Society as a Complex System

Can we find a safe and just operating space for humanity?

John Finnigan

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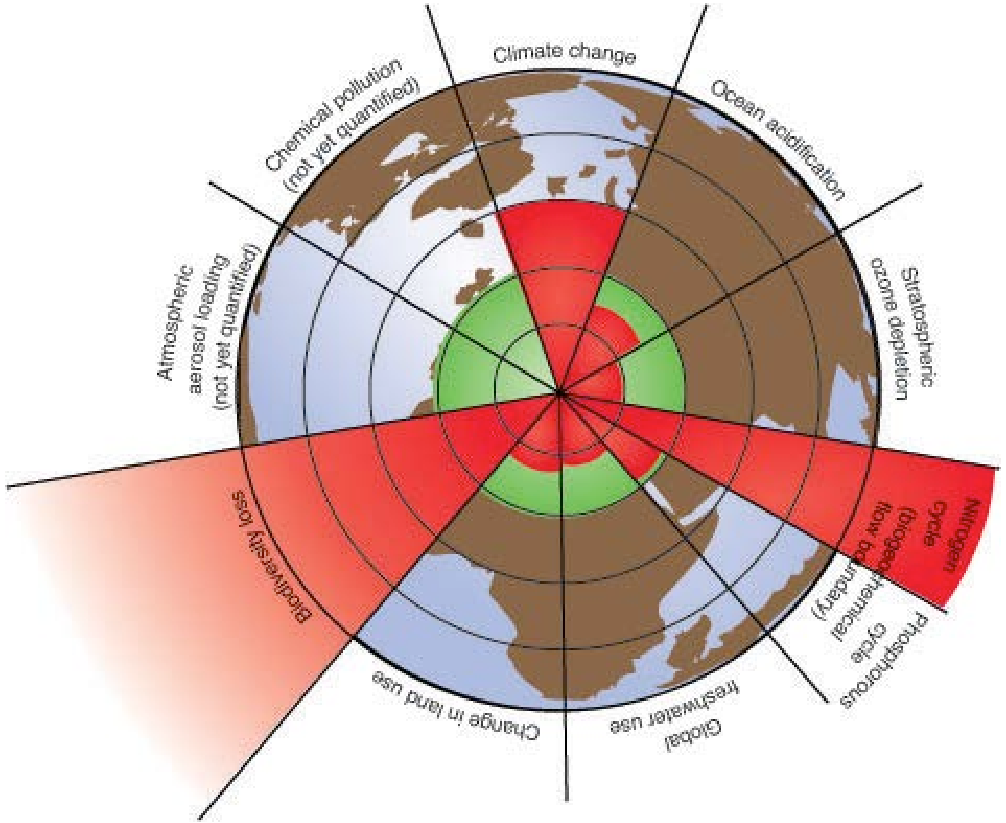
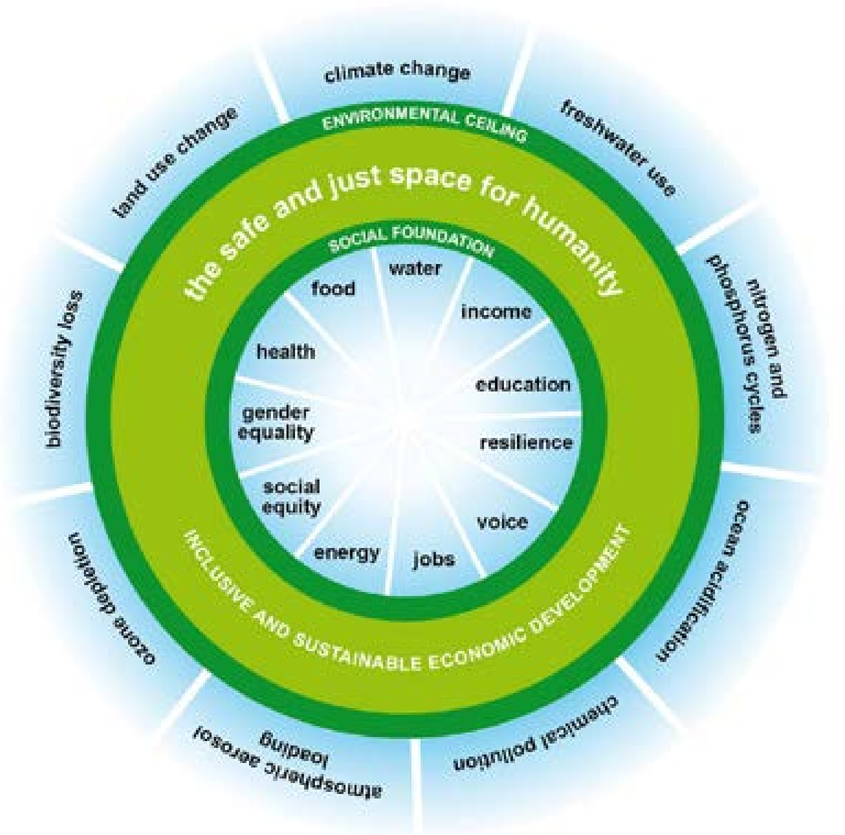
What are the Sustainable Development Goals?

