

# Population and Climate Change: Are they related?

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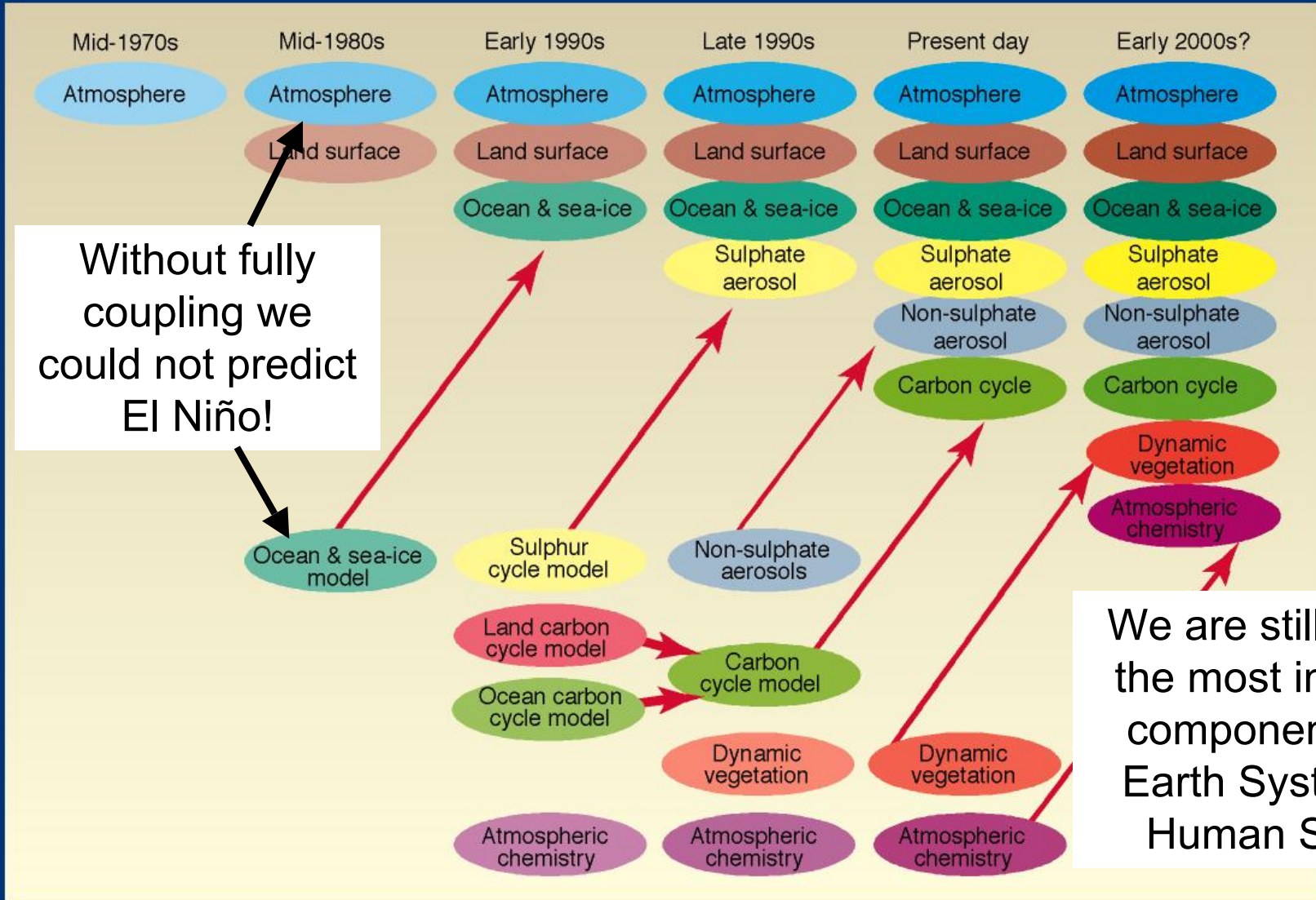
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with thanks to

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Robert Cahalan

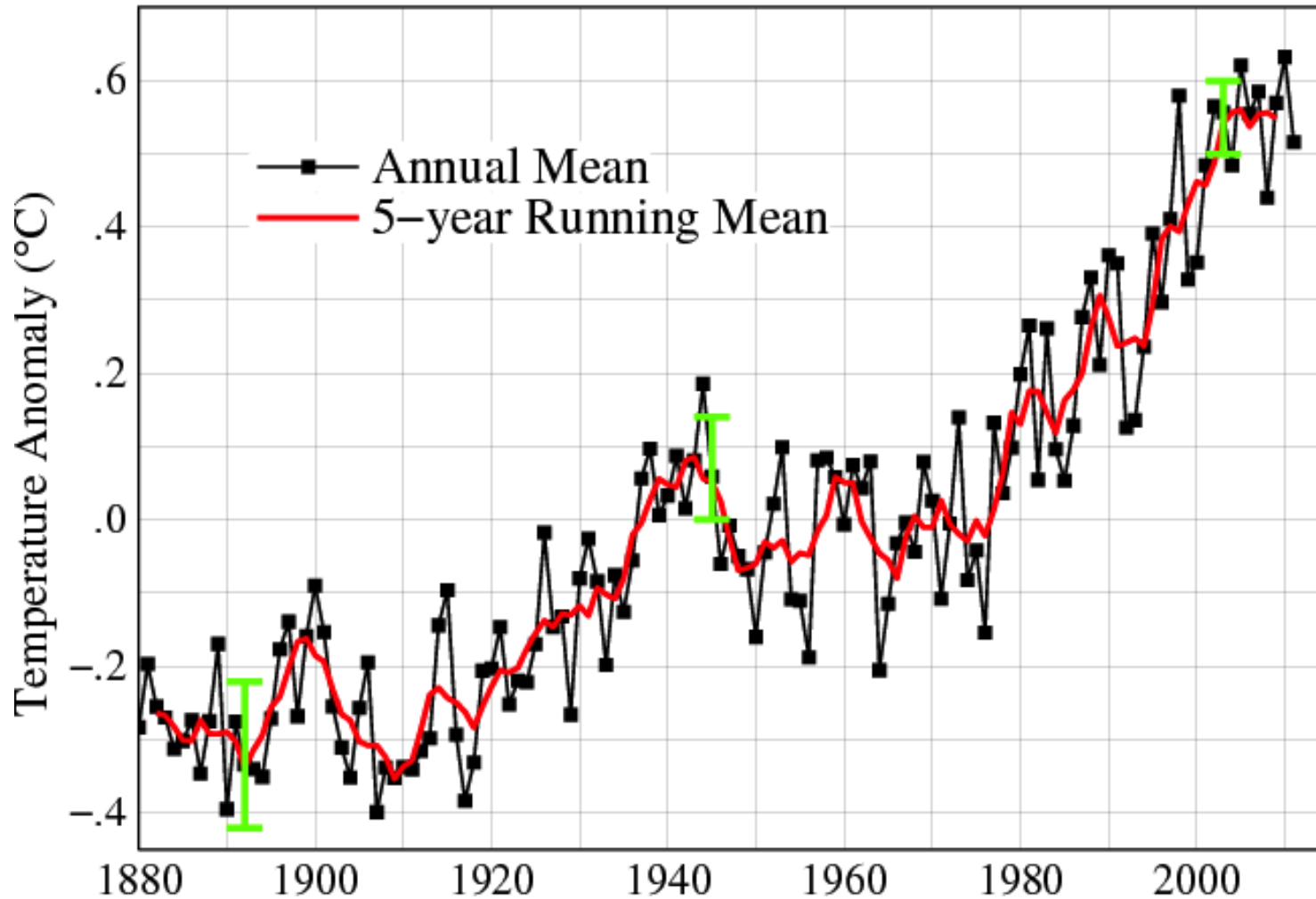
**PSU, 12 December 2012**

# The development of climate models, past, present and future



# Is climate change really happening?

Global Land–Ocean Temperature Index



Is it happening?

# Sea Ice Melt in the Arctic: much faster than projected

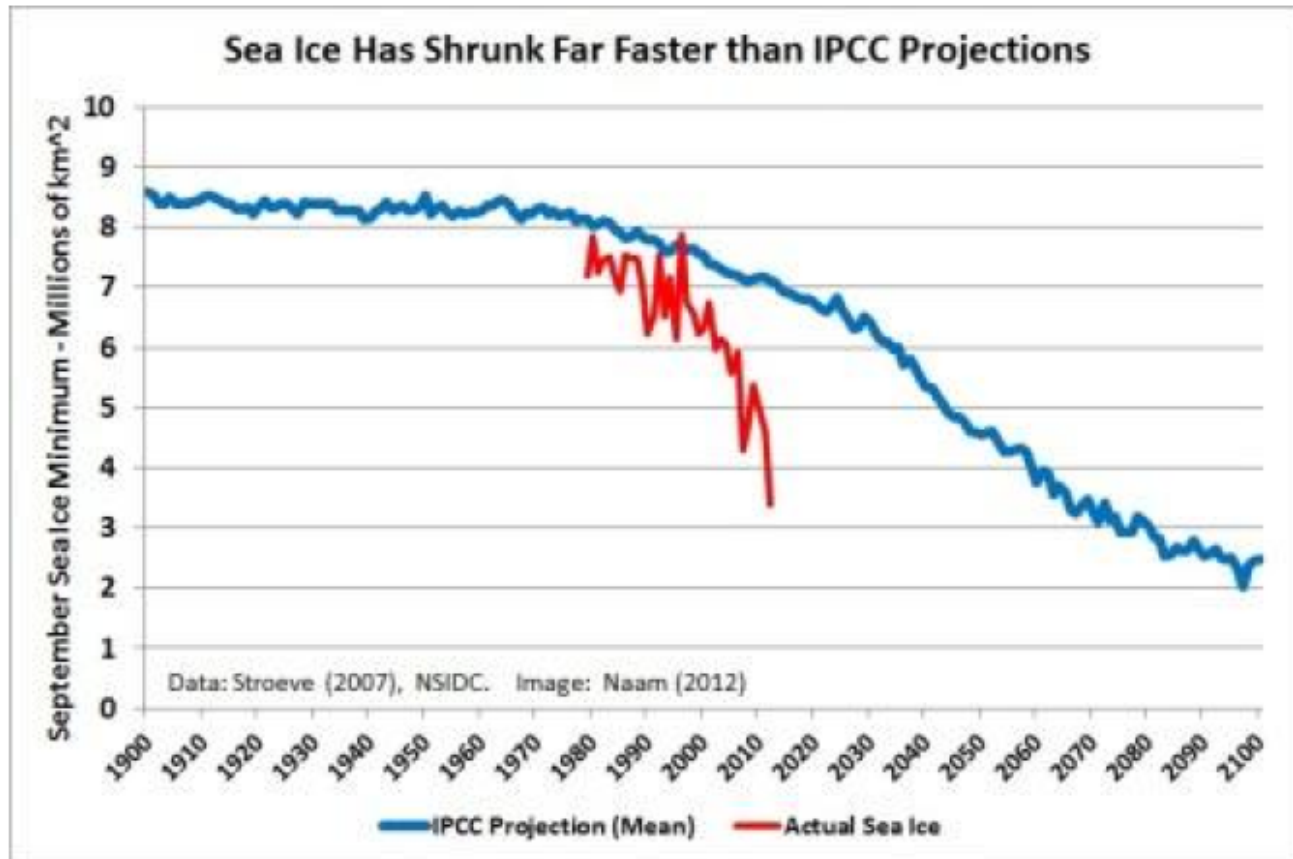
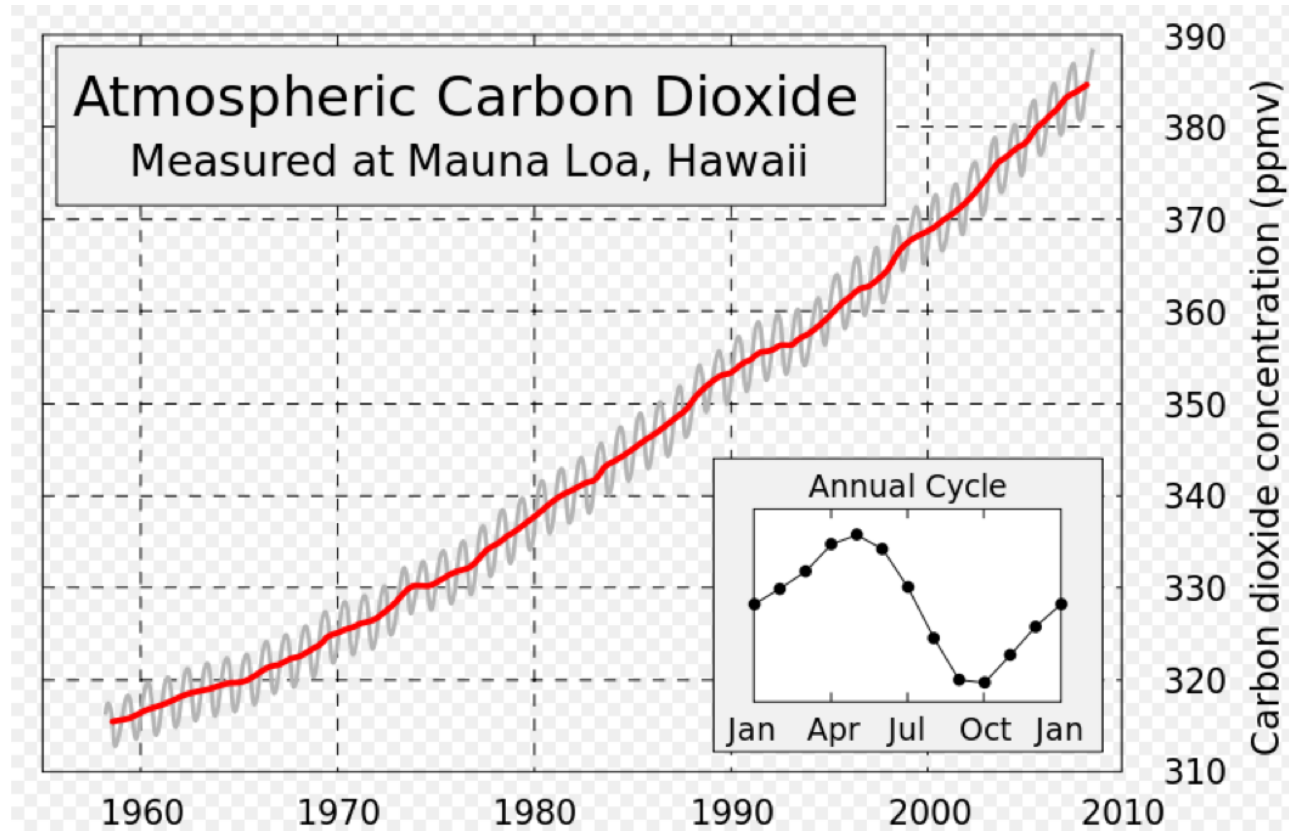


Figure 12 –

*Arctic sea ice has receded dramatically faster than the mean of IPCC models projected, reaching levels not expected until 2065. Positive feedback loops such as those that have accelerated sea ice loss might accelerate the loss of permafrost and the release of additional CO<sub>2</sub> and methane from the Arctic.*

# Why is climate change happening?



After **greenhouse** gases warming, **land-use change** is the **second strongest driver** of climate change

# Climate change

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Since 1800 we are **burning the fossil fuels** that Nature accumulated during **millions of years**.

By burning the accumulated carbon we **emit CO<sub>2</sub>** into the atmosphere.

