \partial t}{U_S\left(C_t, S_t\right) e^{-\delta t}} = \delta + \eta_{SS}\frac{\dot{S}}{S} + \eta_{SC}\frac{\dot{C}}{C}$$

Implications

- For CES utility $\eta_{SS} > 0$ and η_{SC} is positive or negative as the elasticity of substitution is >1 or <1. Likely that $\frac{\dot{S}}{S} < 0, \frac{\dot{C}}{C} > 0$ so it is possible that $\rho_S < \delta$
- Drupp et al find elasticity < 1, complementarity
- Choosing δ is controversial – several paradigms
    - Look to the market
    - Objective, benign planner
    - Social choice

Choosing a discount rate

- There is a connection between these two rates

The marginal rate of substitution between C and S at time t - the price ratio - is $U_S(C_t, S_t)/U_C(C_t, S_t)$ and the rate of change of this is

$$\frac{\partial (U_S/U_C)/\partial t}{U_S/U_C} = \frac{\dot{S}}{S}\{\eta cs - \eta ss\} + \frac{\dot{C}}{C}\{\eta cc - \eta sc\} = \rho c - \rho s \qquad (8)$$

$$\frac{d}{dt}\left(\frac{U_S}{U_C}\right) / \left(\frac{U_S}{U_C}\right) = \rho_C - \rho_S$$

Future C: $\frac{\partial U}{\partial C} e^{-\delta t}$ → **Future S:** $\frac{\partial U}{\partial S} e^{-\delta t}$

$$\rho_C = \frac{\partial \left(U_C\left(C_t, S_t\right) e^{-\delta t}\right) / \partial t}{U_C\left(C_t, S_t\right) e^{-\delta t}} = \delta + \eta_{CC}\frac{\dot{C}}{C} + \eta_{CS}\frac{\dot{S}}{S}$$

$$\rho_S = \frac{\partial \left(U_S\left(C_t, S_t\right) e^{-\delta t}\right) / \partial t}{U_S\left(C_t, S_t\right) e^{-\delta t}} = \delta + \eta_{SS}\frac{\dot{S}}{S} + \eta_{SC}\frac{\dot{C}}{C}$$

Present discounted value

Environmental Discount Rate

Likely that marginal value of environment is rising relative to that of consumption goods

Environment becomes scarcer over time, and IED of WTP for environment > 1

So $\frac{\partial(\frac{U_S}{U_C})/dt}{U_S/U_C} > 0$ so $\rho_C > \rho_S$ and the CDR exceeds the EDR

Drupp et al

INSIGHTS | POLICY FORUM

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ENVIRONMENTAL ECONOMICS

Accounting for the increasing benefits from scarce ecosystems

As people get richer, and ecosystem services scarcer, policy-relevant estimates of ecosystem value must rise

