Sustainability and Natural Resources

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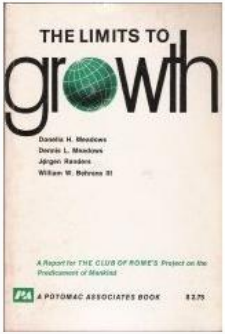
Paris School of Economics

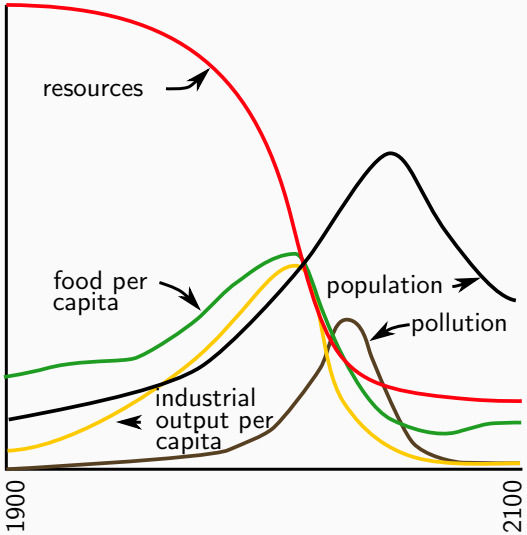
Outline for Today: Intertemporal Externalities

- Sustainability: A Brief History
- Intertemporal Resource Management
  - How to eat a cake in infinite time
  - Sustainability and Natural Capital
  - Discounting
- Common Pool Resources
- Biodiversity

Blue Marble

The Limits to Growth

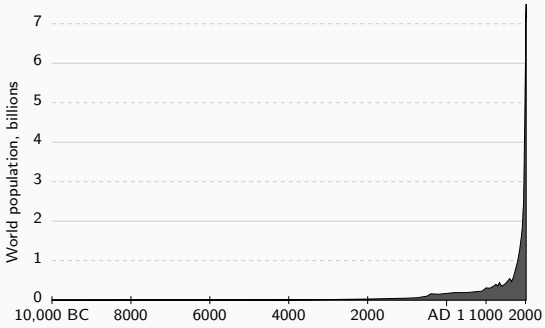




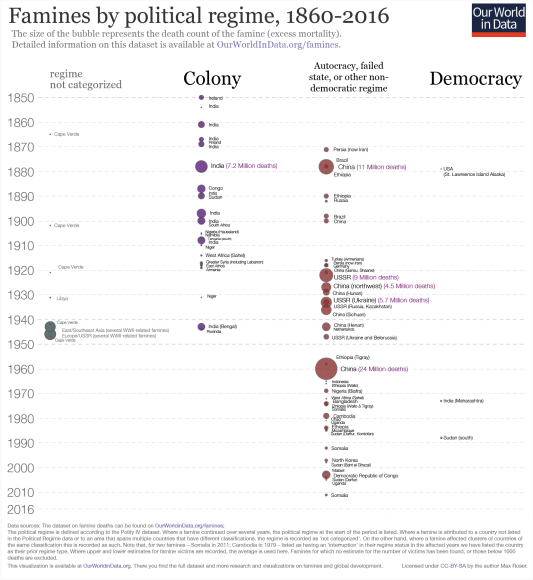
Neo-Malthusianism

Paul Erlich (1968): The Population Bomb

- "The battle to feed all of humanity is over. In the 1970s hundreds of millions of people will starve to death in spite of any crash programs embarked upon now. At this late date nothing can prevent a substantial increase in the world death rate."
- May have been used to justify coercive sterlization programs in India, China and elsewehere



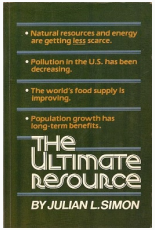
Famines

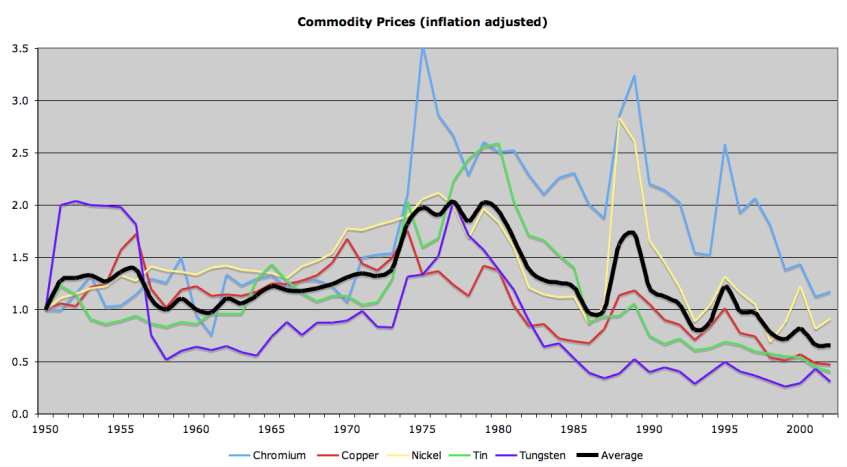


Data sources: The dataset on famine deaths can be found on OurWorldInData.org/famines.
The political regime is defined according to the Polity IV dataset. Where a famine continued over several years, the political regime at the start of the period is listed. Where a famine is attributed to a country not listed in the Political Regime data or to an area that spans multiple countries that have different classifications, the regime is recorded as 'not categorized'. On the other hand, where a famine affected clusters of countries of the same classification this is recorded as such. Note that, for new famines – Somalia in 2011, Cambodia in 1979 – listed as having an 'Immunization' in their regime status in the affected years we have listed the country as their prior regime type. Where upper and lower estimates for famine victims are recorded, the average is used here. Famines for which no estimate for the number of victims has been found, or those below 1000 deaths are excluded.