The CO<sub>2</sub> acts like a blanket (**greenhouse effect**).  
So, the atmosphere is warming up:

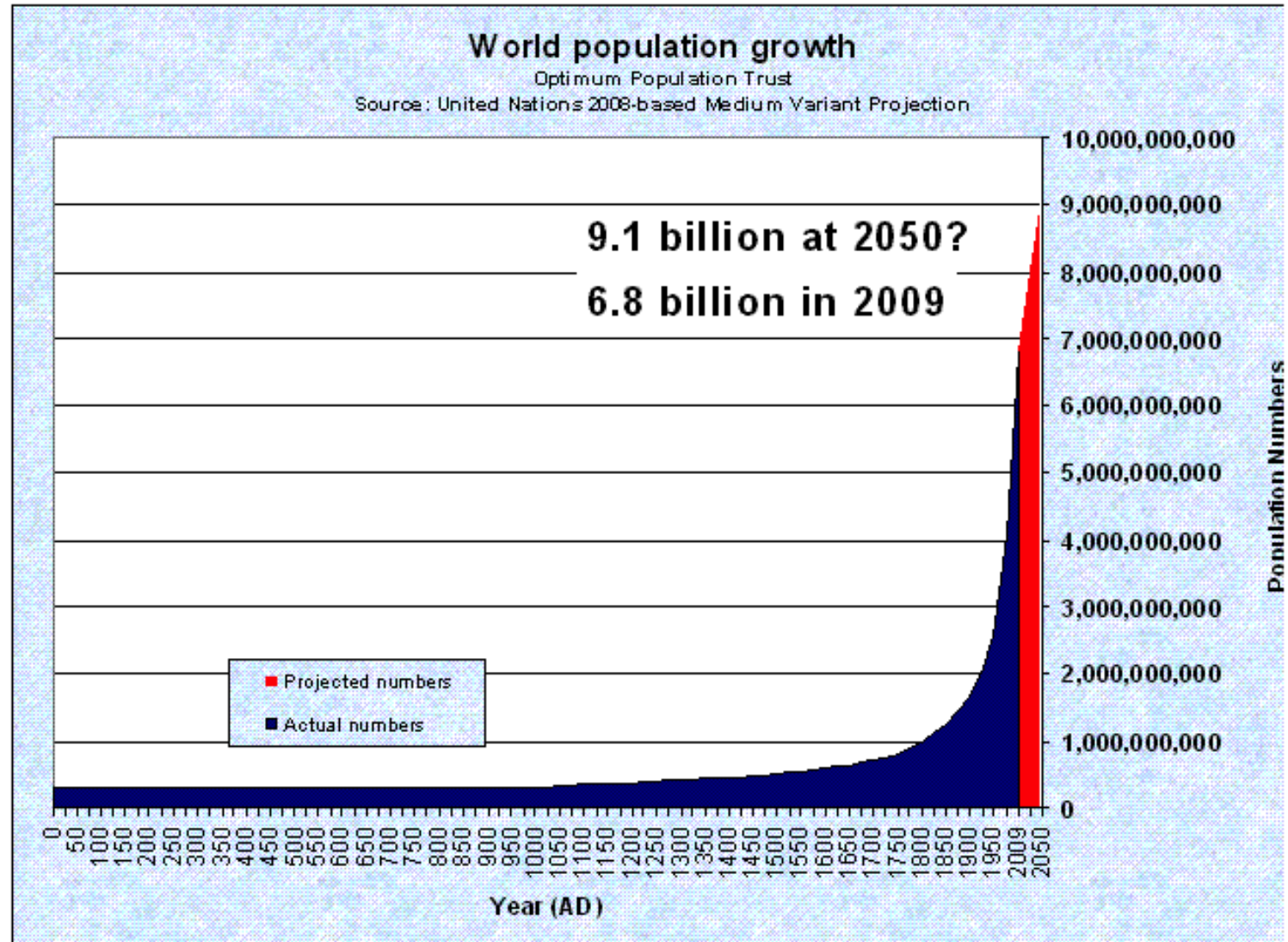
**Total** emission = **population** x emission per person





# Population growth

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



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

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Two reasons:

- 1) Sanitation and antibiotics (living longer)
- 2) Use of fossil fuels in agriculture starting in the 1950's:
  - fertilizers, pesticides, irrigation, mechanization (the Green Revolution).

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

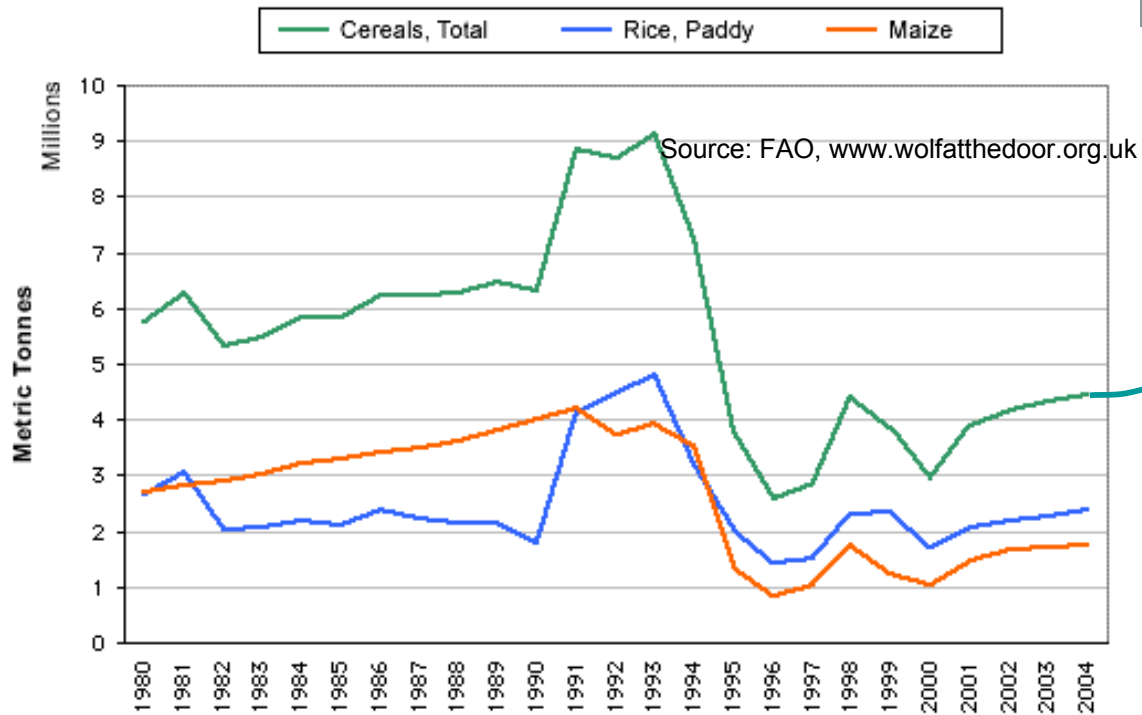
**Without fossil fuels, population would be much smaller!**

- 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

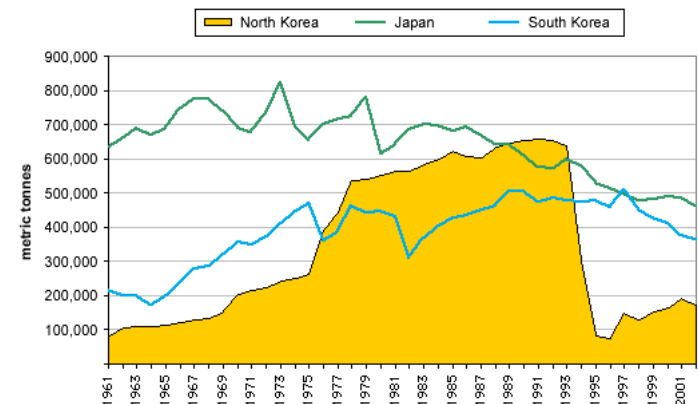


Production of grain in North Korea, updated to 2008

What caused the famines in North Korea?

The famines in North Korea are the result of the sudden loss of access to abundant fossil fuel

## G2. Fertiliser Use (Nitrogenous) - Far East



# Population growth affects every environmental challenge we face:

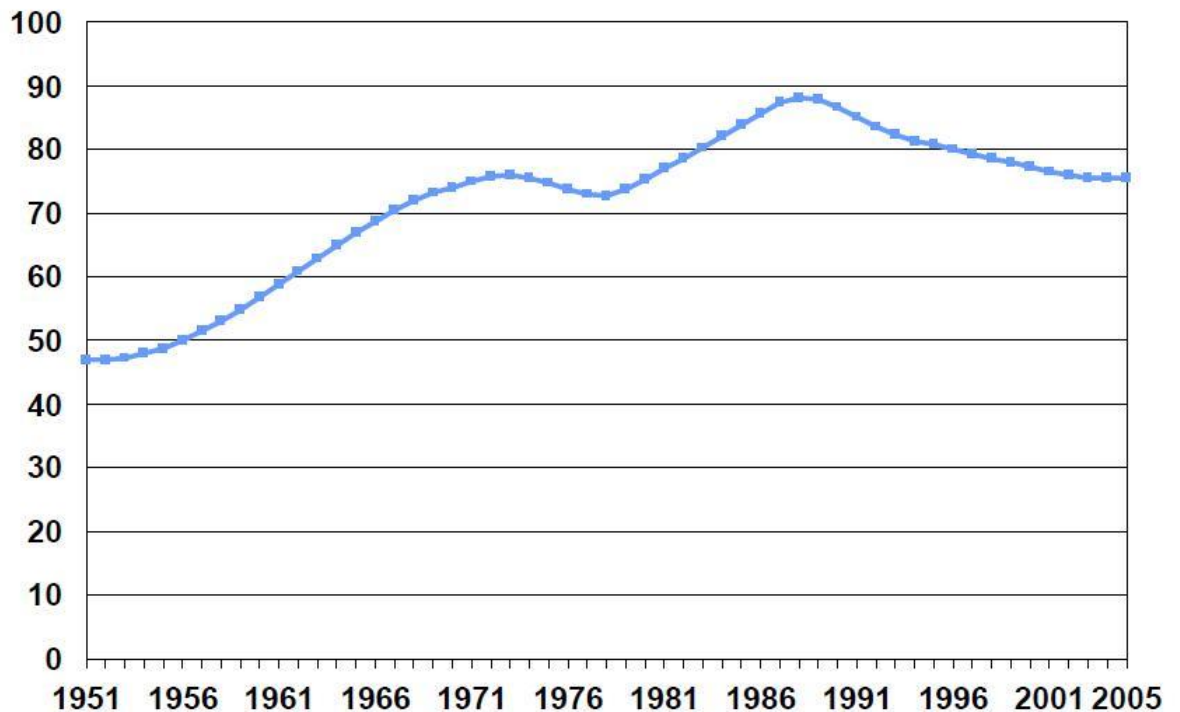
- Generation of **Greenhouse Gases**
- Additional global warming due to **land-use change**
- Generation of other **pollutants** and **toxic waste**
- **Resource depletion**: water, oil, fisheries, topsoil, etc.
- Resource **wars** and civil **conflicts**
- **Malnutrition** and world **hunger**
- Lack 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**...

# 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

## ***Annual Increase in World Population***

Millions



# 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

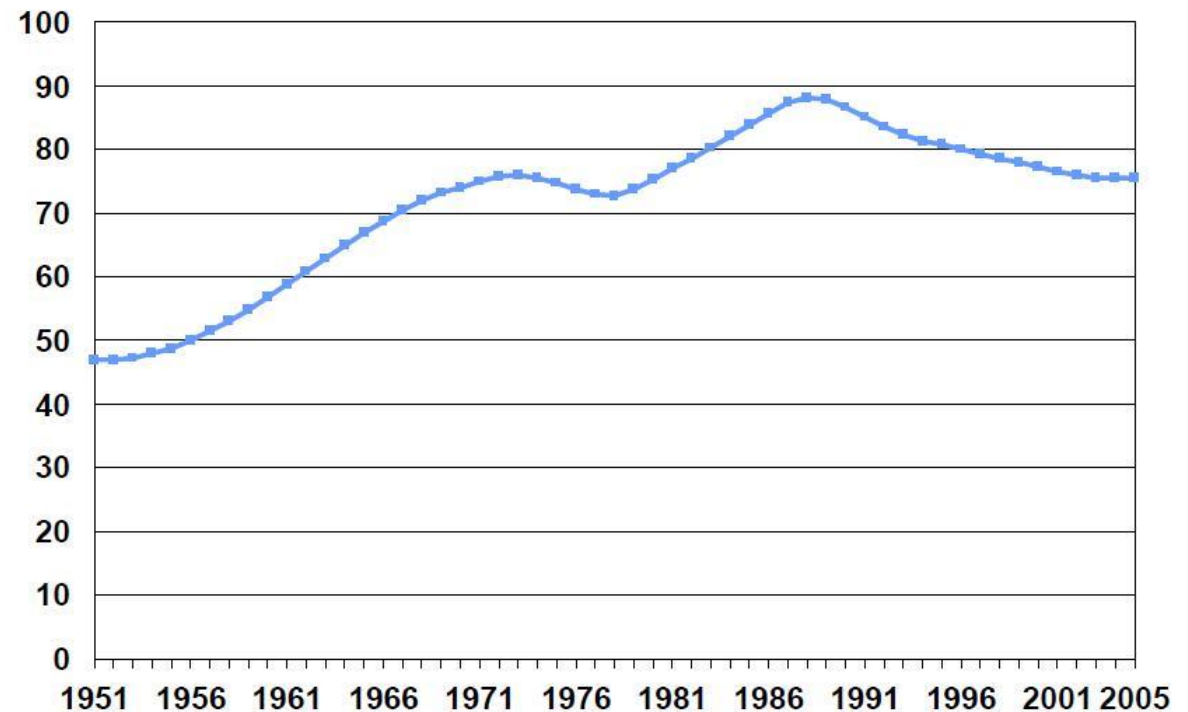
The **population explosion** took place in the second half of the 20th century.

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

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

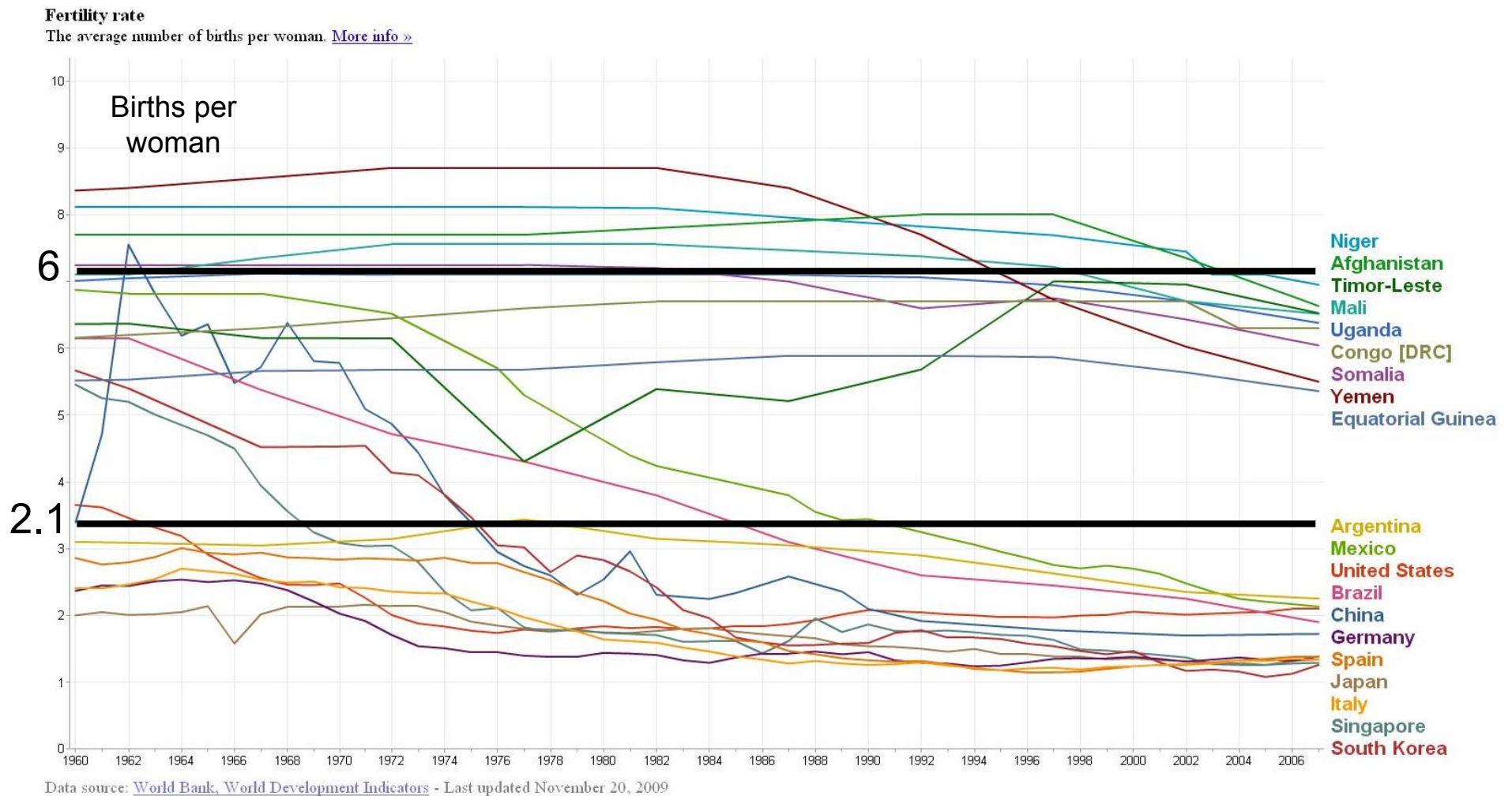
## ***Annual Increase in World Population***