Biophysical Planetary Boundaries-Staying in the Holocene



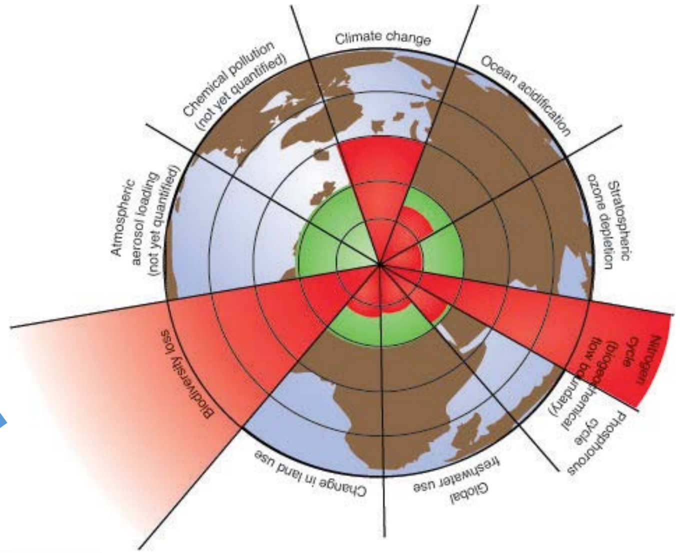
Planetary Boundaries; defining a safe operating space for humanity. Rockstrom et al., (2009)

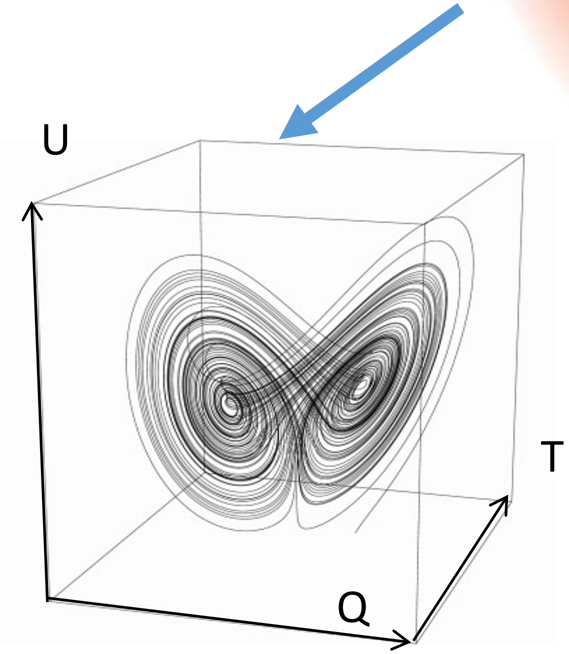
Social Planetary Boundaries- can we live within the doughnut?

