Population and Climate Change: Coupling Population Models with Earth System Models

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The development of climate models, past, present and future

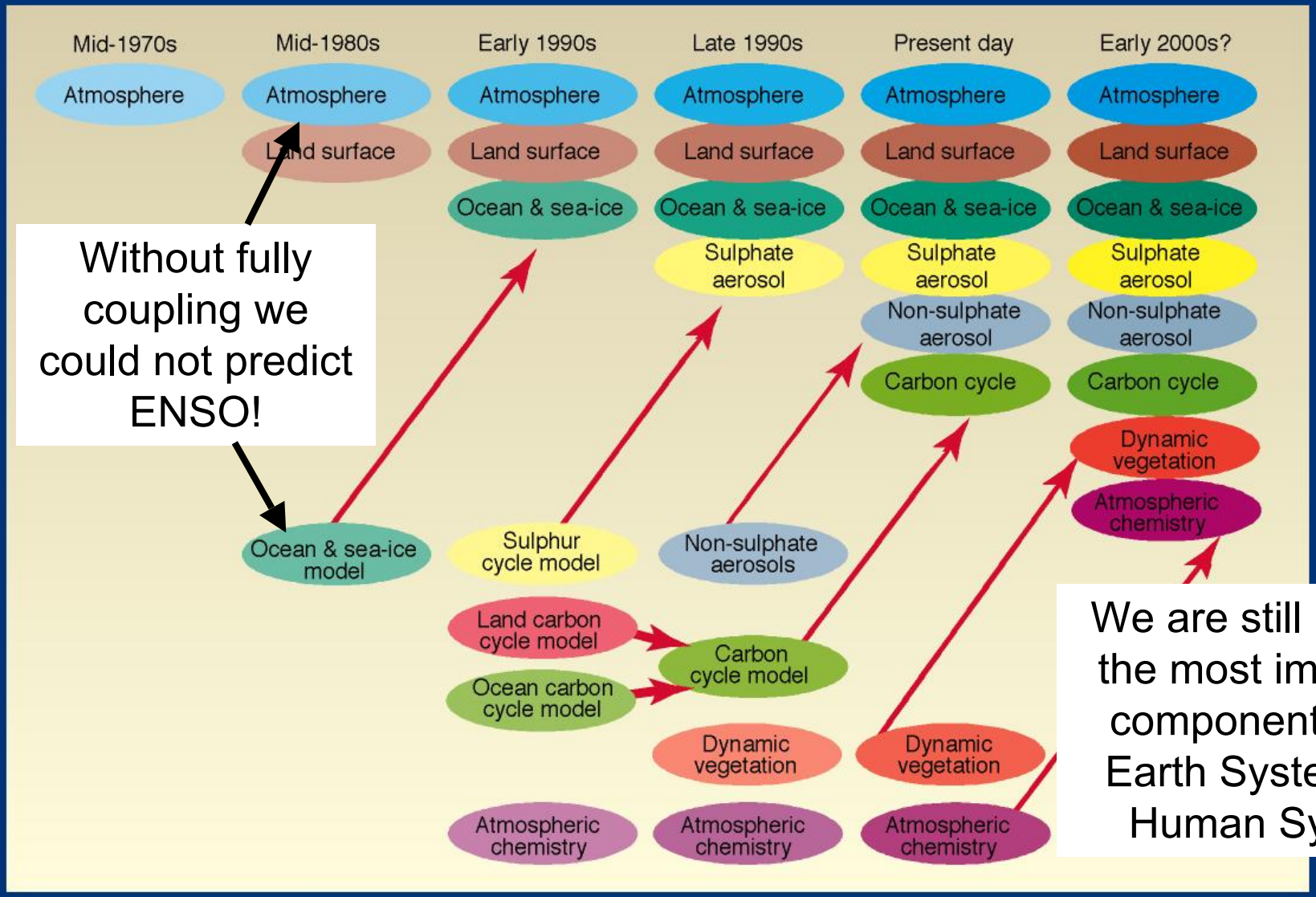
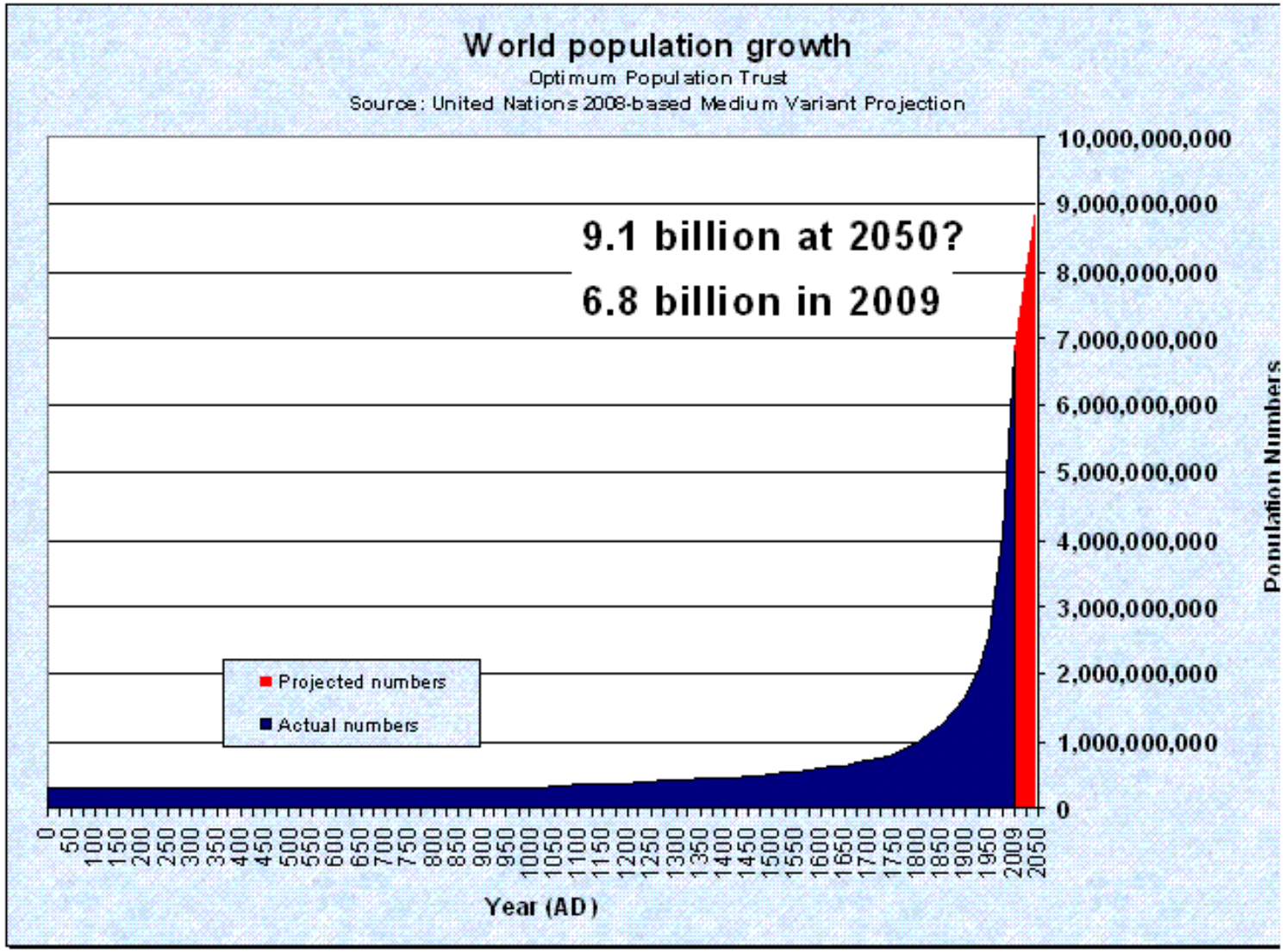


FIGURE 1

Population growth

1AD	0.3b
1650	0.5b
1800	1.0b
1927	2.0b
1960	3.0b
1975	4.0b
1987	5.0b
1998	6.0b
2011	7.0b