Millions



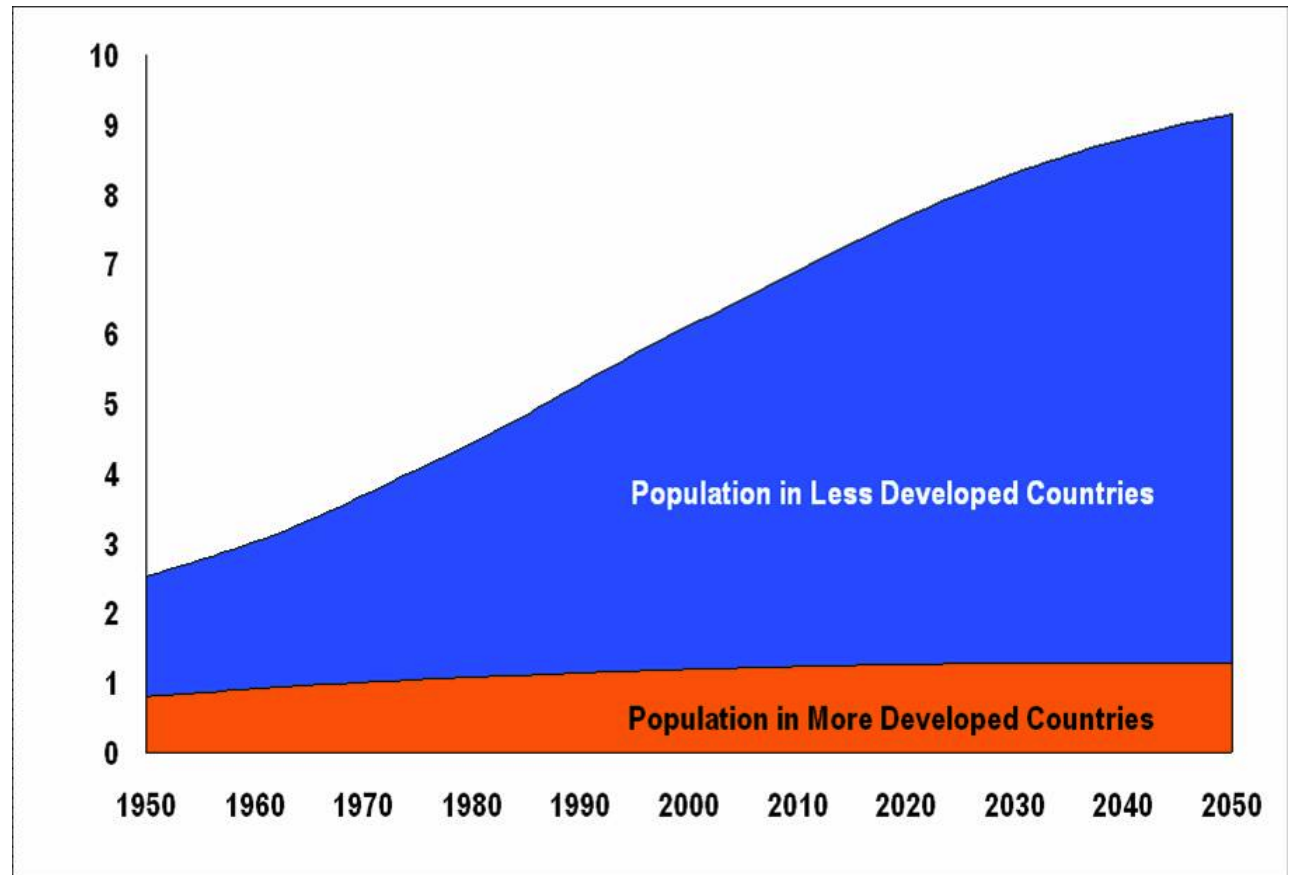
# Births per woman

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



# Still growing...

Most population growth takes place in underdeveloped countries,





# Still growing...

Most population growth takes place in underdeveloped countries, but

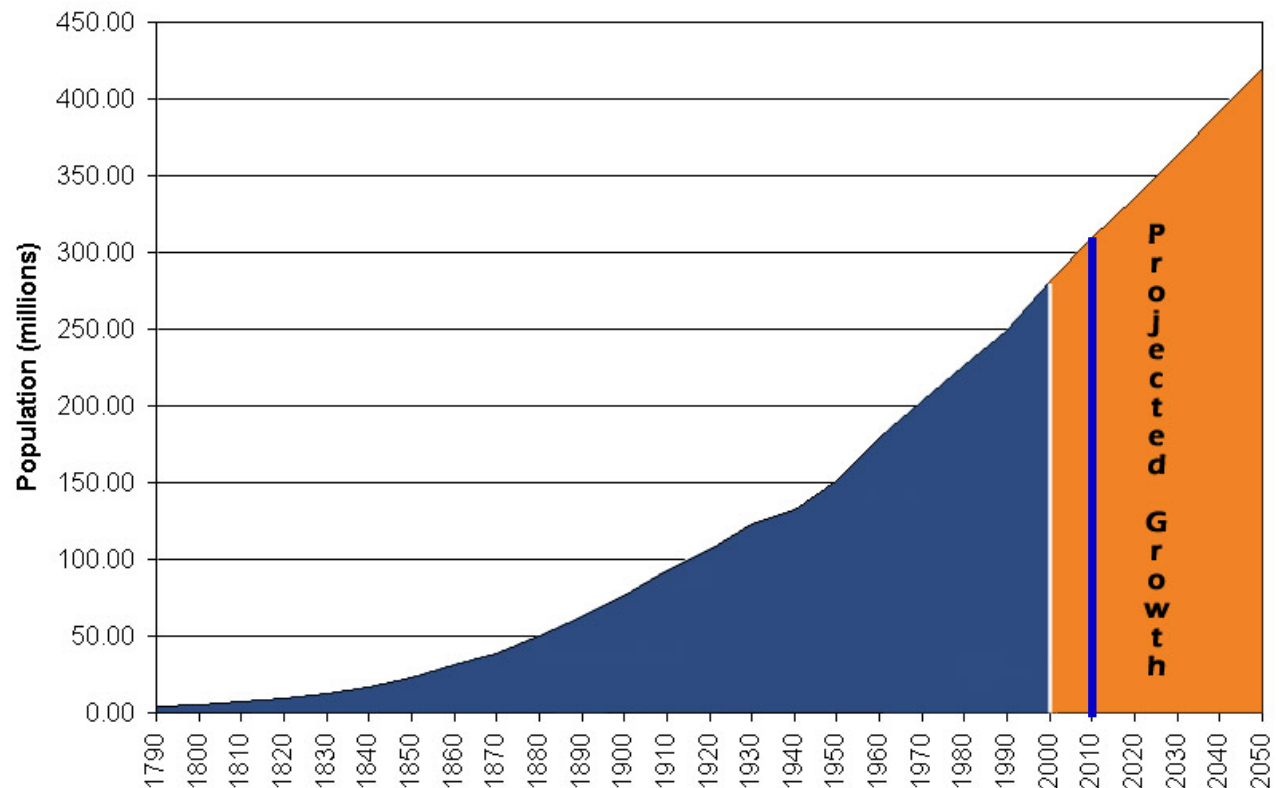
Some developed countries are still growing fast:

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

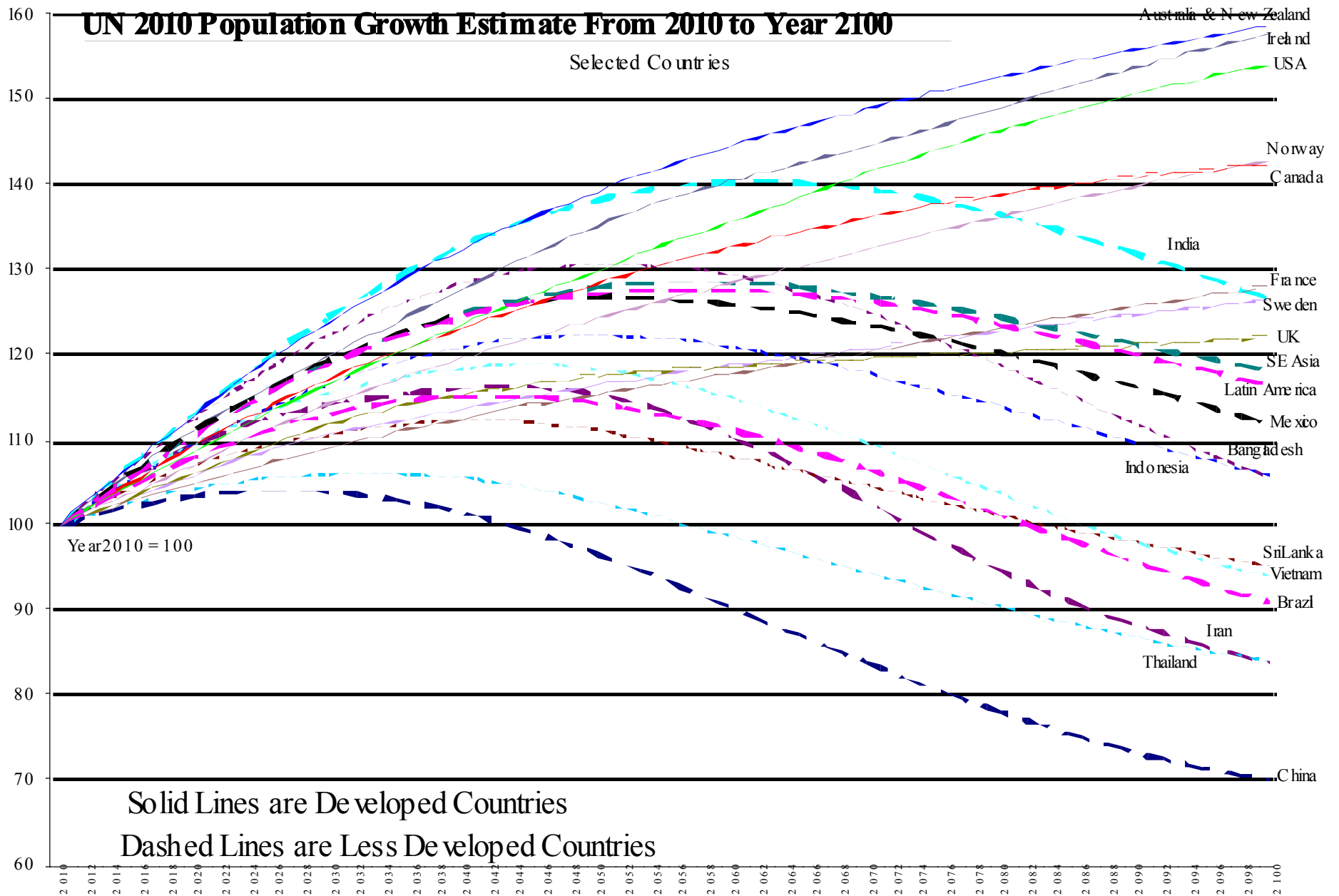
US fertility rate has been creeping upwards for 3 decades:

1.7 in the 1970s, now 2.13.

Historical & Projected U.S. Population



# Population Growth is Not Just about Poor Countries



# Is this population sustainable?

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Ethanol: we all know that it takes as much energy to produce a gallon of ethanol than what we get from burning it (0.75-1.5)

Food: It is not well known that we spend orders of magnitude more calories to grow food than the calories we get from it!!!

# Is this population sustainable?

Ethanol: we all know that it takes as much energy to produce a gallon of ethanol than what we get from burning it (0.75-1.5)

Food: It is not well known that we spend orders of magnitude more calories to grow food than the calories we get from it!!!

This **unsustainable** situation 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”

The real world resources are **finite**, so this is **unsustainable**.

Many researchers think we are well beyond the Earth’s **carrying capacity** (~1-2 billion?), and every year we add ~75m more. Optimistic estimates: leveling off after adding 2 more billion.

# 1972: Club of Rome “Limits to Growth”

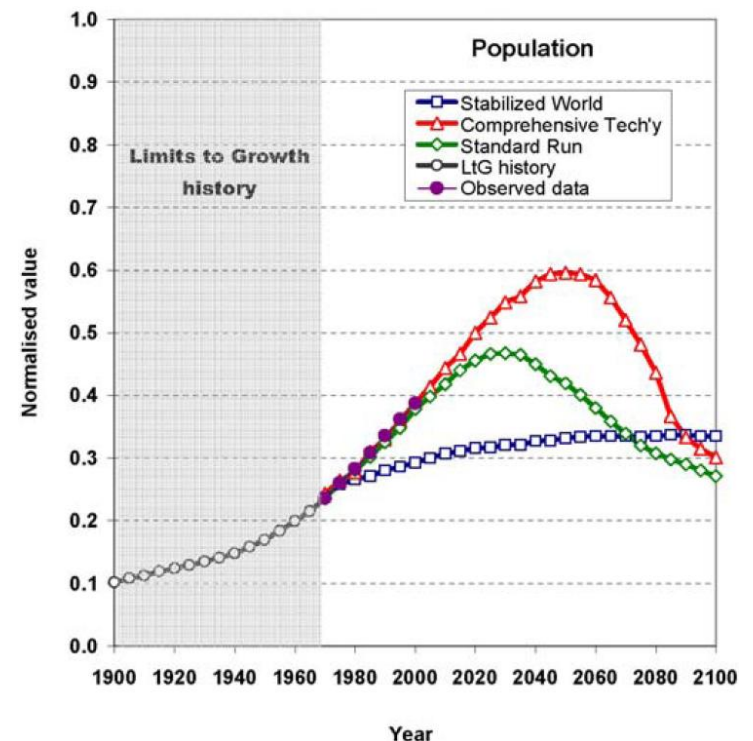
The Club of Rome commissioned a group at the MIT Sloan School of Management to study:

“Are current policies leading to a **sustainable** future or to **collapse**?”

