Growth and Development: Growth and Sustainability

Jonathan Colmer

University of Virginia

Lecture Notes for PhD Growth and Development (EC8510)

Growth

- How does a person or economy grow richer?

Growth

- How does a person or economy grow richer?
  - You have some resources (skills, capital, land) which can be converted into output or income
  - If you consume all your income in the current period, then you cannot grow – at best you will be able to replicate what you did last period (provided that your resources don't depreciate)
  - Savings, and investment, are therefore key to growth
- What are the limits to growth, if any? Can a person or an economy become infinitely rich?

What is Growth?

- Typically, we think that there are diminishing returns to some fixed factor which slows down the growth rate.
  - People and economies reach their "steady states" when there is no growth barring shocks to technology or preferences.
- This delivers the notion of "convergence" in economic growth models
- You grow faster when you are smaller but as you approach the steady state, the growth rate slows down.

Growth

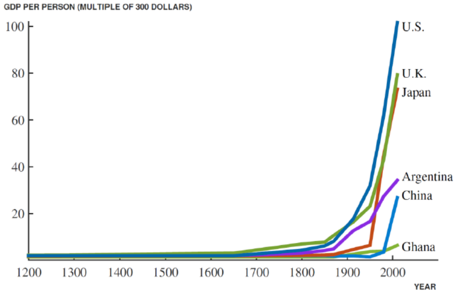
- This is the classical view of development.
  - Resources will flow to take advantage of arbitrage opportunities
  - Given diminishing returns, the poor will catch up faster (convergence)
  - Long run differences in development reflect preferences, technology, and endowments.
  - In open economies, technology flows will remove these differences and equalize factor prices.
    - Any residual differences must be pinned down by innate abilities, natural resources, and attitudes.
    - Only permanent policy measures can make any difference, e.g., tax incentives to encourage savings.

Macro Stylized Facts

- **Assumptions:**
  - Perfect institutions
  - Forward-looking agents
  - Well-behaved technology
- **Predictions:**
  - Solution = accumulating capital stock through savings and investment.
  - Given diminishing returns, the poor will catch up (convergence)
  - Long run differences = preferences, technology, and endowments (conditional convergence)
- Is there any empirical support for this view?

Jones (2015) Growth Facts

Figure 21: The Great Divergence

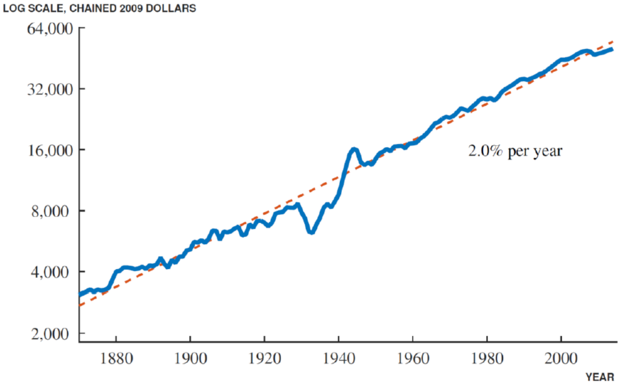


Note: The graph shows GDP per person for various countries, normalized by the value in the United Kingdom in the initial year. Source: The Maddison Project, Bolt and van Zanden (2014).

The Great Divergence: With the modern era of growth the gap between developed and developing countries has increased, with some catch up (e.g., China and India).

Jones (2015) Growth Facts

Figure 1: GDP per person in the United States



Note: Data for 1929–2014 are from the U.S. Bureau of Economic Analysis, NIPA Table 7.1. Data before 1929 are spliced from Maddison (2008).

For nearly 150 years, GDP per capita in the U.S. has grown at a remarkably steady average rate of 2 percent per year.