Population and climate: a study at the London School of Economics

Per dollar spent,

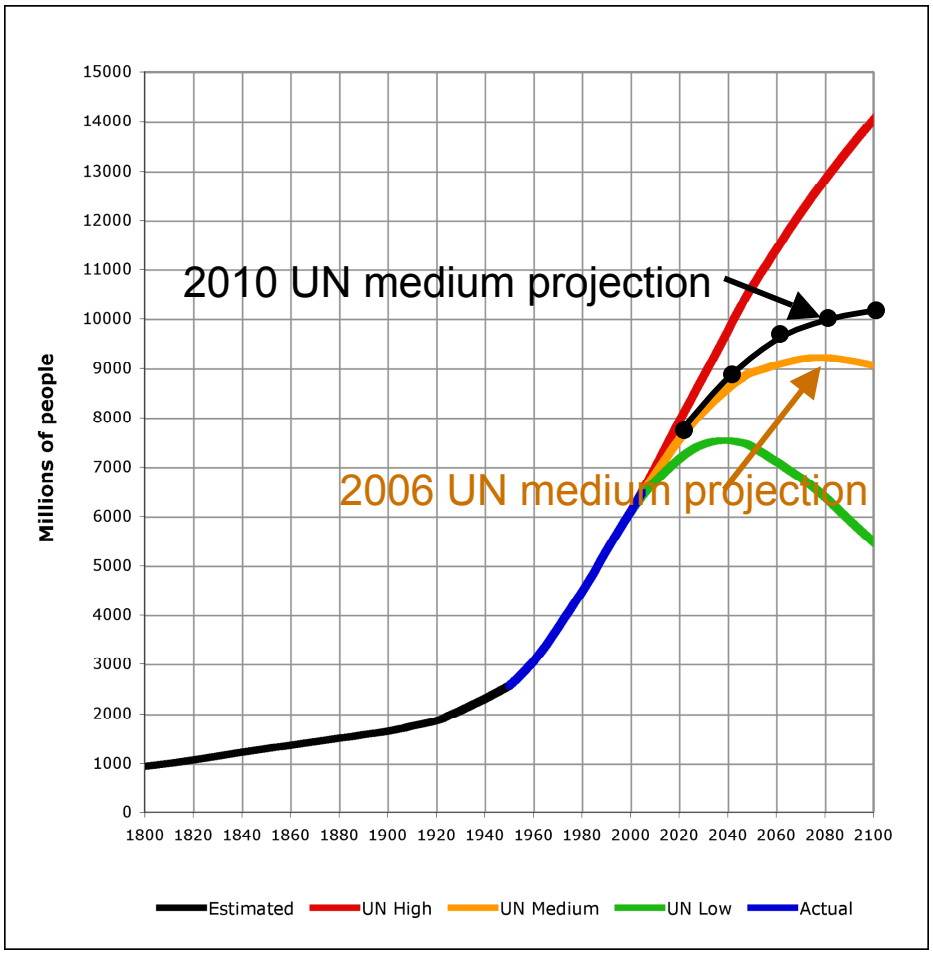
family planning reduces **four times** as much carbon over the next 40 years as

adopting **low-carbon technologies**

Concluded: Family planning is cost effective and should be a primary method to reduce emissions

Copenhagen: no discussion on population or family planning: it is a **taboo** subject

New UN projection is **higher**



Why was the population able to grow so fast since the 1950's?

Two reasons:

1) Sanitation and antibiotics (living longer)

2) Use of fossil fuels in agriculture starting in the 1950's:

- fertilizers, pesticides, irrigation, mechanization (Green Revolution).

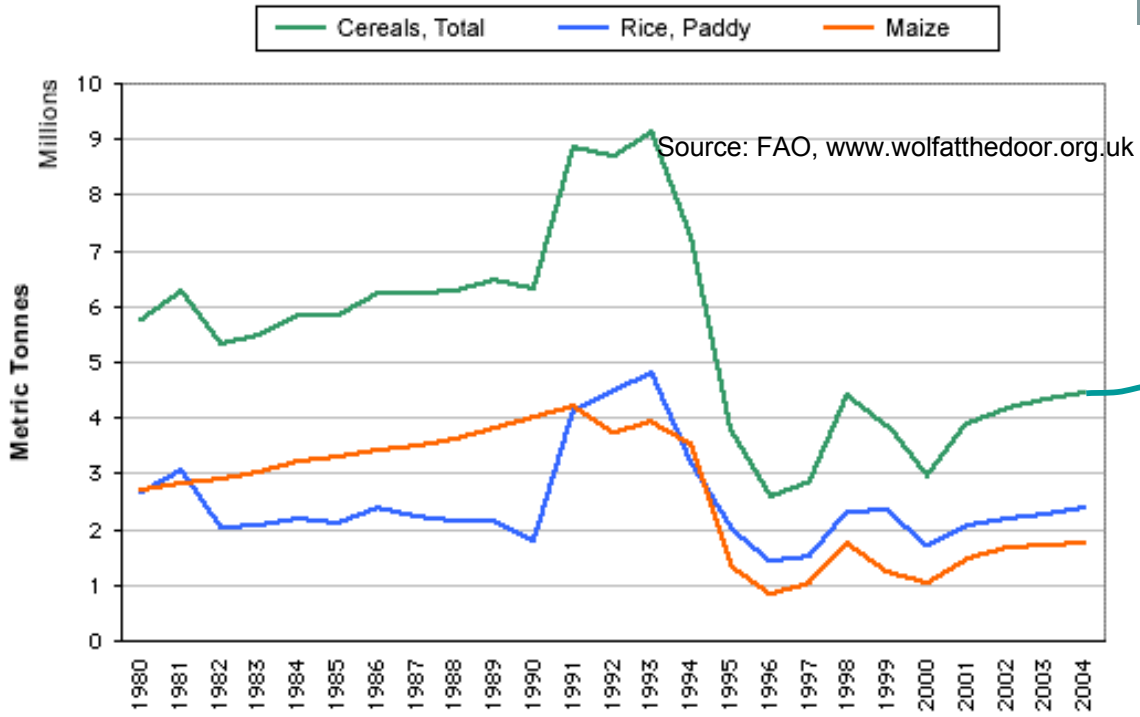
1950 to 1984: production of grains increased by 250% and the population doubled

Without fossil fuels population would be much smaller!

- Growth in grain production is now flattening out
- Industrial farming is destroying forests, soil
- Urban and suburban sprawl is overrunning best farmland

This is not sustainable: "We are drawing down the stock of natural capital as if it was infinite" (Herman Daly)

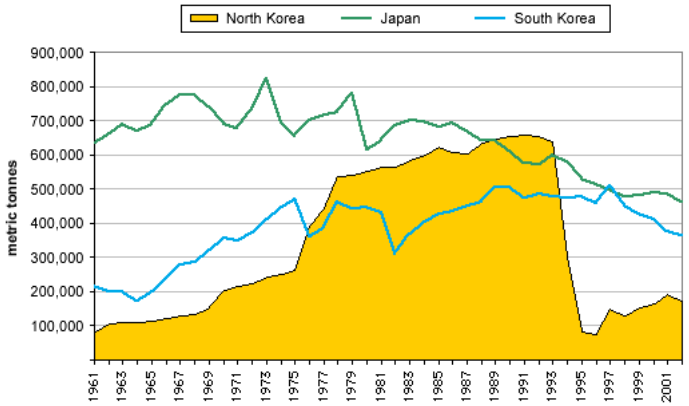
Example: North Korea, got cheap oil from the former Soviet Union until early 1990s



Source: FAO, www.wolfatthedoor.org.uk

Production of grain in North Korea, updated to 2008

G2. Fertiliser Use (Nitrogenous) - Far East



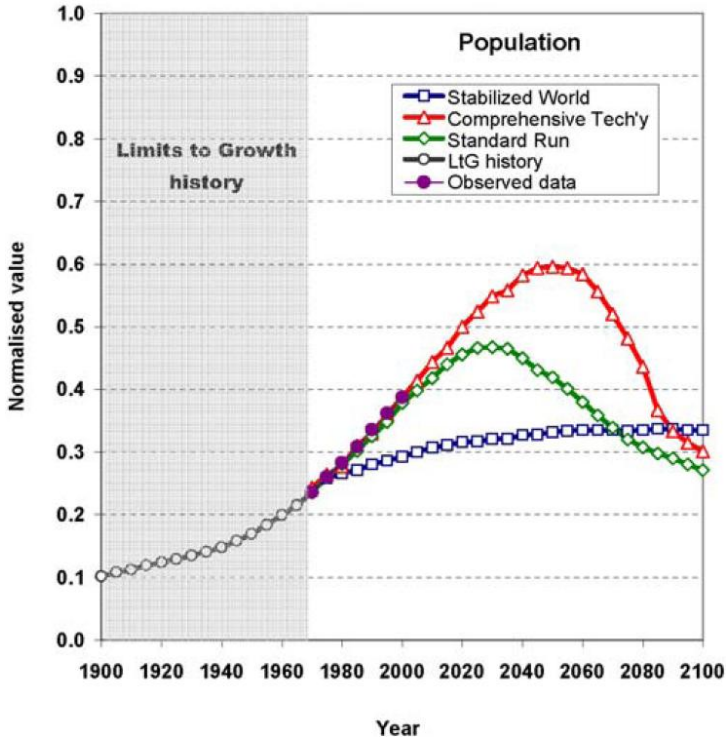
1972: Club of Rome "Limits to Growth"

The Club of Rome commissioned a group at the MIT Sloan School of Management to study:

"Are current policies leading to a sustainable future or to collapse?"