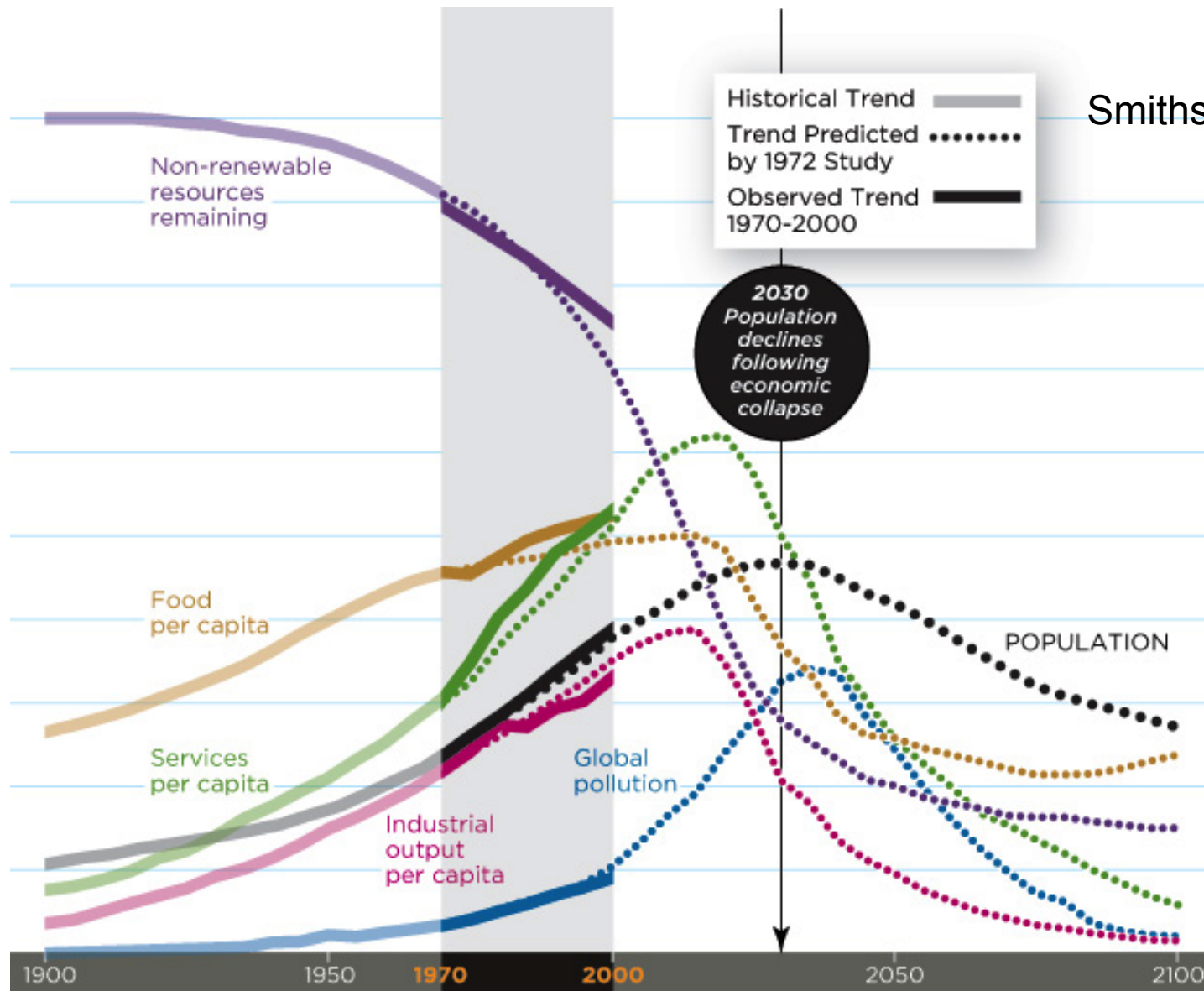
When the results appeared in 1972, the conclusion that **with finite natural resources growth would overshoot and collapse** was dismissed as **absurd** by many economists. (“discredited”)

35 years later the “standard run” model **compares well with reality for all variables.**

(Graham Turner, 2008, Ugo Bardi, 2011)



# Limits to Growth was criticized as being unrealistic, but so far the real data fits the projections closely!

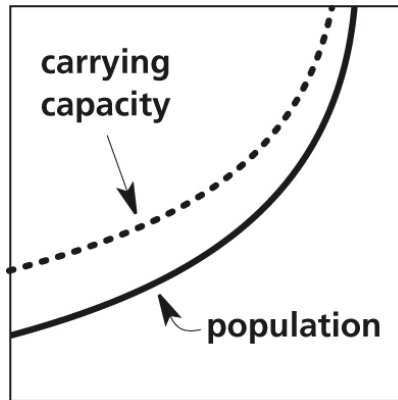


Source:  
Smithsonian Museum

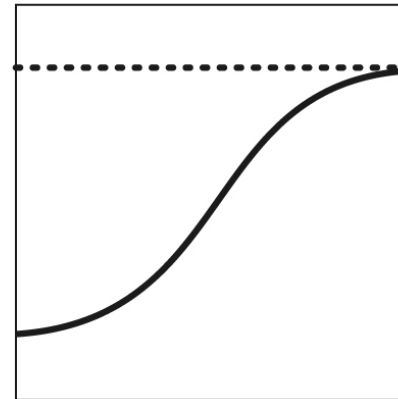


# The model could have four possible types of outcomes

Infinite World



a) Continuous Growth



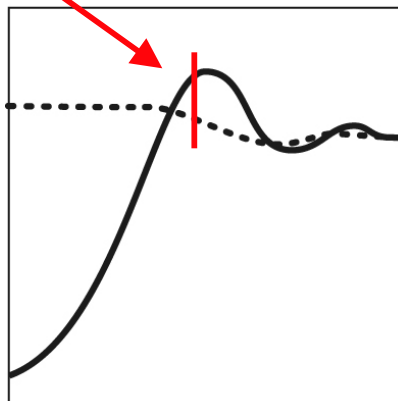
b) Sigmoid Approach to Equilibrium

Ideal  
(no overshoot)

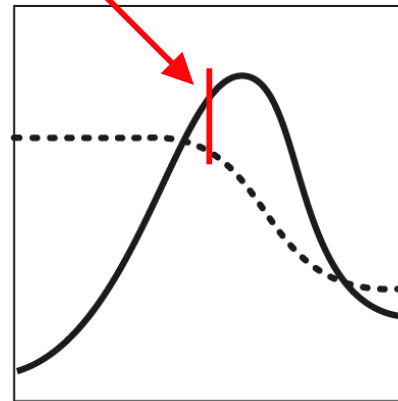
You are here...

Or here...

Hopefully...



c) Overshoot and Oscillation



d) Overshoot and Collapse

Disaster

# The results are sobering: most scenarios collapse

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

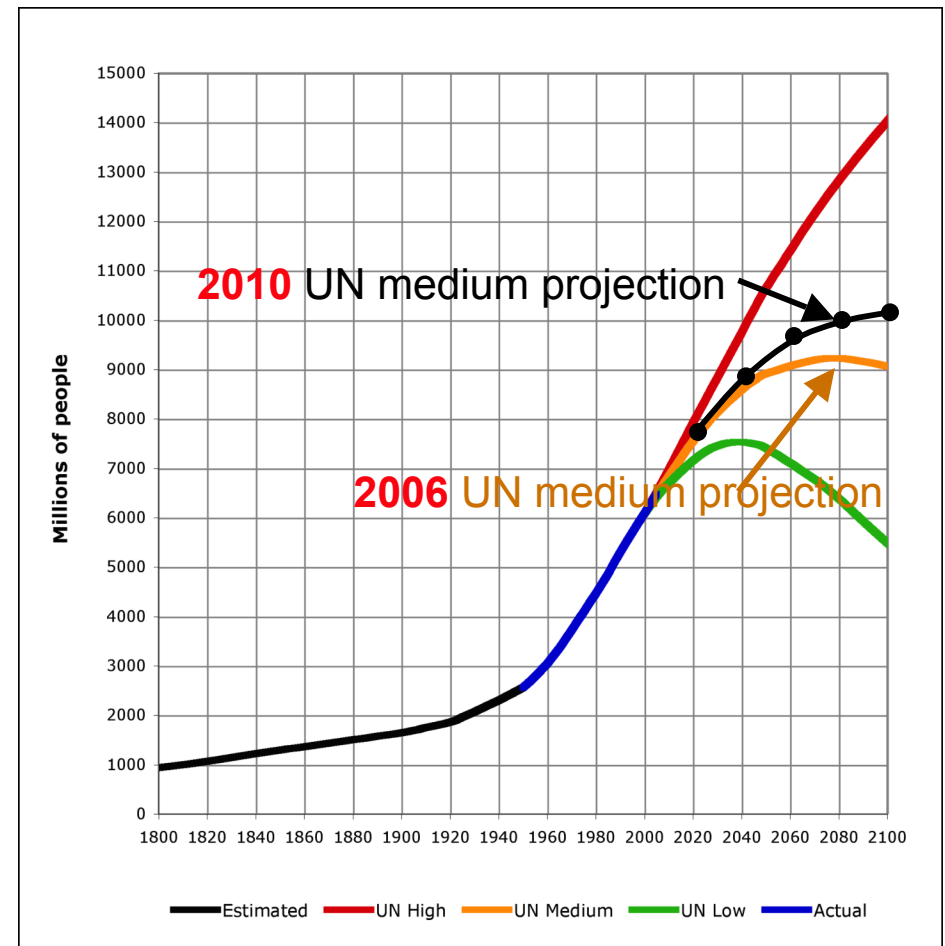
In order to **avoid collapse**,  
government policies are needed to:

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

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

**Total** emission=**population** x  
emission per person

Per dollar spent,  
**family planning** reduces  
**four times** as much  
carbon over the next 40  
years as  
adopting **low-carbon  
technologies**



# What about human rights?

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When people think of reducing population growth, they think **only 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

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The UN estimates that 40% of all pregnancies worldwide are **unintended**.

Just helping women to avoid unintended pregnancies would have a huge impact.

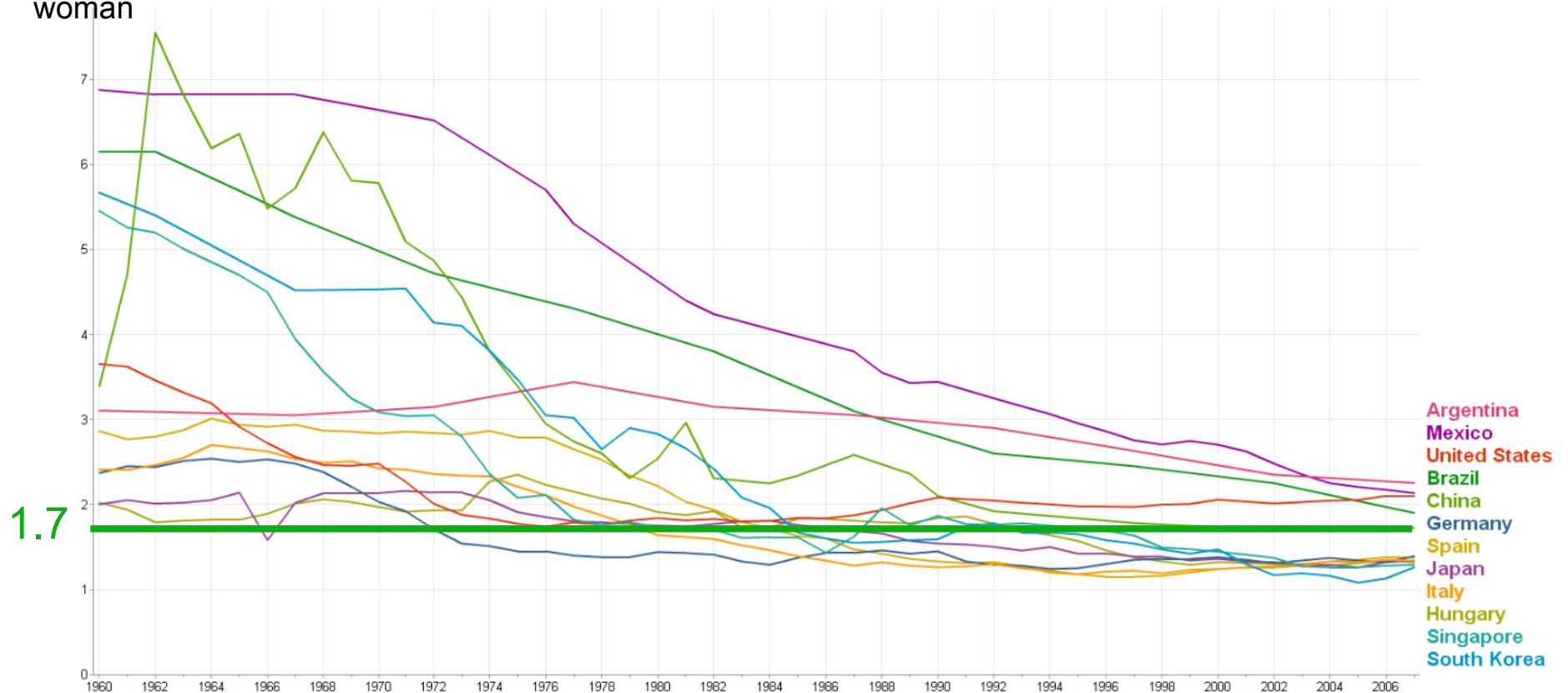
**Non-coercive** ways to drastically reduce fertility:

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

# 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 the economics of reducing population?

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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: births/woman 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 human history.**

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

In contrast, the Philippines, which had higher population growth, had 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, today virtually all economies suffer from very large **labor surpluses** and **high unemployment** rates.

(Even in Japan, the country with the highest of ratio of retirees to workers.)

**This alleged "demographic horror story" would actually be good!**

## **This alleged "demographic horror story" would actually be good!**

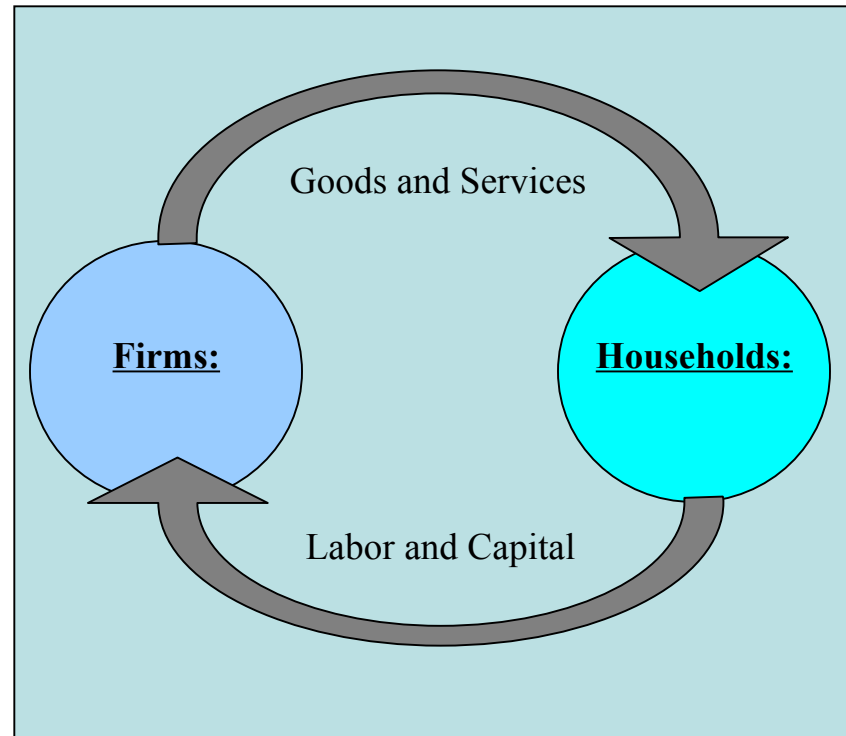
We are repeatedly told that in Europe, Japan, the US, and China, **lower birth rates** will create a huge **demographic crisis** due to a **shortage of workers**. However, today virtually all economies suffer from very large **labor surpluses** and **high unemployment** rates. (Even in Japan, the country with the highest of ratio of retirees to workers.)