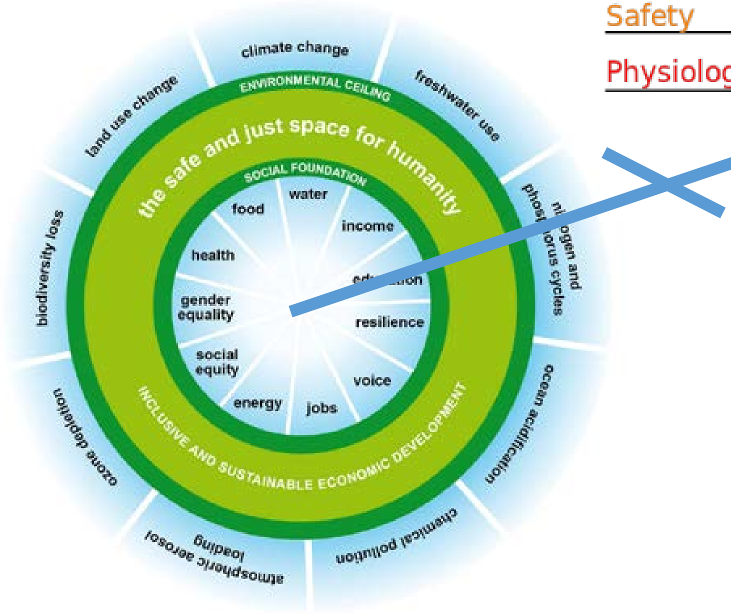


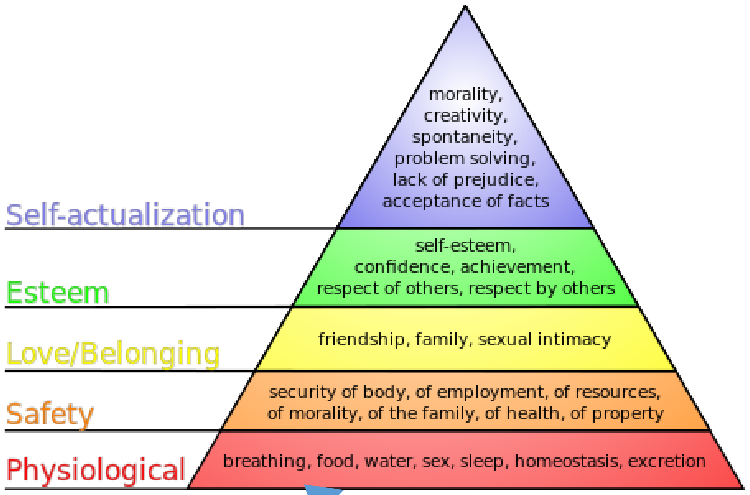
Raworth, K. (2012) A safe and just space for humanity. Oxfam Discussion paper, www.oxfam.org.

These biophysical and social boundaries are fundamentally different









What is a complex system?

Two essential characteristics distinguish complex systems from those that are merely fiendishly complicated

- **Emergence**: the whole is is greater that the sum of the parts

- **Self-organisation:** the system tends *spontaneously* towards some level of ordered organization

Emergence

Many underlying *microstates* of the system correspond to the same emergent *macrostate*

Physics-symmetry breaking

Biology-termite mounds, ant colonies

Social systems-bands, tribes, empires, currency, economy, religion





Self organization-Attractors

This just means that there are some preferred states that the system would like to be in and its internal workings will drive it towards these configurations.

Physical systems will often 'seek' configurations with the lowest energy

It takes extra energy to move the system out of these low energy configurations-eg. add heat and the snowflakes melt and become just a bunch of disordered water molecules

