

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

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with
Harald Rybka and Jason Wong

AOSC Seminar, 2 September 2010

My research at the U. of Maryland

- 1) Data assimilation, Ensemble Kalman Filter and the LETKF, CO2, AIRS data and Mars data assimilation
 - 2) Impact of land use and land-use change on climate (Observations minus Reanalysis): over the last 30 years, changes of land cover have significantly increased surface temperature: “Green is cool”.
-

But today I will talk about something very different:

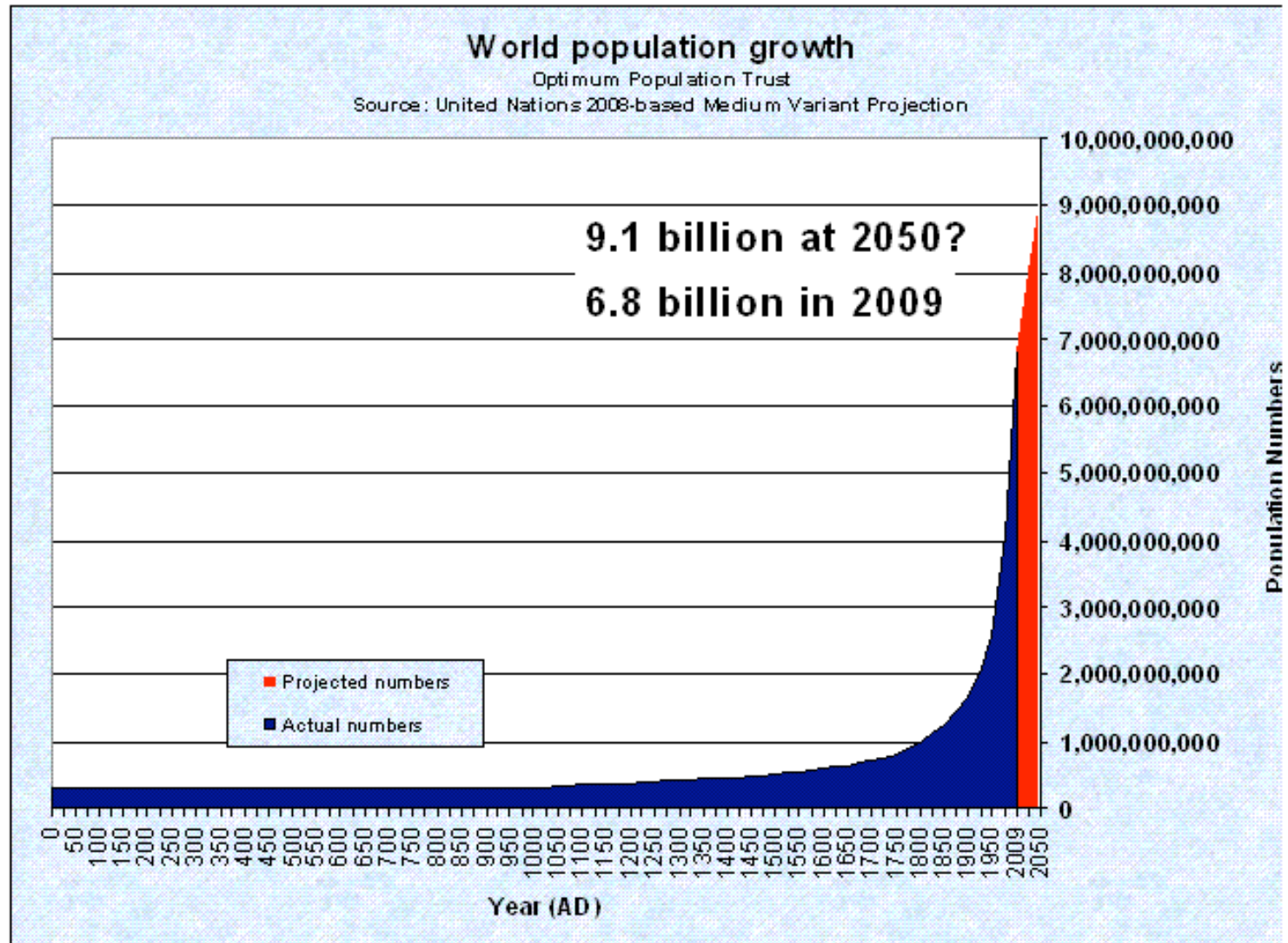
“Population and Climate Change:

A Proposal to Couple Population and Earth System Models”

Harald Rybka, a German RISE intern, will talk about the first steps he completed with the population model

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

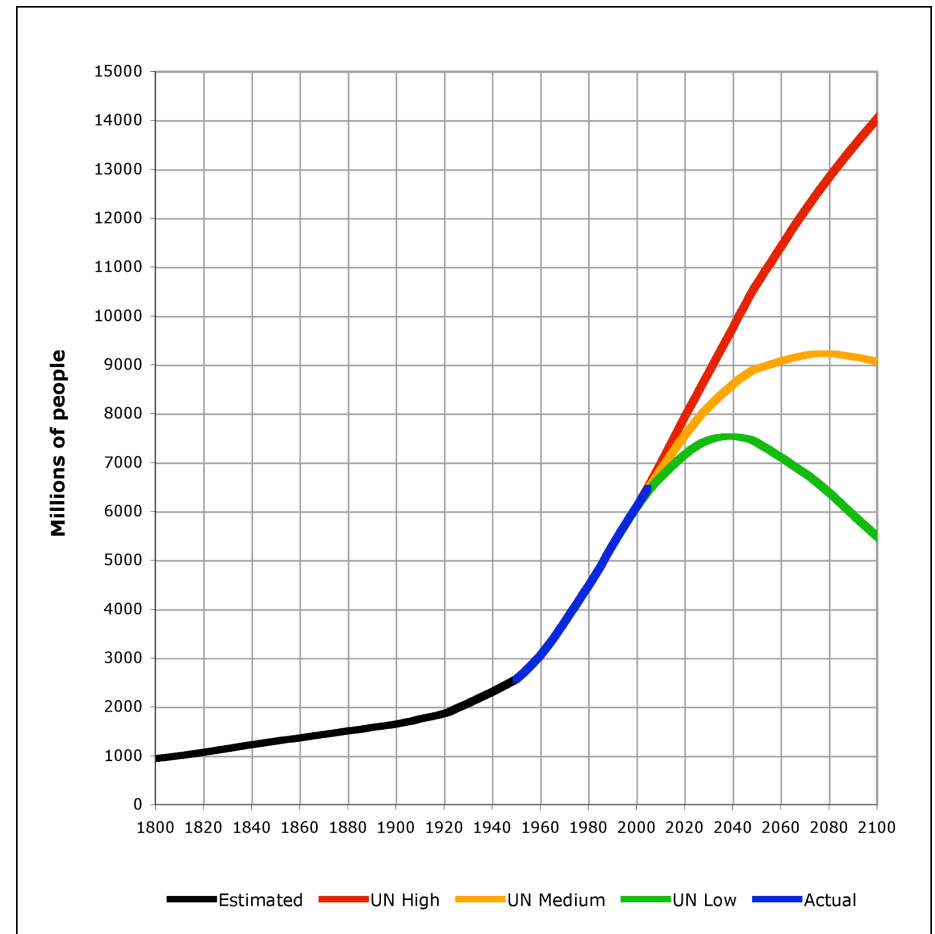
Per dollar spent,

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**

UK Royal Soc: **New population study underway!**



Population growth affects every environmental challenge we face:

- Generation of GHG, other pollutants and toxic waste
- **Resource depletion**: water, oil, fisheries, topsoil, etc.
- Resource wars and civil conflicts
- Malnutrition and world hunger
- Lack of resources for education and health care, especially in poor countries
- Best farmland converted to urban and suburban sprawl
- Garbage disposal and need to find more landfill space
- Species extinction...

**Feedbacks between coupled human and natural systems exhibit nonlinear dynamics, time lags,..., and surprises...
(Liu,..., Lubchenko,...Science, 2010)**

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

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

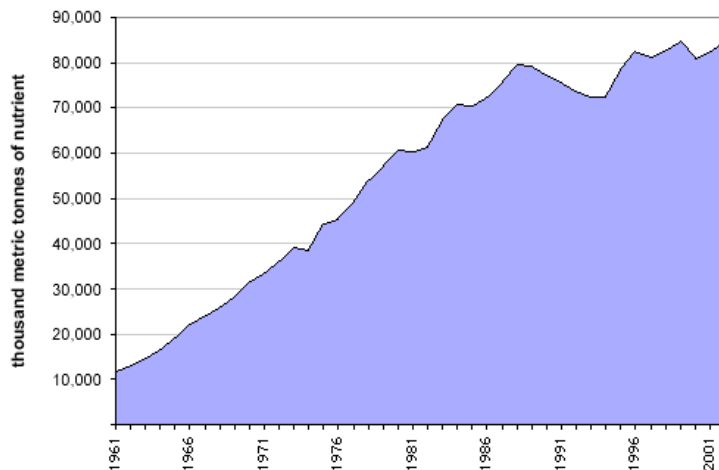
Without fossil fuels population would be much smaller!

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

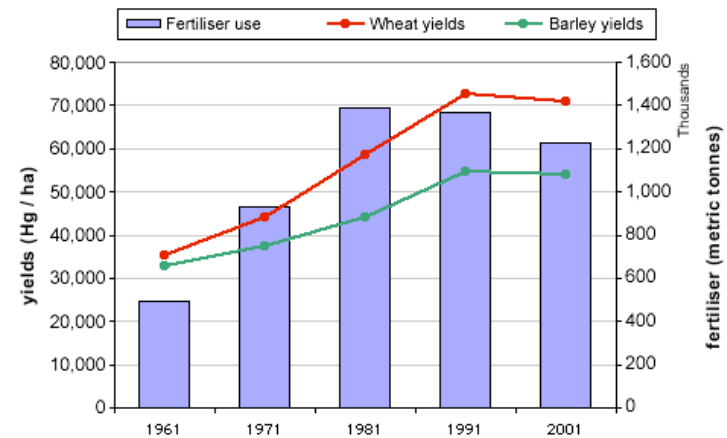
Is this population sustainable?

We spend orders of magnitude more calories to grow food than the calories we get from it!!!