Jones (2015) Growth Facts

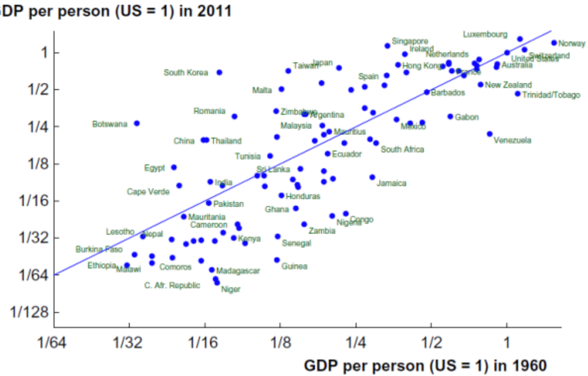
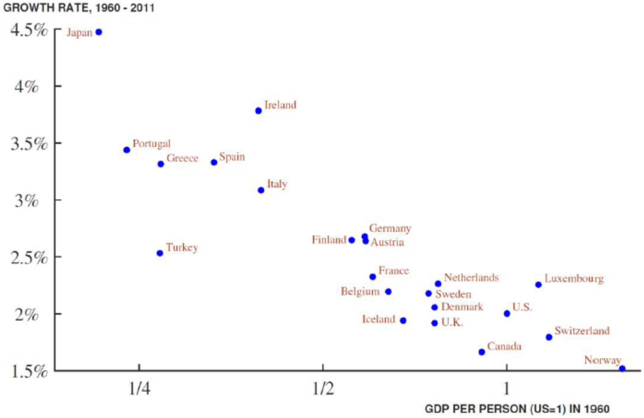


Fig. 24 GDP per person, 1960 and 2011. Source: *The Penn World Tables 8.0.*

Lots of persistence in the distribution.

Jones (2015) Growth Facts

Figure 25: Convergence in the OECD

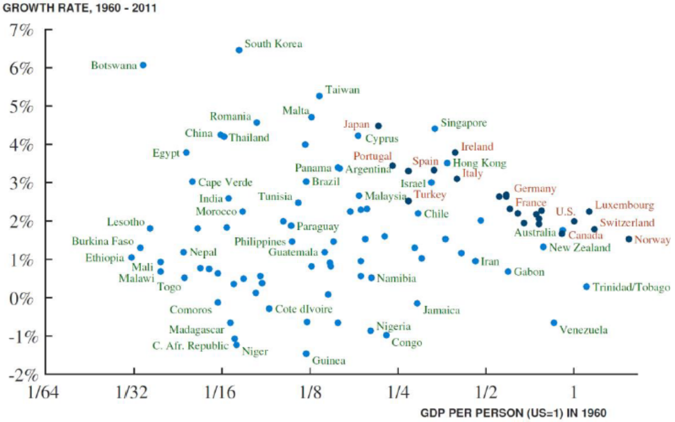


Source: The Penn World Tables 8.0. Countries in the OECD as of 1970 are shown.

Evidence of Convergence: "Catch-up" behavior for OECD countries since 1960

Jones (2015) Growth Facts

Figure 26: The Lack of Convergence Worldwide



Source: The Penn World Tables 8.0.

No evidence of catch-up globally though. Conditional convergence?

Overview

- We see $\approx$ constant growth across the distribution post-1950.
- Periods of sustained high growth were examples of catchup to the frontier, i.e., growth miracles represent transitional dynamics associated with change in the relative income distribution.
- Growth decreased as distance to the frontier lessened.
- Changes in position in the relative income distribution seems to reflect level effects not growth effects (consistent with exogenous rather than endogenous growth theory).
- No countries experienced 7-8% growth without a low level.

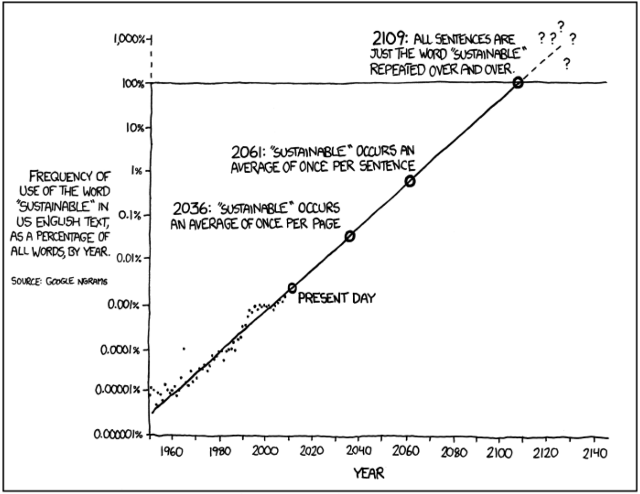
Convergence or Divergence?

- Limited support for conditional convergence
  - Non-convexities may matter, resulting in poverty traps
- $A_{it} = \tilde{A}_{it}\hat{A}_t$
  - $\hat{A}_t$, the world technology frontier, changes slowly.
  - $\tilde{A}_{it}$, can change rapidly due to events, changes in policies/institutions.
  - Miracles and disasters reflect transition dynamics associated with large changes in $\tilde{A}_{it}$.
  - Key question: what factors influence $\tilde{A}_{it}$.

