Sustainability

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When does GDP line up with Welfare?

- When people only care about market consumption; no market failures.
    - $\rightarrow$ market prices equal shadow (social) prices.
- When there is no depreciation
- A welfare-consistent object would be **Net National Product at shadow prices**: output minus depreciation of *all* capital valued at social prices (Weitzman, 1976)
- Still a backward-looking flow: questions about sustainability are forward looking.

Flows vs. Stocks

- Improvements in living standards are typically captured by **flow** measures
  - consumption levels
  - mortality rates
  - GDP
- Welfare-relevant accounting should adjust for the depletion of **stocks**
  - Physical and intangible capital stocks
  - Ecosystems, non-renewable resources, and a liveable climate

"Sustainability"

"Asking whether society is sustainable without some clear metric is not particularly useful." (Solow, 1993)

- Sustainability is about maintaining an opportunity set.

- Arrow et al., 2003; Dasgupta (2007); Arrow et al., 2012: if society follows a sustainable economic program then comprehensive/inclusive wealth is non-declining and approximates changes in welfare.

NNP and Comprehensive Wealth

- **Comprehensive wealth (stock)**: $W(t) = \sum_i p_i(t)\, K_i(t)$
  includes *produced, human, knowledge, health, natural, and social/institutional* capital, valued at *accounting (shadow) prices* p_i.

- **Welfare-consistent NNP (flow)**: $\mathrm{NNP}^*(t) = C^*(t) + I^*(t), \quad I^*(t) = \sum_i p_i(t)\, \dot{K}_i(t)$

- **Mapping (fundamental identity)**: $\dot{W}(t) = I^*(t) = \mathrm{NNP}^*(t) - C^*(t)$

- **Hicksian Income Sustainability**: non-declining comprehensive wealth $\Rightarrow \dot{W}(t) \geq 0$

“If comprehensive wealth rises while median consumption falls, are we sustainable?”

Natural Capital

- An Economic perspective: nature as capital
  - **stock** that yields a **flow** of services
  - More generally, **state** rather than **stock** of nature
- Features of stock/state of nature
  - Evolves in response to human activities $\rightarrow$ **intertemporality**
  - Often **not owned** by anyone $\rightarrow$ **externalities**
- Management of nature: intertemporal problem not solved by the market.

Natural Capital is Not a New Idea

"In agriculture, Nature labours along with man; and though her labour costs no expense, its produce has its value, as well as that of the most expensive workmen."

Adam Smith, 1776

"Things for which nothing could be obtained in exchange, however useful or necessary they may be, are not wealth in the sense in which the term is used in Political Economy. Air, for example, though the most absolute of necessaries, bears no price in the market, because it can be obtained gratuitously."

J.S. Mill, 1848

Limited Natural Resources and Sustainability

- Stocks aren't depleted if natural capital can be substituted with physical capital (weak sustainability)

- However, some stocks may not be very substitutable.

- High consumption given by the depletion of stocks that have low substitutability with man-made capital $\rightarrow \dot{W}(t) < 0$ (unsustainable).

Natural Capital Valuation

- Evaluating whether society is on a sustainable path requires us to measure K_i and p_i
- Physical scientists are getting very good at measuring changes in stocks of natural capital.
- Economists really struggle to determine appropriate prices, when the prices are not observable in markets.
- "The Achilles' heel of the wealth based method for measuring sustainability is the determination of shadow prices" – Smulders (2012)
    - Shadow prices can be negative or undefined with missing, thin, or distorted markets.

Does Nature Matter?

"Everything should be made as simple as possible, but no simpler." – Albert Einstein

- How much do we lose by leaving nature out?
- Simple measure: factor share of natural resource rents
- Intuition: suppose that $K_1^{env}, \ldots, K_k^{env}$ is a comprehensive list of natural stocks (units in service flows)

$$\alpha^{env} = \frac{\sum_i F_{K_i^{env}} \times K_i^{env}}{Y}$$

  - Share of natural resource rents in competitive market
  - α^{env} = elasticity of output w.r.t. stock of nature