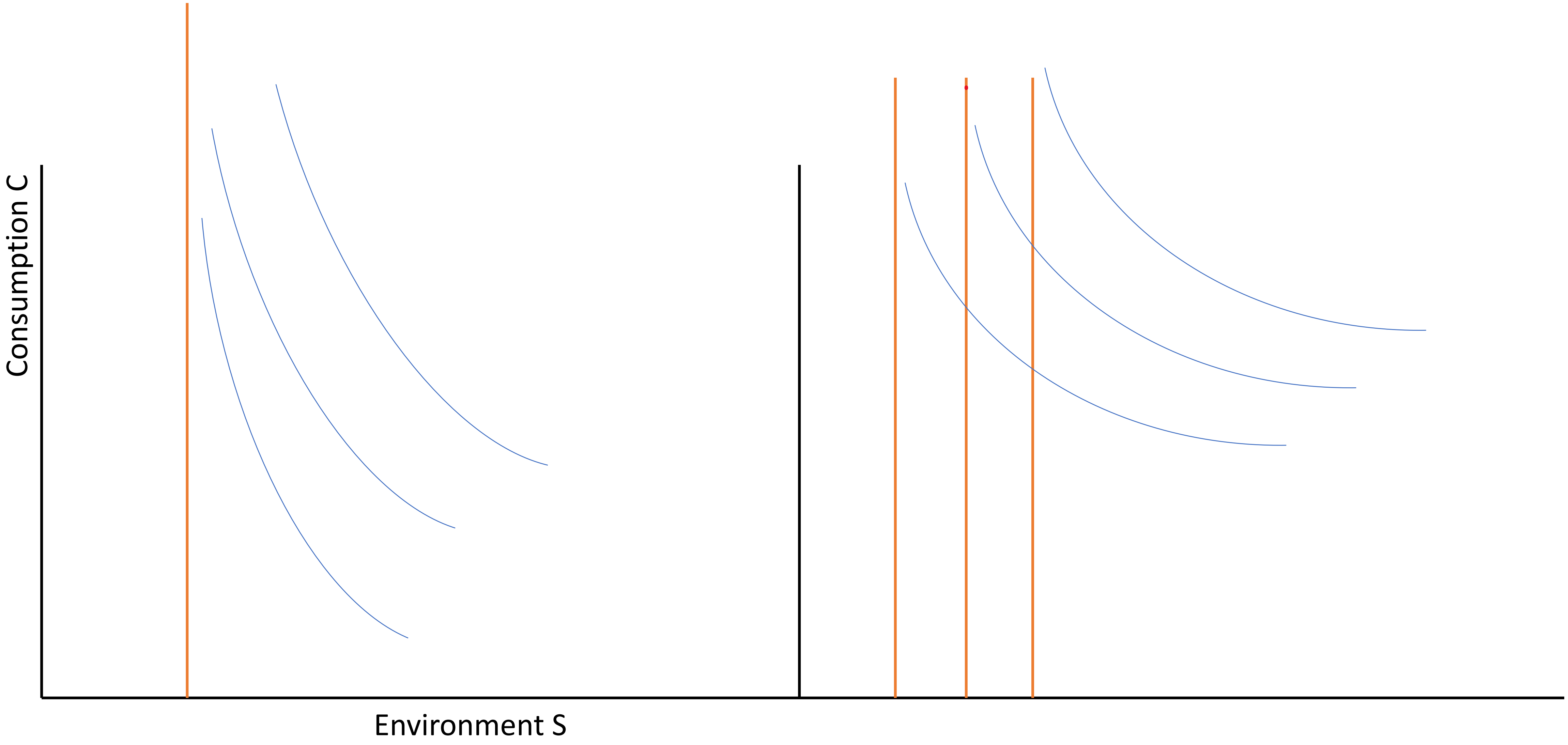
By **M.A. Drupp*[1], M.C. Hänsel[2,3], E.P. Fenichel[4], M. Freeman[5], C. Gollier[6], B. Groom[7,8], G.M. Heal[9], P.H. Howard[10], A. Millner[11], F.C. Moore[12], F. Nesje[13], M.F. Quaas[2,14], S. Smulders[15], T. Sterner[16], C. Traeger[17], F. Venmans[8]**

C and S

- $[\alpha C^{\sigma} + (1-\alpha)S^{\sigma}]^{1/\sigma}$ a CES utility function in C and S.
- If $\sigma > 1$ C and S are complements and vice versa
- Suppose there is a minimum level of environmental/climate services we need to survive – see figure. Then we have
- $[\alpha C^{\sigma} + (1-\alpha)(S-\varepsilon)^{\sigma}]^{1/\sigma}$

Welfare, C & S

- Two possible cases –
- There exists a min level of $S, \tilde{S}$ for human existence and all C-S isoquants asymptote to this
- For each welfare level $\widehat{U}$ ∃ $\widehat{S(\widehat{U})}: isoquant\ U\widehat{(C,S)}$ asymptotes to $\hat{S}$