### **This alleged "demographic horror story" would actually be good!**

As Dean Baker, of the Center for Economic and Policy Research, explains: Fewer workers would mean **unemployment levels would fall**, Workers' wages will rise and **higher wages** shift the labor force from **low productivity** 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?*)

# Standard Mainstream Economic Model

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



The standard Model does not account for:

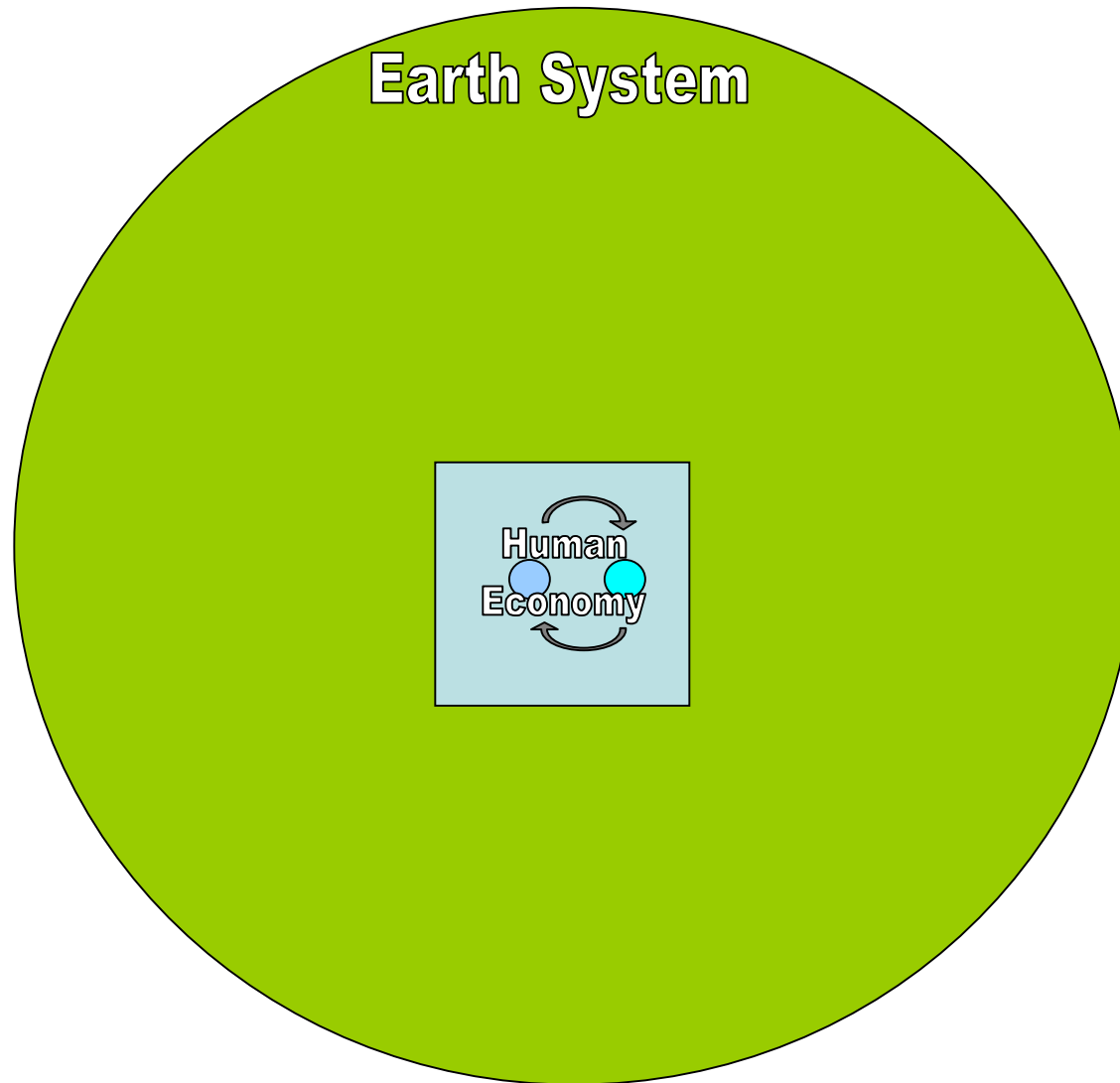
- Inputs (resources), Outputs (pollution), Stocks of Natural Capital
- Dissipation of Energy (i.e., a Perpetual Motion Machine)
- Depletion, Destruction or Transformation of Matter

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

**Herman Daly (UMD) introduced Ecological Economics,  
including the Earth System**

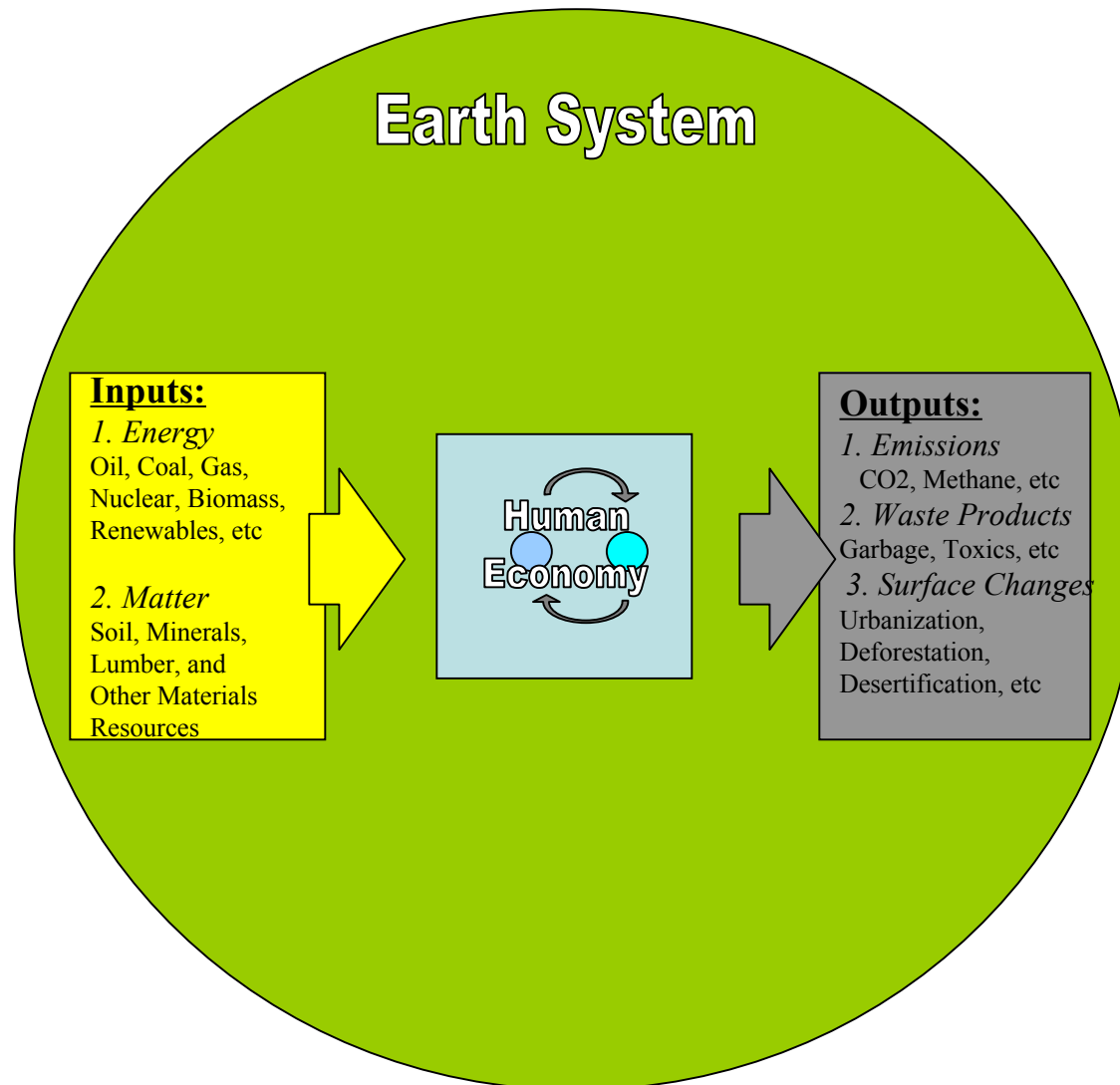
# A More **Realistic** Ecological Economic Model

- Recognizes the **Human Economy** is located within an Earth System



# A More **Realistic** Ecological Economic Model

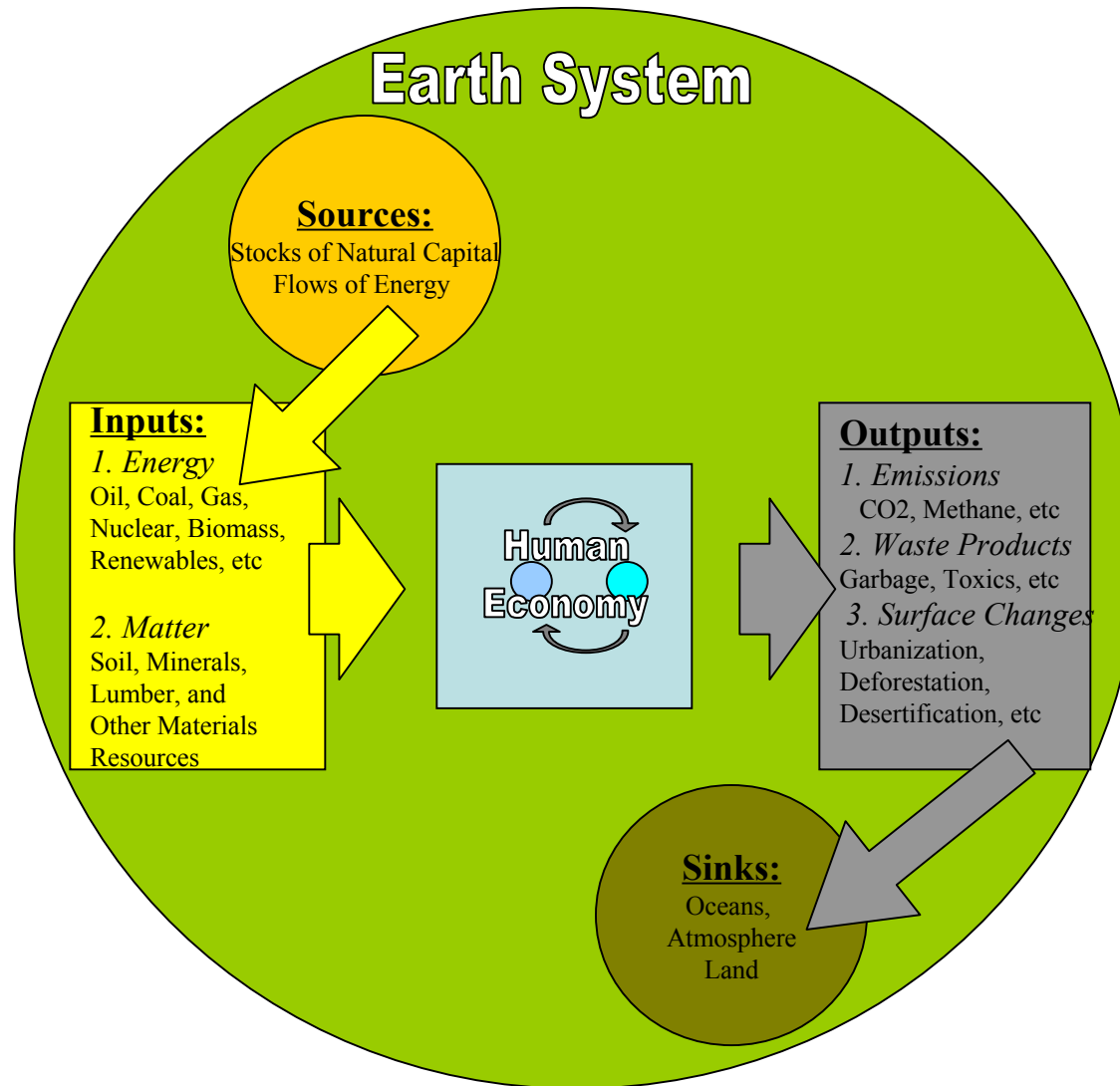
- It is **Not A Closed System**
- It requires **INPUTS** from the Earth system, and
- It accounts for **OUTPUTS** into the Earth system





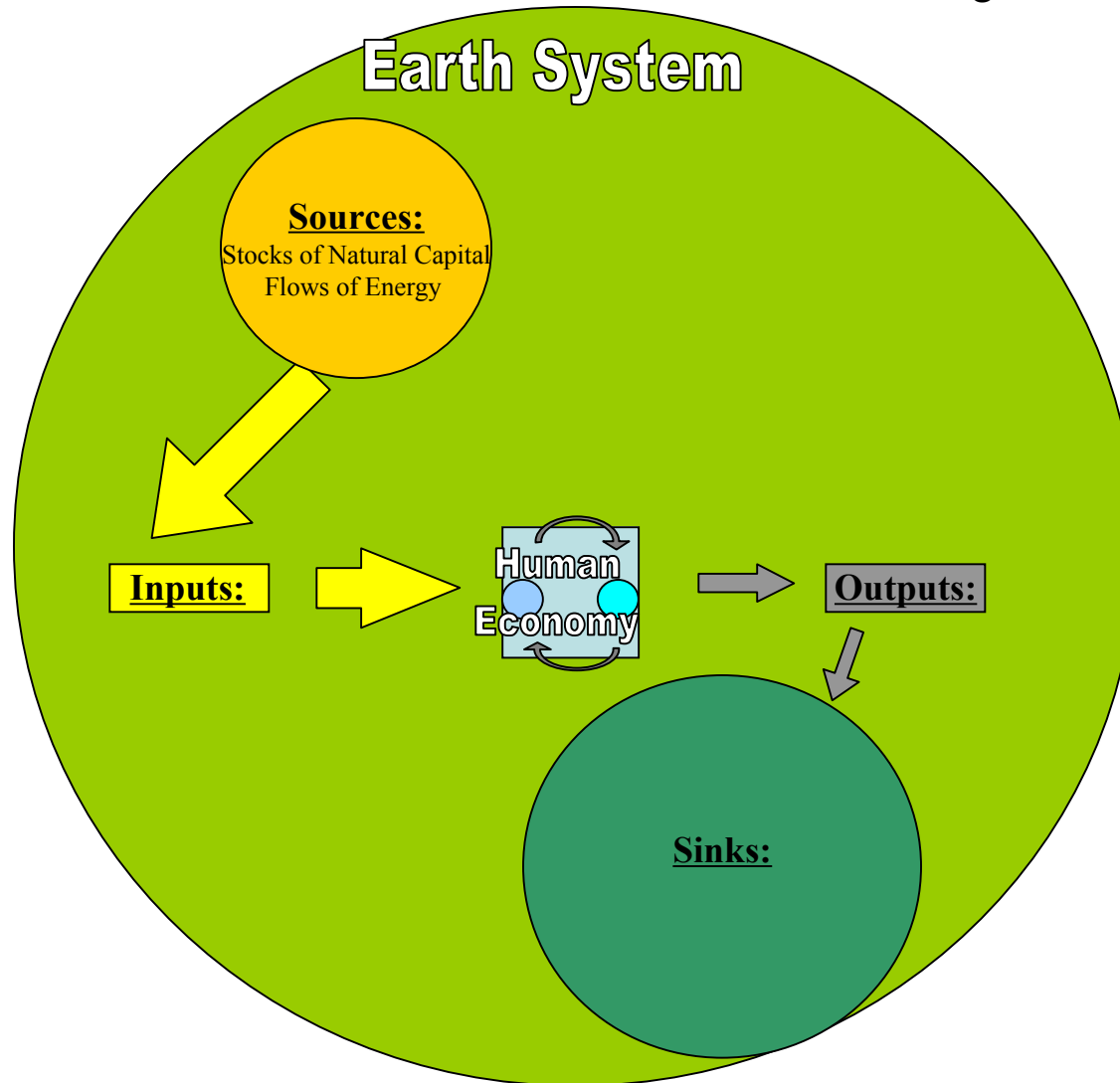
# A More **Realistic** Ecological Economic Model

- The **INPUTS** come from SOURCES in the Earth System
- The **OUTPUTS** go to SINKS in the Earth System