Extracting the Contribution of Natural Resources

- Starting point: output measure in natural resource industries and agriculture

- Observed output in, e.g., oil,

$$Y_{oil} = F_{oil}[K, L, O]$$

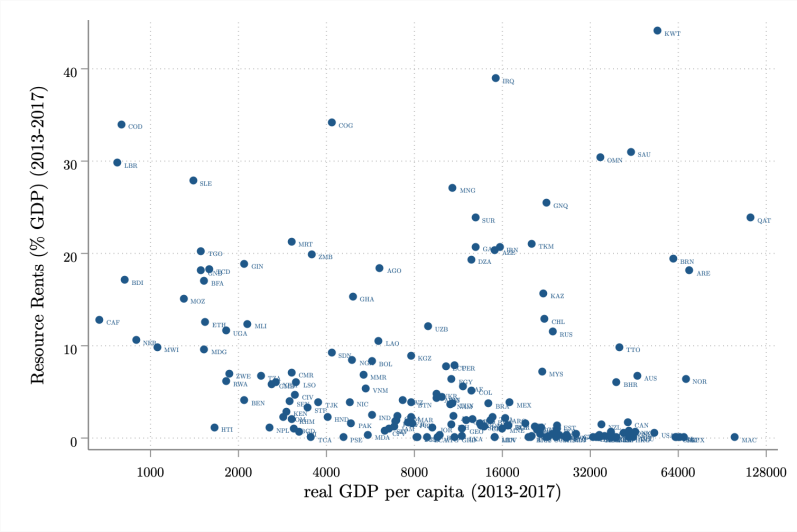
- Value of oil resource constructed by removing other inputs and using Euler's theorem,

$$p_{oil\ \ resource} \times O = p_{oil} Y_{oil} - F_{oil,K} K - F_{oil,L} L$$

World Bank Definition

"The estimates of natural resources rents are calculated as the difference between the price of a commodity and the average cost of producing it. *This is done by estimating the world price of units of specific commodities and subtracting estimates of average unit costs of extraction or harvesting costs (including a normal return on capital). These unit rents are then multiplied by the physical quantities countries extract or harvest to determine the rents for each commodity."*

World Bank Definition



World Bank Definition

- Natural resource rents are a very small share of GDP in most countries
    - Often $<2\%$
- Implication: reducing natural resources by 2 log points leads to a first-order reduction in output of $\sim 4\%$
- Is this first order correct?

First-Order Pitfalls

- Competitive economy
  - Elasticity of output w.r.t factor = factor compensation share

$$\frac{\partial F}{\partial X}\frac{X}{F} = \frac{pX}{F} = \alpha_x$$

  - Similar for utility and expenditure shares,

$$\frac{\partial U}{\partial c}\frac{c}{U} = \frac{\lambda p_c c}{U} = \frac{p_c c}{E} \text{ when } U = \lambda E$$

  - A powerful tool for bounding and back of the envelope calculations.

First-Order Pitfalls

- Too powerful?
  - Water share of expenditures $\sim 2\%$ (70 dollars a month)
  - 99.99999% reduction in water $\rightarrow\sim$ 7 log points $\rightarrow$ 14% reduction in income equivalent welfare

Second-Order Effects

- Water logic consistent w/growth accounting → second order terms key

$$F(W, Y) = \left[W^{\frac{\sigma-1}{\sigma}} + Y^{\frac{\sigma-1}{\sigma}} \right]^{\frac{\sigma}{\sigma-1}}$$

  - W: water
  - Y: other output
  - $\sigma < 1$: complements

- Relative factor shares,

$$\frac{\alpha_w}{\alpha_Y} = \frac{F_W W}{F_Y Y} = \left(\frac{W}{Y} \right)^{1-\frac{1}{\sigma}}$$

- As W → 0, $\frac{F_W W}{F_Y Y} \to \infty$ and $\alpha_w \to 1$

Second-Order Effects

- Numerical example:
  - With $\sigma = 0.1$ and 99.99999% reduction in W
  - $\Delta log(\frac{\alpha_w}{\alpha_Y}) = \frac{\sigma-1}{\sigma}\Delta logW = -9 \times -7 = 63$
  - **Calculation:** Change in output is, $F_1/F_0 = (0.02 \times 10^{63} + 0.98)^{-1/9} = 1.54445 \times 10^{-7}$ $\rightarrow$ 99.99% fall in income-equivalent welfare!
- **Small factor shares do not imply small welfare stakes when inputs are complements.**

Shouldn't Prices be Higher?

- Second order argument confirms that natural capital is,
  - Welfare relevant
  - Even when current flow implies low factor shares
  - As long as "nature" complements other inputs ($\sigma < 1$), which is reasonable.
- However, if this is where we're headed, shouldn't prices be high already today?
- Intuition: owner of oil wells would not pump today if oil is expected to be very expensive tomorrow.
- To evaluate this argument we need to understand scarcity rents.

Shouldn't Prices be Higher?