This visualization is available at OurWorldInData.org. There you find the full dataset and more research and visualizations on famines and global development.

The Bet


• Natural resources and energy are getting less scarce.
• Pollution in the U.S. has been decreasing.
• The world's food supply is improving.
• Population growth has long-term benefits.
THE ULTIMATE RESOURCE
BY JULIAN L. SIMON


Commodity Prices (inflation adjusted)
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
Chromium
Copper
Nickel
Tin
Tungsten
Average

Sustainability: The Brundtland Commission

Prophesies of doom mostly did not come to pass, however raised important questions:

- Are we consuming too much?
- How are current activities affecting the future?
- What are the tradeoffs between different types of capital investments: natural, produced, and human?

Sustainable development: The Brundtland Report (1987)

- Development that meets the needs of the present without compromising the ability of future generations to meet their own needs.

Technical Preliminaries

A brief mathematical digression: How to eat a cake in infinite time

Basically a model for managing an non-renewable resource:

$$\max_{c} \sum_{t=0}^{\infty} \beta^t U(c_t) \tag{1}$$

- Let W be the initial size of the cake.
- In each period, the agent decides how much to consume, c_t, subject to $0 \leq c_t \leq W_t$.
- The remaining cake evolves as $W_{t+1} = W_t - c_t$.
- How much cake should we eat in each time period?
  - Answer will be a *time path* of optimal consumption - or equivalently a policy function that tells us how much to eat as a function of the amount of cake remaining.

Bellman Equation

Key insight:

$$V(W) = \max_c \sum_{t=0}^{\infty} \beta^t U(c_t) \tag{2}$$

$$V(W) = \max_c U(c_0) + \sum_{t=1}^{\infty} \beta^t U(c_t)$$

$$V(W) = \max_c U(c_0) + \beta V(W - c_0)$$

First order condition implies:

$$U'(c_0) = \beta V'(W - c_0) \tag{3}$$

Bellman Equation

$$V(W) = \max_{c_t} U(c_t) + \beta V(W - c_t) \tag{4}$$

$$U'(c_t) = \beta V'(W - c_t)$$

Now we use the envelope theorem, to take the derivative of V wrt the size of the cake:

$$\frac{dV}{dW_t} = \frac{dU(c)}{dW_t} + \beta \frac{dV}{dW_{t+1}} \frac{dW_{t+1}}{dW_t} \tag{5}$$

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$$U'(c_t) = \beta U'(c_{t+1}) \tag{6}$$

Bellman Equation

$$V(W_t) = \max_c U(c_t) + \beta V(W - c_t) \tag{7}$$
$$U'(c_t) = \beta U'(c_{t+1})$$

This is called the Euler equation.

- For log utility, you can show that $c_t = (1 - \beta)W_t$. More generally, computational methods are required to solve
- Relatively straightforward to modify for renewable resources, multiple resources, etc...
- What happens if future regulations are announced?
  - I announce next period, I will throw the cake in the garbage

$$\max_{c} U(c_t) + \beta V(0) \text{ s.t. } c_t \leq W \tag{8}$$

The Green Paradox

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- Redwood logging in California accelerated after national parks were announced
- What effect will falling solar prices have on fossil fuel extraction?

The Green Paradox

Lemoine (2017). Green Expectations: Current Effects of Anticipated Carbon Pricing

- If fossil fuel extractors expect a tax on fossil fuel extraction in the future, how will they respond today?

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  - Future marginal benefits are lower
  - Today's marginal benefits will be lower
  - Extract more today (at a lower price)

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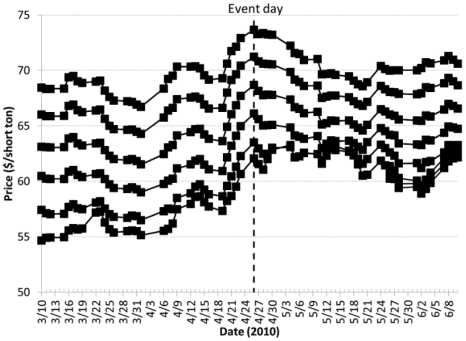
  - At 10pm on Friday 4/27, lead Republican negotiator and pivotal vote texts co-sponsor 'Sorry buddy'.