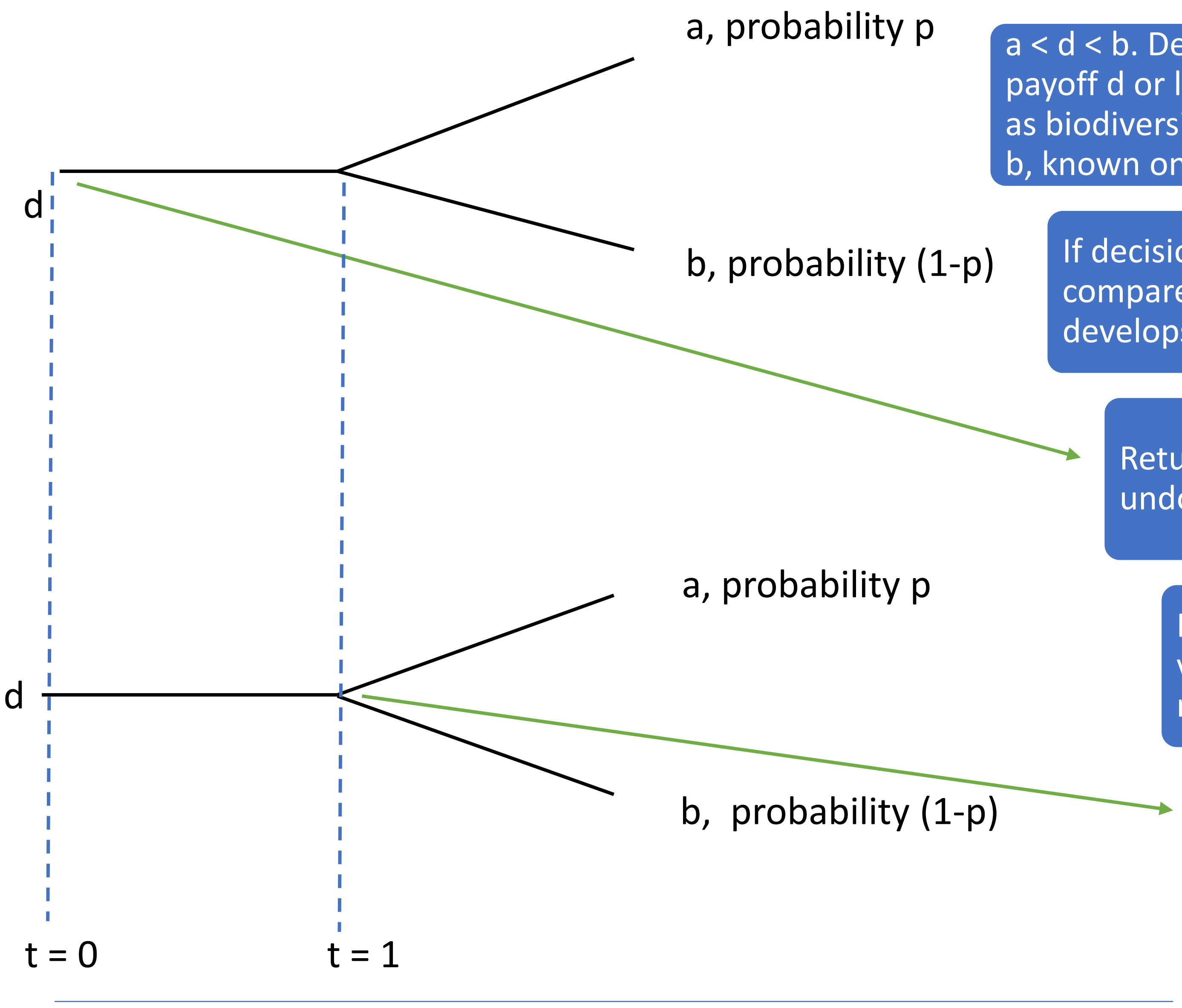


$$Y = [\alpha C^{\sigma} + (1-\alpha)(S-\varepsilon)^{\sigma}]^{1/\sigma}$$

$$Y = (C-\alpha)^{a}(S-\beta(S))^{b}$$

Implications - irreversibility

- The combination of irreversibility, uncertainty and the possibility of learning raise the threshold for policy choices that damages natural capital or the climate
- Implies the existence of a quasi-option value associated with conservation
- Means that the expected payoff to conservation understates the value of conservation



a < d < b. Develop land at t = 0 for payoff d or leave in which case value as biodiversity reserve is either a or b, known only at t = 1.