- The Hotelling rule tells us that the extraction rate of exhaustible resources adjusts so that prices rise with the interest rate.
- However, 2nd order effects imply rapidly rising prices eventually.
- This is inconsistent with extensive extraction today.
- **Finding:** well-functioning markets in stocks of nature bound the future price level.

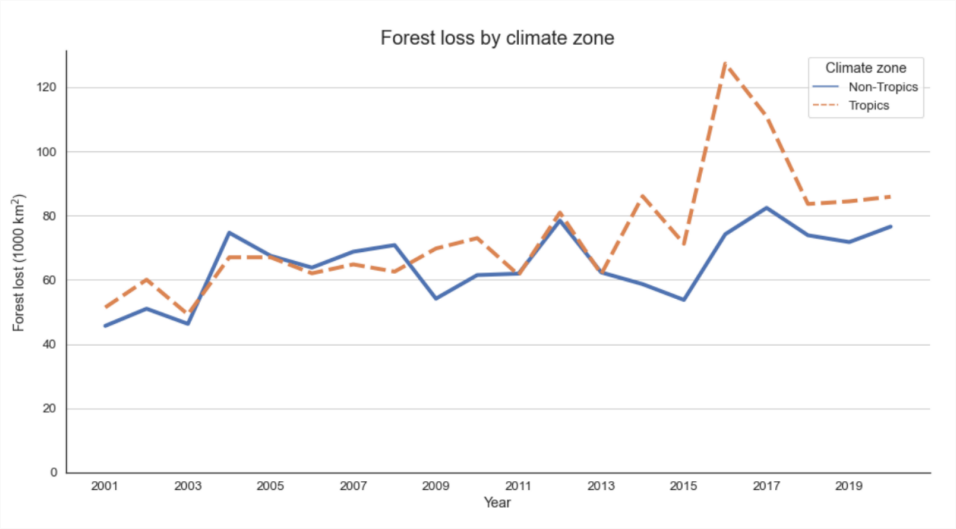
Missing Markets

- However, the key with many natural "stocks" is missing ownership
- Much of natural resource consumption is not traded in markets
- Hence, scarcity rents could be very high without showing up in market outcomes.
- More generally, the ecosystem share of output might be underestimated since we do not price it.
- **Implication**: market measures can only take us so far.

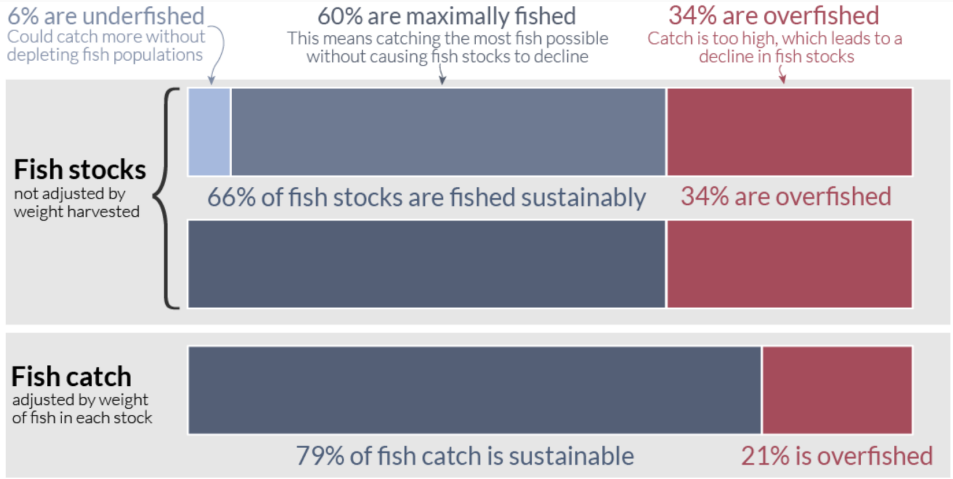
Overview

- Natural capital may be a large share of the wealth of nations...
- ... however, it is underpriced in markets and unaccounted for in national accounts.
- Is some value better than no value?