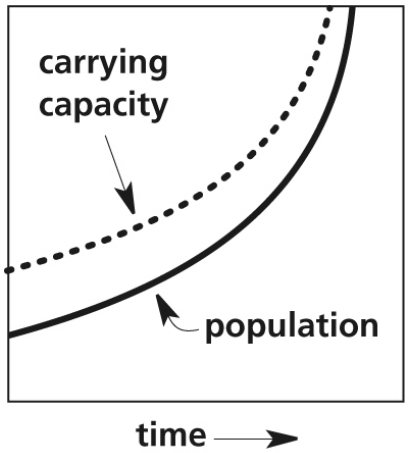
When the results appeared in 1972, the conclusion that with **finite** natural resources growth would overshoot and collapse was dismissed as **absurd** by many economists. ("discredited")

35 years later the "standard run" model compares well with reality for all variables.
(Graham Turner, G.E.C., 2008)

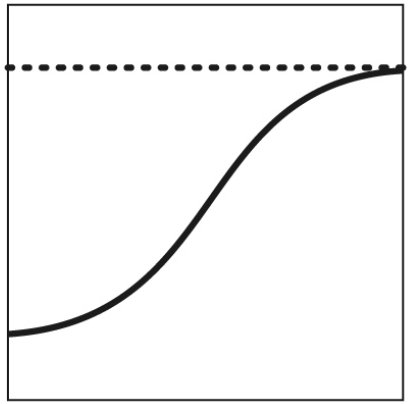


The model could have four possible types of outcomes

Infinite World



a) Continuous Growth

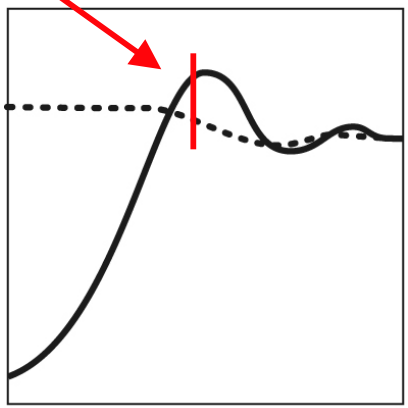


b) Sigmoid Approach to Equilibrium

Ideal
(no overshoot)

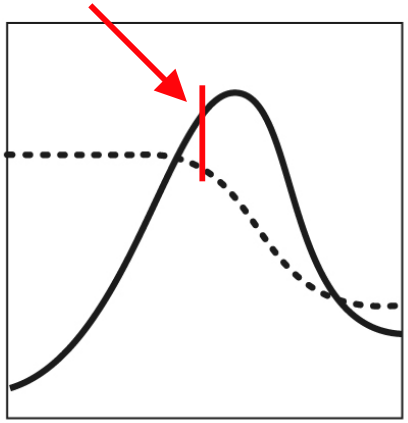
You are here…

Hopefully…



c) Overshoot and Oscillation

Or here…



d) Overshoot and Collapse

Disaster

The results are sobering: most scenarios collapse

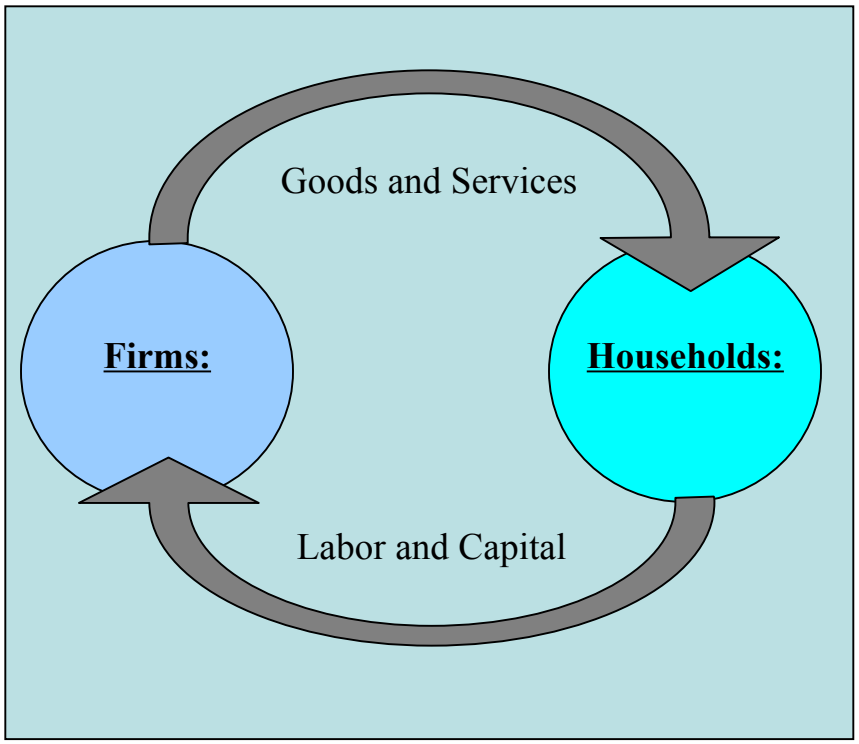
Even if resources are doubled, collapse is only postponed ~20 years

In order to avoid collapse, government policies are needed to:

- Stabilize population and
- Stabilize industrial production per person
- Adopt technologies to
  - abate pollution
  - conserve resources
  - increase land yield
  - protect agricultural land

Standard Neoclassical Economic Model

As Herman Daly, Robert Costanza, and other scholars in the field of Ecological Economics describe,



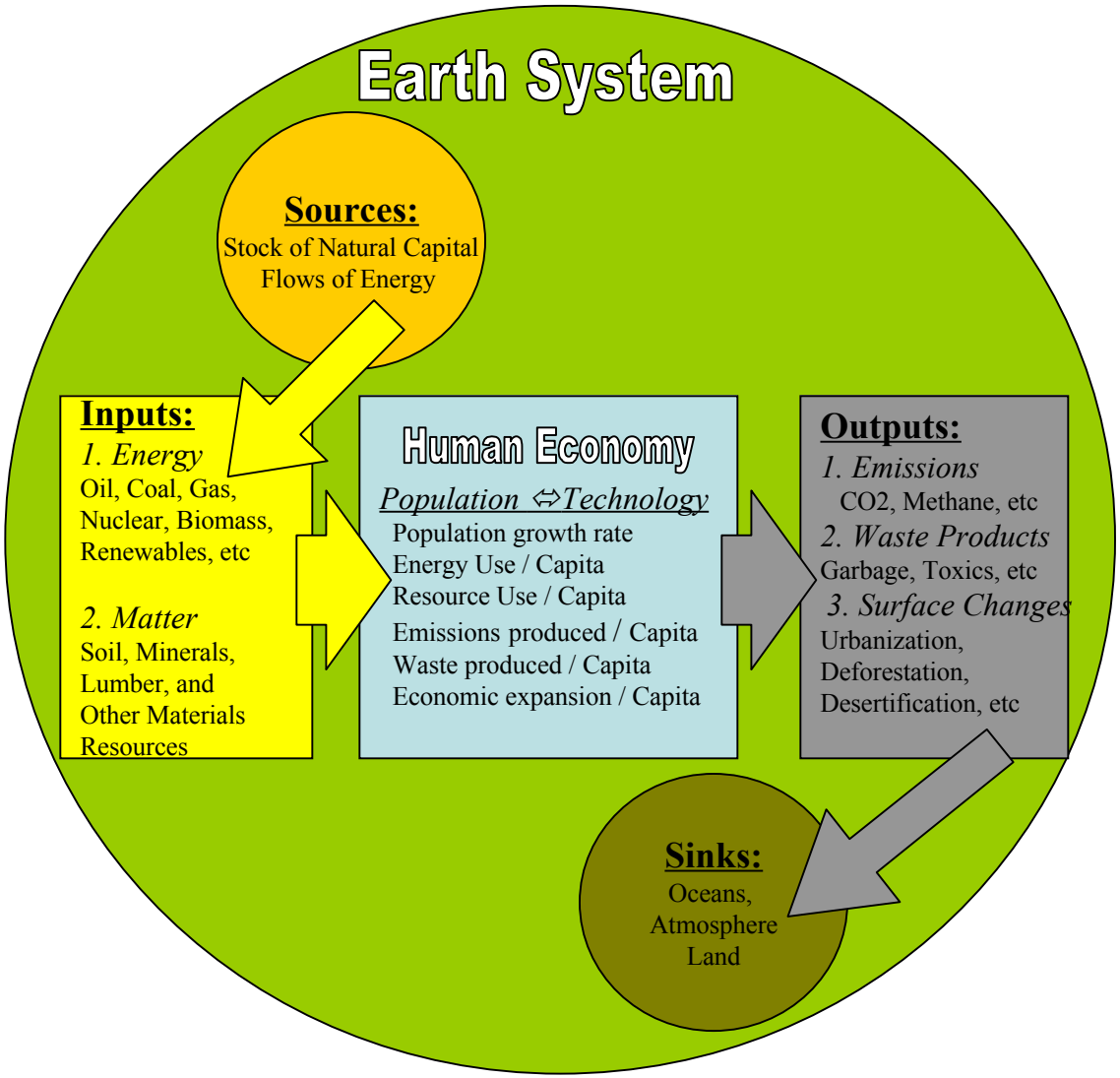
The standard Neoclassical Economic Model does not account for:

- Inputs (resources)
- Outputs (pollution)
- Stocks of Natural Capital
- Dissipation of Energy (i.e., a Perpetual Motion Machine)
- Depletion, Destruction or Transformation of Matter

Therefore, no *effects on the Earth System*, and *No Limits to Growth*.