This is only possible because **we are using non-renewable resources**. Herman Daly (UMD, founder of Ecological Economics): “We are drawing down the stock of natural capital as if it was infinite”

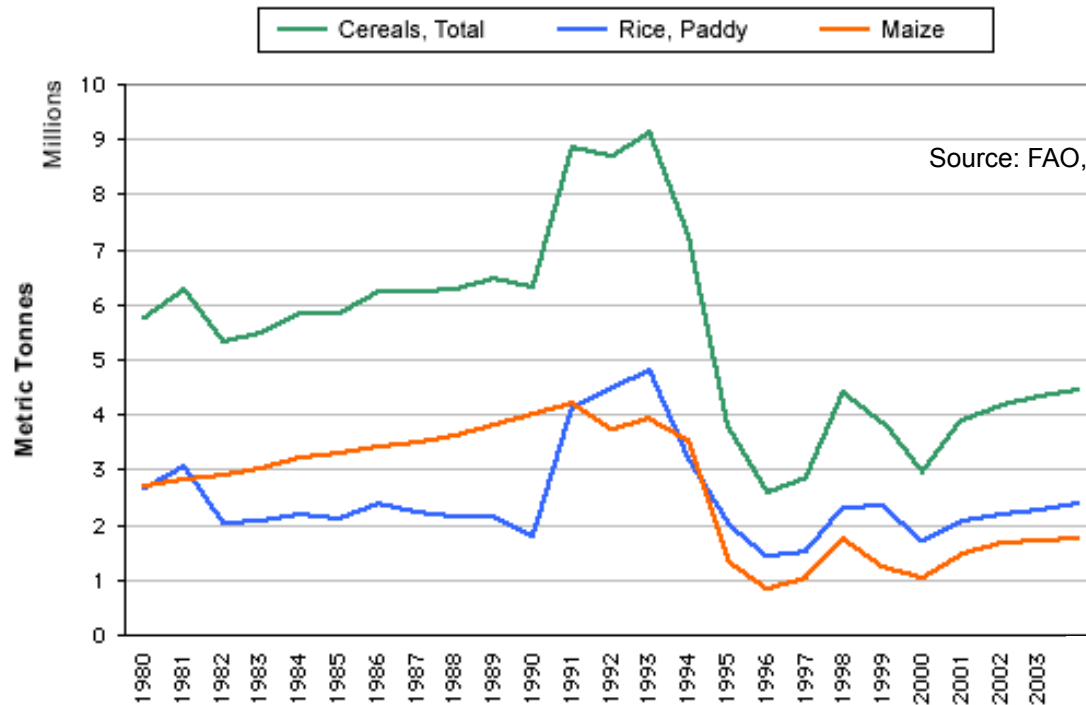


Fertilizer Use (Nitrogenous) - World (FAO)



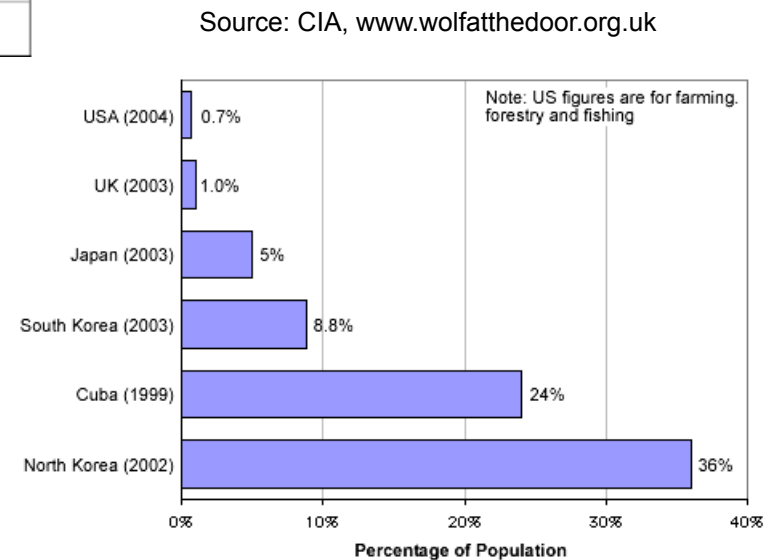
Fertilizer use and crop yields (UK)

Example: North Korea, got cheap oil from the former Soviet Union until it collapsed in 1990



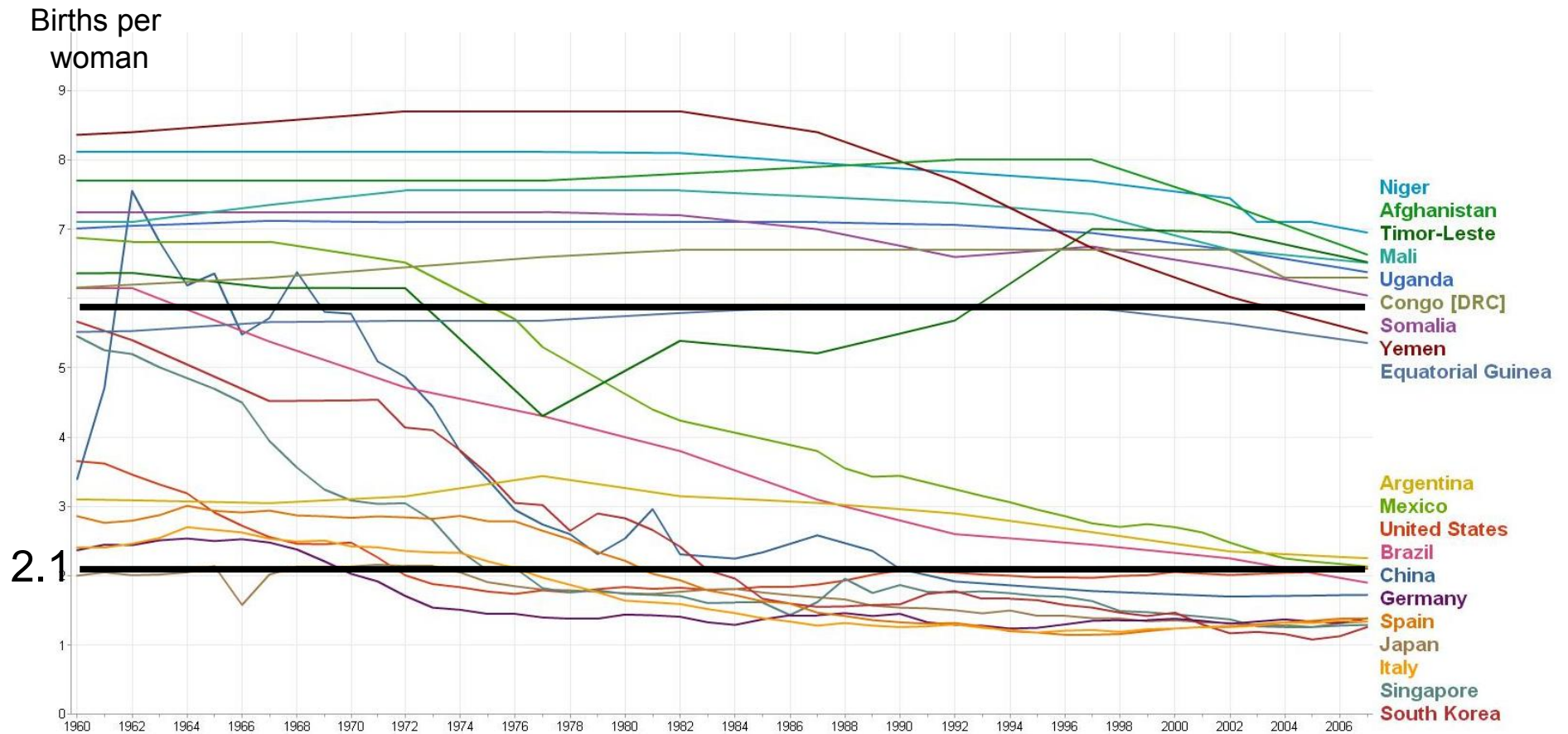
Production of grain in North Korea.
Also, without oil, they burn biomass, increasing loss of soil.

Percentage of workers in the agricultural sector



Births per woman

There are many countries that are still at the level of 6 or more births per woman. Many countries are close to or below replacement level. China is at 1.7 b/w



Data source: World Bank, World Development Indicators - Last updated November 20, 2009

Are we past the problem of population growth?

Conventional wisdom is that population growth is **no longer a problem** because the rate of growth is going down

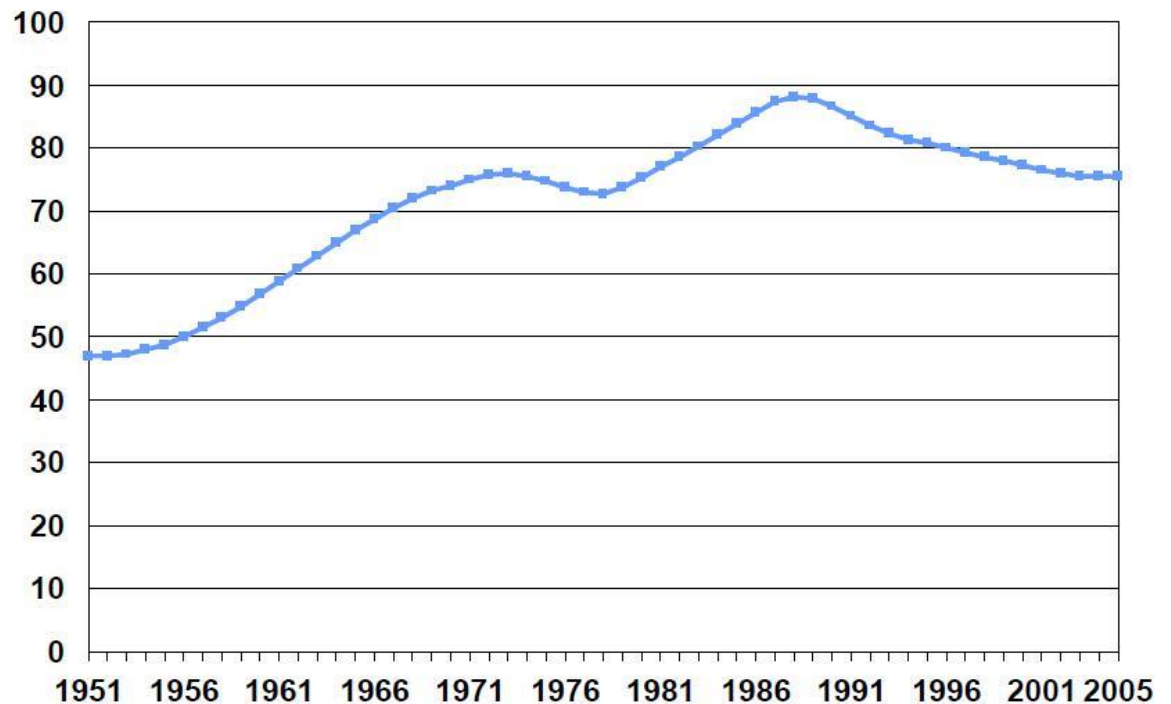
The **population explosion** took place in the second half of the 20th century.

Although **the rate of growth is going down**, in absolute terms we are still adding about **75m every year**.

This is more than during most of the population explosion period!