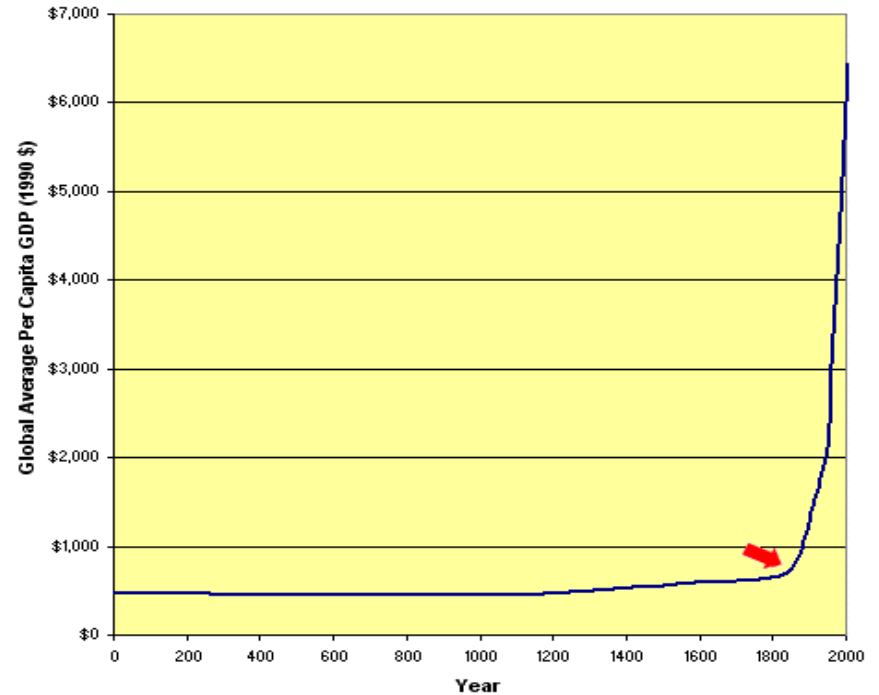
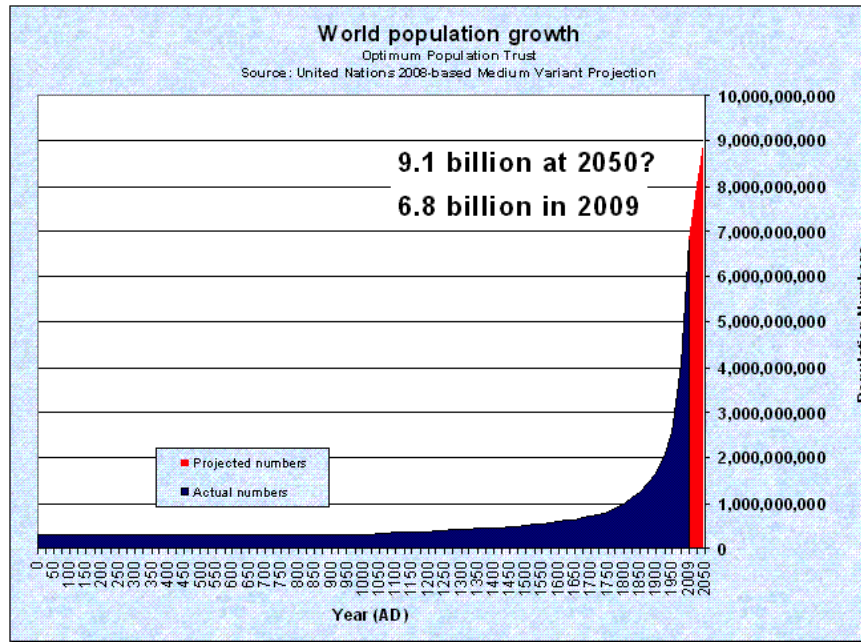


For much of history, we lived in an “**Empty World**”

- Throughout much of human history, the **Human Economy** was small relative to the **Earth System**, so it had **small 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 skyrocketed,

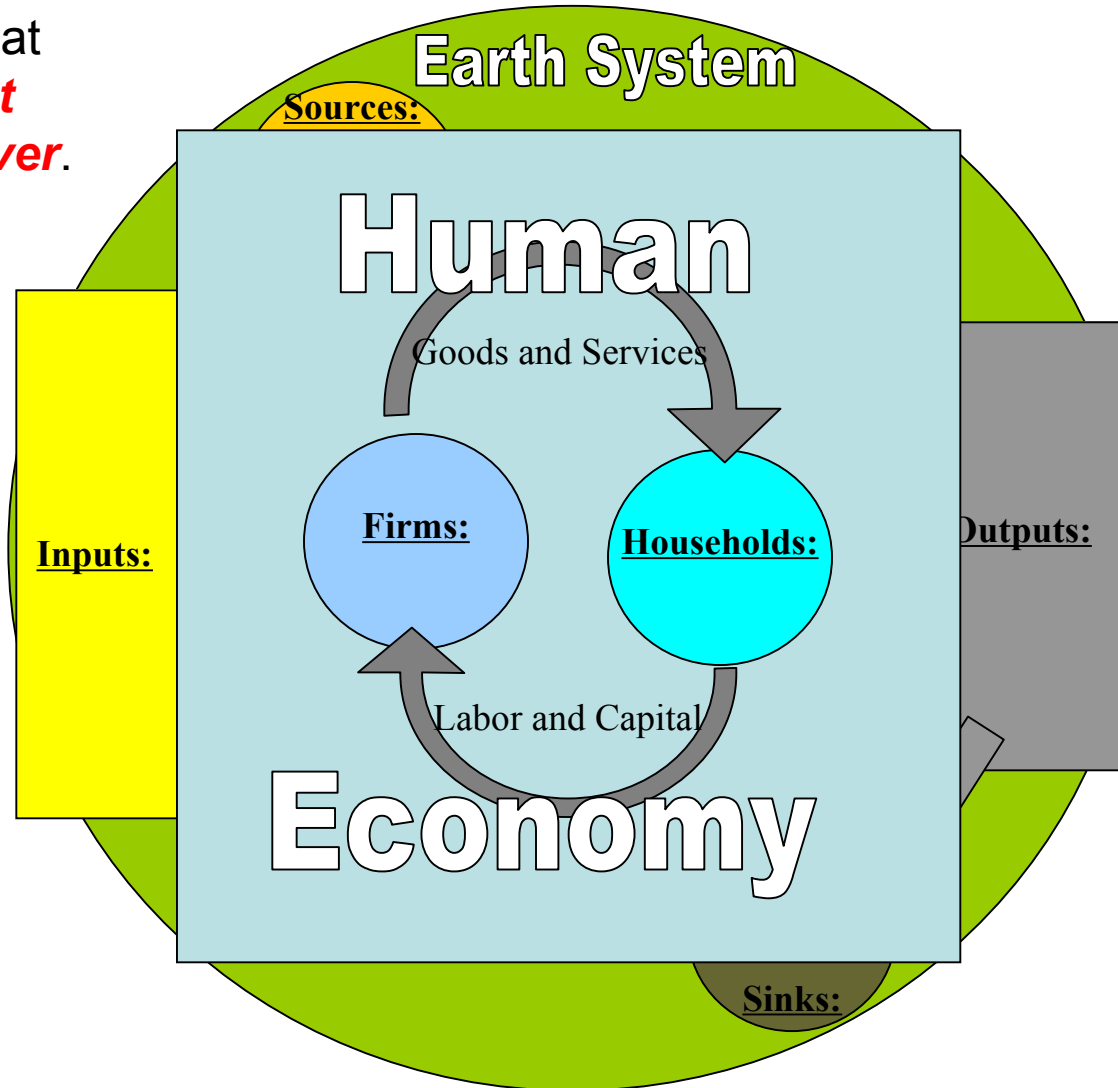


and the **total impact** is their **product!**  
(population) x (output per capita)

**Technology** allows more efficient production,  
but also much **greater consumption!**

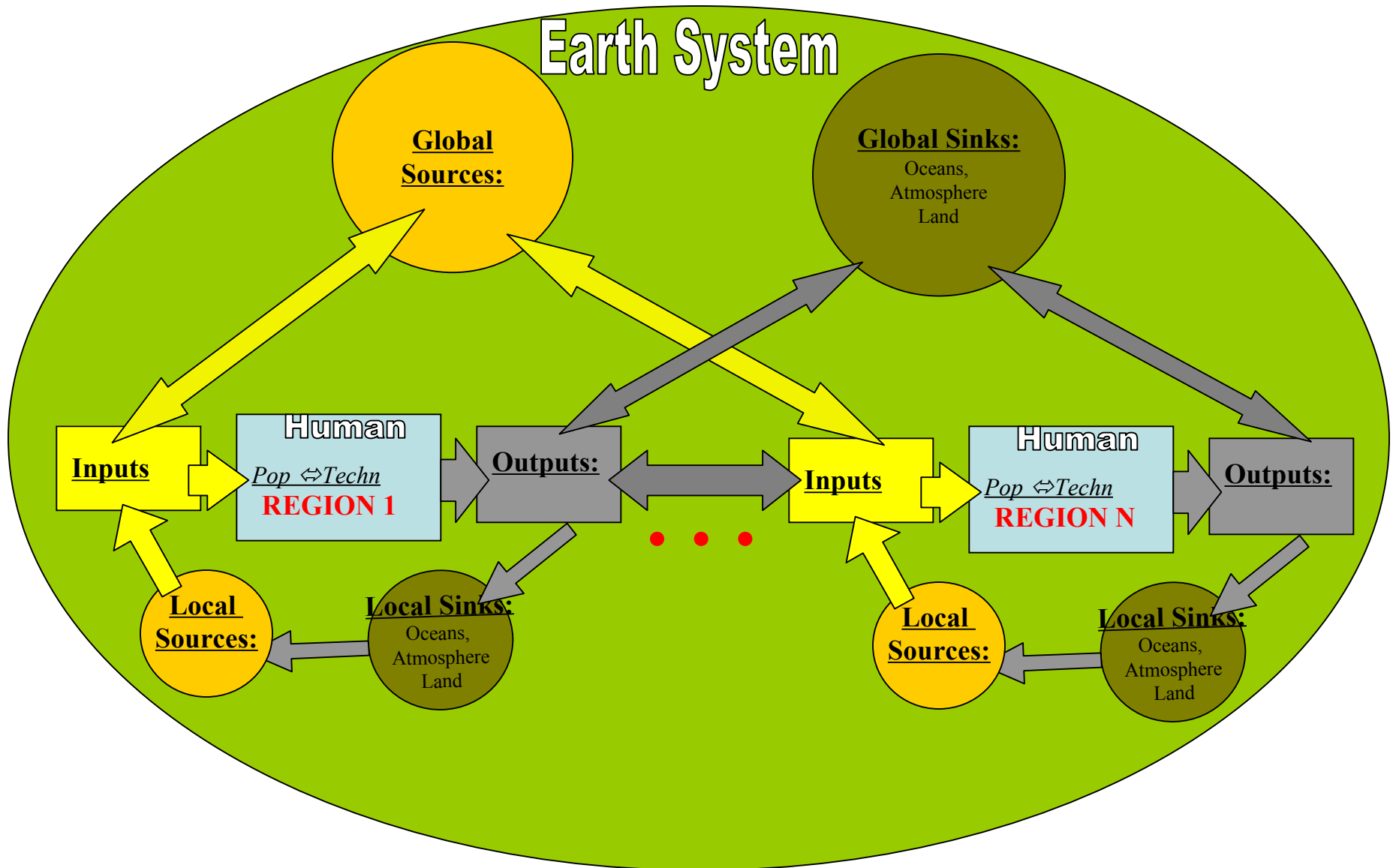
# “Full World” Ecological Economic Model

- 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  $\Leftrightarrow$  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  $\Leftrightarrow$  pollution, emissions
- Resource depletion  $\Leftrightarrow$  trade, resource conflicts
- Population  $\Leftrightarrow$  CO2 emissions  $\Leftrightarrow$  climate change  $\Leftrightarrow$  vulnerability

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

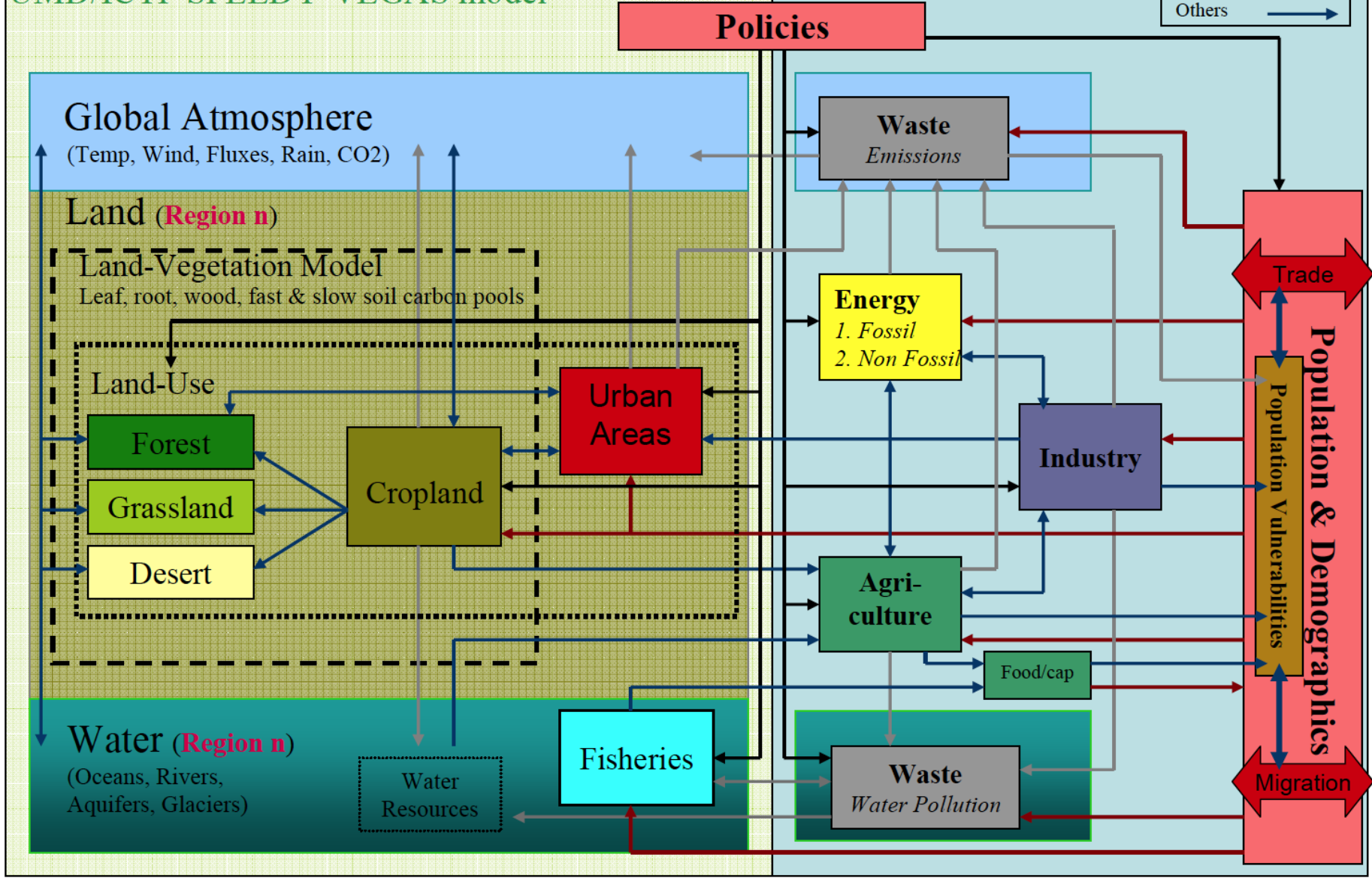
# Prototype Earth System - Human System Feedbacks