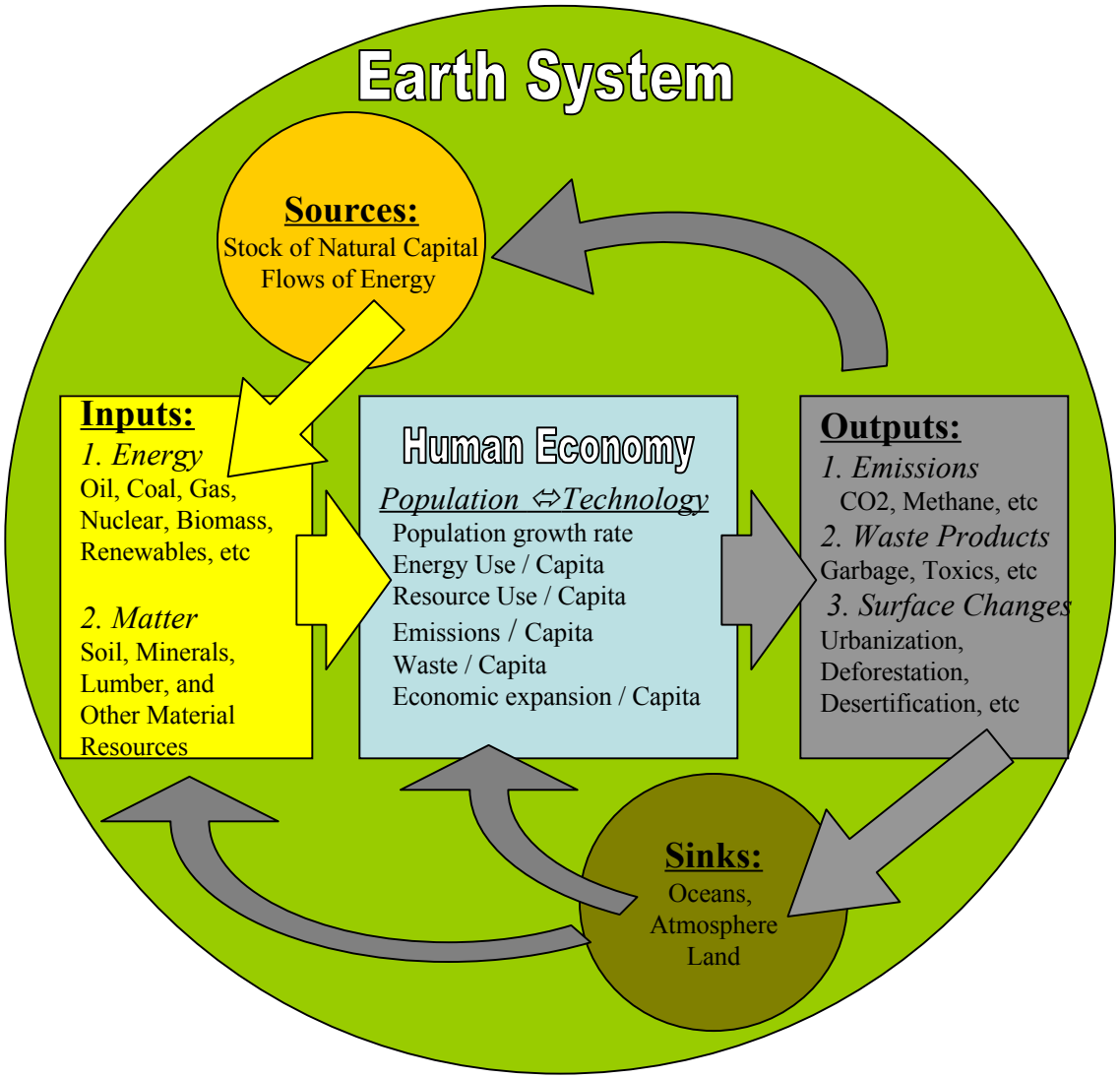
Realistic **Ecological** Economic Model (Herman Daly)

- Incorporates INPUTS, including **DEPLETION** of **SOURCES**
- Incorporates OUTPUTS, including **POLLUTION** of **SINKS**



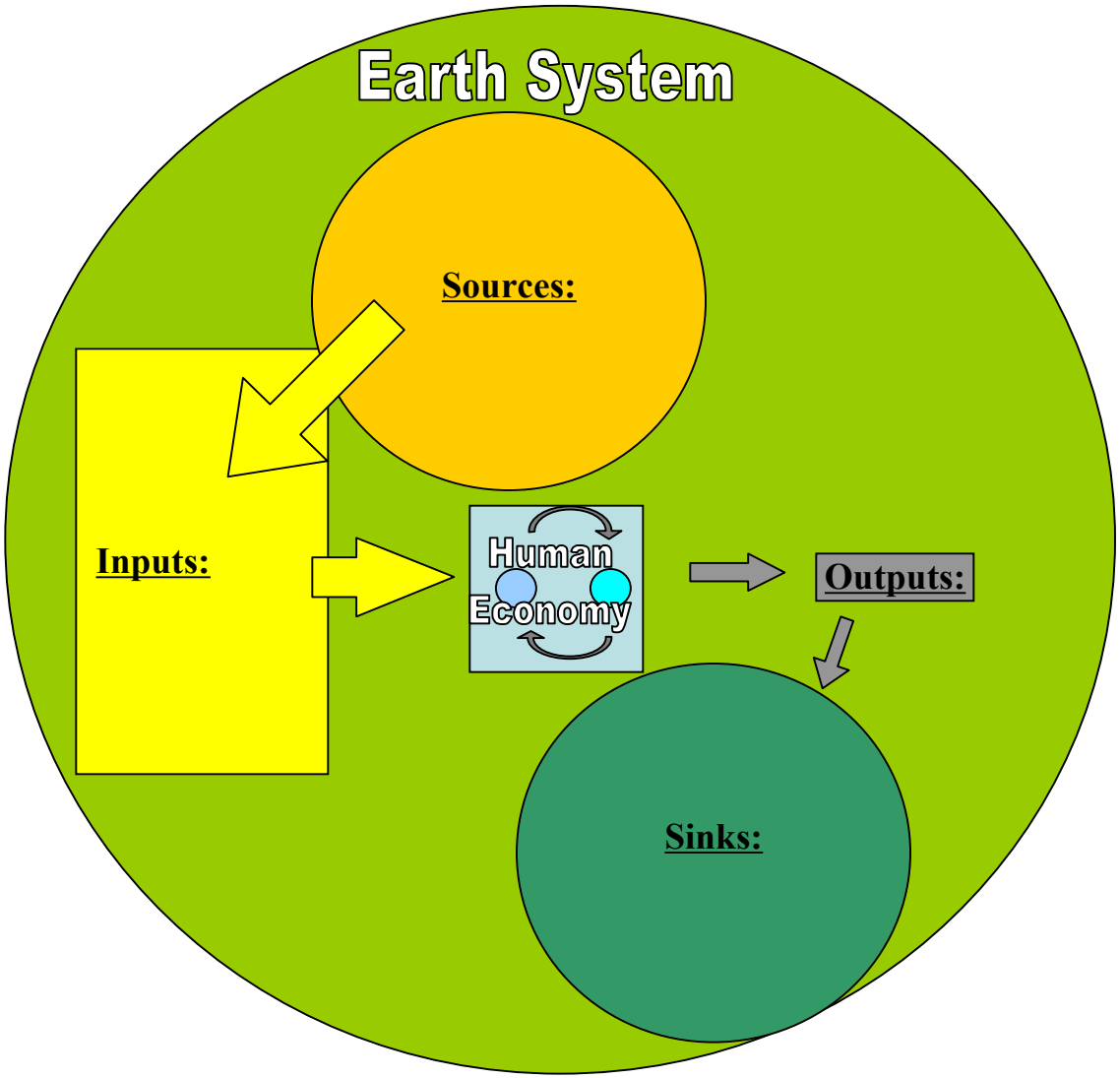
Feedbacks in an Ecological Economic Model

Of course, the OUTPUTS and the **filling up** of **SINKS,** have **feedbacks** on the **Human Economy**, the Quantity and Quality of the INPUTS, and the **depletion of SOURCES** :

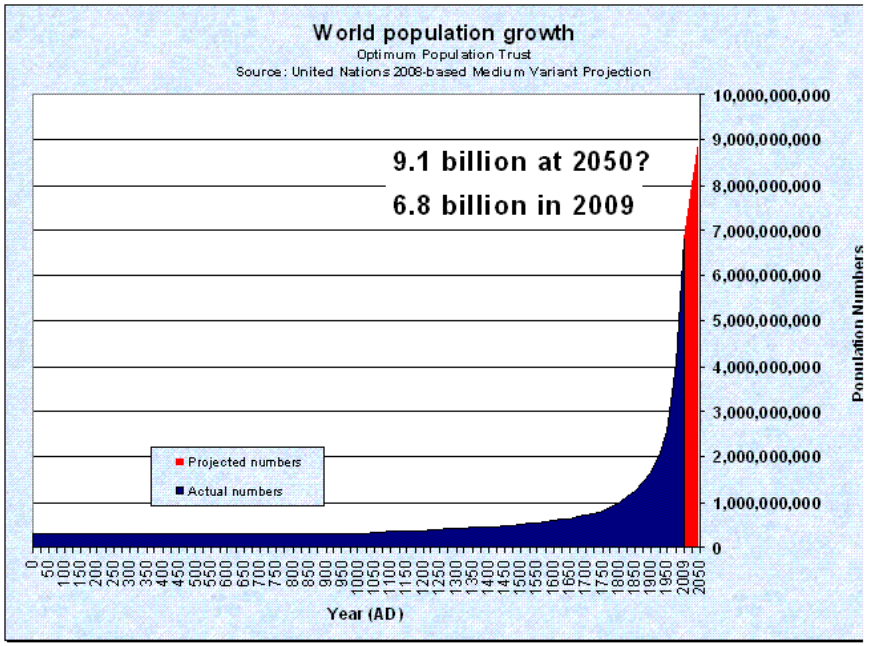


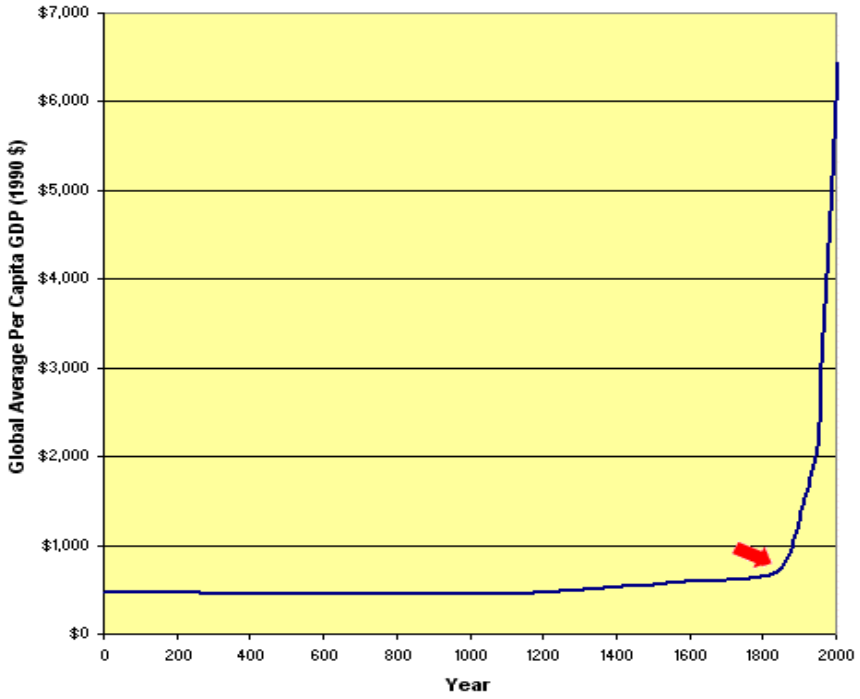
“Empty World” Model

- Throughout most of human history, the **Human Economy** was so small relative to the **Earth System**, that it had little impact on the **Sources** and **Sinks**.
- In this scenario, the standard isolated economic model might have made sense.