Annual Increase in World Population

Millions



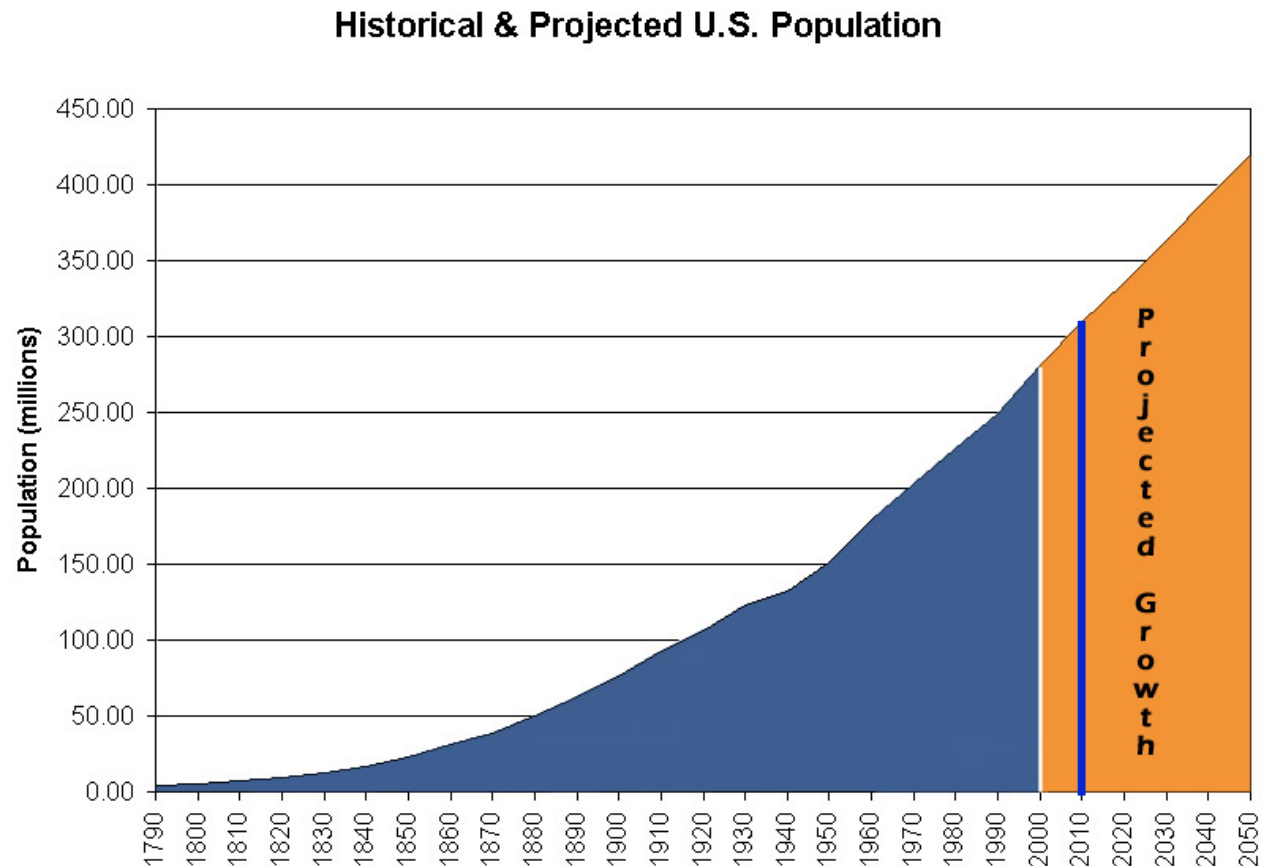
Still growing...

Most population growth takes place in underdeveloped countries, but

Some developed countries are still growing fast:

UK grew more in 2008 than in the previous 50 years despite lower immigration

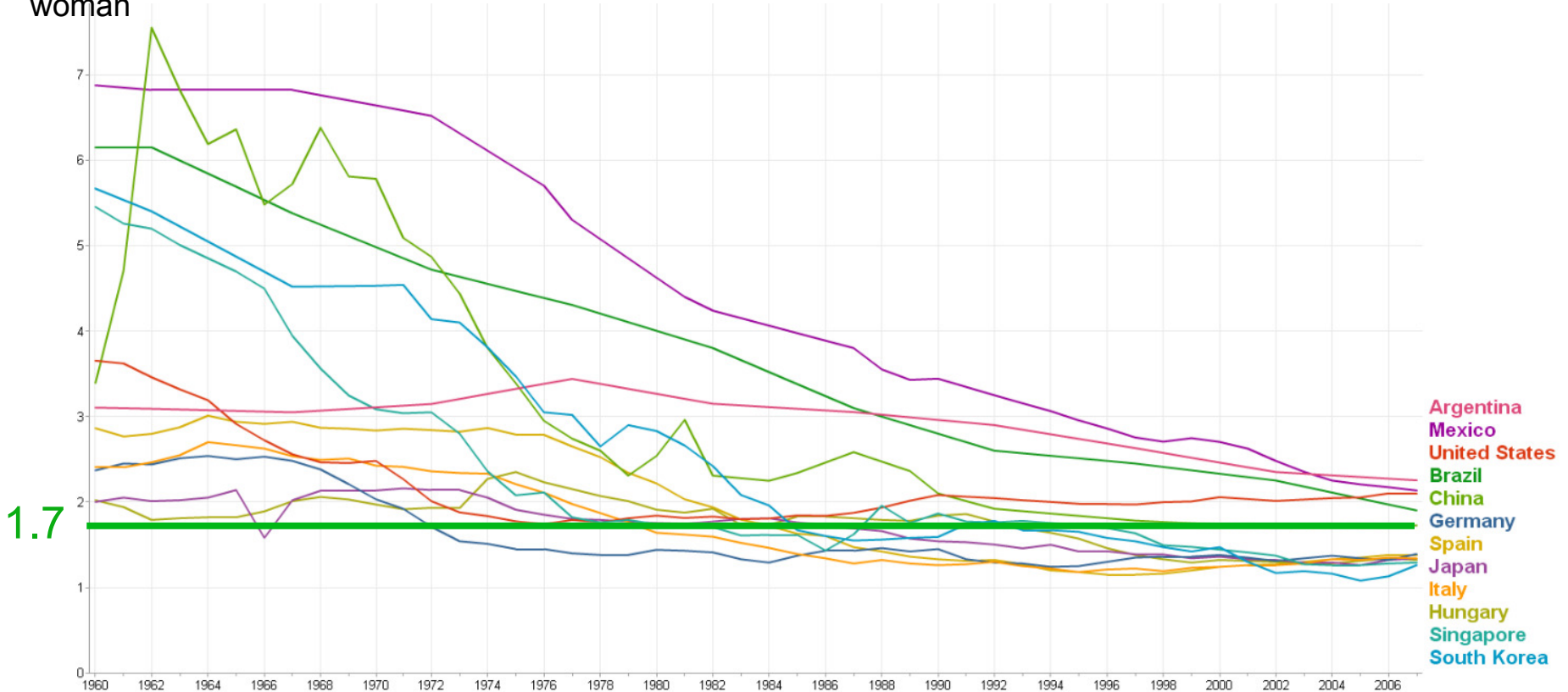
US fertility rate is increasing: 1.7 in the 1970s, now it is 2.13.



The good news!

~40 countries (Canada, most of Europe, South Korea, Taiwan, Cyprus, etc.) have reached a birth/woman rate

Births per woman **lower than China's 1.7 without coercive measures!**



Data source: [World Bank, World Development Indicators](#) - Last updated November 20, 2009

What about human rights?

When people think of reducing population growth, they think of **coercive** measures: the one-child target in China, forced sterilizations in India.

This misses the fact that ***most women are forced to have more children than they want.***

It is a human rights issue indeed but in the **opposite** direction. International UN polls show in many countries more than 80% of married women of reproductive age with 2 children, do **not** want to have more children.

A nurse I know was asked by a Somali patient why she had no children, and she responded she had not wanted any yet. The response of the Somali woman was: “Wow! You are so lucky to have that choice. I have 6 children already and I have no choice in the matter. I wish I had that choice!”.

Non-coercive methods to reduce growth

The UN estimates that 40% of all pregnancies worldwide are **unintended**. Just helping women to avoid unintended pregnancies would have a huge impact.

Non-coercive ways to drastically reduce fertility:

- **Education,**
- **access to birth-control** and
- **equal economic opportunity for women**

Population control is both feasible and effective.

In stark terms,

if every woman of bearing age had only one child,
the population would be reduced to a level
between 1 and 2 billions in about 150 years.

**Supportive government policies (national and
international) to empower women are
essential for reducing growth.**

What about the economics of reducing population?

We hear a lot about the dire problems that reducing the population will bring... Let's look at the evidence:

China has had the strictest population control policies since the 1970's: b/w went down from more than 6 to 1.7. It is estimated that 300-400 million births have been avoided (more than the population of the US!)

At the same time China has had **the highest rate ever of sustained economic growth in the human history.**

Similarly Japan, South Korea, Taiwan have had extremely high sustained economic growth with lower birth rates.

A counter example is the Philippines, with higher population growth and lower economic growth.

Will we face a shortage of workers?

We are repeatedly told that in Europe, Japan, the US, and China, **lower birth rates** will create a huge **demographic crisis** due to a **shortage of workers**.

However, as Dean Baker, of the Center for Economic and Policy Research, explains:

Prices reflect supply and demand. A shortage of labor means workers' wages will rise and higher wages shift the labor force from low to high productivity work. So, we may have fewer greeters at Wal-Mart, valet parking or all-night convenience stores. And dangerous or unpopular work would be mechanized.

(has this "crisis" scared you yet?)

This alleged "demographic horror story" would actually be good: today these economies suffer from **labor surpluses** and **high unemployment** rates.

1972: Club of Rome “Limits to Growth”

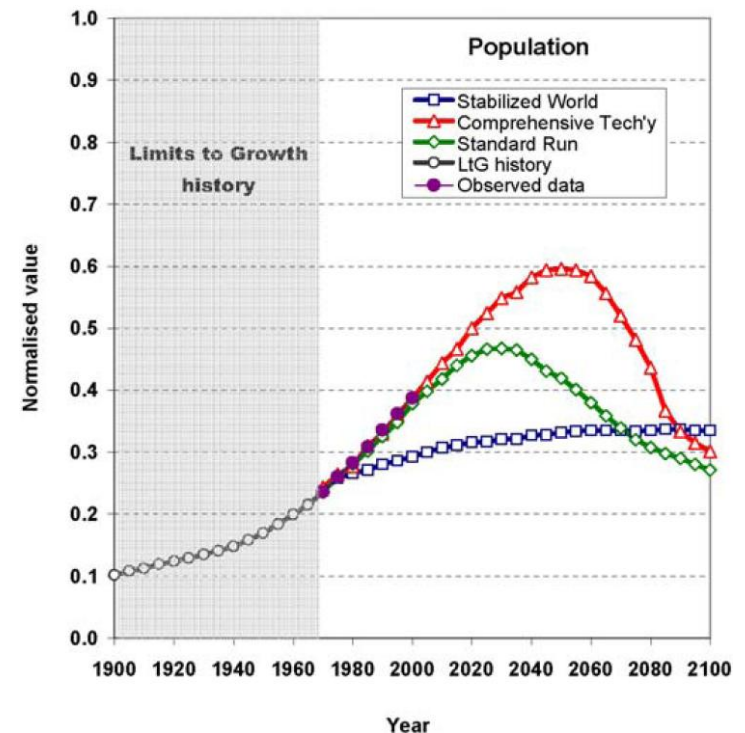
The Club of Rome commissioned a group at the MIT Sloan School of Management to study:

“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)