The Green Paradox

Lemoine (2017): Effects on coal futures prices



(a) Prices

This is the price of coal before the bill would have become law

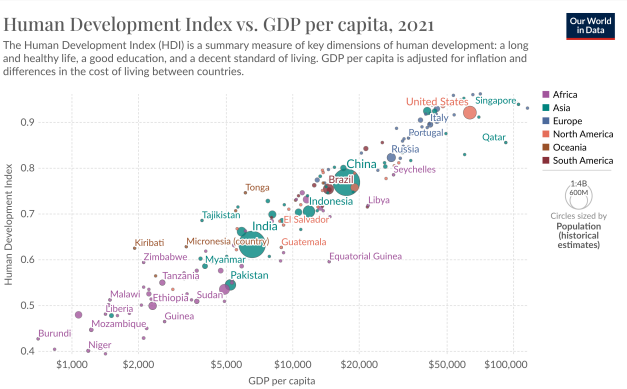
Sustainability and Welfare

Sustainability and Welfare

Nordhaus and Tobin 1973: Is Growth Obsolete?

A major question raised by critics of economic growth is whether we have been growing at all in any meaningful sense. Gross national product statistics cannot give the answers, for GNP is not a measure of economic welfare. Erlich is right in claiming that maximization of GNP is not a proper objective of policy. Economists all know that, and yet their everyday use of GNP as the standard measure of economic performance apparently conveys the impression that they are evangelistic worshipers of GNP.

Nordhaus and Tobin 1973: Is Growth Obsolete?



Data source: UNDP, Human Development Report (2021-22), Data compiled from multiple sources by World Bank
Note: GDP per capita is expressed in international-^{1} at 2017 prices.
OurWorldInData.org/human-development-index | CC BY

1. International dollars: International dollars are a hypothetical currency that is used to make meaningful comparisons of monetary indicators of living standards. Figures expressed in international dollars are adjusted for inflation within countries over time, and for differences in the cost of living between countries. The goal of such adjustments is to provide a unit whose purchasing power is held fixed over time and across countries, such that one international dollar can buy the same quantity and quality of goods and services no matter where or when it is spent. Read more in our article: What are Purchasing Power Parity adjustments and why do we need them?

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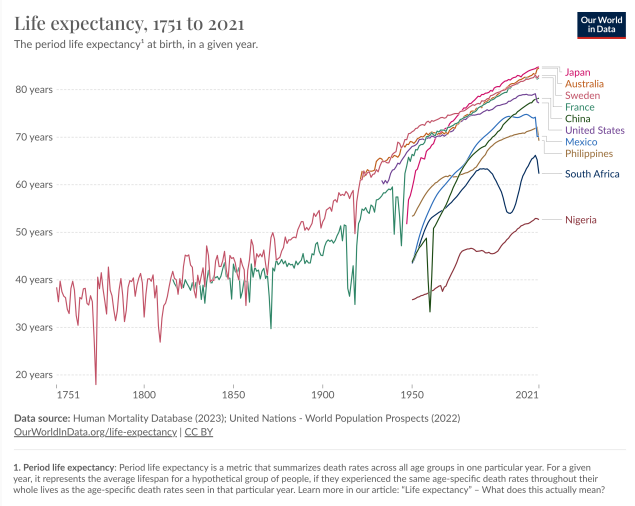

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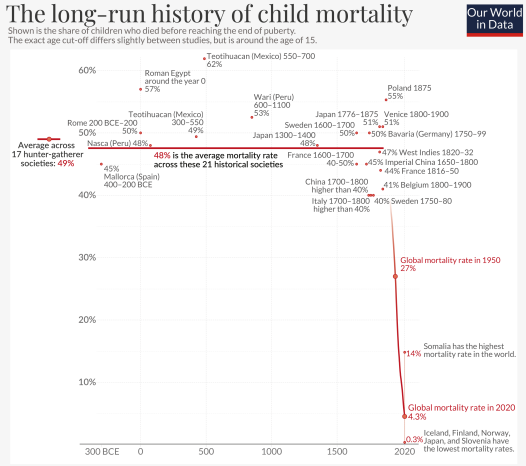

Nordhaus and Tobin 1973: Is Growth Obsolete?

Although the numbers presented here are very tentative, they do suggest the following observations. First, MEW is quite different from conventional output measures. Some consumption items omitted from GNP are of substantial quantitative importance. Second, our preferred variant of per capita MEW has been growing more slowly than per capita NNP (1.1 per cent for MEW as against 1.7 per cent for NNP, at annual rates over the period 1929—65). Yet MEW has been growing. The progress indicated by conventional national accounts is not just a myth that evaporates when a welfare-oriented measure is substituted.

Sustainability and Welfare

Nordhaus and Tobin 1973: Is Growth Obsolete?

- Cottage industry of GDP alternatives (GPI, ISEW,...)
- Adjustments for leisure, environment, inequality...
- Most show strong correlations with GDP, at least until 1970s
- Does maximizing welfare conflict with other goals? Recall:
  - Sustainable Development: Development that meets the needs of the present without compromising the ability of future generations to meet their own needs.