## Earth System

UMD/ICTP SPEEDY-VEGAS model

## Human System (Region n)

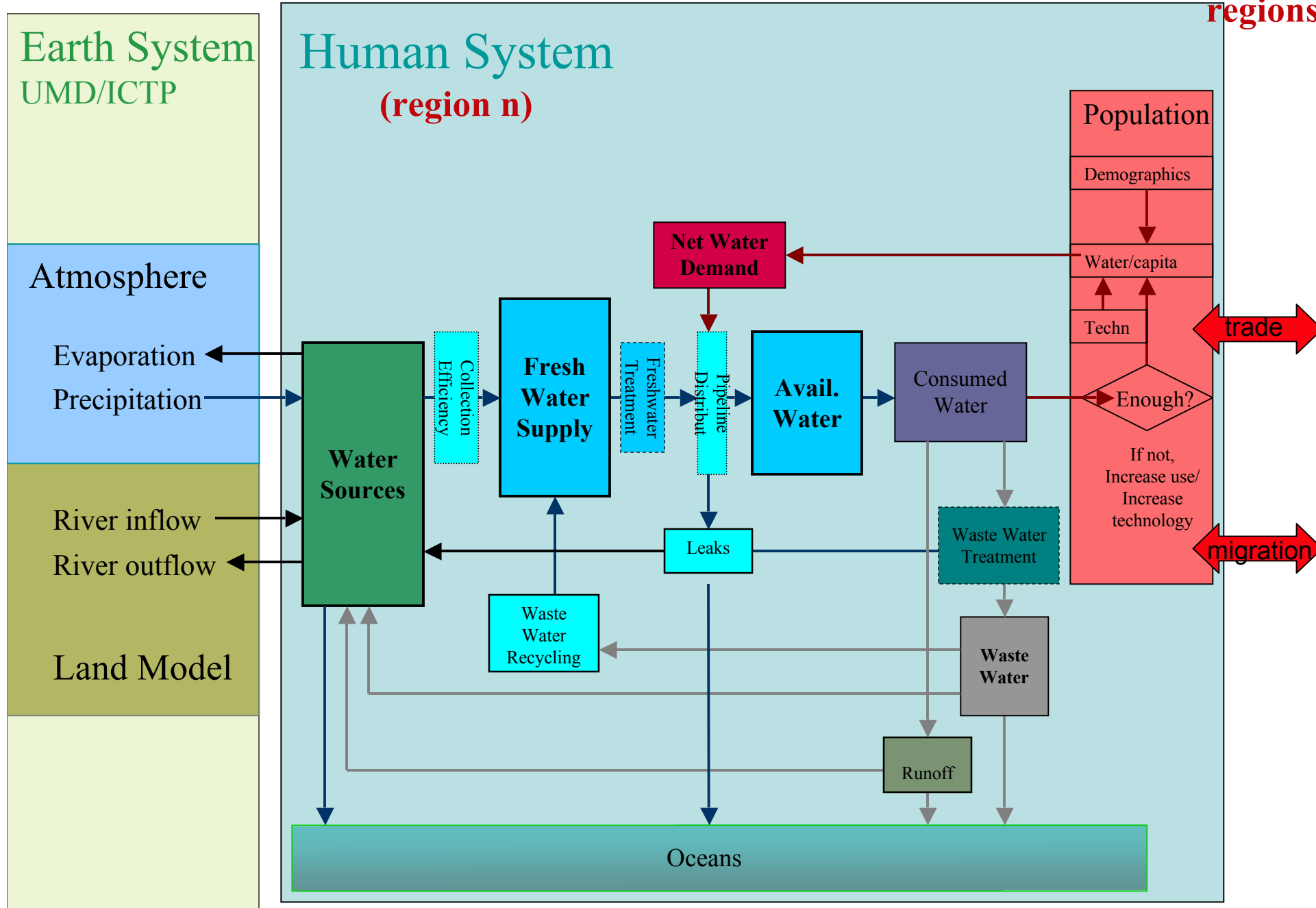
Effects and Feedbacks	
Policies	→ (Black arrow)
Population	→ (Red arrow)
Waste	→ (Grey arrow)
Others	→ (Blue arrow)





# Coupled Simple Water Submodel (SIWA)

Other regions





## Population control is both feasible and effective.

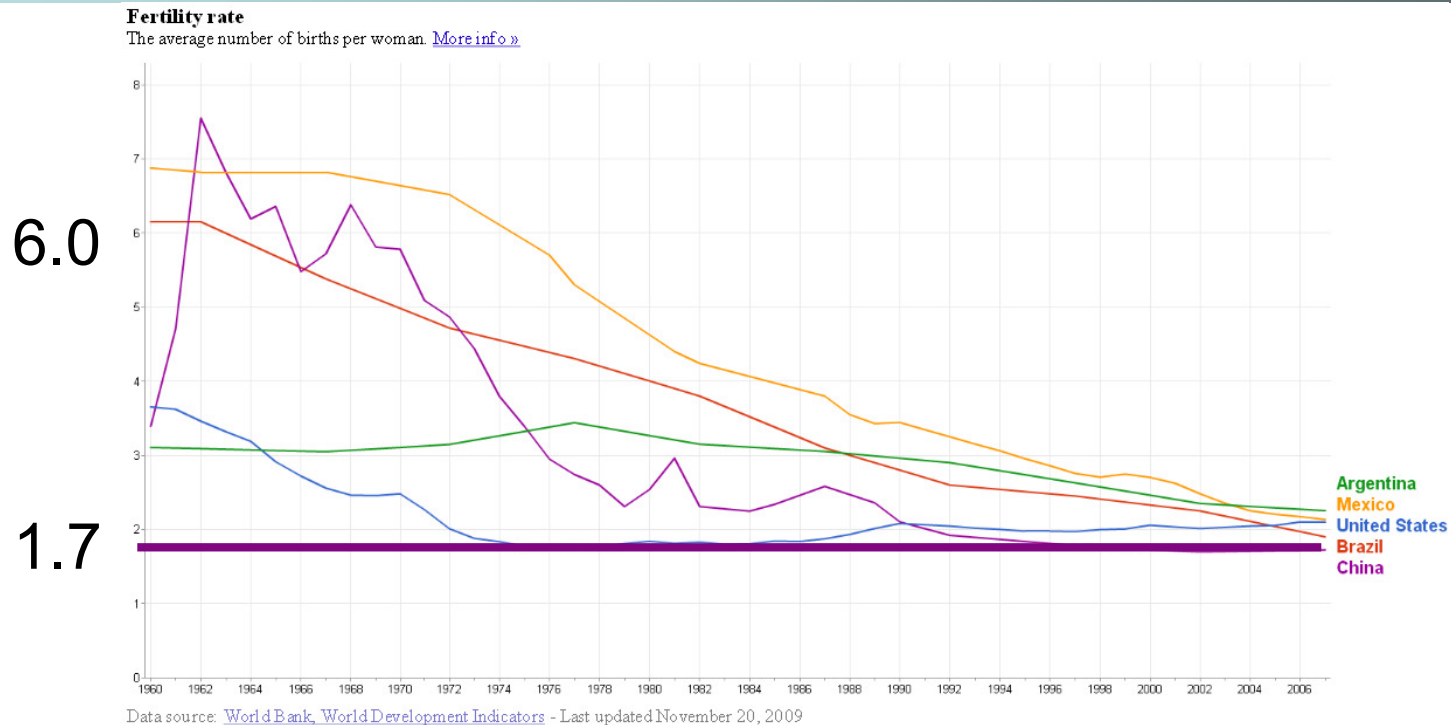
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In stark terms,

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.**

# Can government policies be effective?



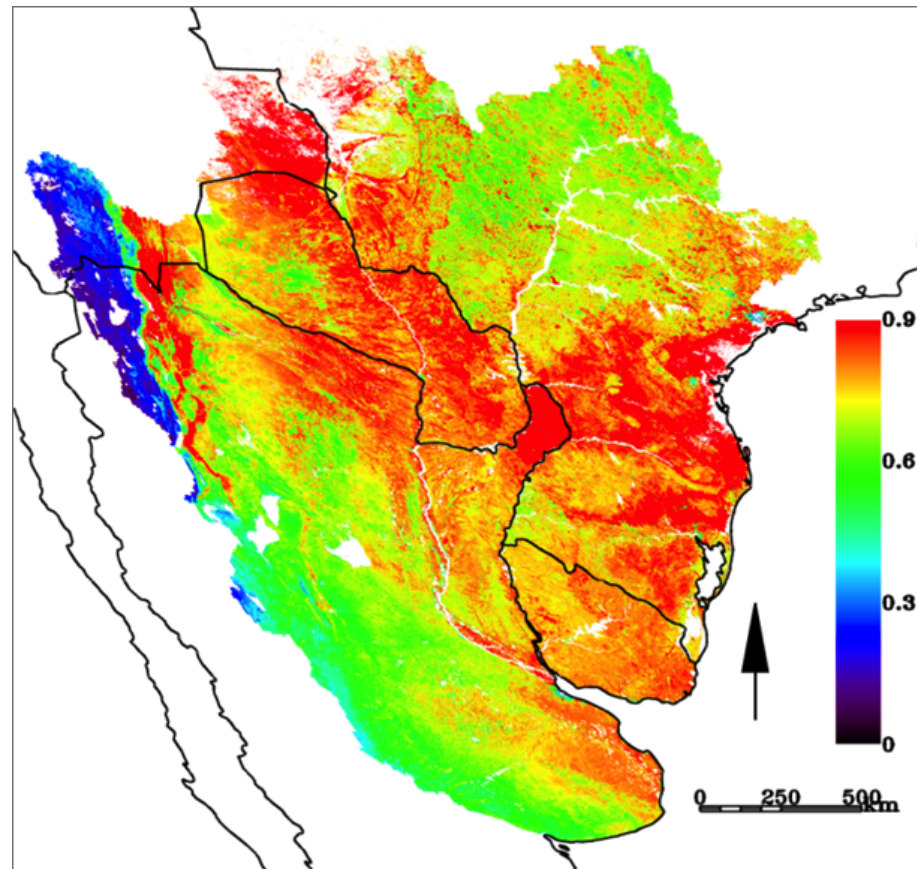
In the 1960's **Argentina's** fertility rate was **less than half** of **Brazil** and **Mexico**.

The governments in Brazil and Mexico instituted family planning policies to lower population growth, Argentina did not.

**Brazil and Mexico have now much lower fertility rates than Argentina.**

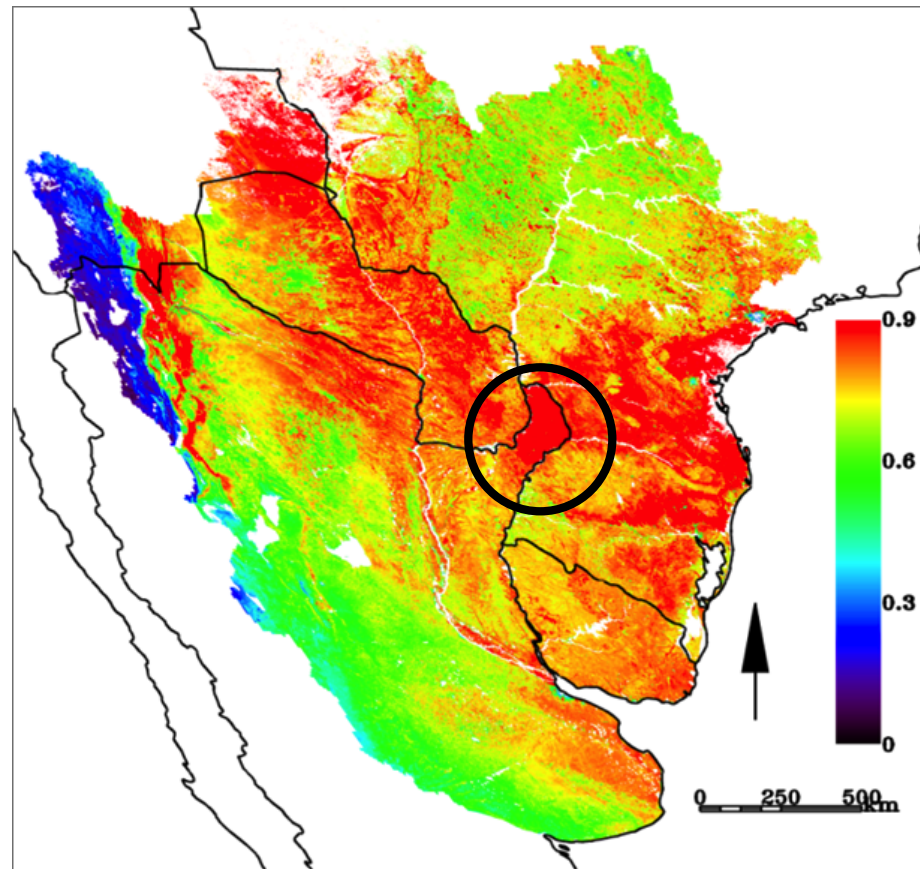
**Government policies matter!**

# Can government policies be effective?



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

# Can we use nature sustainably?



The red area in the circle is in the **province of Misiones**, Argentina, that **protects the forest**.  
Compare Misiones with Brazil, Paraguay and the rest of Argentina!

# Forest policy in Japan (Edo period)

- During the Edo period (17th and 18th centuries) in Japan:
- Increased demand for timber resources for construction, shipbuilding and fuel had led to **widespread deforestation**, which resulted in **floods, soil erosion and forest fires**.
- In response, **beginning around 1666**, the Tokugawa government developed an **advanced forest management** policy.
- **Instituted a policy to reduce logging and increase tree planting.**
- The government had to authorize the use of trees.
- 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.
- By the 18th century, Japan had developed detailed scientific knowledge about silviculture and plantation forestry.
- **With these policies, Japan averted a deforestation collapse.**

# “Kerala model”: a low-wealth state, with high social development and welfare

- Kerala's Human Development Index rating is the highest in India.  
**Life expectancy** at birth is 75 years compared to 64 in India and 77 in the US.  
**Literacy rate** is 91%, the highest in India, compared to India's 65%.
- How did they do it with just \$300 GDP?
  - 1.70 children born per woman (2001 Census): same as China
  - 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 policies, it can be done!**

# Human and Nature Dynamical model (HANDY) with Rich and Poor: for thought experiments

Just 4 equations!

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

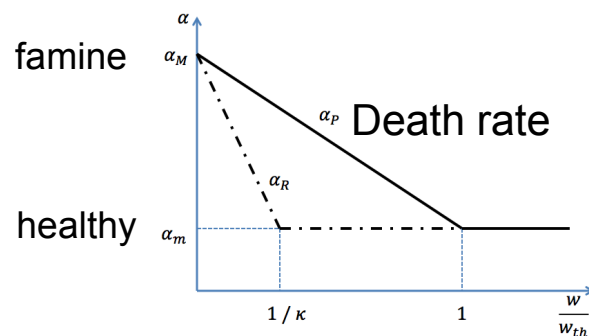
Nature equation: (only the poor produce!)