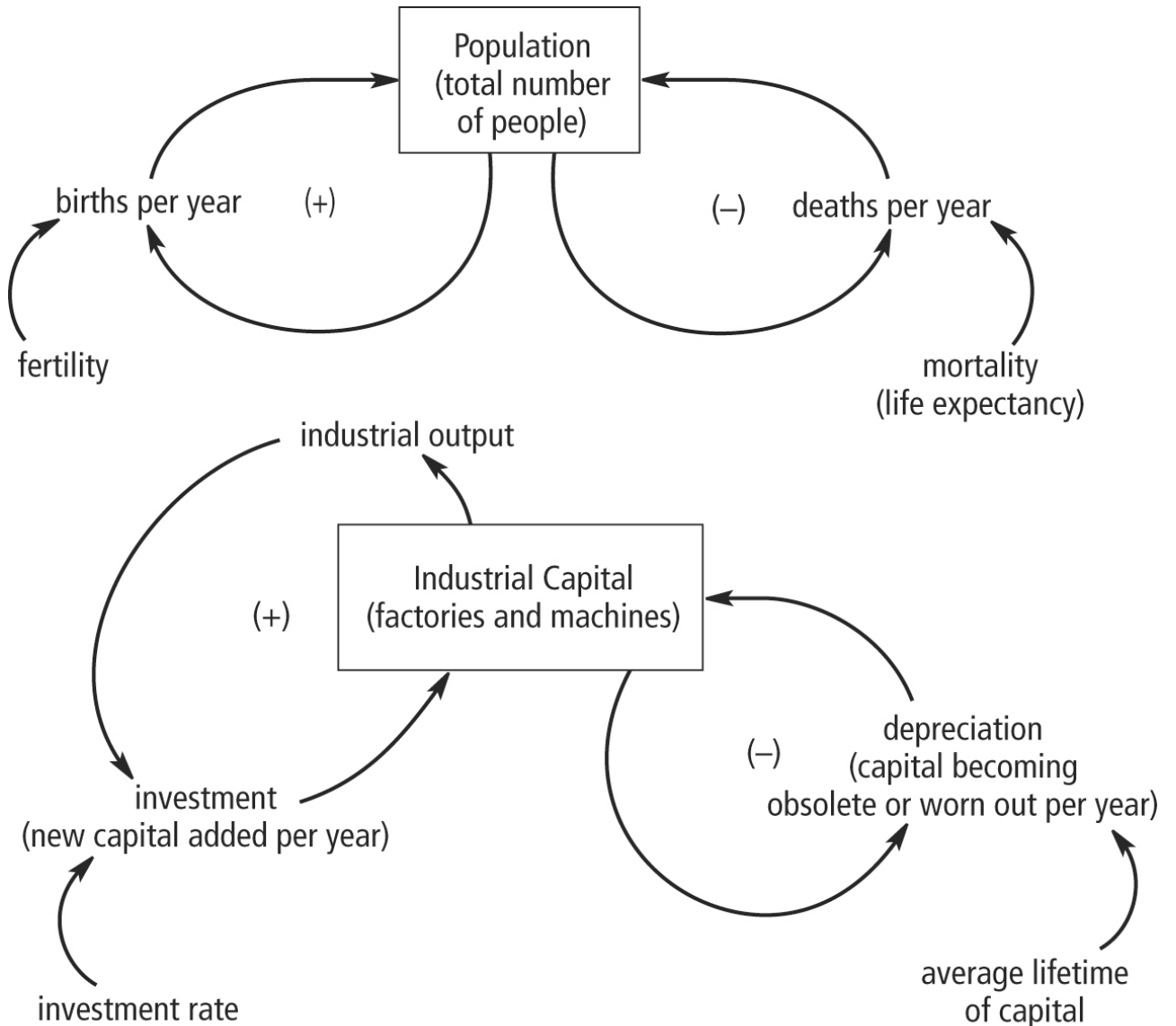
The “World3” model they used:

The model is relatively simple:

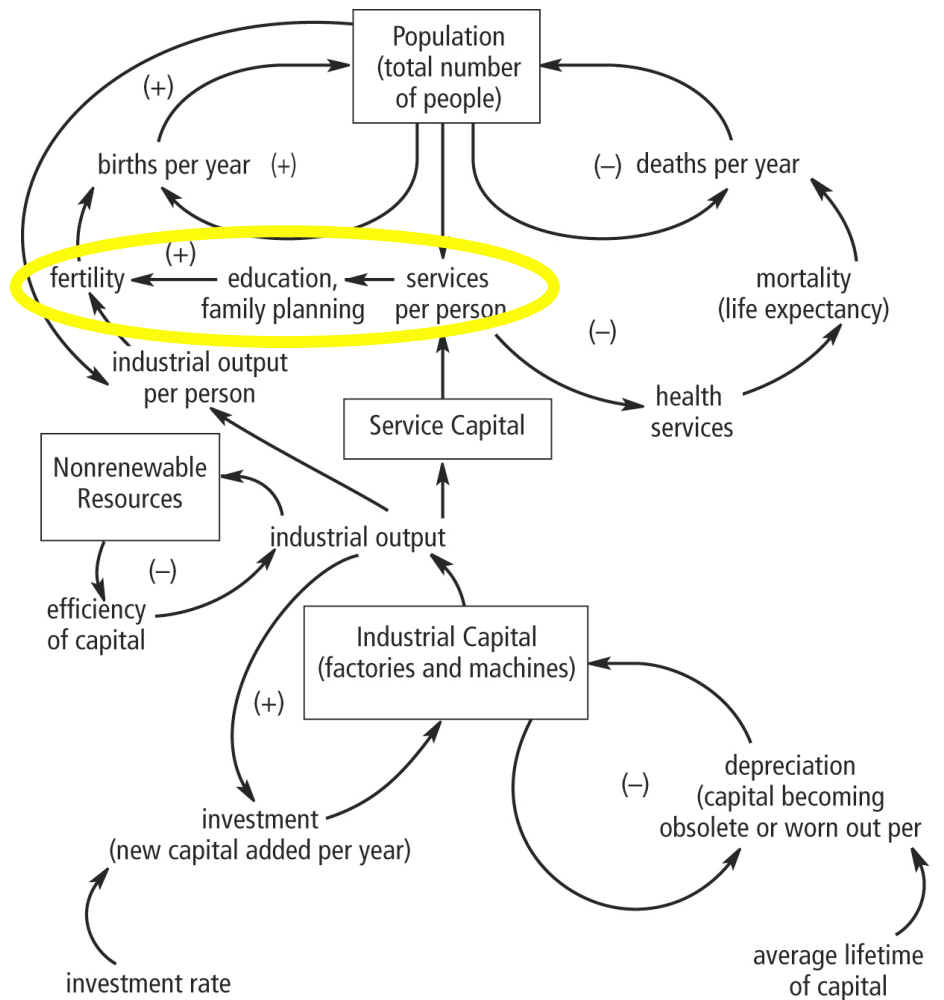
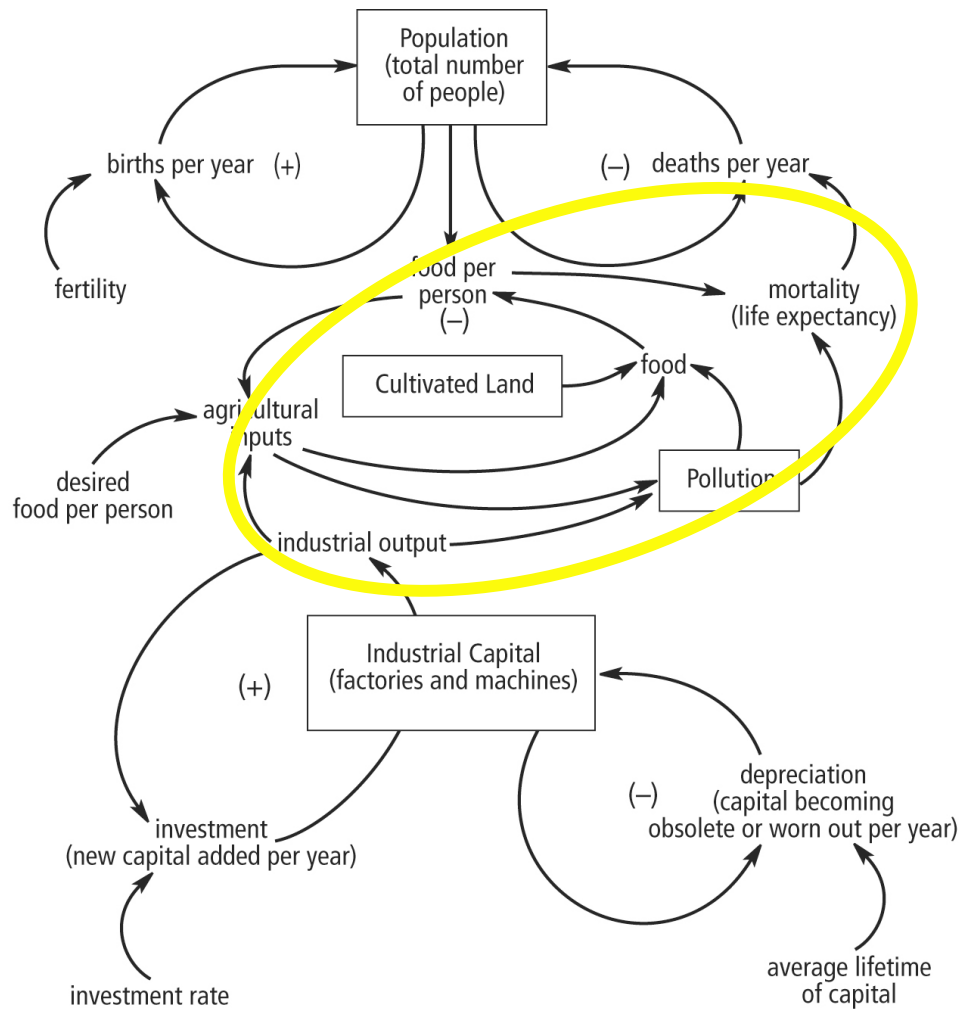
There are “stock” variables [boxes]:
population, cultivated land, industrial capital, non-renewable resources, pollution, etc.

There are interactions (arrows) with positive or negative feedbacks.

The model is then integrated from 1900 to 2100 (model tuned using 1900-1970).