Sustainability vs Maximize NPV

More generally, for a planner or an individual, the NPV criterion maximizes:

$$V(t) = \int_{t=0}^{\infty} U[c(t)]e^{-\delta t}dt \tag{9}$$

- $c(s_t)$: Consumption (incl leisure and environment, aggregate? weights?)
- δ: Discount rate
- Consumption depends on many types of capital (natural, produced, human): K_{it}

On the other hand, the sustainability criterion requires: $\frac{dV}{dt} > 0$

- Satisfied if *genuine investment* is always positive

$$\frac{dV}{dt} = \sum_i \frac{dV}{dK_{it}} \frac{dK_{it}}{dt} = \sum_i p_{it} I_{it} \tag{10}$$

Sustainability

Measurement Issues

- Measuring changes in natural and human capital stocks: non-use values and ecosystem services
- Measuring prices of non-market types of capital (depends on substitutability)

Theoretical Issues

- Focuses on changes in V not levels
- Might not be intertemporally efficient
- Might not be possible (if non-renewable resources are important)
- Per capita or total? Population ethics and the repugnant conclusion
- What about technological change? More output from same capital stocks?

But they're going to try anyway...

Kenneth Arrow, Partha Dasgupta, Lawrence Goulder, Gretchen Daily, Paul Ehrlich, Geoffrey Heal, Simon Levin, Karl-Goran Maler, Stephen Schneider, David Starrett and Brian Walker (2004): Are we consuming too much?

Table 1

Genuine Investment and Components as Percentage of GDP

			Natural Resource Depletion				
Country	*Domestic net investment*	*Education expenditure*	*Damage from CO_2 emissions*	*Energy depletion*	*Mineral depletion*	*Net forest depletion*	*Genuine investment*
Bangladesh 1973–2001	7.89	1.53	0.25	0.61	0.00	1.41	7.14
India 1970–2001	11.74	3.29	1.17	2.89	0.46	1.05	9.47
Nepal 1970–2001	14.82	2.65	0.20	0.00	0.30	3.67	13.31
Pakistan 1970–2001	10.92	2.02	0.75	2.60	0.00	0.84	8.75
China 1982–2001 (without 1994)	30.06	1.96	2.48	6.11	0.50	0.22	22.72
Sub-Saharan Africa 1974–82; 1986–2001	3.49	4.78	0.81	7.31	1.71	0.52	−2.09
Middle East & North Africa 1976–89; 1991–2001	14.72	4.70	0.80	25.54	0.12	0.06	−7.09
United Kingdom 1971–2001	3.70	5.21	0.32	1.20	0.00	0.00	7.38
United States 1970–2001	5.73	5.62	0.42	1.95	0.05	0.00	8.94

Source: Authors' calculations, using data from World Bank (2003).

But they're going to try anyway...

Table 2

Growth Rates of Per Capita Genuine Wealth

Country	(1) Genuine Investment as Percent of GDP	(2) Growth Rate of Unadjusted Genuine Wealth	(3) Population Growth Rate	(4) Growth Rate of Per Capita Genuine Wealth—before TFP Adjustment	(5) TFP Growth Rate	(6) Growth Rate of Per Capita Genuine Wealth—after TFP Adjustment	(7) Growth Rate of per capita GDP
Bangladesh	7.14	1.07	2.16	−1.09	0.81	0.30	1.88
India	9.47	1.42	1.99	−0.57	0.64	0.54	2.96
Nepal	13.31	2.00	2.24	−0.24	0.51	0.63	1.86
Pakistan	8.75	1.31	2.66	−1.35	1.13	0.59	2.21
China	22.72	3.41	1.35	2.06	3.64	8.33	7.77
Sub-Saharan Africa	−2.09	−0.31	2.74	−3.05	0.28	−2.58	−0.01
Middle East/ North Africa	−7.09	−1.06	2.37	−3.43	−0.23	−3.82	0.74
United Kingdom	7.38	1.48	0.18	1.30	0.58	2.29	2.19
United States	8.94	1.79	1.07	0.72	0.02	0.75	1.99

How can we measure genuine investment?

Fenichel and Abbott (2014): From Metaphor to Measurement

- "Capital assets store wealth and generate production for future consumption. This is certainly a property of ecological structures."

The price of an asset is the NPV of future expected cash flows:

$$p_a = c_1 + (1-\delta)c_2 + (1-\delta)^2 c_3 .... \tag{11}$$

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If c_t is constant:

$$p_a = \frac{c_t}{\delta} \tag{11}$$

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Fenichel and Abbott (2014): From Metaphor to Measurement

The shadow price of natural capital *under current management conditions*:

$$p_a = \frac{c_a(a) + \dot{p}}{\delta - (g_a(a) - h_a(x, a))} \tag{12}$$

- c_a: Change in ecosystem service flows from adding a bit more natural capital
- $\dot{p}$: Capital gains
- $g_a(s) - h_a(x, s)$: Change in 'depreciation' of the capital stock: difference between marginal changes in biological growth and harvest

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Most of these are measurable, at least in principle:

- c_a: Non-market valuation techniques
- $g_a(s)$: Studied by ecologists
- $h_a(x, s)$: Economics/Behavioral science
- $\dot{p}$: Not directly measurable, since we don't know p_a, but can be found using numerical approximation methods

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- That leaves δ...

Intertemporal Tradeoffs and Discounting

Discounting

Many questions in economics analyze tradeoffs between different points in time:

Nuclear Waste Warnings to the Distant Future

This place is a message... Sending this message was important to us. We considered ourselves to be a powerful culture.

This place is not a place of honor... no highly esteemed deed is commemorated here... nothing valued is here.