Frontier vs. Catchup Growth?

- Endogenous growth theory is about the forces that determine the evolution of the technology frontier, $\hat{A}_t$
- For countries close to the frontier, growth is only possible by moving the frontier.
- For countries far away from the frontier, frontier growth is second order to their growth possibilities.
- For many developing countries, it is probably reasonable to view the technology frontier as exogenous.

Sustainability



THE WORD "SUSTAINABLE" IS UNSUSTAINABLE.

More seriously. . .

- The tension between humanity and nature has always been a focus in the natural and social sciences (Marsh, 1865; Malthus, 1798; Sen, 1981).
- Humanity strives to improve their welfare by pursuing economic growth
- Truism: human activity depends on the natural environment
- The growth process damages nature and imposes negative externalities on society through environmental degradation and pollution.

Limited Natural Resources and Sustainability

- 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

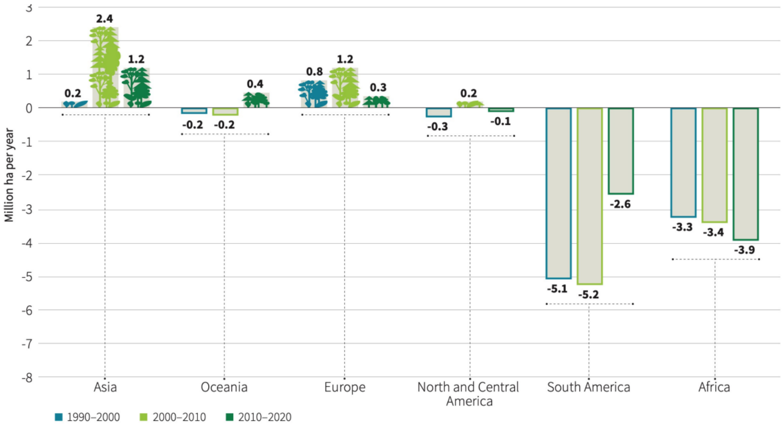
Limited Natural Resources and Sustainability

- 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.

Limited Natural Resources and Sustainability

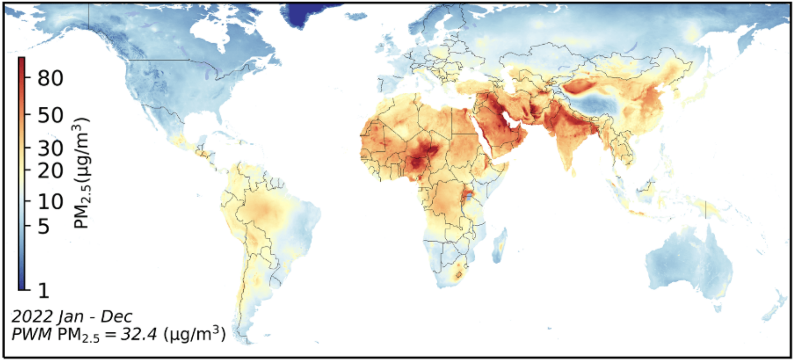
- Stocks aren't depleted if natural capital can be substituted with physical capital (weak sustainability)
- However, some stocks may not be very substitutable.
- High consumption given by the depletion of stocks that have low substitutability with man-made capital $\rightarrow$ unsustainable.

Forests

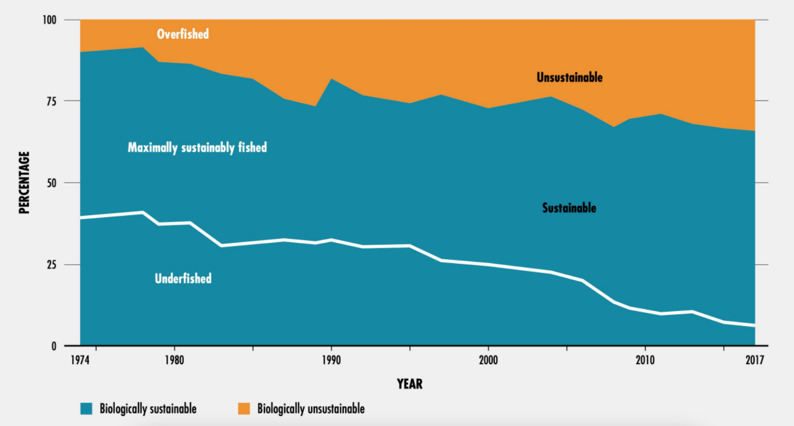


Million ha per year
3
2
1
0
-1
-2
-3
-4
-5
-6
-7
-8
0.2
2.4
1.2
-0.2
-0.2
0.4
0.8
1.2
0.3
-0.3
0.2
-0.1
-5.1
-5.2
-2.6
-3.3
-3.4
-3.9
Asia
Oceania
Europe
North and Central America
South America
Africa
1990–2000
2000–2010
2010–2020