But Population and Economic Output *per Capita* have grown, and the net impact is their product!

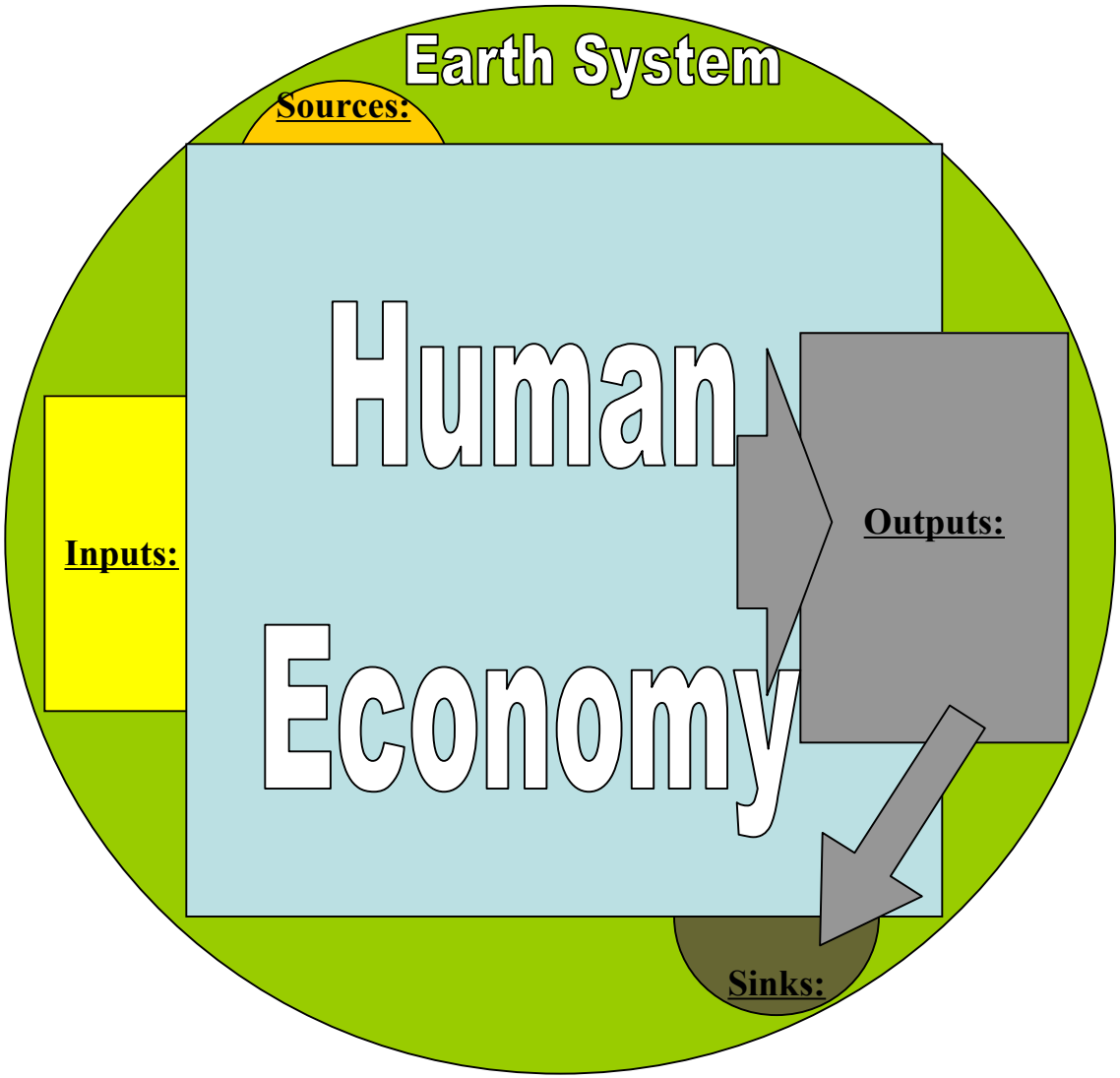




Technology allows more efficient production, but also much faster consumption!

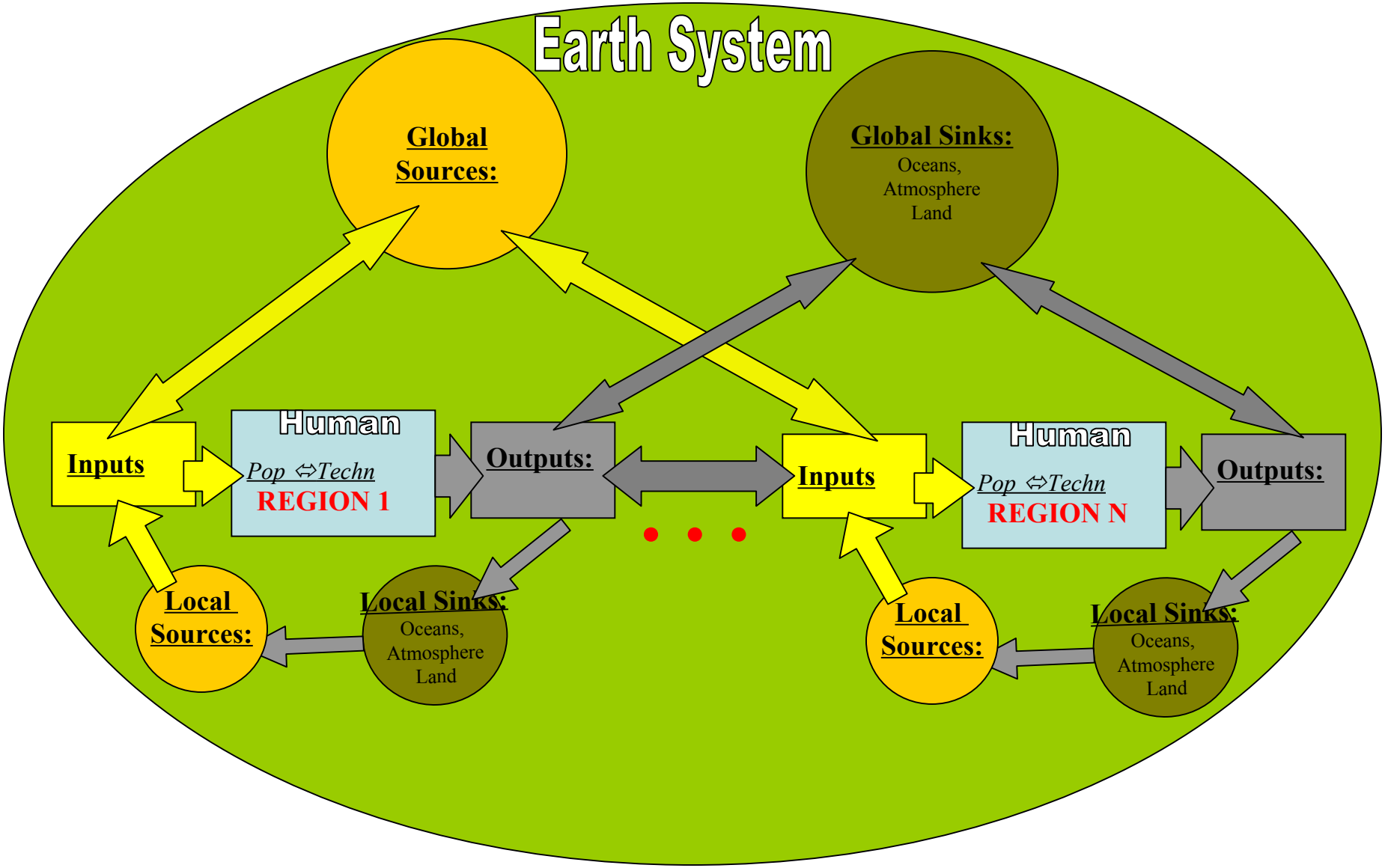
“Full World” Ecological Economic Model

- Today, the **Human Economy** has grown so large, it has very large **Effects** on the **Earth System**, ***Depleting*** the **Sources** and ***Filling*** the **Sinks**. It is clear that ***growth cannot continue forever***.



Regional Population Models

with two-way coupling is needed!