What is here was dangerous and repulsive to us. This message is a warning about danger....The danger is still present, in your time, as it was in ours...

The danger is unleashed only if you substantially disturb this place physically. This place is best shunned and left uninhabited

Discounting

Many questions in economics analyze tradeoffs between different points in time:

Living Bridges of Meghalaya

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Social Cost of Carbon

Emissions Year	Discount Rate and Statistic			
	5% Average	3% Average	2.5% Average	3% 95th Percentile
2020	14	51	76	152
2025	17	56	83	169
2030	19	62	89	187
2035	22	67	96	206
2040	25	73	103	225
2045	28	79	110	242
2050	32	85	116	260

Discounting

How can we compare projects that have different payoffs in different times or states of the world?

$$\max_{c} U(c_0, ..., c_{st}) \text{ s.t. } \sum_s \sum_t p_{st} c_{st} = \sum_s \sum_t p_{st} w_{st} \tag{13}$$

Implies agent can shift consumption to any time or state of the world at the relevant price. Normalize $p_0 = 1$:

$$\frac{\frac{dU}{dc_{st}}}{\frac{dU}{dc_0}} = p_{st} \tag{14}$$

Discount rate is the price of shifting consumption from one time-state to another:

- We might be able to get market information on these prices
  - 10-year government treasuries
  - 99-999 year leases (Giglio et al 2015)
  - Insurance/futures contracts

Correlation with risk?

State dependence often ignored in CBA (except in France!)

Intution: If a project has aggregate insurance value (e.g. pays off more in bad states of the world) then the discount rate is even lower!

- Luxury resort development
- Vaccines for pandemics
- Military technology
- Direct air capture of carbon dioxide

Discounting: The Market Approach

An argument for the market approach: Let's say government is deciding whether to issue debt to pay for a project with future benefits:

- If the project's benefits in the future are less than the debt payment required in the future, then the people in the future are worse off.

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Still, several critiques:

- Tyranny of the present?
- Incomplete markets - gov't might not be able to take out 1,000 year loan? Or buy insurance against a catastrophic future climate shock...
- Assumes project has no impact on prices (marginal)

Normative Approaches to Discounting

The Ramsey Equation: derived from social planner maximizing intertemporal welfare:

$$r = \rho + \eta g \tag{15}$$

- r: discount rate
- ρ: Pure rate of time preference
- $\eta = \frac{U''(c)}{U'(c)}c$: Curvature of utility function
- g: growth rate of consumption

ρ is often argued to be 0 on the basis of intergenerational equity:

- May have to sacrifice Pareto efficiency (Diamond 1965)
- The infinitely postponed splurge: if interest rates are high enough and time horizons long enough, every generation starves itself for a future payoff that never arrives!
- What if each generation faces some small probability of an existential catastrophe?

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η governs risk aversion, inequality aversion, and impatience:

- Consider a transfer to person A, with wealth $= 1$, from person B, with weath $= 2$. Maybe the same person at a different time!
- Some fraction τ gets lost in transit
- $\tau = 1 - \frac{1}{2^\eta}$: If $\eta = 2$ we are fine with losing 75% of the transfer.

Takeaways

Perhaps best to acknowledge that for long term projects, economics into close contact with philosophy

- Declining discount rates with uncertainty (Weitzman 2001)
- Current research on 'pluralist' approaches - how to discount when we can't agree about the discount rate (Milner and Heal 2021)

Even if pure rate of time preference is 0, we may still want to discount:

- In the future we will be richer, and thus project will be worth less
- Maybe no one will be around to benefit?

Common Pool Resources

Common Pool Resources

Up to this point we have modelled with a single agent - either an individual or the social planner

How do multiple agents change the story?

Common Pool Resources

Recall difference from public goods: non-excludable, but rival

- My consumption diminishes your ability to consume
- Many natural resources fall in this bucket: fisheries, forests, etc...

Hardin (1968): Tragedy of the Commons

- Town commons is where villagers would graze their sheep
- Each villager gets personal benefits from adding to their herd, but contributes to overgrazing, which creates costs for all.
- Since marginal benefits are personal, but marginal costs are shared, overgrazing results.

Tragedy of the Commons

	Cooperate	Defect
Cooperate	(1,1)	(-1, 2)
Defect	(2, -1)	(0, 0)

Buffalo Hunt

Taylor (AER: 2011)

- Estimated 30 million buffalo pre-contact, reduced to $\approx$ 100 by late 1800s
  - Possibly 15 million killed in 10 years
- New tanning process in UK created demand for hides
  - Open access
  - Inelastic demand (cattle close substitute)

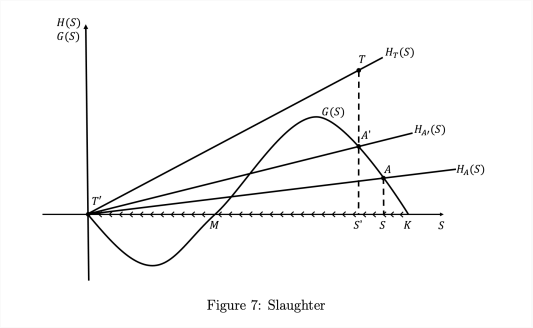

Figure 7: Slaughter

Buffalo Hunt

Taylor (AER: 2011)