Pollution

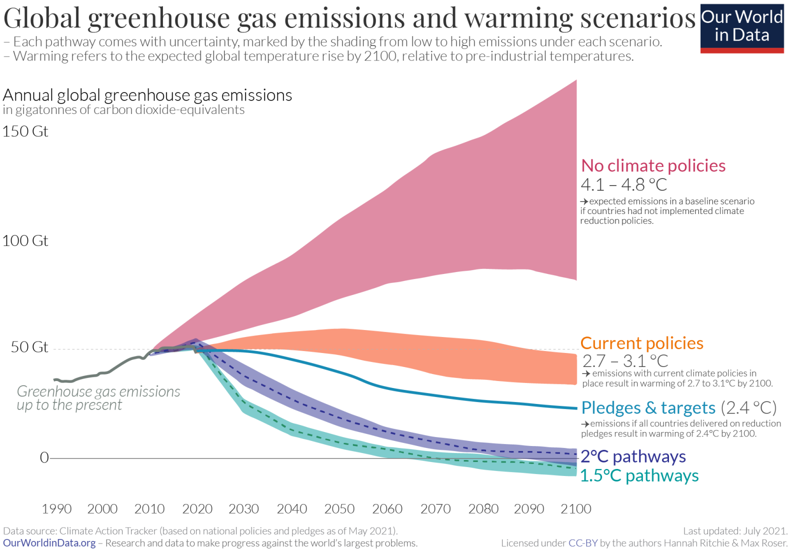


Fish

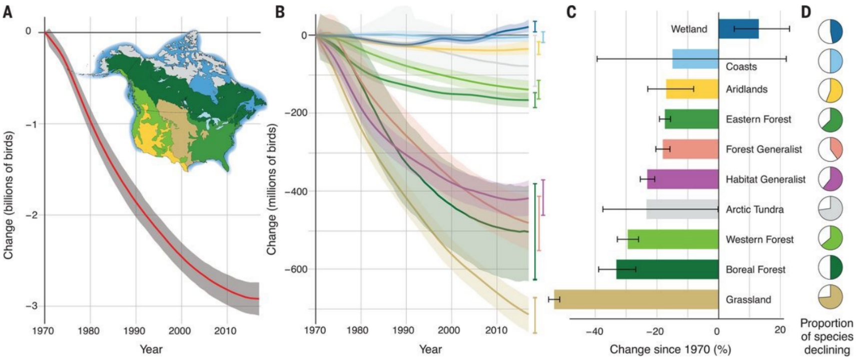


100
75
50
25
0
PERCENTAGE
Overfished
Unsustainable
Maximally sustainably fished
Sustainable
Underfished
1974
1980
1990
2000
2010
2017
YEAR
Biologically sustainable
Biologically unsustainable

Climate Change



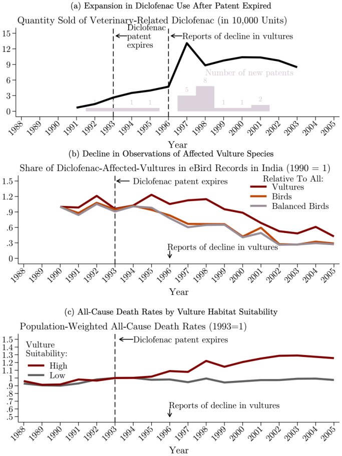
Biodiversity



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

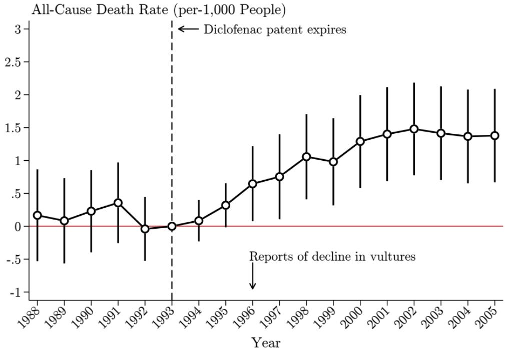
↓ Keystone Species → ↑ Mortality

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



How Might Nature Show Up in Models?