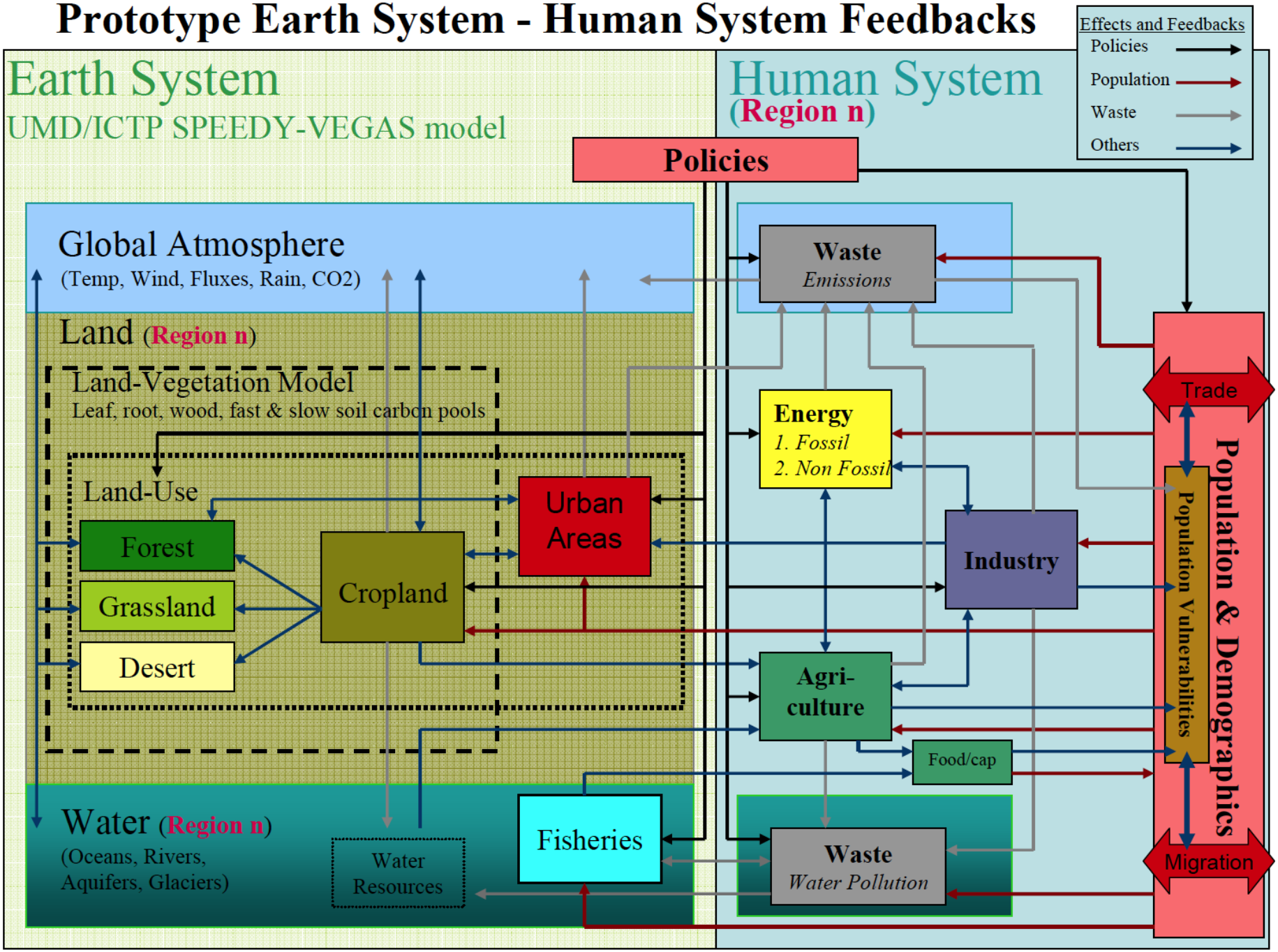


Some of the Essential Feedbacks needed

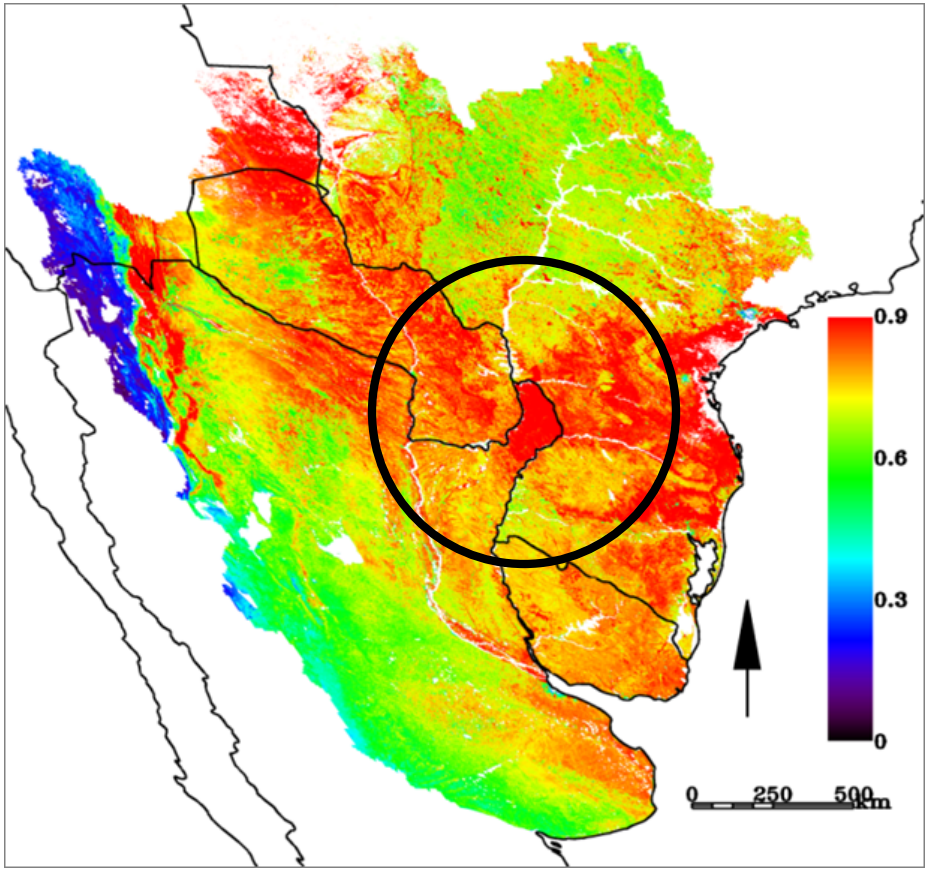
- Vegetation <=> albedo (climate change)
- CO2 emissions <=> climate change <=> vegetation
- Vegetation <=> water use, fossil fuel use <=> crops
- Population <=> crops, food/capita <=> mortality
- Population <=> food/capita <=> fisheries
- Population <=> CO2 emission, pollution <=> atmosphere, land
- Population <=> urban sprawl <=> loss of cultivated land
- Technology <=> non-renewable resources <=> alternative resources
- Policies <=> education, birth rate <=> pollution, emissions
- Resource depletion <=> trade, resource conflicts
- Population <=> CO2 emissions <=> climate change <=> vulnerability

We proposed to experiment first using an intermediate Earth System model (Speedy-VEGAS) and a prototype Human-Economy-Population model.