- Estimated 30 million buffalo pre-contact, reduced to $\approx$ 100 by late 1800s
  - Possibly 15 million killed in 10 years
- New tanning process in UK created demand for hides
  - Open access
  - Inelastic demand (cattle close substitute)

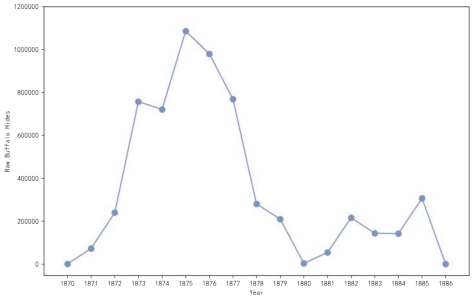

Figure 8: Buffalo Hide Exports During The Slaughter

Elinor Ostrom

So are we doomed to exploit the commons?

Mancur Olson: The Logic of Collective Action

- The logic of free riding
- Inequality can improve management of public goods! (Why?)
- Need for centralized authority to manage common pool resources

Elinor Ostrom 2009 Nobel Prize

- First woman...and a political scientist!
- Empirical work: in many cases small organizations seemed to outperform larger ones (police departments, irrigation systems in Nepal)

Self-Governing Irrigation Systems

Ostrom and Gardner (1993): Coping with Asymmetries in the Commons

- Compared irrigation systems in Nepal built by government engineers with locally constructed and managed systems
- Annual maintenance required contributions from all, even though those higher up get more benefits from working system
- Permanent structure changes need for labor, benefits from working system

Ostrom and Gardner (1993): Coping with Asymmetries in the Commons

Table 1

Water Adequacy[a] by Type of Governance as Arrangement and Season

Season of Year	*% of FMIS with Adequate Water at the Head*	*% of FMIS with Adequate Water at the Tail*	*% of AMIS with Adequate Water at the Head*	*% of AMIS with Adequate Water at the Tail*
Monsoon	97	88	92	46
Winter	48	38	42	13
Spring	35	24	25	8

[a]Water adequacy was measured on a four-point scale from adequate to nonexistent based on structured coding of field visits and case studies.

Ostrom's Principles for Collective Action

- Boundaries of users & resource are clear
- Congruence between benefits & costs
- Users had procedures for making own rules
- Regular monitoring of users and resource conditions
- Graduated sanctions
- Conflict resolution mechanisms
- Minimal recognition of rights by Government
- Nested enterprises

Cooperate, Defect, Punish

Two new elements: 1) Game is repeated over multiple rounds

- 2) Players can 'punish' defections at some cost to themselves (social norms? violence?). Consider tit-for-tat strategy:

$$a_t^i = \begin{cases} R \text{ if } a^{t-1} = (\ ..., ...,\ (R,R)\ ) & \text{reward} \\ R \text{ if } a^{t-1} = (\ ..., ...,\ (P,P)\ ) & \text{reward for sticking to punishment} \\ P \text{ if otherwise} & \text{punishment} \end{cases} \tag{16}$$

Cooperate, Defect, Punish

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For this to be optimal, need to rule out deviations. Let B be the benefits of defecting:

- Benefits of cooperating forever greater than benefits of defecting, then punishment in any round

$$\frac{1}{1-\delta}R \geq B + \delta P + \frac{d^2}{1-\delta}R \tag{18}$$
$$(1+\delta)R \geq B + \delta P$$

Cooperate, Defect, Punish

$$a_t^i = \begin{cases} R \text{ if } a^{t-1} = (\ ..., ...,\ (R,R)\ ) & \text{reward} \\ R \text{ if } a^{t-1} = (\ ..., ...,\ (P,P)\ ) & \text{reward for sticking to punishment} \\ P \text{ if otherwise} & \text{punishment} \end{cases} \tag{17}$$

For this to be optimal, need to rule out deviations. Let B be the benefits of defecting:

- Benefits of cooperating forever greater than benefits of defecting, then punishment in any round
- Benefits of punishing, then returning to cooperation greater than defecting again, then punishment

$$P + \frac{\delta}{1-\delta} R \geq B + \delta P + \frac{d^2}{1-\delta} R \tag{18}$$
$$\delta R \geq B + (1-\delta) P$$

Deforestation

Foster and Rosenzweig (2003): Economic Growth and the Rise of Forests

- One implication: as a commodity becomes more valuable, increased incentives for better management
  - More surplus to share: greater R
- Structural change in India and the Green Revolution:
  - High yield seed varieties may have increased demand for agricultural land, but also increased productivity of existing land
  - Rising household incomes increased demand for forest products
- Net effect seems to be more forests!