- Simple setup

$$\max \int_0^\infty e^{-\rho t} u[c(t)] dt$$

subject to,

$$\begin{aligned} c(t) + x(t) + x^{env}(t) &\leq F[k(t), l(t), s(t)] \\ \dot{k}(t) &= x(t) - \delta k(t) \\ \dot{s}(t) &= g[s(t), x^{env}(t)] \end{aligned}$$

  - $x(t)$: standard investment
  - $x^{env}(t)$: environmental investments
  - $s(t)$: state of nature

How Might Nature Show Up in Models?

- What's the optimal allocation?
- Are the planner and decentralized solution the same?
- Optimal policy if not?

How Does Nature Show Up in Models?

- Standard neoclassical model

$$\max \int_0^\infty e^{-\rho t} u[c(t)]dt$$

subject to

$$c + \dot{k} \leq F[k(t), l(t)] - \delta k(t)$$

$\rightarrow$ **no nature at all**

How Does Nature Show Up in Models?

- Neoclassical model with land

$$\max \int_0^\infty e^{-\rho t} u[c(t)] dt$$

subject to

$$c + \dot{k} \leq F[k(t), l(t), z] - \delta k(t)$$

$\rightarrow$ **nature does not respond to human actions**

But 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 Contribution of Natural Resources

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

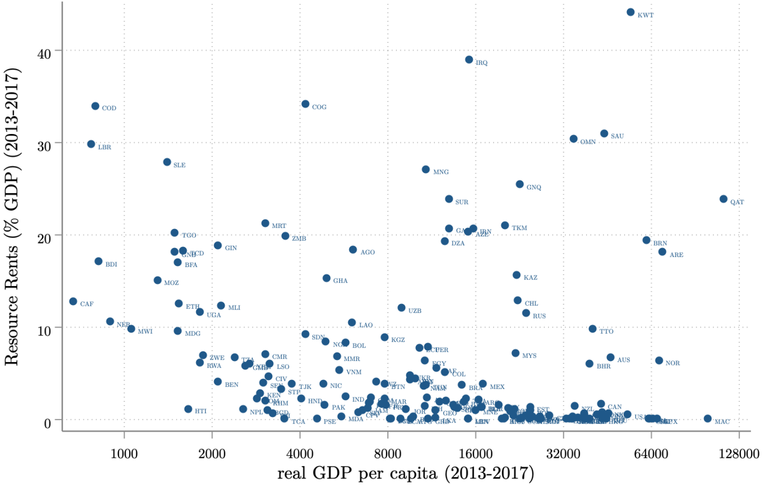
- Observed output in, e.g., oil,
$$Y_{oil} = F_{oil}[K, L, O]$$

- 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?

Growth Accounting: 1st Order and 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.

Growth Accounting: 1st Order and Pitfalls

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

Growth Accounting: 2nd Order Effects

- Water logic consistent w/growth accounting $\rightarrow$ 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 $\rightarrow 0$, $\frac{F_W W}{F_Y Y} \rightarrow \infty$ and $\alpha_W \rightarrow 1$

Growth Accounting: 2nd Order Effects

- Numerical example:
  - With $\sigma = 0.1$ and 99.99999**%** reduction in W
  - $\Delta log(\frac{\alpha_W}{\alpha_Y}) = \frac{1-\sigma}{\sigma}\Delta logW = 9\Delta logW = 63$
  - $\rightarrow$ factor of 2.3×10^{27}!
  - Calculation: 98.4% fall in output!

Shouldn't Prices be Higher Then?

- Second order argument confirms that natural resources $\to 0$
  - Welfare relevant
  - Even when current flow implies low factor shares
  - As long as "nature" complements other inputs ($\sigma < 1$), which is reasonable.
- However, if that 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 super-expensive tomorrow.
- To evaluate this argument we need to understand scarcity rents.

Shouldn't Prices be Higher Then?