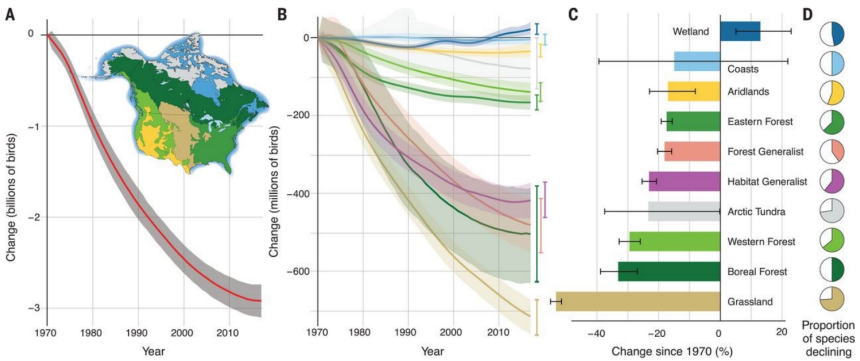
Deforestation



Fish


6% are underfished
Could catch more without depleting fish populations
60% are maximally fished
This means catching the most fish possible without causing fish stocks to decline
34% are overfished
Catch is too high, which leads to a decline in fish stocks
Fish stocks
not adjusted by weight harvested
66% of fish stocks are fished sustainably
34% are overfished
Fish catch
adjusted by weight of fish in each stock
79% of fish catch is sustainable
21% is overfished

Biodiversity



Source: Rosenberg et al. (2019) "Decline of the North American avifauna", *Science*

Biodiversity: ↓ Keystone Species → ↑ Human Mortality

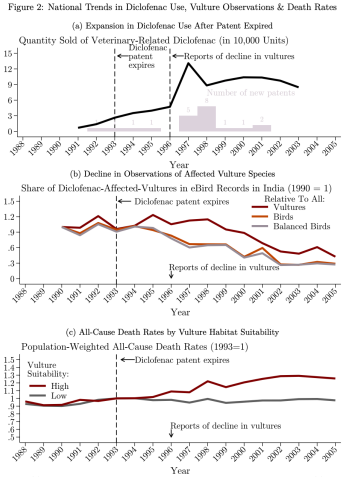
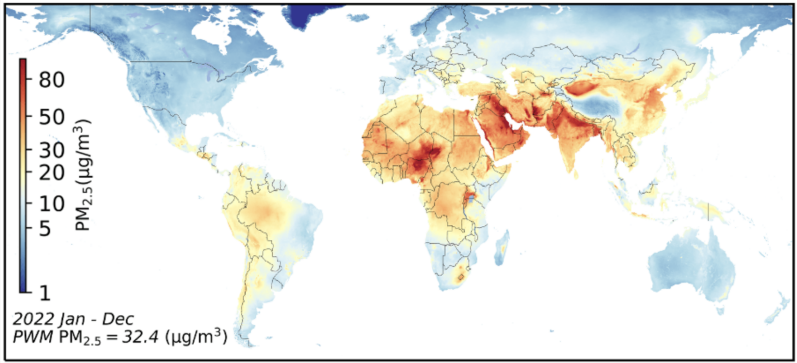


Figure 2: National Trends in Diclofenac Use, Vulture Observations & Death Rates

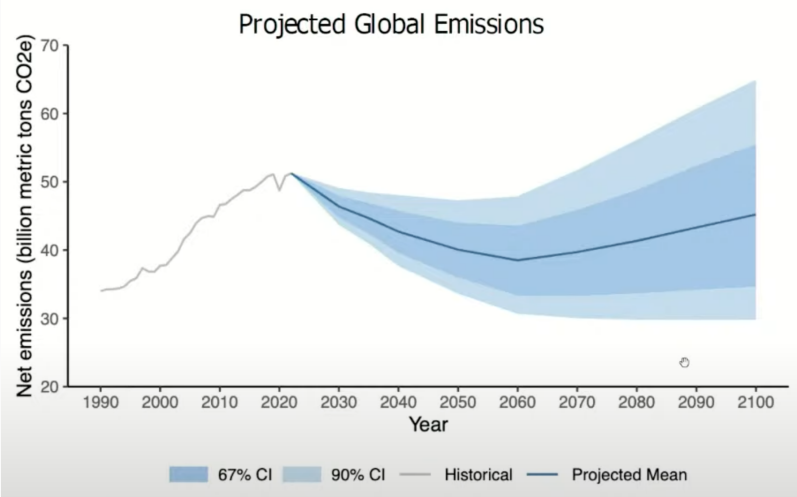
Notes: (a) Veterinary-related diclofenac sales, and the number of new product entries. (b) The share of diclofenac-affected-vultures relative to all other vultures species, all bird species, and all bird species that are consistently reported every year. (c) Mean all-cause death rates (balanced and not residualized) by vulture suitability classification for diclofenac-affected-vultures.