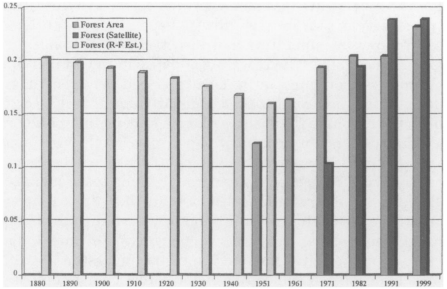

FIGURE II
Proportion of Total Land Area Classified as Forest (Government Statistics) and Proportion of Land Forested (Richards and Flint Estimates and Satellite Data for Survey Villages), India 1880–1999

Deforestation

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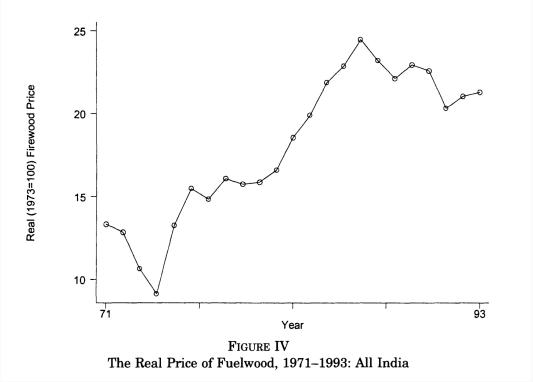
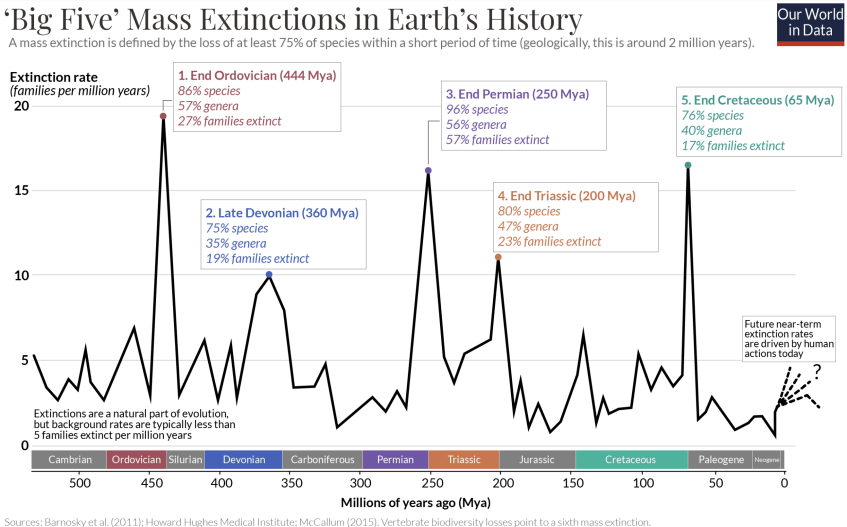


FIGURE IV
The Real Price of Fuelwood, 1971–1993: All India

Biodiversity

Benefits to biodiversity?

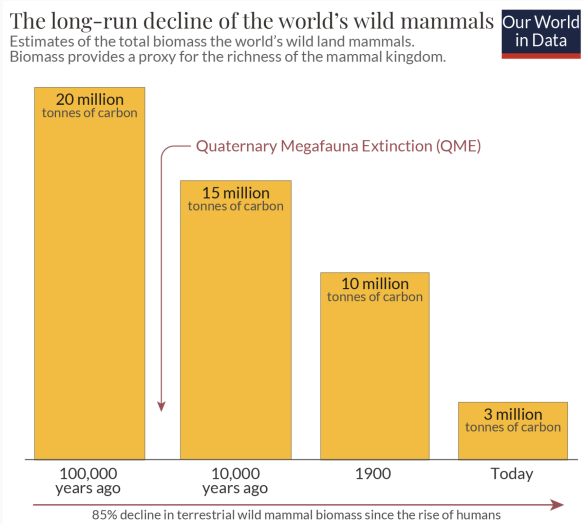
Are we in the midst of a mass extinction?



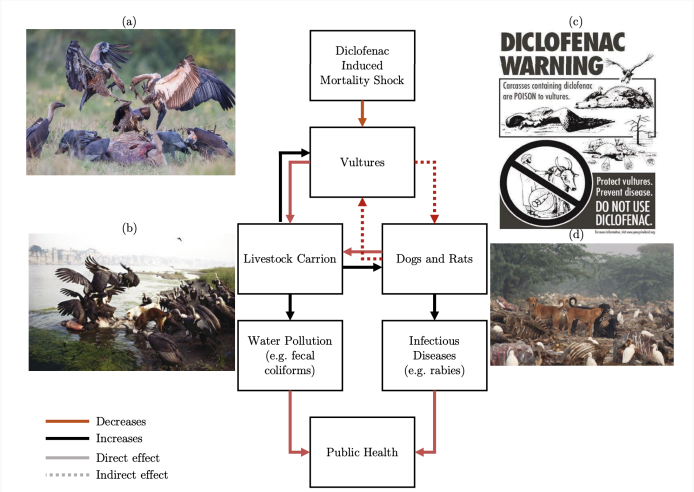
Benefits to biodiversity?

What is the value of preserving a species?