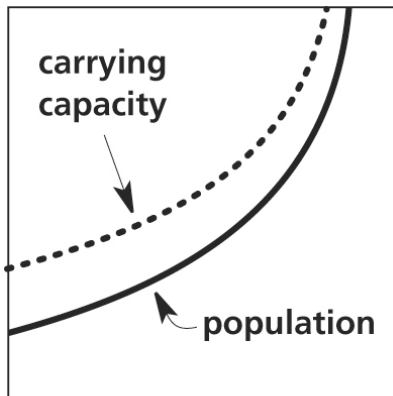


Feedbacks of Population, Capital, Agriculture and Pollution (left) and Population, Capital, Services and Resources (right)

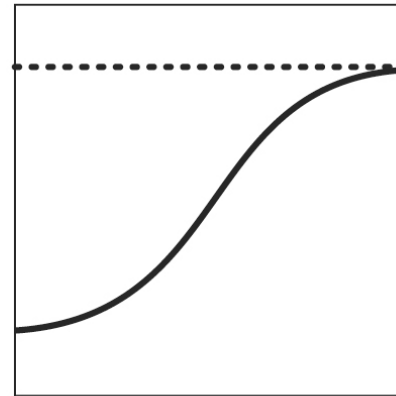


The model could have four possible types of outcomes

Infinite World



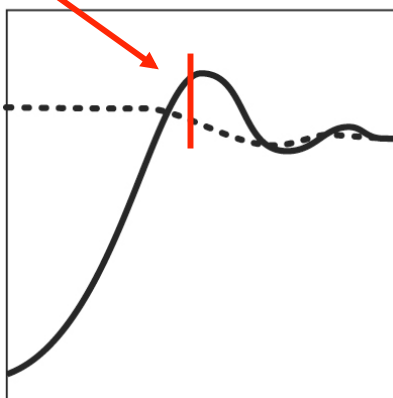
a) Continuous Growth



b) Sigmoid Approach to Equilibrium

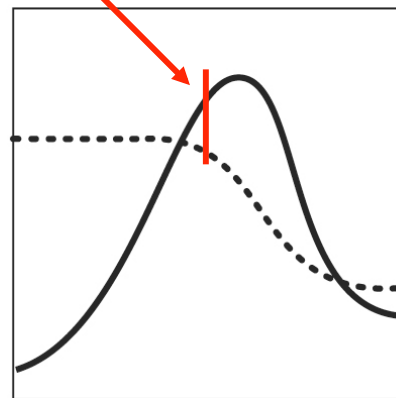
Ideal
(no overshoot)

You are here...



c) Overshoot and Oscillation

Or here...



d) Overshoot and Collapse

Disaster

Hopefully...

The results are sobering: most scenarios collapse

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

In order to **avoid collapse**
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

We proposed to develop regional population models and to **couple** them to an ESM.

The Limits to Growth model aggregates the **whole world** into a **single model**. Therefore it cannot include:

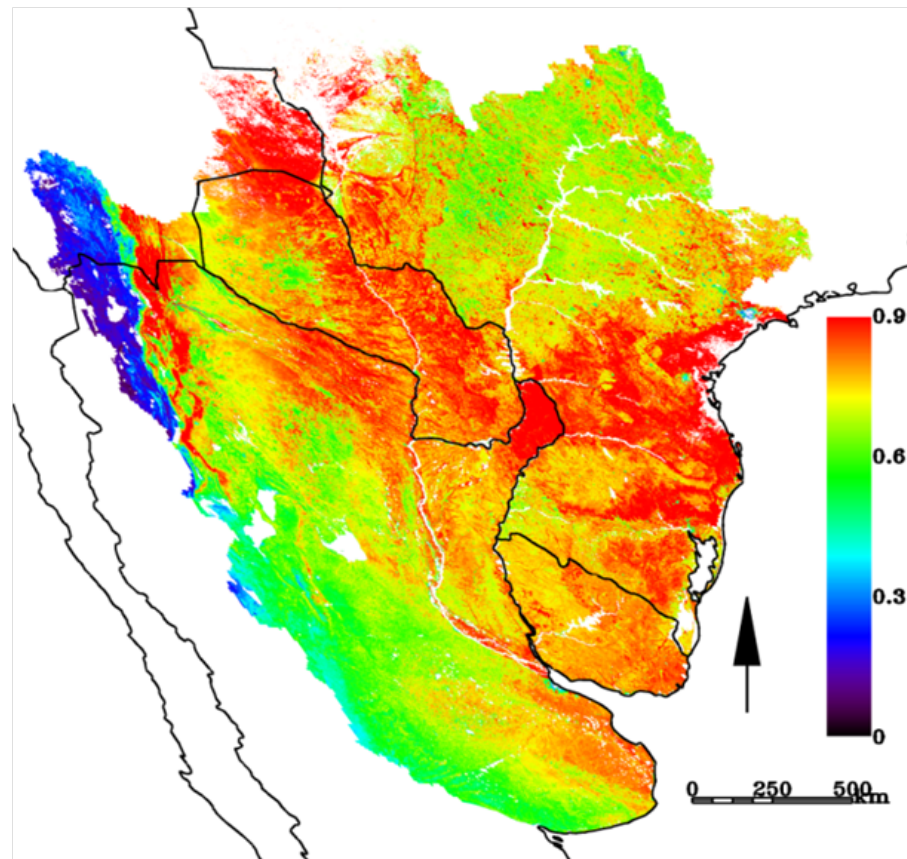
- Rich vs. poor (differential consumption rates)
- Resource wars
- International migration
- **Government policies**
- ...

To include these important factors we need to develop regional population models.

We will start with ~ 6 -10 regions, e.g., North America, South America, Africa, Europe, China, Rest of Asia

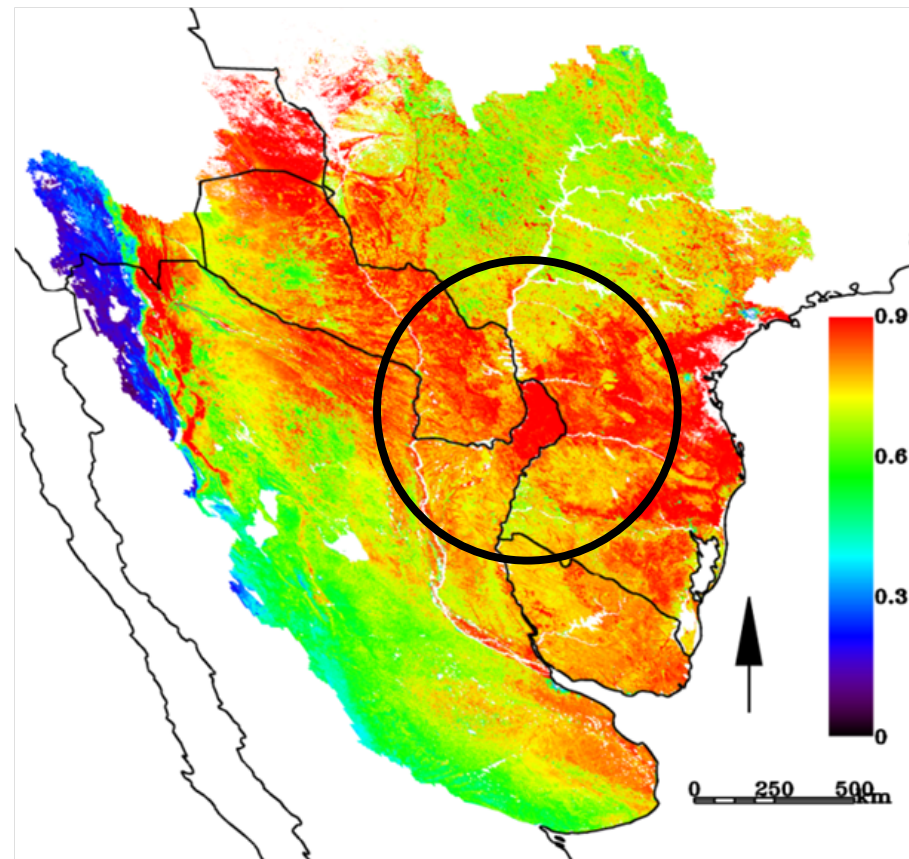
This is **computationally very feasible** (about 10 stocks and 1000 parameters per region)

Can government policies be effective?



Vegetation productivity (NDVI) in South America:
red is maximum primary (vegetation) productivity

Government policies are important!

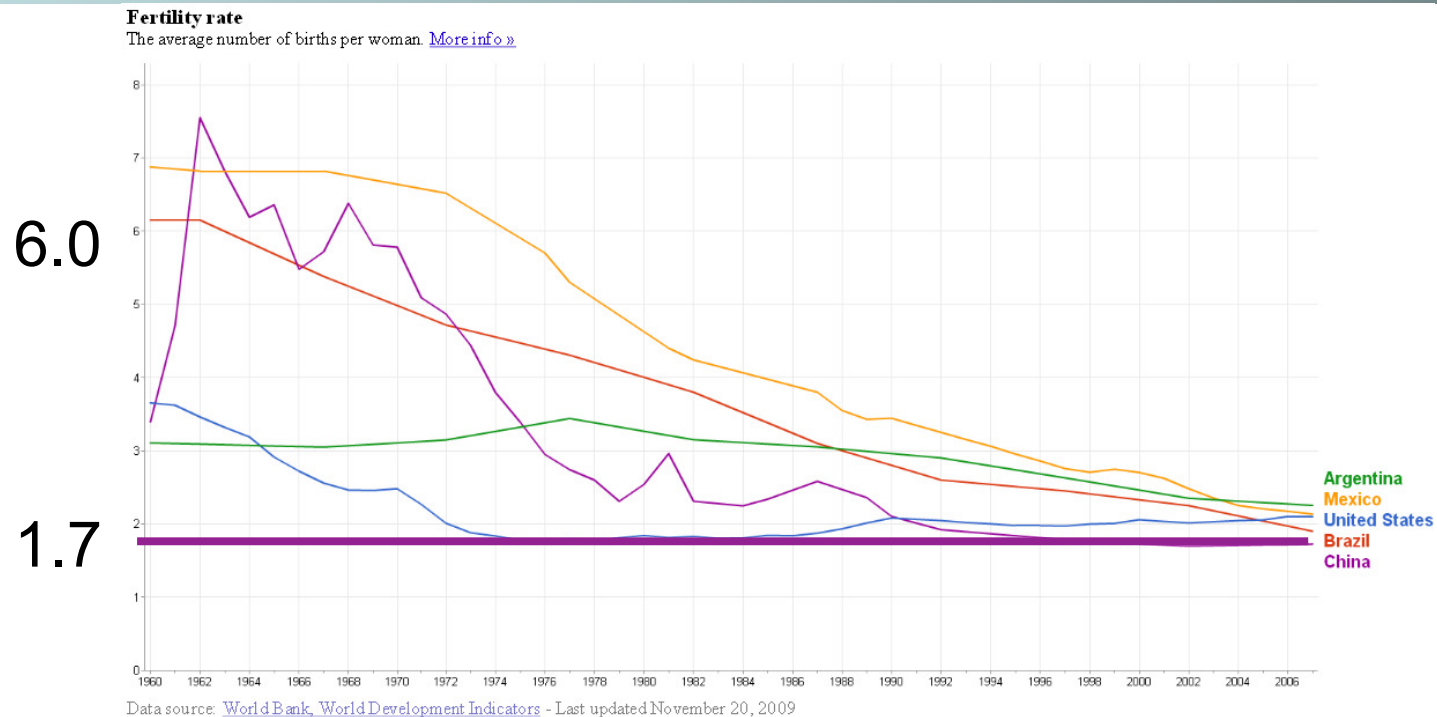


The red (highest NDVI) is in the **province of Misiones**, Argentina, that **protects the forest**. Compare Misiones with Brazil, Paraguay and the rest of Argentina!

Another example of government policies: Forest policy in Japan (Edo period)

- During the Edo period (17th and 18th centuries) the Tokugawa shoguns in Japan developed an **advanced forest management** policy.
- Increased demand for timber resources for construction, shipbuilding and fuel had led to **widespread deforestation**, which resulted in **forest fires, floods and soil erosion**.
- In response, the shogun, beginning around 1666, **instituted a policy to reduce logging and increase the planting of trees**.
- The policy mandated that only the shogun and daimyo could authorize the use of wood. By the 18th century, Japan had developed detailed scientific knowledge about silviculture and plantation forestry.
- They **stopped and reversed the deforestation** of the preceding centuries through substituting timber by other products and more efficient use of land that had been farmed for many centuries.
- **With these policies, Japan averted a deforestation collapse.**

Example: impact of government support for family planning



In the 1960's **Argentina's** fertility rate was **less than half** of **Brazil** and **Mexico**. Brazil and Mexico enacted strong policies on family planning. Argentina did not.