- The Hotelling rule tells us that the extraction rate adjusts so that prices rise with the interest rate.
- However, ecocalypse due to 2nd order effects implies rapidly rising prices eventually.
- This is inconsistent with extensive extraction today.
- Finding: well-functioning markets in stocks of nature places an upper bound on 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 w/o showing up in market outcomes.
- More generally, the ecosystem share of output might be underestimated since we do not price it.
- **Conclusion**: market measures can only take us so far.

Natural Capital Accounting

- Strong theoretical basis for natural capital accounting (Weitzman, 1976; Hartwick, 1990; Heal, 1998; Daily et al., 2000; Arrow et al., 2004; Dasgupta, 2007; Arrow et al., 2013)
- "Asking whether society is sustainable without some clear metric is not particularly useful." (Solow, 1993)
- Sustainability is about maintaining an opportunity set.
- Dasgupta (2007) argues that if society follows a sustainable economic program then comprehensive/inclusive wealth, $\mathcal{W} = \sum p_i s_i$, is non-declining and approximates changes in welfare.
- Mostly metaphor at present.

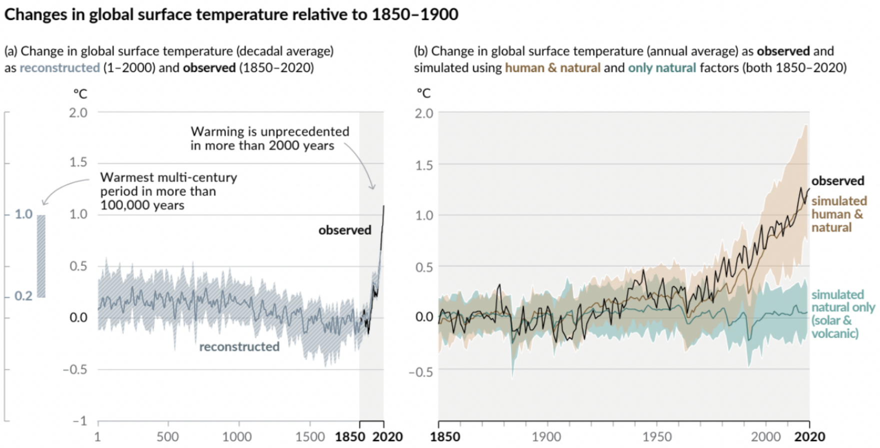
Natural Capital Valuation

- Evaluating whether society is on a sustainable path requires us to measure s_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 Achiles' heel of the wealth based method for measuring sustainability is the determination of shadow prices" – Smulders (2012)
- The challenge is determining appropriate price functions to measure changes in wealth, particularly for assets that are subject to thin, distorted, or missing markets – as is the case for many critical forms of natural capital.

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?

Climate Change



A global challenge that is experienced locally

$\uparrow$ Extreme Heat

$\uparrow$ Intense Rainfall

$\uparrow$ Wildfires

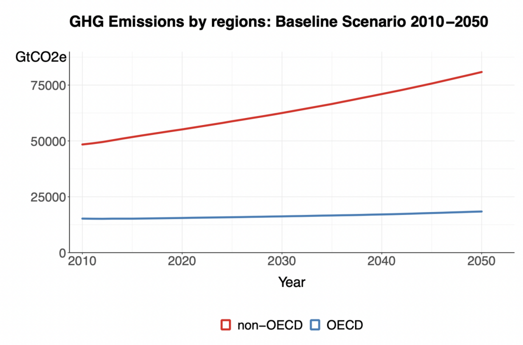
$\uparrow$ Droughts

$\uparrow$ Intense Storms

$\uparrow$ Relative Sea Level Rise

A Changing Composition

- Developed economies got us into this mess.
- LMICs:
  - currently generate 2/3 of emissions
  - account for almost all emissions growth
  - are rightly focused on alleviating poverty and increasing relative living standards.
- Emissions will continue to increase unless decoupled from growth.
- **Fundamental Question:** How do we balance growth and the externalities from growth?



Decarbonization and Growth

- Low-carbon "frontier" growth opportunities largely will come from developed economies – a "new industrial revolution" (Acemoglu et al., 2012; Aghion et al., 2016; Van Reenen et al., 2020; Stern and Valero, 2021)
- No guarantees (Besley and Persson, 2023).
- To what degree will LMICs "catch up"?
  - We need to understand constraints to financing, adoption, transfer, and integration.
  - It doesn't matter where emissions reductions occur (Glennester and Jayachandran, 2024)
  - Rephrased: How do we get LMICs onto the world technology frontier?

How will climate change affect growth and development?