If decision is made at t = 0 then one compares d with p.a + (1-p).b and develops iff d > p.a + (1-p).b.

Return is max{d, p.a + (1-p).b} (Can’t undo development if value is b.)

If decision is delayed till t = 1 then value a or b is known. Develop if b, not if a.

Return is max{d,b} >= max{d, p.a+(1-p).b}

Public goods

Well-known that markets don't allocate public goods efficiently.

Why? Because an extra unit of the good benefits everyone. With the standard individualistic utility function, I will be willing to pay for the benefits to me but won't consider the benefits to everyone else.

Hence under-provision from a social perspective

How to resolve this problem?

Two approaches

Incentive mechanism design. When I increase the amount of the public good, I benefit everyone else but am not rewarded for this – I generate a positive externality for everyone

Internalize this by paying me for the benefits I generate for others – the Clarke-Groves-Vickery mechanism. Makes truthful revelation a dominant strategy.

Problems with this mechanism – government expenditure exceeds revenues

Two approaches

Suppose instead of the usual individualistic utility function people place value on the wellbeing of others

Then they will value the benefits they convey to others by supporting the public good

With sufficient interpersonal solidarity or empathy public goods will be provided efficiently

Bundling public & private goods

Safaris in S or E Africa are big business. What guests pay for is transport and accommodation in tents - may pay $20,000+ for a week

They are willing to pay so much to stay in a tent because of the presence of biodiversity – lion, elephants, leopards, rhinos, hippos,etc

The organizers are not just selling tented accommodation – they are selling that bundled with access to biodiversity

The BD or natural capital – a public good - raises the willingness to pay for the accommodation – so bundling a public good with a private raises the WTP for the private and can be good business

556 Journal of the European Economic Association April–May 2003 1(2–3):553–560

PROPOSITION 1: *If utility functions are strictly concave and the cost function strictly convex, then a profit-maximizing producer who provides a private and a public good and can practice first-order price discrimination will provide an economically efficient combination of the public and private goods.*

Bundling public & private goods

- The safari business is an illustration of this proposition – that it can be profitable for the seller of a private good to provide and bundle with it a public good
- If the seller is a discriminating monopolist, it can lead to an efficient outcome

No good models

- We know that BD affects human welfare but don’t have a compelling model of how this occurs
- Several different models of this relationship, each giving a different map from policy choices to welfare outcomes
- How to act given this uncertainty – we have a “multiple priors” situation
- Growing literature suggests two dominant approaches

No good models: *Scientific uncertainty*

- MaxMin Expected Utility – evaluate each policy alternative according to the model that makes it look worst (Gilboa-Schmeidler)
- Evaluate choices by a non-linear weighted average of outcomes according to the the alternative models (Klibanoff Marinacci Mukherji)
- Both involve some degree of focus on worst-case outcomes not unlike the precautionary principle

CHAPTER

10

Uncertainty and ambiguity in environmental economics: conceptual issues

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Uncertainty

- Uncertainty has a cost - similar to risk, people will pay to avoid it
- Consider KMM approach with ambiguity aversion function $\emptyset$, distributions θ_j,

  a actions and π_j second order probabilities so maximand is $\sum \pi_j \emptyset\{E_j\left(U(a)\right)\}$
- Cost of uncertainty is $-\left({\emptyset''}/{\emptyset'}\right)\left({\sigma^2 E}/{2}\right)$
- Uncertainty discourages investment more than risk*

* Flammer, Giroux, Heal & Luccetta: "Ambiguity vs Risk in investment Decisions," NBER WP *34516*

Summary

- We need to “think big” – there are connections between different environmental problems that we may be missing
- Big environmental issues have distinctive analytical characteristics which we already understand -
  - Long time horizon
  - Irreversibility
  - Public goods
  - Uncertainty
  - Complex dynamics
- We need to understand more about how BD etc impact human welfare and about how they enter into utility function