Brazil and Mexico have now much lower fertility rates than Argentina. Government policies matter!

Example: Kerala, a low-wealth state in India, with high social development and welfare

- **Life expectancy** in Kerala at birth is 75 years compared to 64 in India and 77 in the US (and Cuba!).
- **Literacy rate** is 91%, the highest in India, compared to India's 65%.
- Kerala's Human Development Index rating is **the highest in India**.
- How did they do it?
 - Building a **statewide infrastructure of primary health centers**, with over 2,700 government medical institutions in the state, and 330 beds per 100,000 population, the highest in India.
 - Building **a statewide infrastructure for education**:
 - More than **94% of the rural** population has access to primary school within **1 km**, 98% benefit from a facility for secondary education within 8 km.
- **With the right government policies, population growth can be reduced and quality of life increased.**

A proposal to NSF, DOE, NASA, NOAA, State Department

Call for Earth System modelers and social scientists to develop coupled scenarios for climate change with regional modules for population:

This would achieve two major goals:

- 1) Study different scenarios for world development and population policies.
- 2) Force us to look at the population problem from a scientific point of view.

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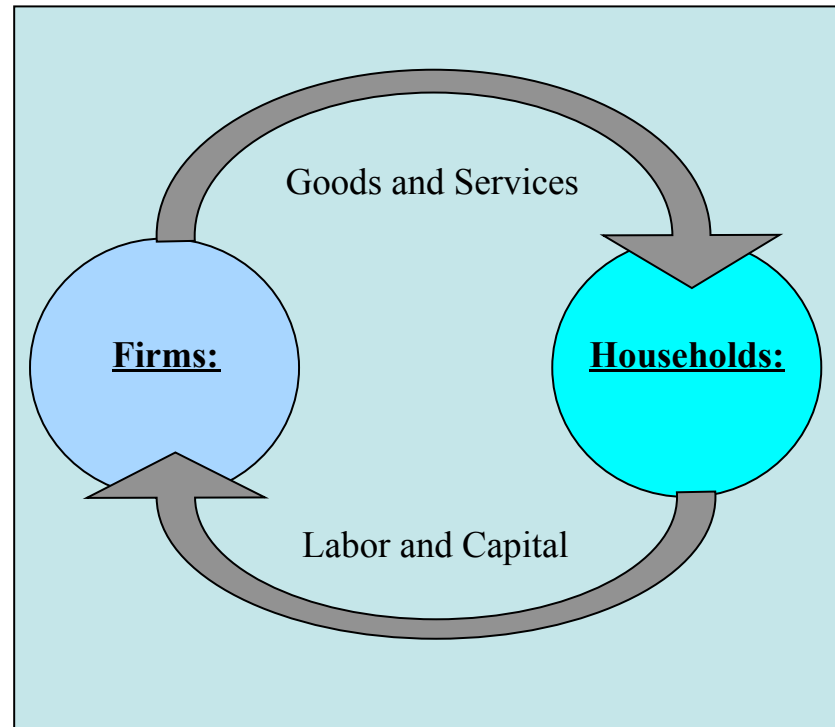
This would achieve two major goals:

- 1) Study different scenarios for world development and population policies.
- 2) Force us to look at the population problem from a scientific point of view.

It would eliminate “the elephant in the room”

Standard Neoclassical Economic Model

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



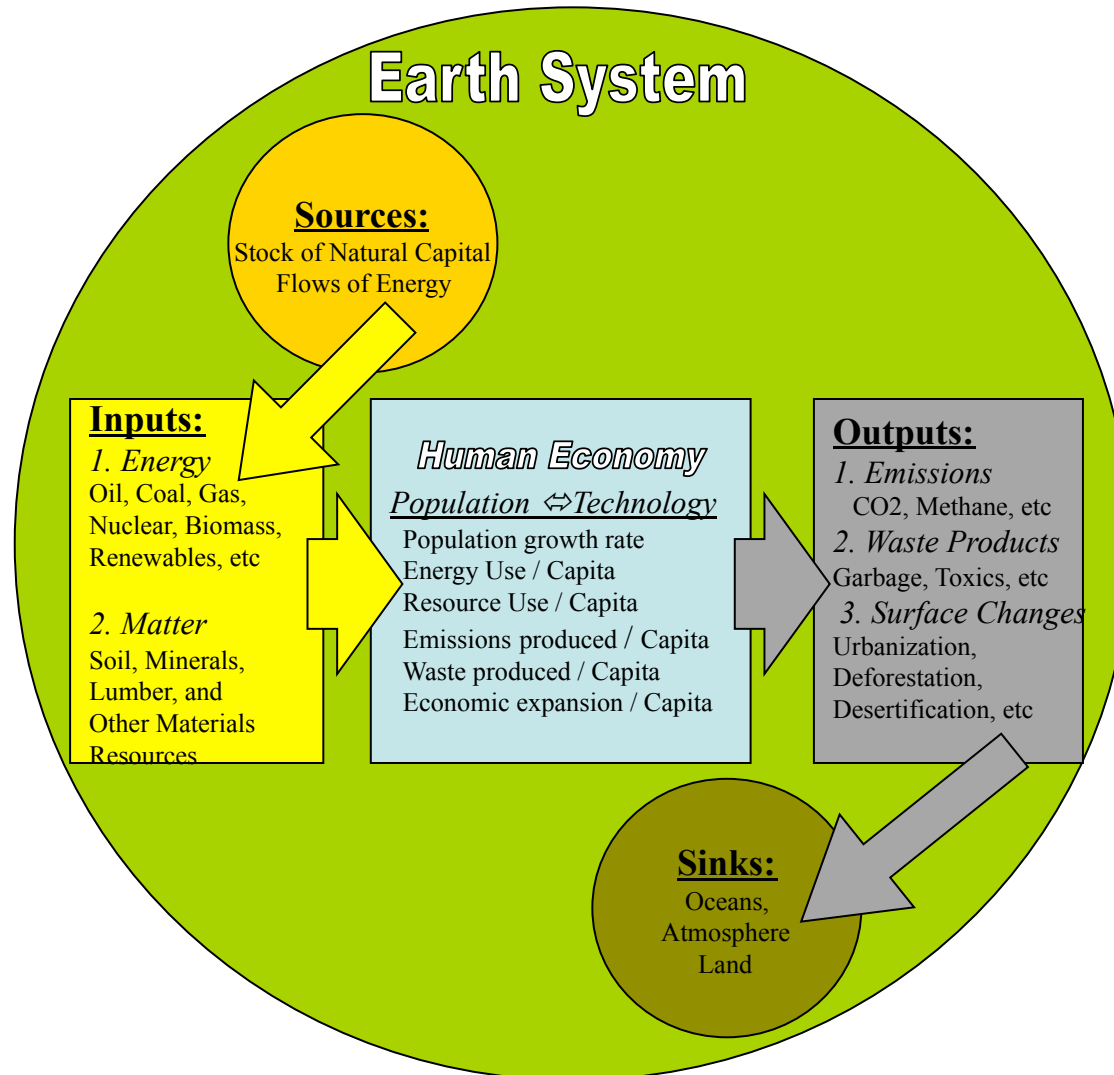
The standard Neoclassical Economic Model does not account for:

- 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*.

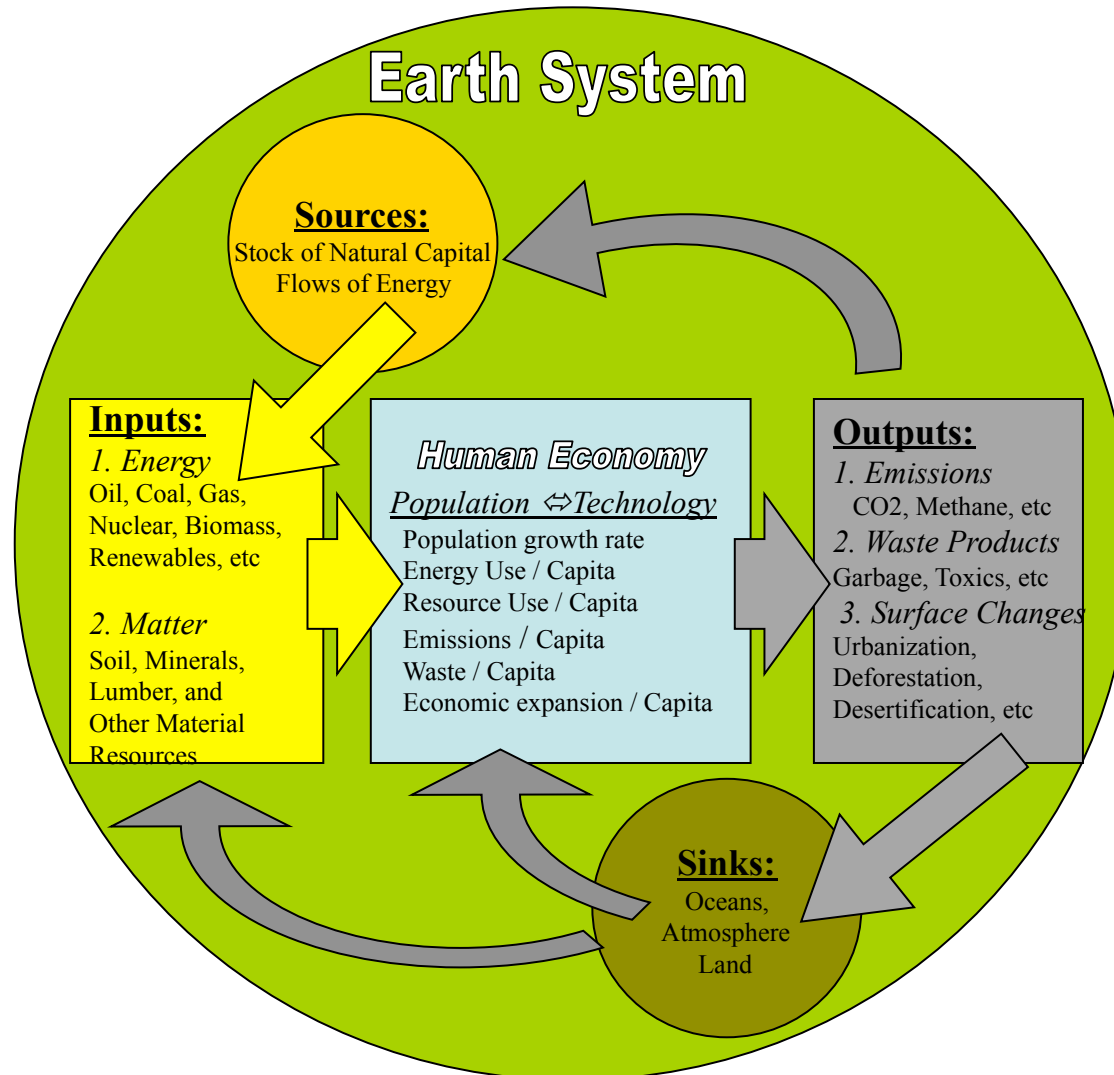
Realistic Ecological Economic Model (Herman Daly)