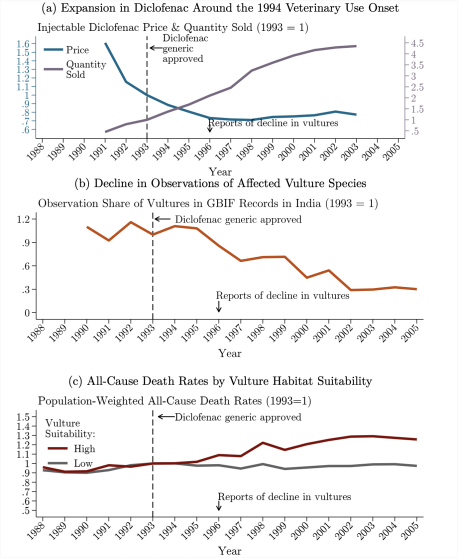
- Difficult area of research: data is poor, benefits mostly intangible
- Weitzman (1992) gives a theoretical starting point, but measurement tough
- Sometimes indirect benefits easier to measure



Frank and Sudarshan: The Social Costs of Keystone Species Collapse



Vultures: The Social Costs of Keystone Species Collapse



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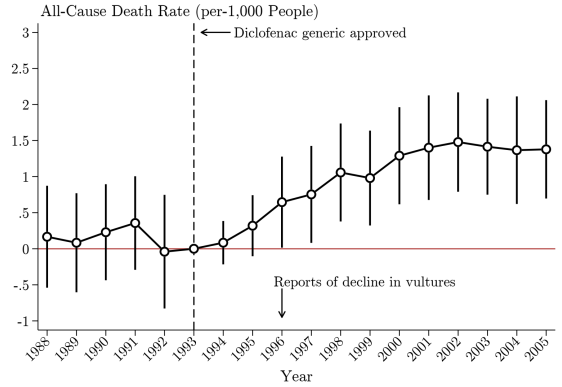
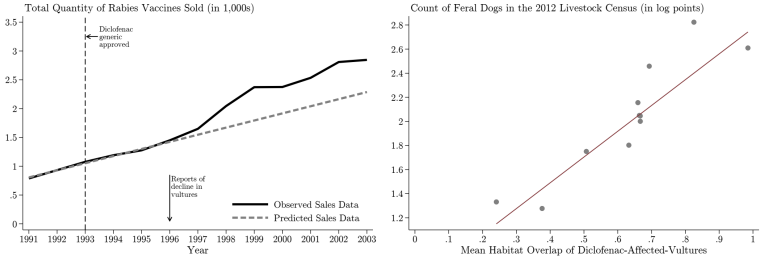


Notes: Estimation results from Equation (1) showing coefficients and 95% CIs. The regression compares the high- to low-suitability vulture districts around the timing of the vulture population collapse. Sample includes all districts (combining census urban and rural areas) with balanced data from 1988 to 2005. The regression includes district and zonal council-by-year fixed effects. Observations are population-weighted. We calculate Conley standard errors that are serially correlated at the district level, and are allowed to be spatially correlated up to 200km.

Figure 5: Suggestive Evidence for Feral Dog Mechanism

(a) Sales of Rabies Vaccines

(b) Feral Dogs (2012) VS. Vulture Suitability

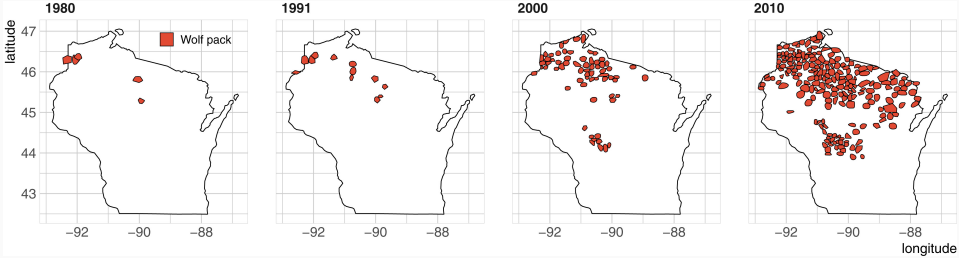


Notes: (a) National-level data on all rabies vaccines sold from 1991 to 2003. The solid black line shows the total sold quantity, and the dashed gray line shows a linear trend using the data from 1991 to 1995. (b) District-level data on feral dogs was counted for the first time during the 2012 livestock census.

Wolf Reintroductions

Raynor, Grainger, Parker (2021): Wolves make roadways safer, generating large economic returns to predator conservation

- Debates on 'rewilding' often hinge on direct effects (losses to ranchers)
- Sometimes indirect benefits are unexpected and large!



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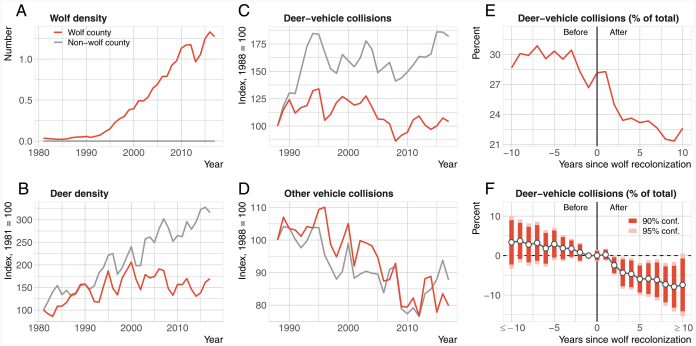

Takeaways

Assessing sustainability is challenging both in terms of measurement and the normative/philosophical issues.

Economists can still be useful:

- Highlight (intertemporal) tradeoffs
- Mechanism design/policy interventions
- Measurement