Prototype Earth System - Human System Feedbacks

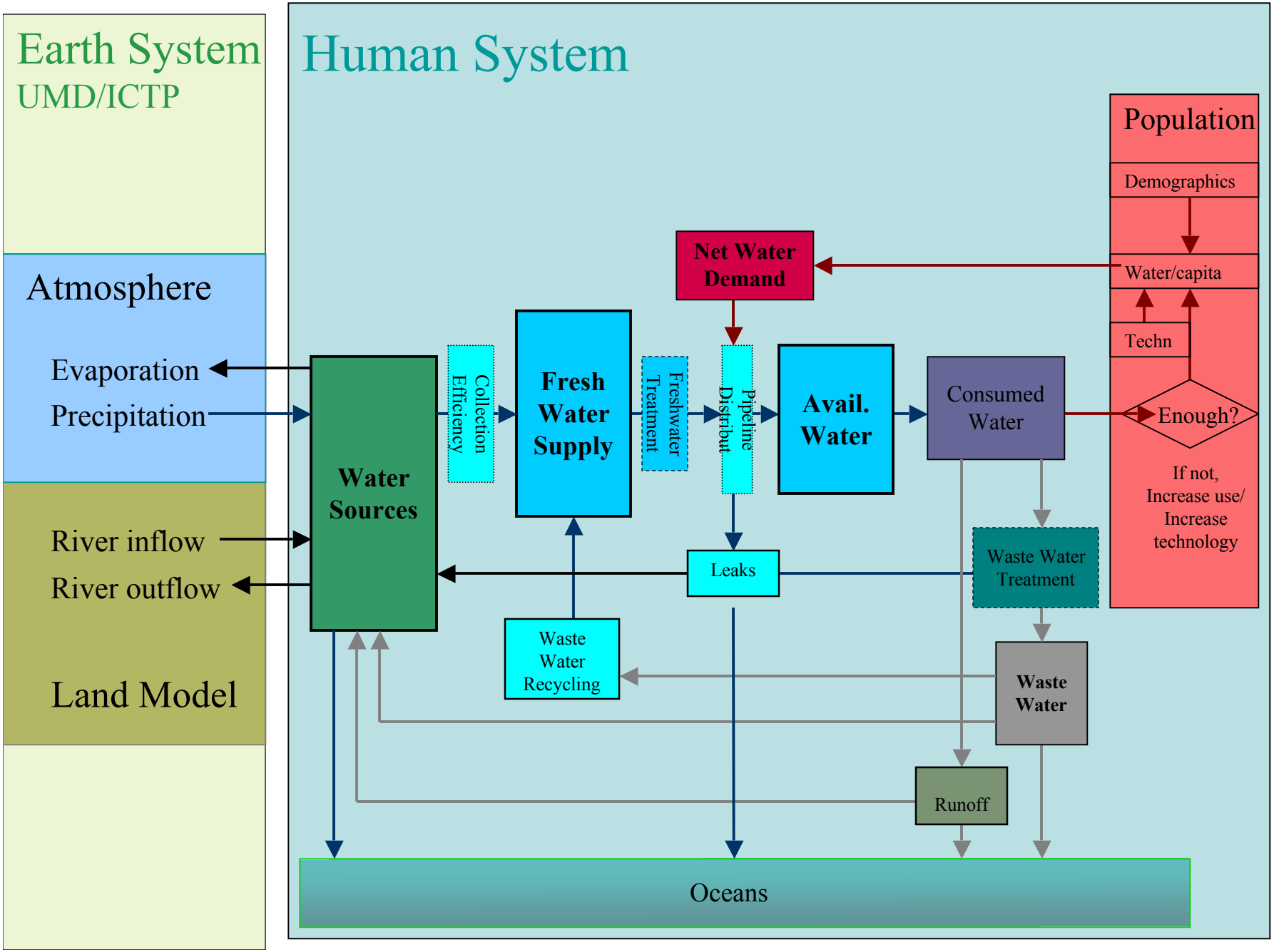


Government policies are important!



The red (highest NDVI vegetation index) is in the province of Misiones, Argentina, that protects the forest.
Compare Misiones with Brazil, Paraguay and the rest of Argentina!

Coupled Simple Water Submodel (SIWA)



Human **a**nd **N**ature **Dy**namical model (HANDY) with Rich and Poor: for thought experiments

Just 4 equations!

Total population: Rich +Poor $x = x_R + x_P$

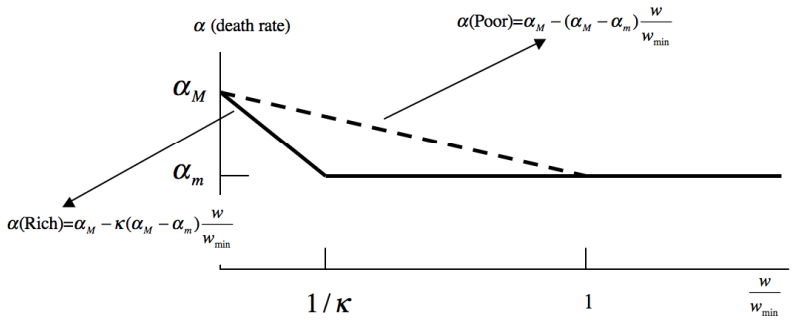
Nature equation: (only the poor produce!)

$$\dot{y} = \text{Regeneration}\,\gamma\, y(1-y) - \text{Production}\,\delta x_P y$$

The Wealth belongs to the Rich: Inequality factor $\kappa \sim 100$

$$\dot{W} = \text{Production - Poor consumption - Rich consumption} = \delta x_p y - s x_p - \kappa s x_R$$

Population equations: death rate depends on whether there is enough food:

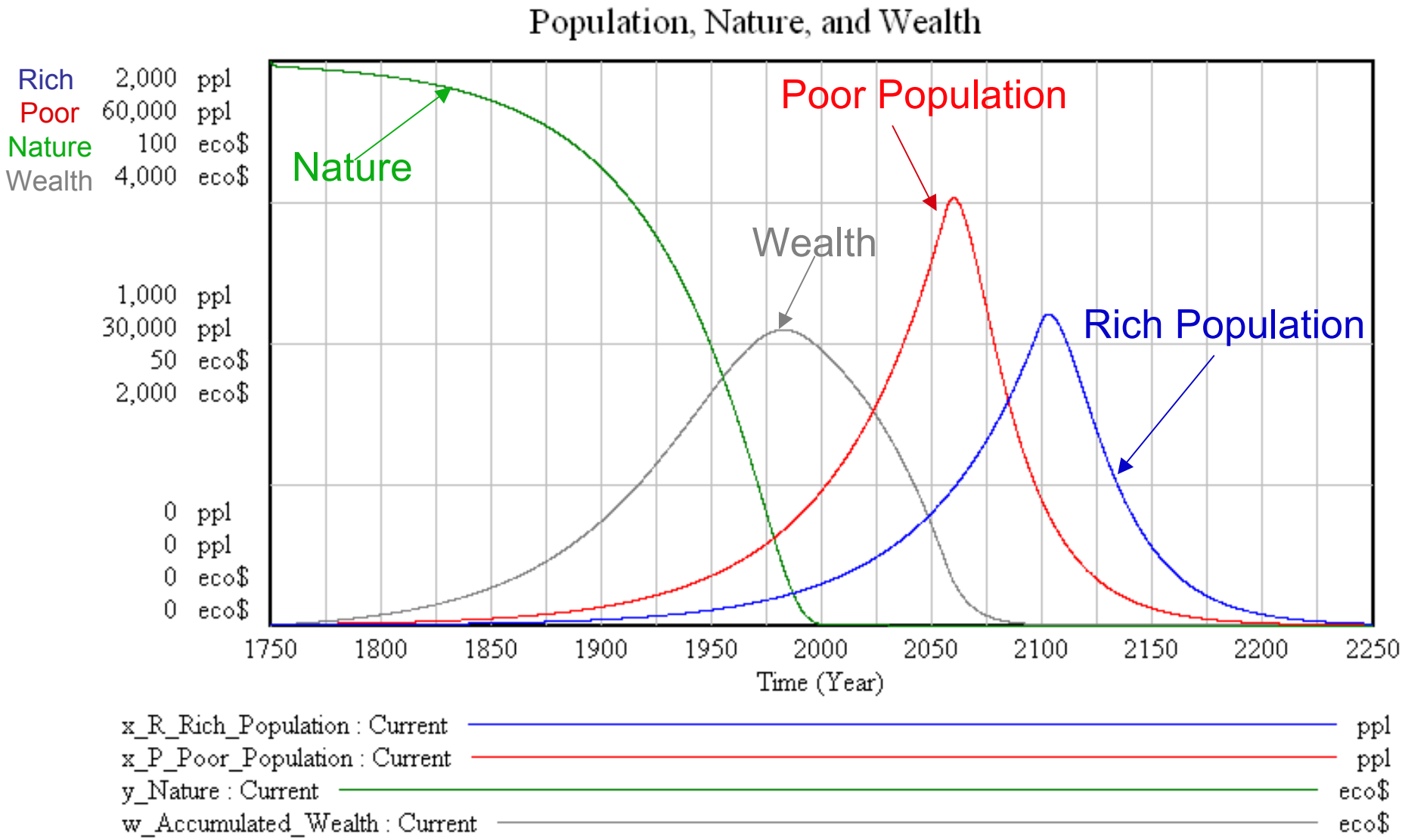


$$\dot{x}_P = -\alpha_P x_P + \beta_P x_P$$

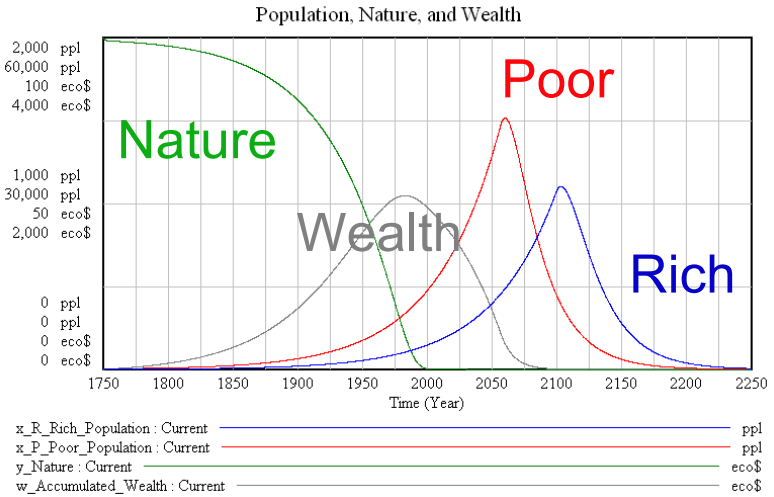
$$\dot{x}_R = -\alpha_R x_R + \beta_R x_R$$

The **rich elite** accumulates wealth from the work of everyone else (here referred to as the **poor**). When there is a crisis (e.g., famine) the elite can spend the accumulated wealth to buy food.