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



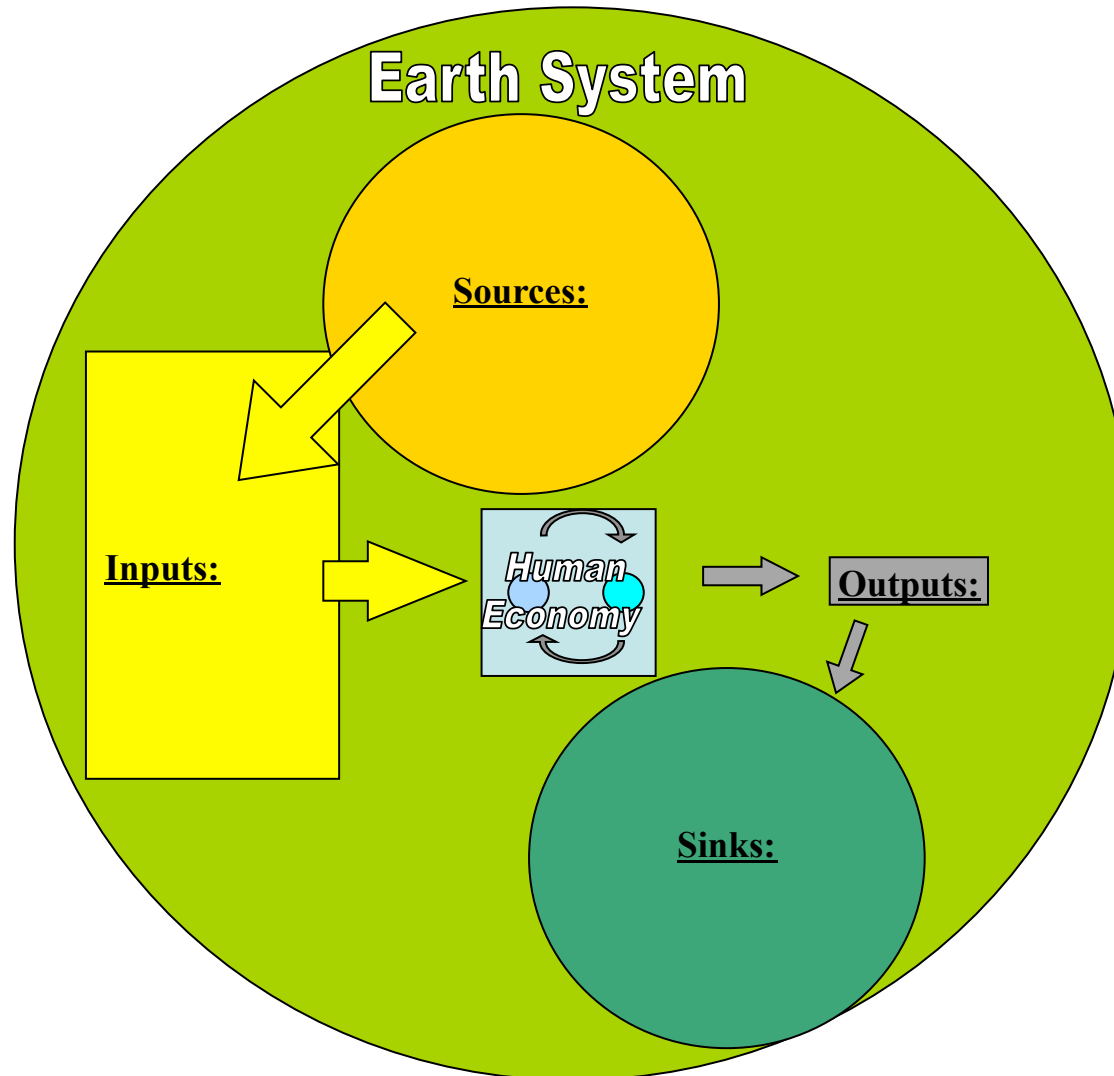
Feedbacks in an Ecological Economic Model

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

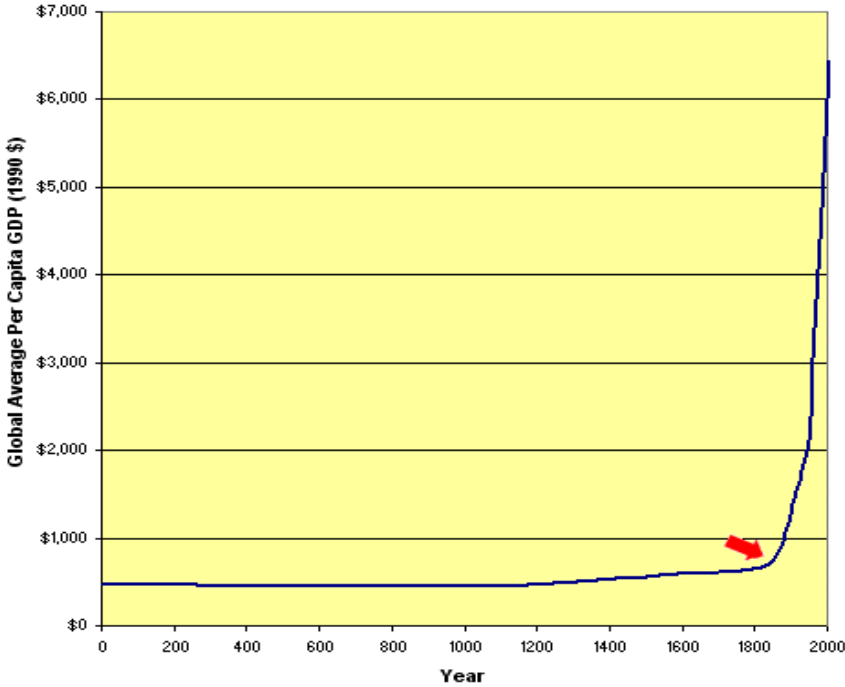
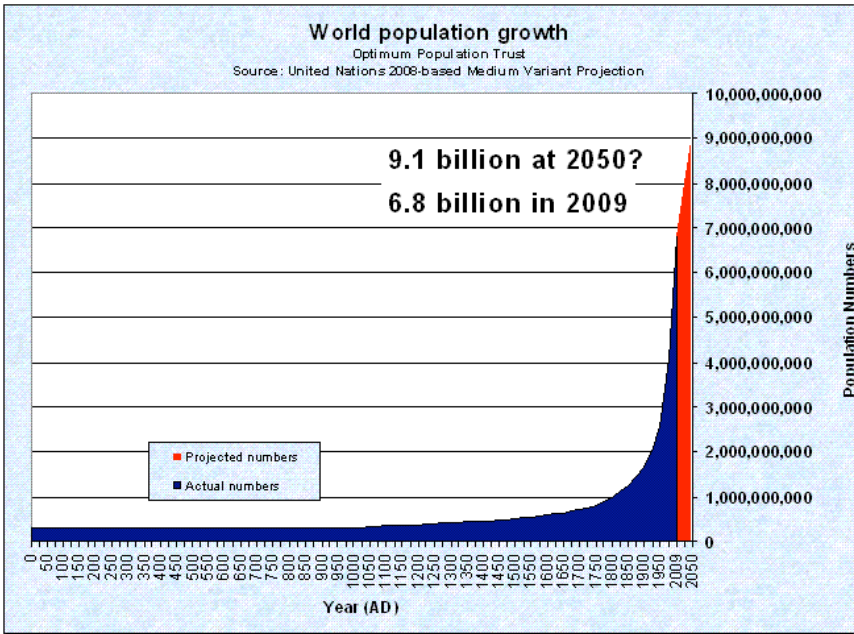


“Empty World” Model

- 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.