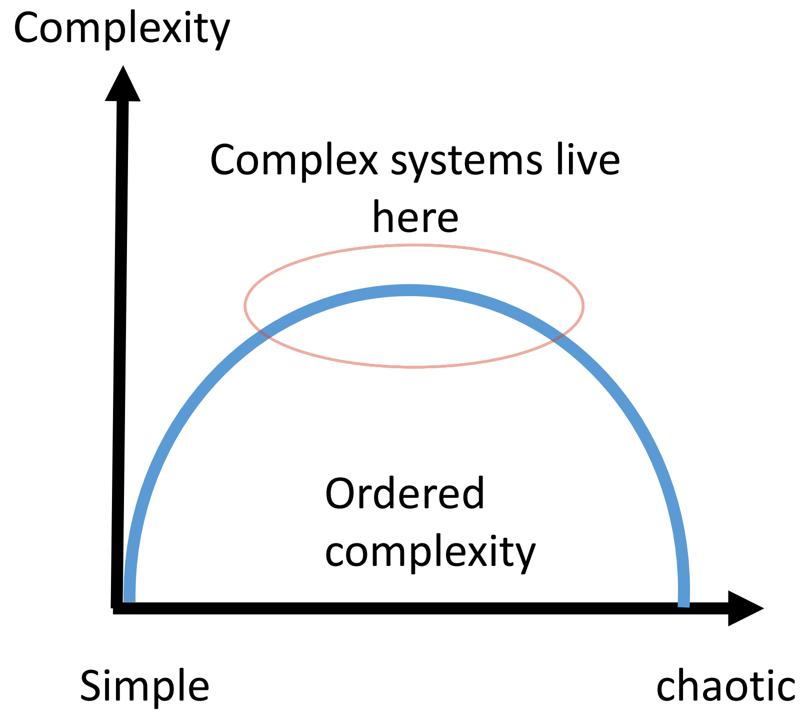
Self organization-Attractors

Villages, towns and cities are attractors in the case of people producing a surplus of food (humankind after the neolithic revolution) and solving the problem of how to live on the landscape. They provide cooperative labour, security against predation, access to specialists etc., etc.

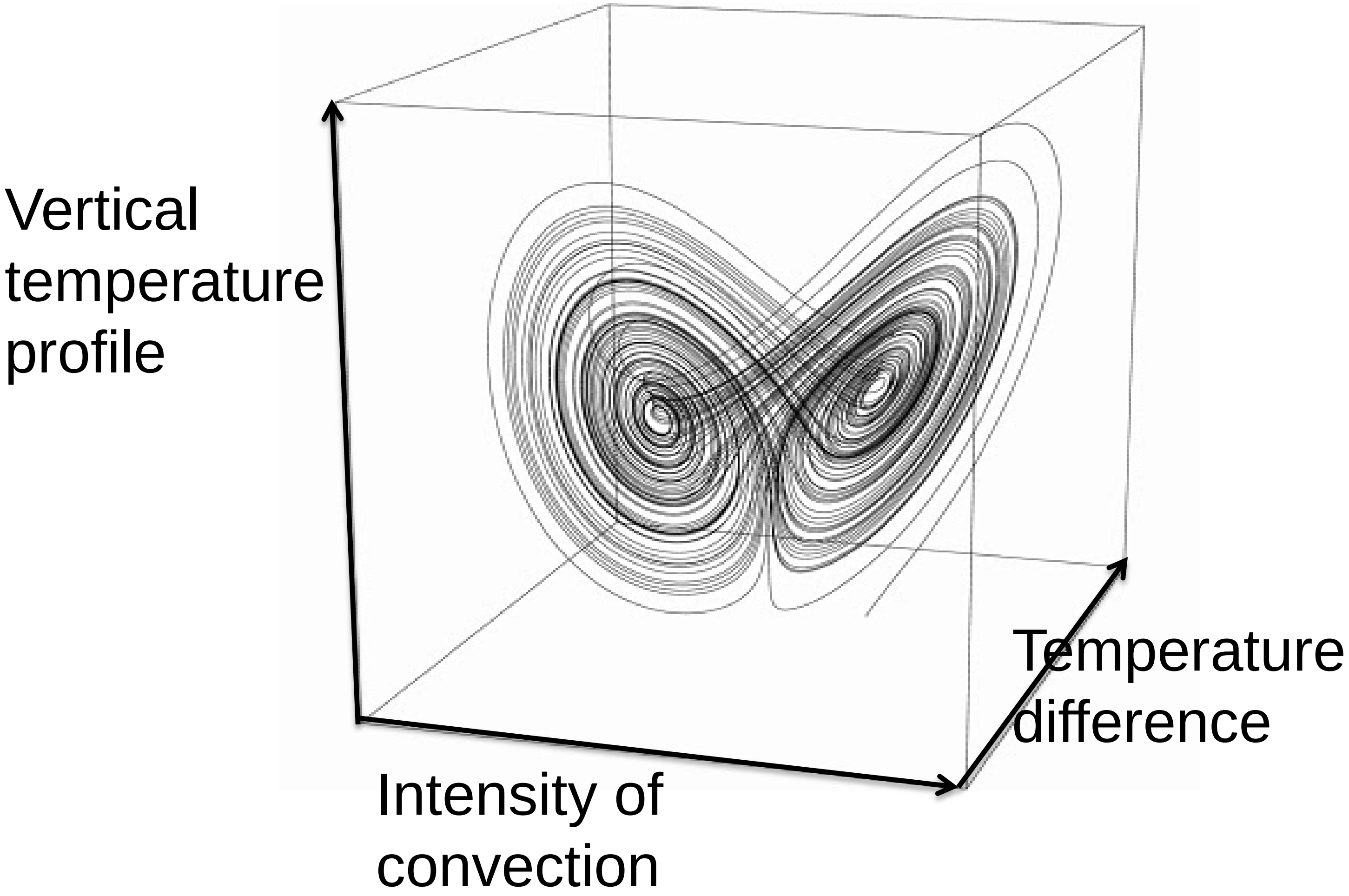
The great paired experiment resulted in almost all the same solutions to the problems of living in a society producing food surpluses:

- Political systems: Tribes to empires
- Urbanisation
- Economy
- Religion

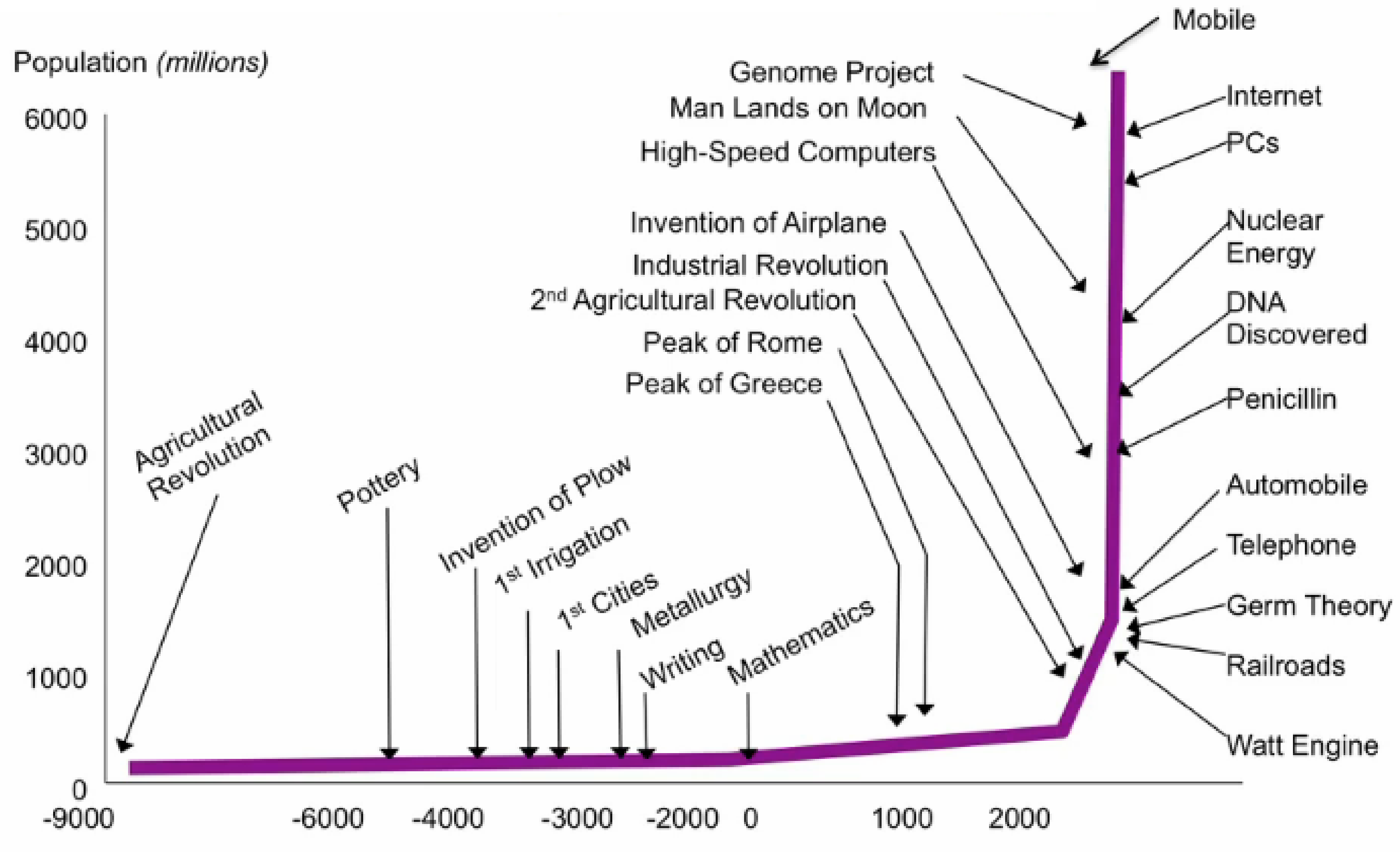
Complexity versus Chaos



The Lorentz attractor
Convection in a thin layer of fluid:



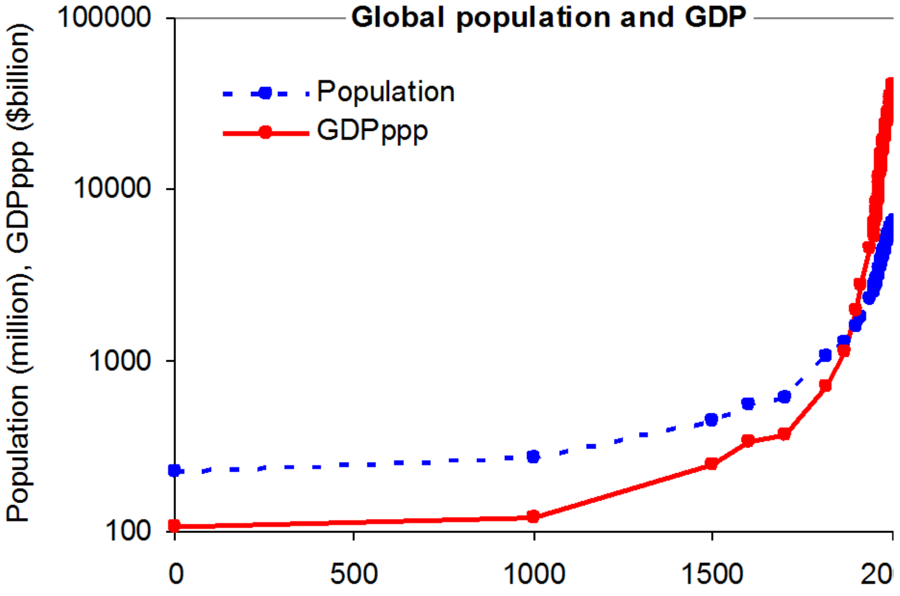
History of the world in two graphs: 1, Population and technology