Human **a**nd **N**ature **Dy**namical model (HANDY) with Rich and Poor: a thought experiment



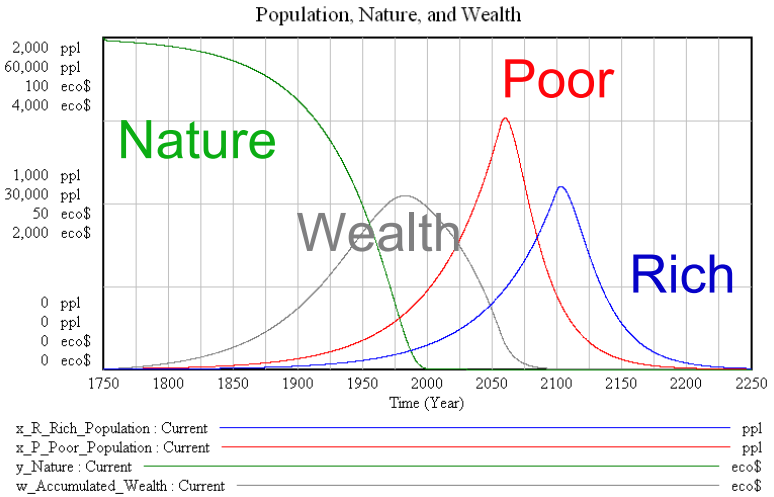
Human **a**nd **N**ature **Dy**namical model (HANDY) with Rich and Poor: a thought experiment



- Nature declines with population growth
- Using their wealth, the Rich can shield themselves from environmental degradation, which first affects the poor
- Eventually it reaches the upper classes as well, when it is too late to take preventive measures

By the end of the 20th century, having surpassed the sustainable carrying capacity of the planet, the population is drawing down the accumulated capital to survive

Human **a**nd **N**ature **Dy**namical model (HANDY) with Rich and Poor: a thought experiment



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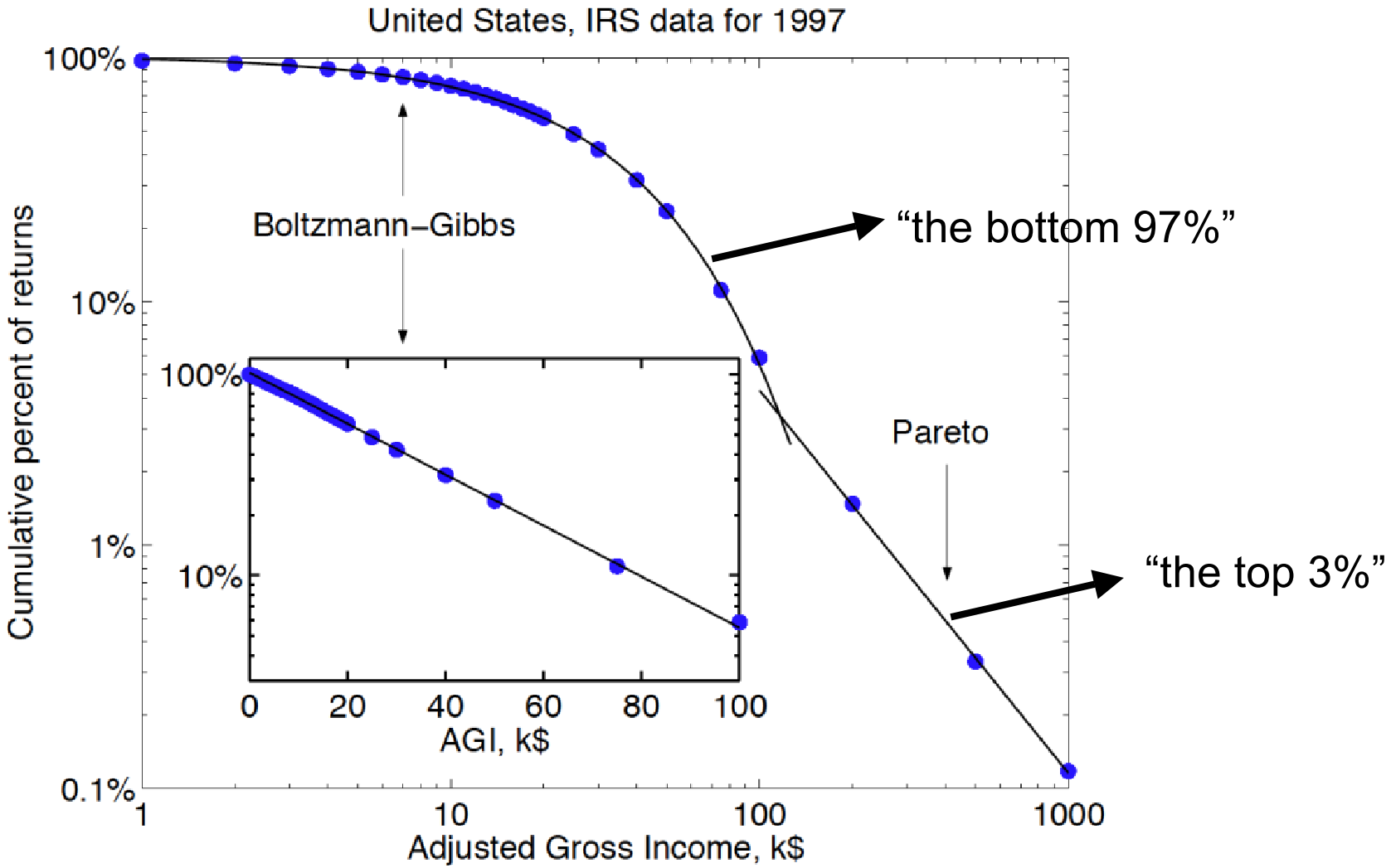
This thought experiment shows how a crisis can happen rapidly, even though it appears that population is rising steadily without any problems, and that the wealthy would not feel the effects of the collapse until it is too late for the poor (and then it is too late for the rich as well!).

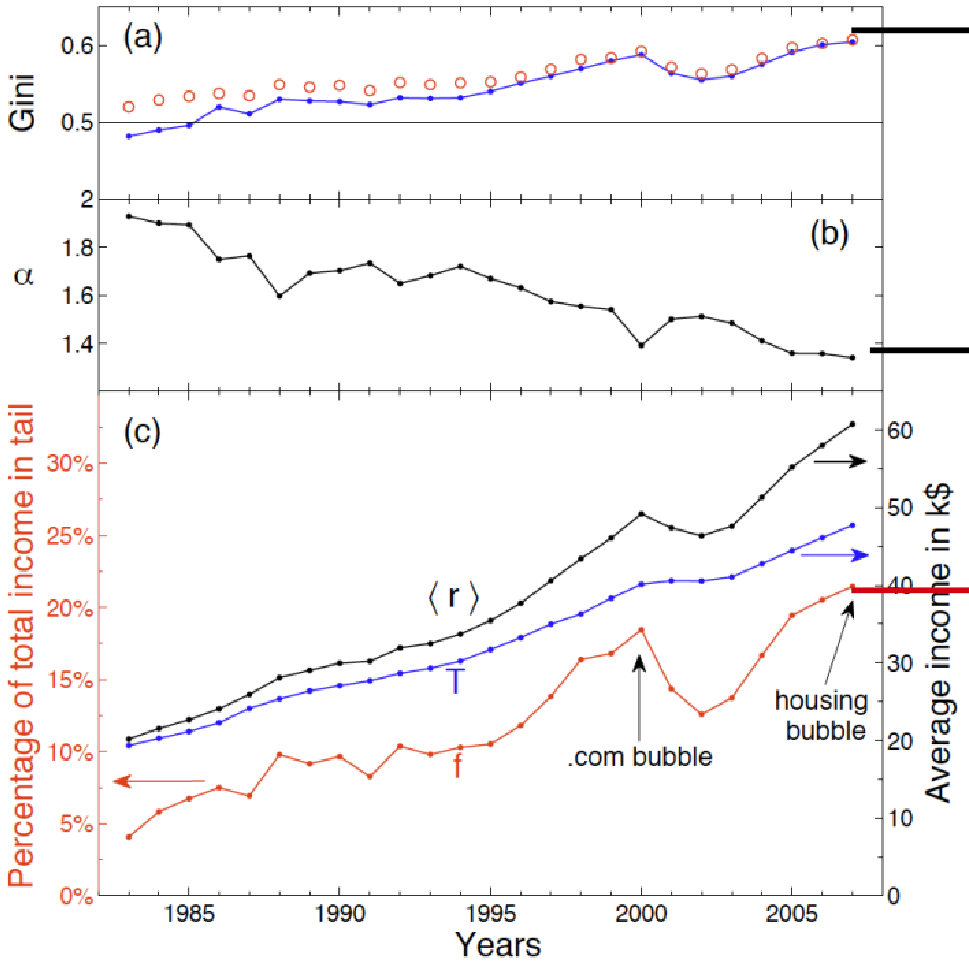
Analogy between atomic distribution of energy and the distribution of income (Yakovenko et al., 2000, …)

- Atoms in a gas are identical, but the probability distribution $P(E)$ of their energies E is highly unequal, with few atoms having high energies and many atoms having low energies.
- In statistical physics, $P(E)$ is given by the exponential Boltzmann-Gibbs distribution following from maximization of entropy in the ensemble of interacting atoms.
- Yakovenko applied a similar probabilistic approach to ensembles of interacting economic agents, with remarkable agreement with IRS data

Yakovenko (2000) applied a similar probabilistic approach to ensembles of interacting economic agents and obtained probability distributions that are in remarkable agreement with the empirical data



An analysis between 1983 and 2003 of IRS data shows that the inequality increased and all the growth went to the top 3%



Gini coefficient of inequality (increases)

Exponent of the Pareto distribution

Percentage of total income in the “rich tail”

Our plans

- Continue developing the submodels of the Prototype Human system and fully coupling with the Earth System.
- Post the codes…
- Couple the Yakovenko statistical model with the HANDY model first, replacing the Rich/Poor classes with realistic continuum wealth distributions.
- Apply the same statistical analysis to the full prototype coupled system.
- Welcome multidisciplinary collaborations!

Thanks…, we welcome your feedback