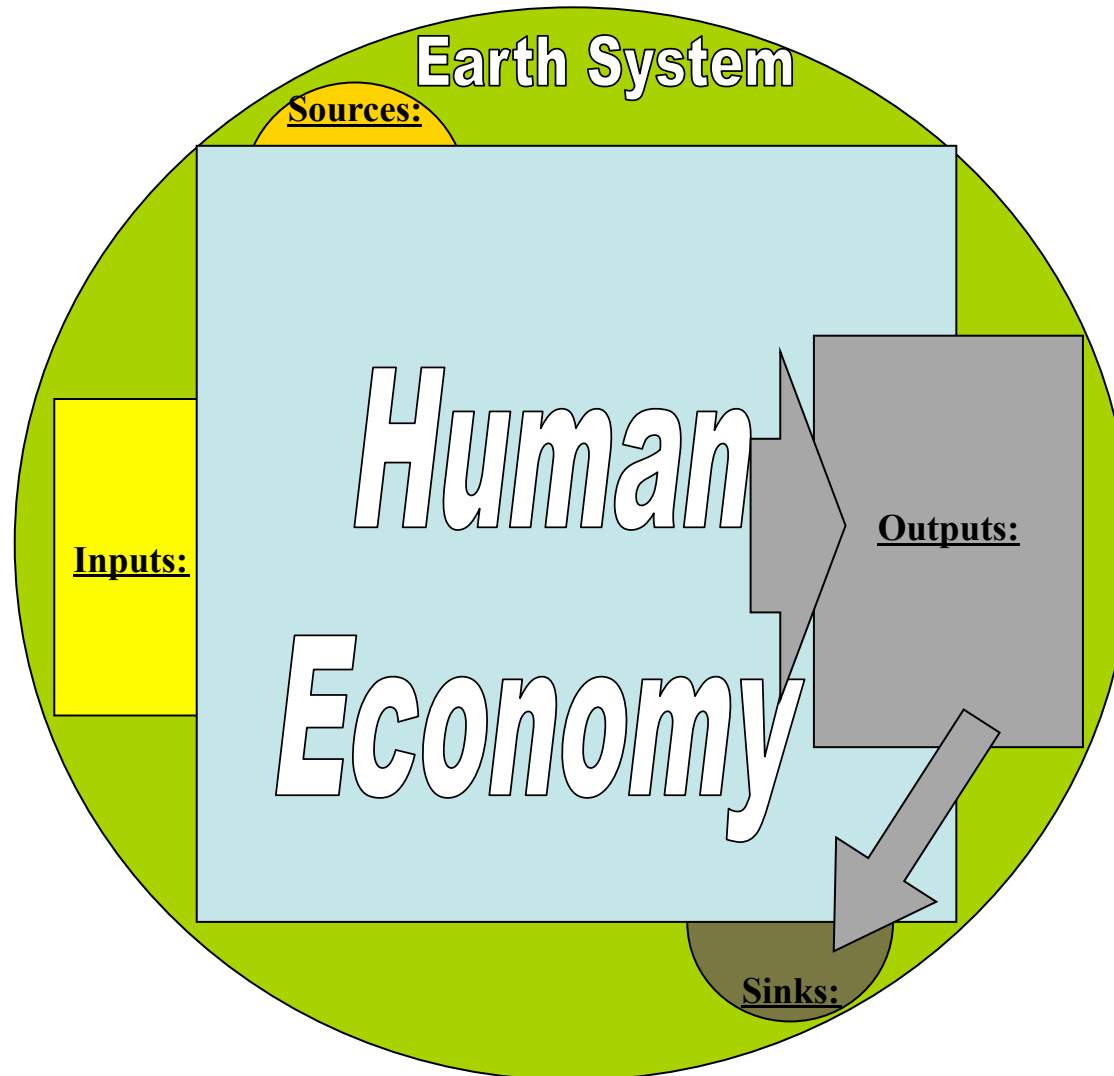


But Population and Economic Output per Capita have grown

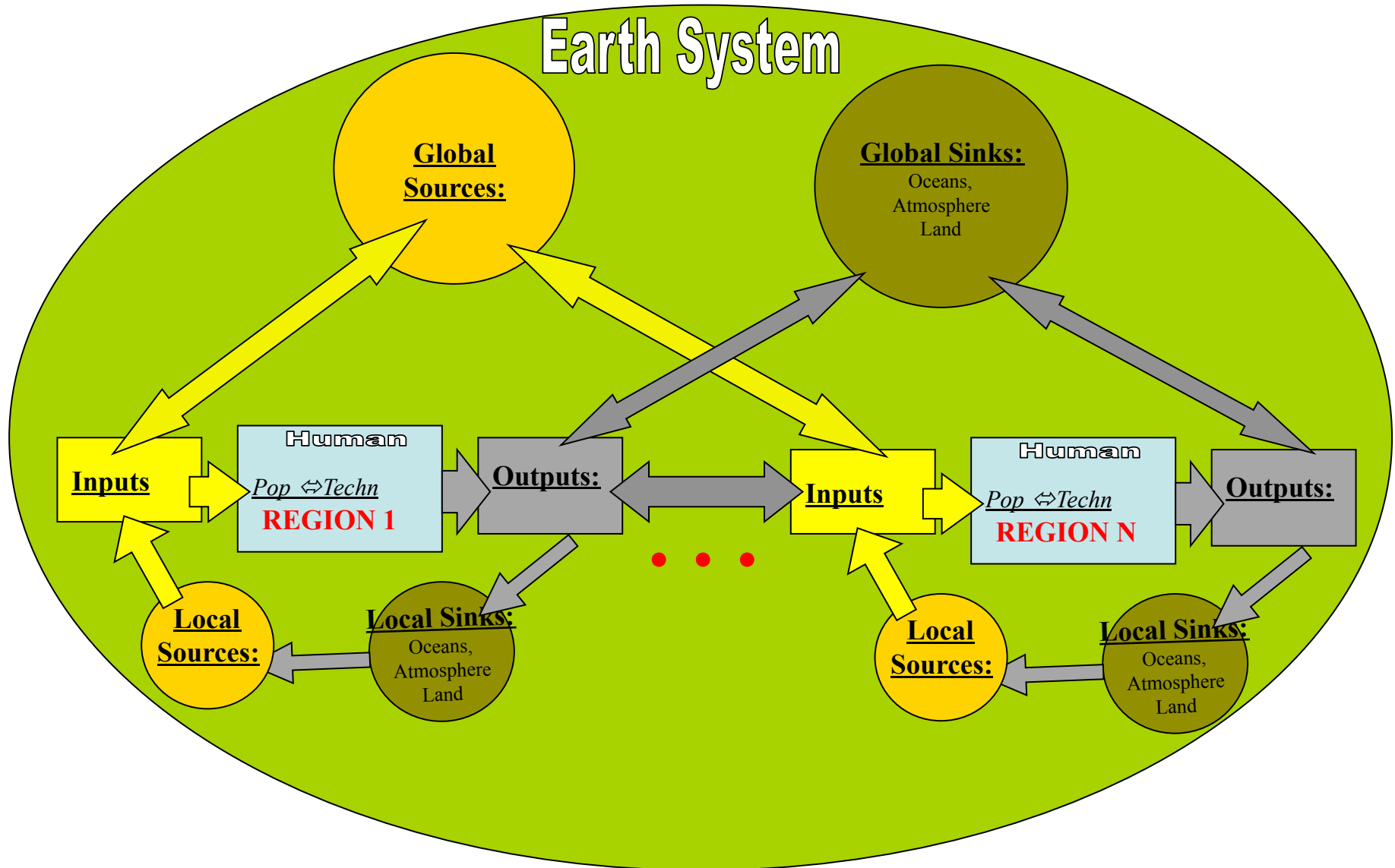


“Full World” Ecological Economic Model

- 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

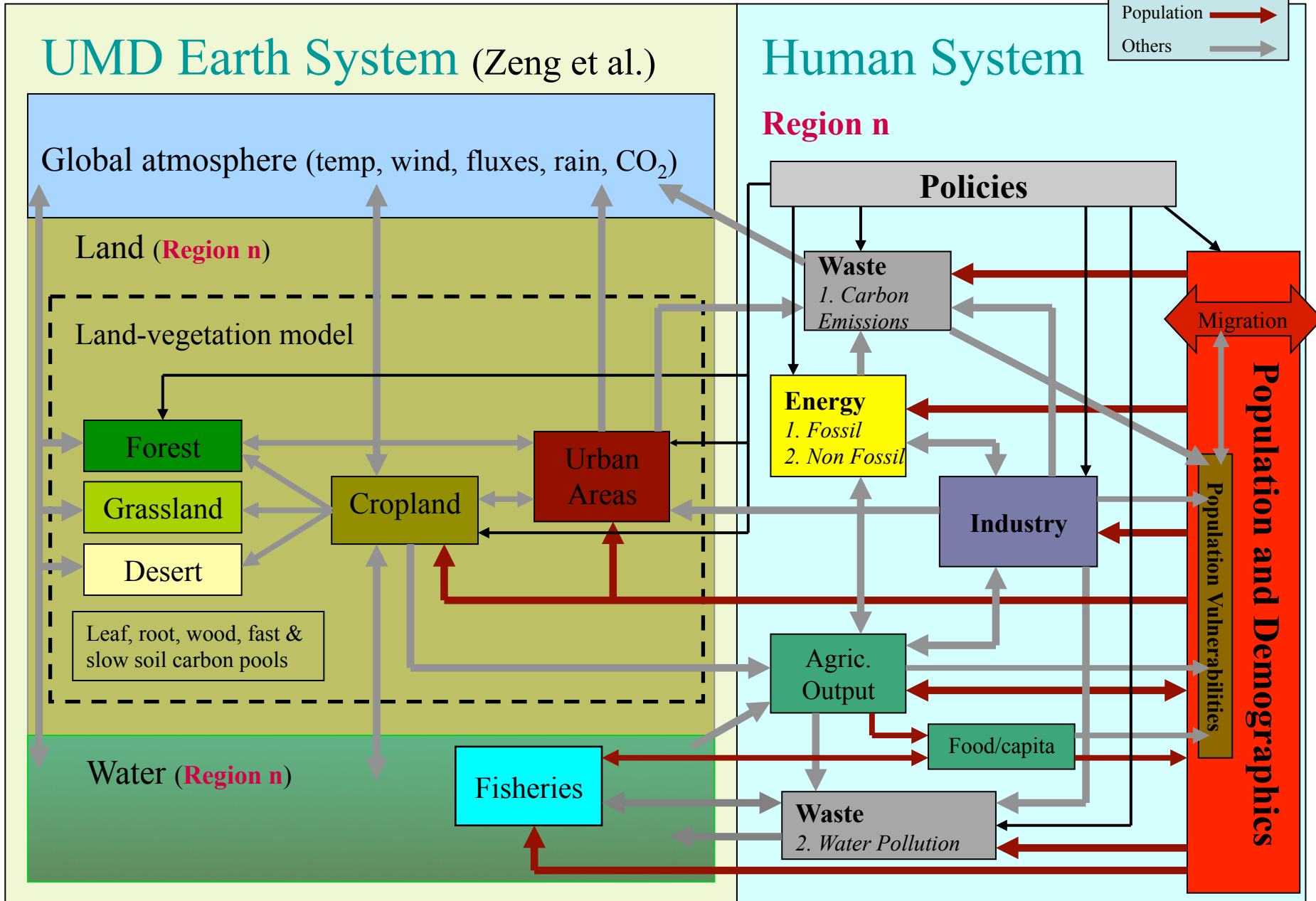
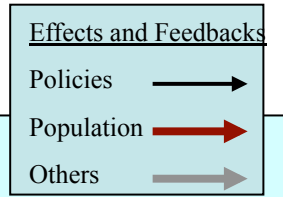


Some of the Essential Feedbacks needed

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

We proposed to experiment first using an intermediate model (UMD ESM). Then we would use the NCAR CCSM with more realistic population/economic feedbacks

Prototype Earth System - Human System Feedbacks



Components of the Human System for the Prototype Model

* Indicates a two way coupling with the UMD Earth System model

1. Population Sector

Expand on World3 Model, representing 5 to 10 regions/countries with their own resources/population/policies.

Four population cohorts (0-14, 15-44, 45-64, 65+) distinguish population structures and growth.

Parameters include education levels, employment of labor force, healthcare. Migration (external)

2. Land and Water Sector

* Land Use: (by type)

Rural (Crops, Forest, Deserts, Grasslands etc) and Urban. Crops and Urban will be added to the UMD EaSM.

Urban represented by a % of total land, driven by population, wealth, policies.

* Agriculture & Forestry

Total Acreage. Inputs: Agricultural Capital, Outputs: Crops, Lumber. Changes:

+/- Acreage: Deforestation, Irrigation / Urban Sprawl, Desertification, Flooding (hydroelectric dams),

+/- Productivity: Inputs (fertilizers, water, etc.) / Soil erosion, salinity, water scarcity, etc

Components of the Human System for the Prototype Model

* Water:

Sources (aquifers, rivers, lakes, rainwater)

Demand (agriculture, industry, energy, residential)

Stock Capacity (vulnerabilities, e.g., low reservoirs)

Fisheries and Fish Farms

Fisheries: Stocks with Rates of Depletion and Replenishment. No interactive ocean.

Food output:

Per capita consumption, minimum needs, vulnerabilities

3. Energy Sector

Sources: Fossil Fuels, Renewables, Biomass

Uses: Electricity production, Industry, Transportation, etc

Parameters: Energy use per capita & growth rates

* Coupling of Energy components with Earth System primarily through emissions (see **5.**

Waste)

4. Other Economy Sector (in addition to Energy and Agriculture)

Industry: Industrial capital, inputs and outputs.

Components of the Human System for the Prototype Model

5. Waste Sector

* Emissions: Anthropogenic Carbon

Other pollution (land/water)

* Absorptive capacity of environmental sinks

6. State/Government Sector:

Policies: Policy-tuning knobs for each parameter in the model as stand-ins for more elaborate systems representing regulations, caps, subsidies, tax-based policies, etc.

7. Technology, Development and Diagnostic Indicators:

Representative Technological Indicators: Energy Use (per capita and per unit of economic output). Agricultural Labor Force (% of total). Productivity of Labor (per hour worked).

Representative Development Indicators: Infrastructure (% pop. with access to clean water and sanitation), Education levels, Healthcare levels (infant mortality, life exp, beds & doctors/capita).

Now we go to Harald Rybka