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

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

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

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



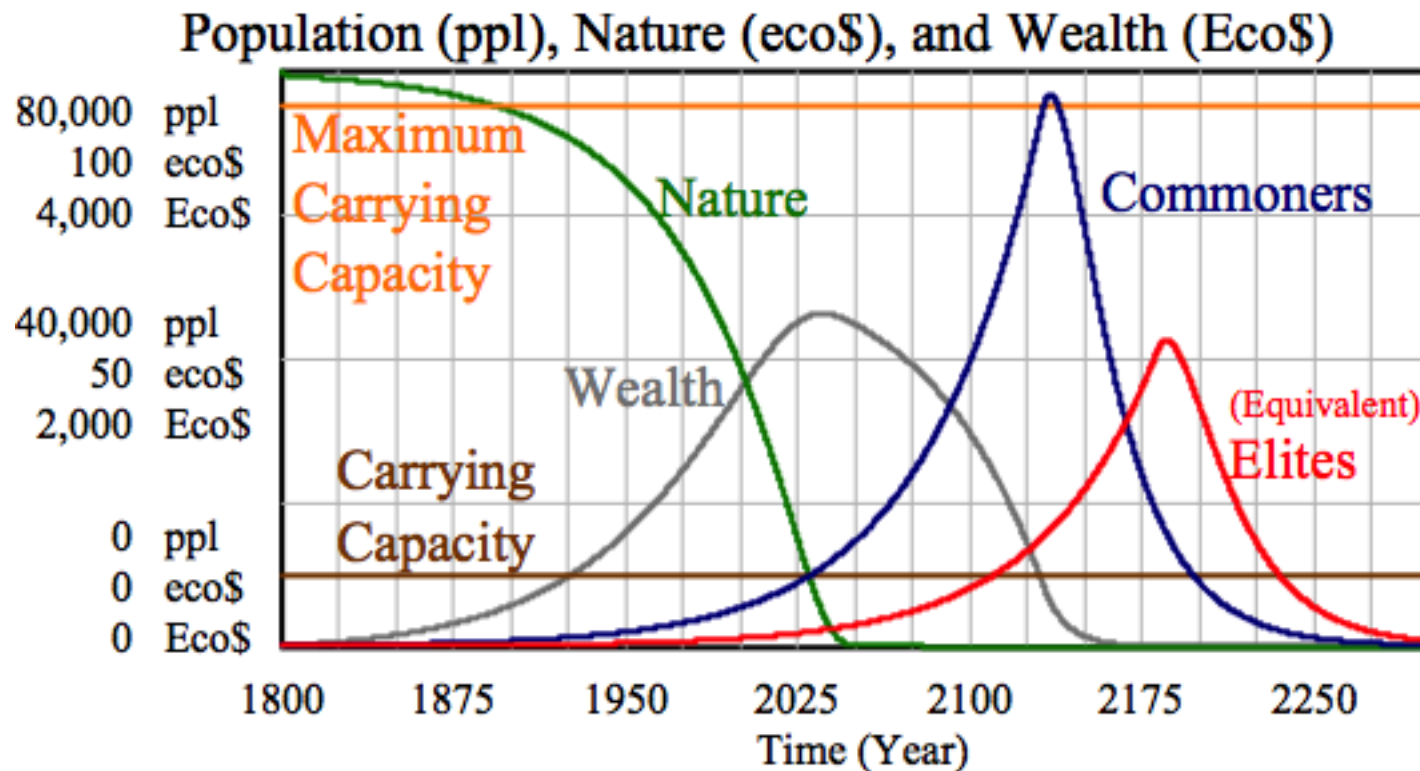
$$\dot{x}_P = -\alpha_P x_P + \beta_P x_P$$

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

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.



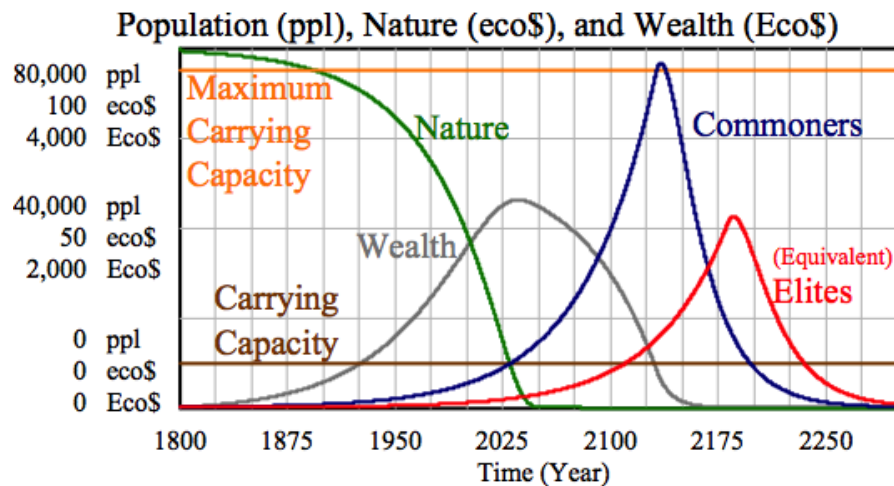
# Human and Nature Dynamical model (HANDY) with Rich and Poor: a thought experiment



If the natural resources are used as if they were infinite, and the top 1% has as much wealth as the bottom 99%, the system collapses.



# Human and Nature Dynamical model (HANDY) with Rich and Poor: a thought experiment

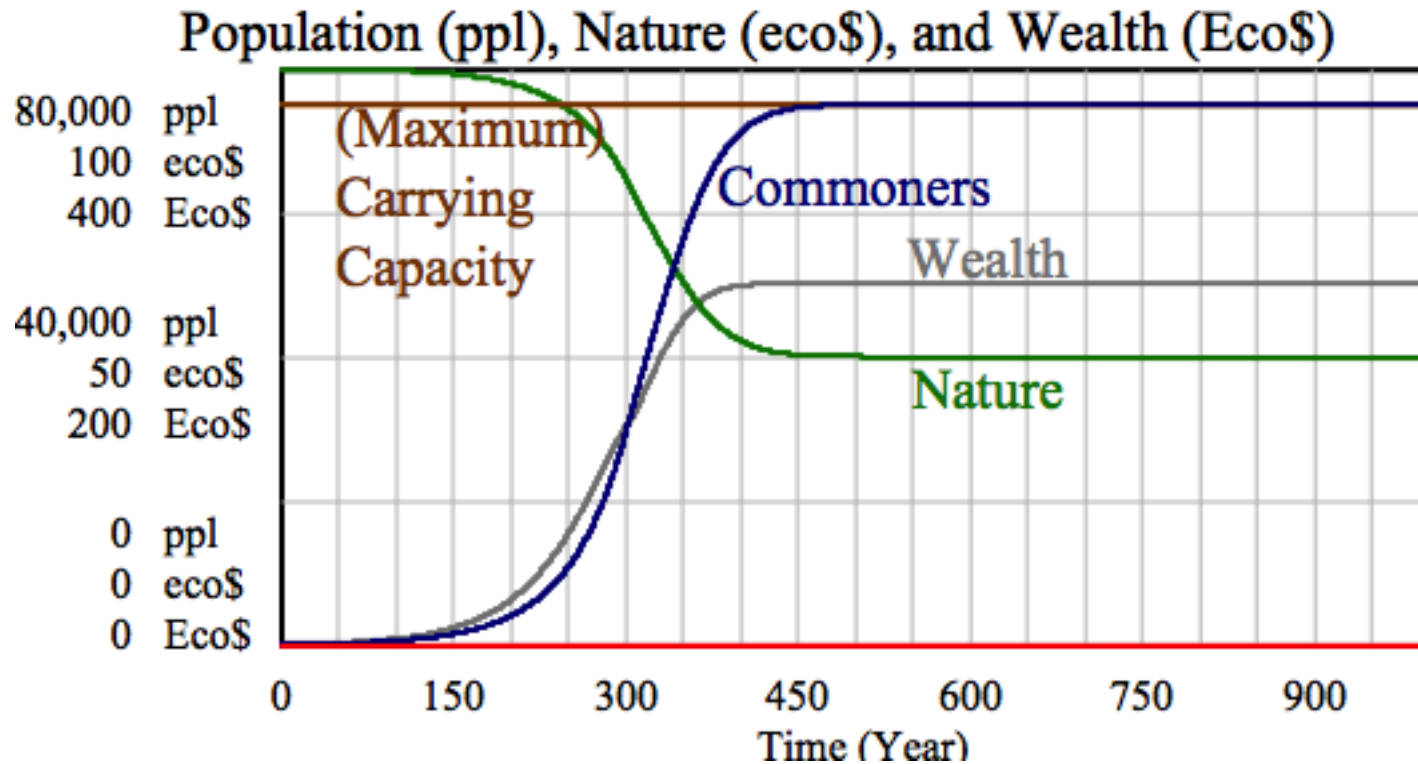


- Nature declines with population growth
- Using their wealth, the Rich (Elites) can shield themselves from environmental degradation, which first affects the Commoners
- Eventually it reaches the upper classes as well, when it is too late to take preventive measures

In this simple model, by 2020 the population surpasses the sustainable carrying capacity of the planet, and is drawing down the accumulated capital to survive.

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!).

# Can we survive? **Yes!**



but only if we reduce:

- economic stratification
- depletion per capita &
- population growth!

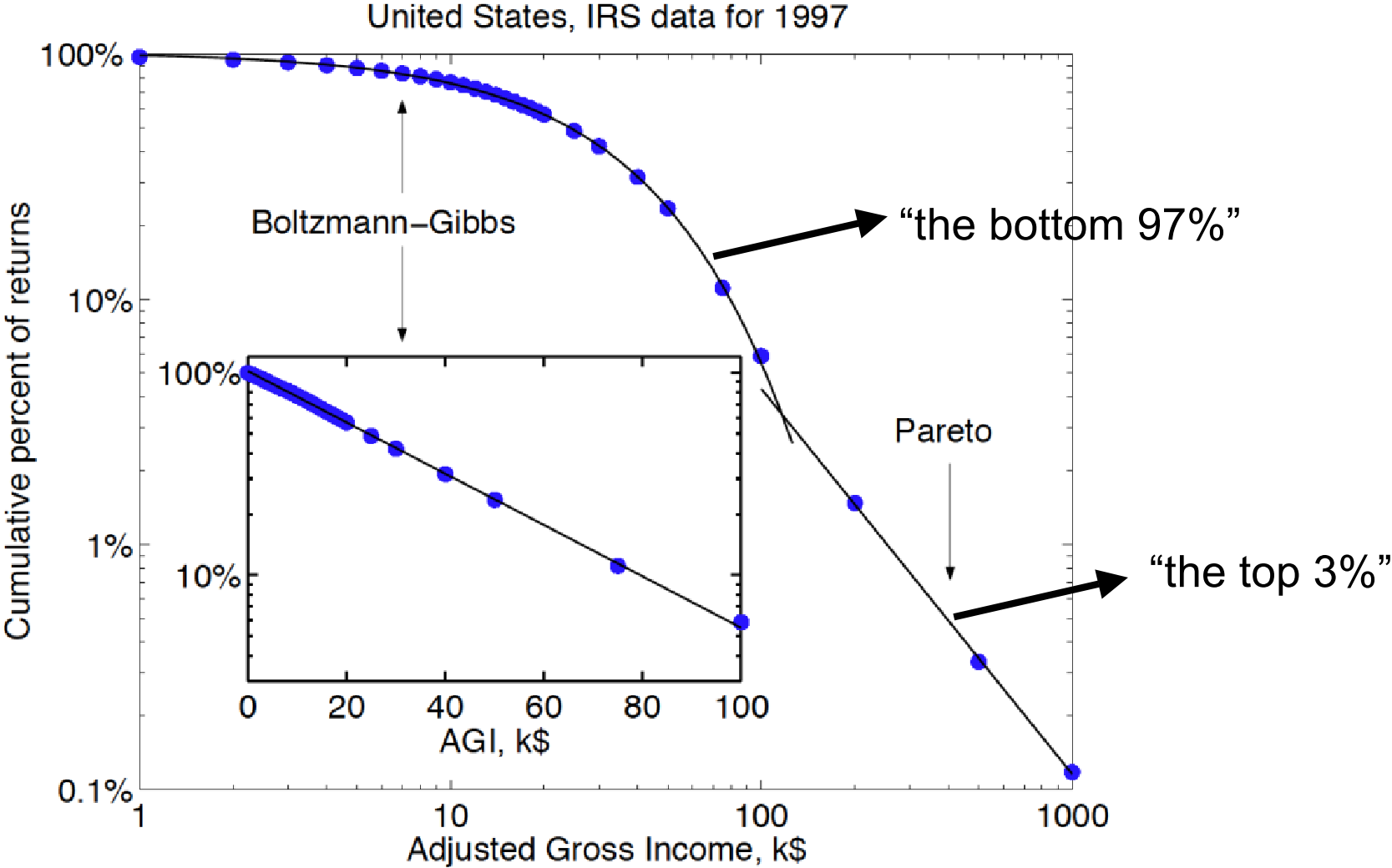
**Carrying capacity:** the population that nature can sustain forever.

If we use nature in a sustainable way, and consume only as much as nature can regrow, we can reach a good state of equilibrium

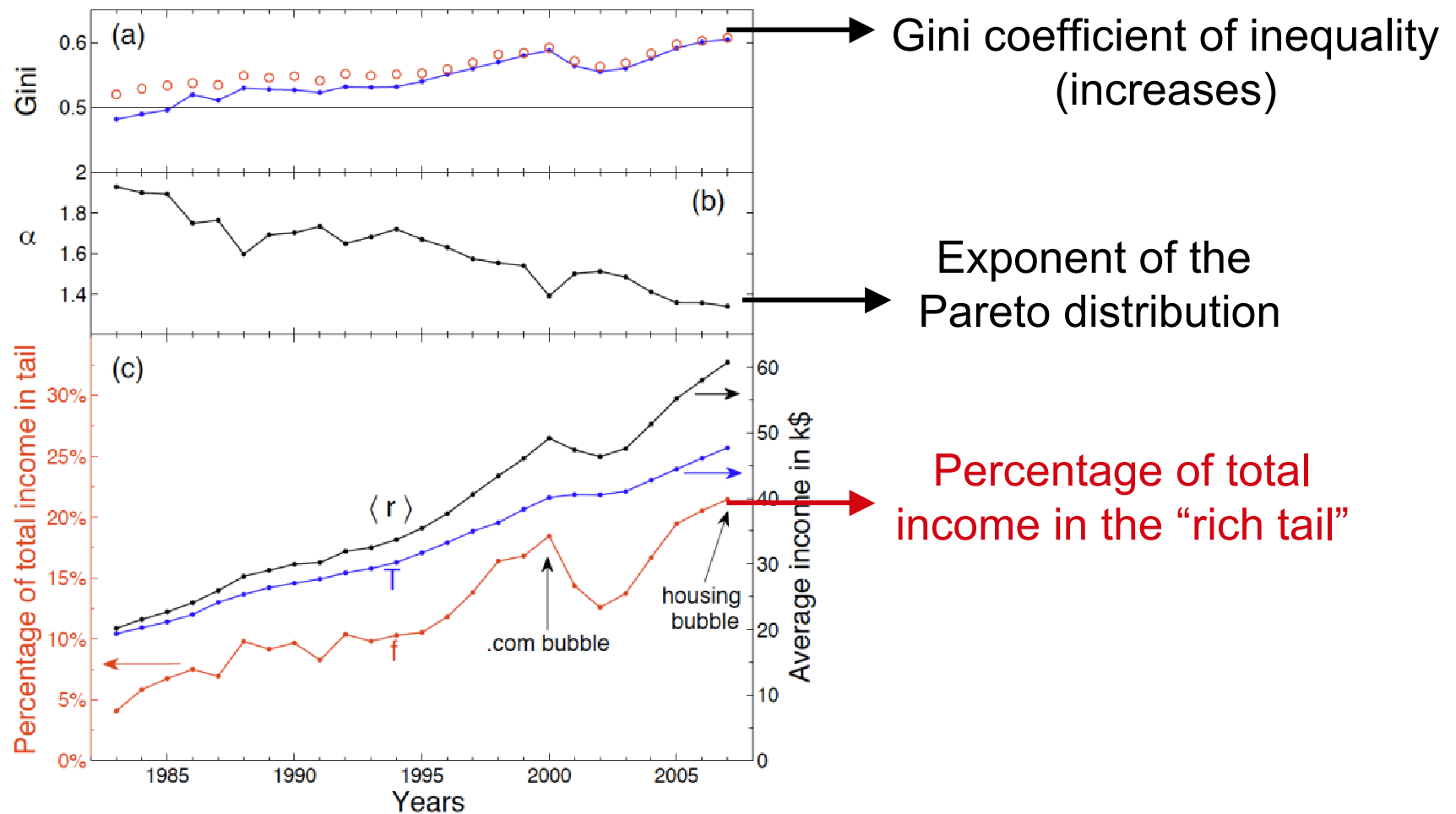
# Analogy between atomic distribution of energy and the distribution of income (Yakovenko et al., 2000, ...)

- 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 (i.e., people), 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 2008 of IRS data shows that the inequality increased and **all the growth went to the top 3%**



# Summary

- We are using up in 200+ years the fossil fuels that nature accumulated over millions of years!
- Climate change is due to **Total emissions** = (emissions per capita) x (number of people)
- The use of fossil fuels for agriculture increased food production and population after 1950.
- Land-use change also produces climate change.
- The way we are growing is not sustainable.
- We need to reduce growth and consume sustainably, since the Earth has a finite carrying capacity.
- Renewable energy (solar, wind, geothermal) is sustainable.
- Social inequity accelerates societal collapse