Figure 3: All-Cause Death Rates DD Estimation Results

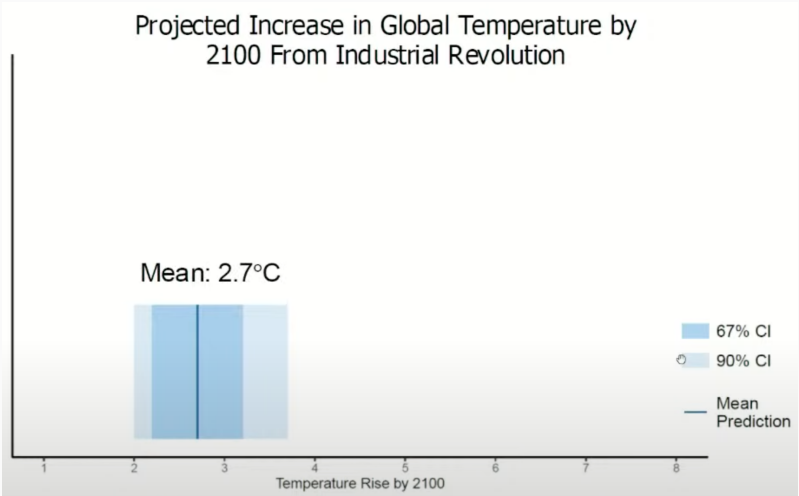
Air Quality



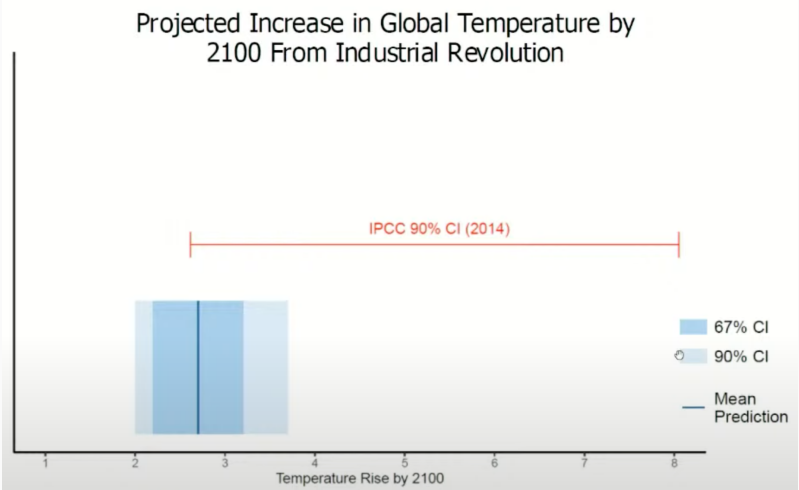
A Livable Climate: Where Emissions Are Headed



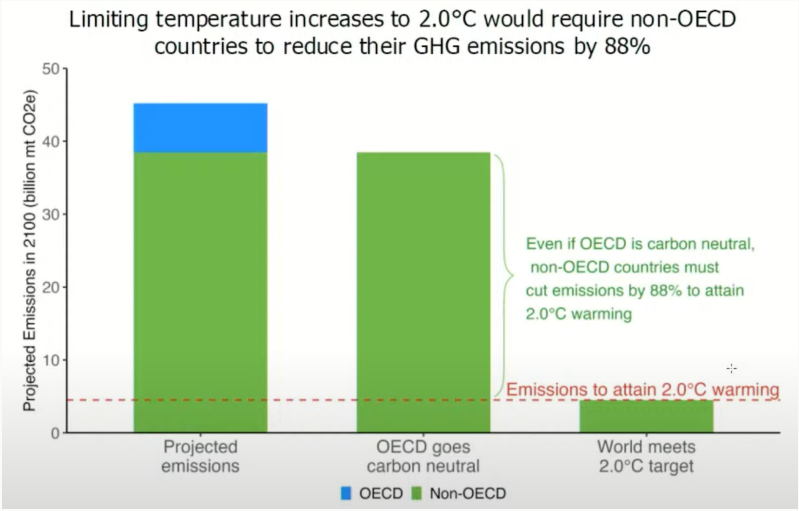
A Livable Climate: The Consequences for Global Temperature



A Livable Climate: We Are Reducing Uncertainty!



A Livable Climate: Emissions Avoidance in LMICs is Necessary



A Livable Climate: 98% of estimated damages are in LMICs

Climate Change Damages Caused by Current Annual CO_2 Emissions

	Mortality partial SCC	**Emissions 2022**	**Total damages to** (billions of USD)	
	(USD)	(Bt CO_2e)	World	Non-OECD
World	130	50.1	6,530	6,359
OECD	3	14.4	1,876	1,826
Non-OECD LMIC	127	33.8	4,405	4,290
Non-OECD high income	0	1.9	249	242