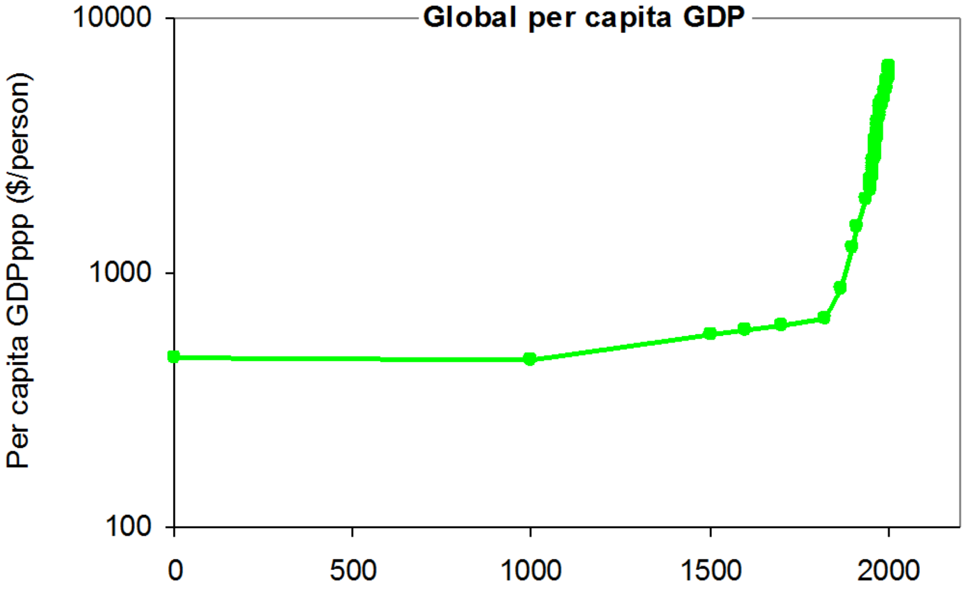


Source: Milken Institute, Robert Fogel/University of Chicago

History of the world in two graphs: 2, Population and wealth

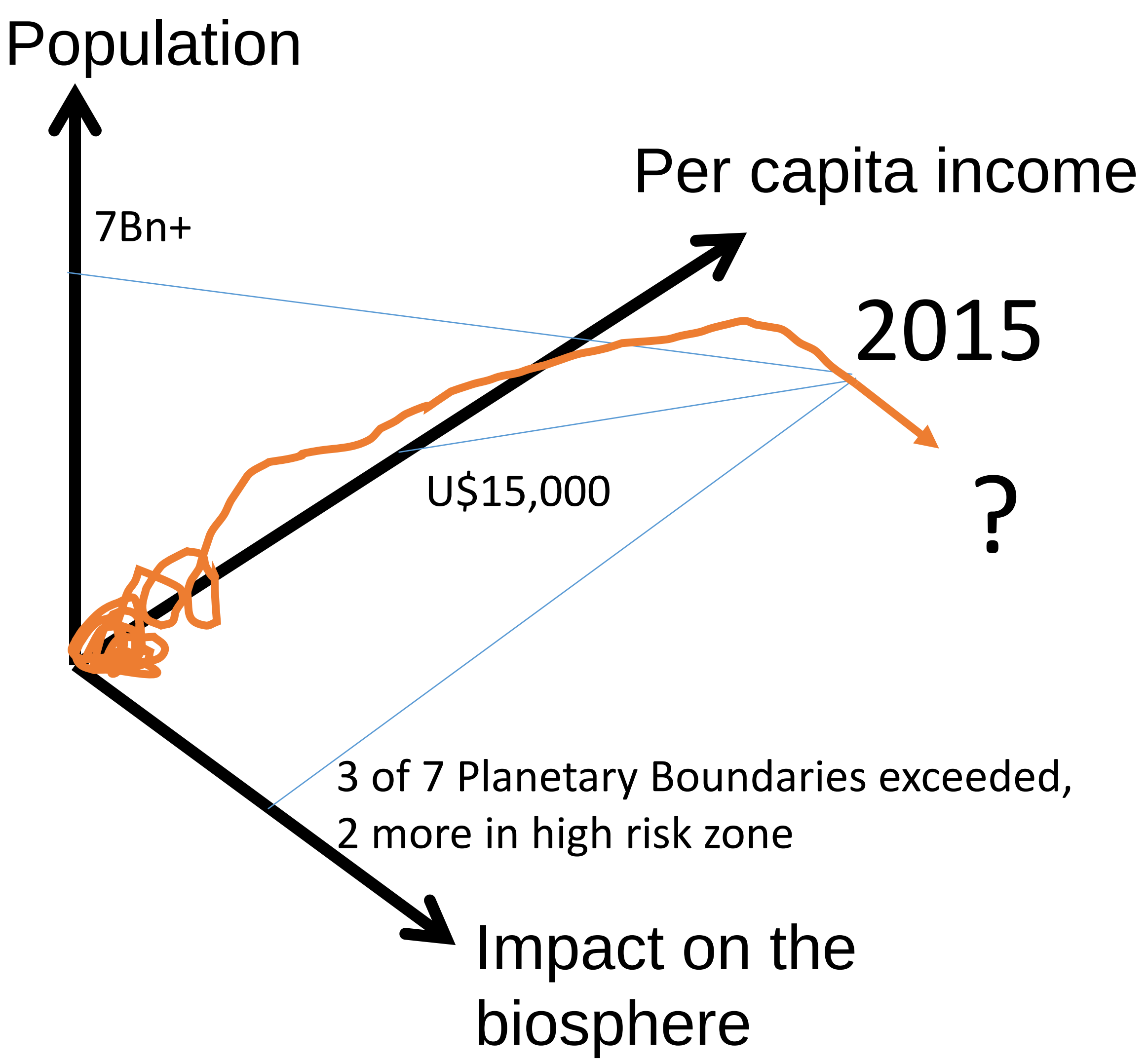
More-than-exponential growth in population through the Industrial Revolution was accompanied by even more rapid growth in wealth and, critically, in per capita wealth



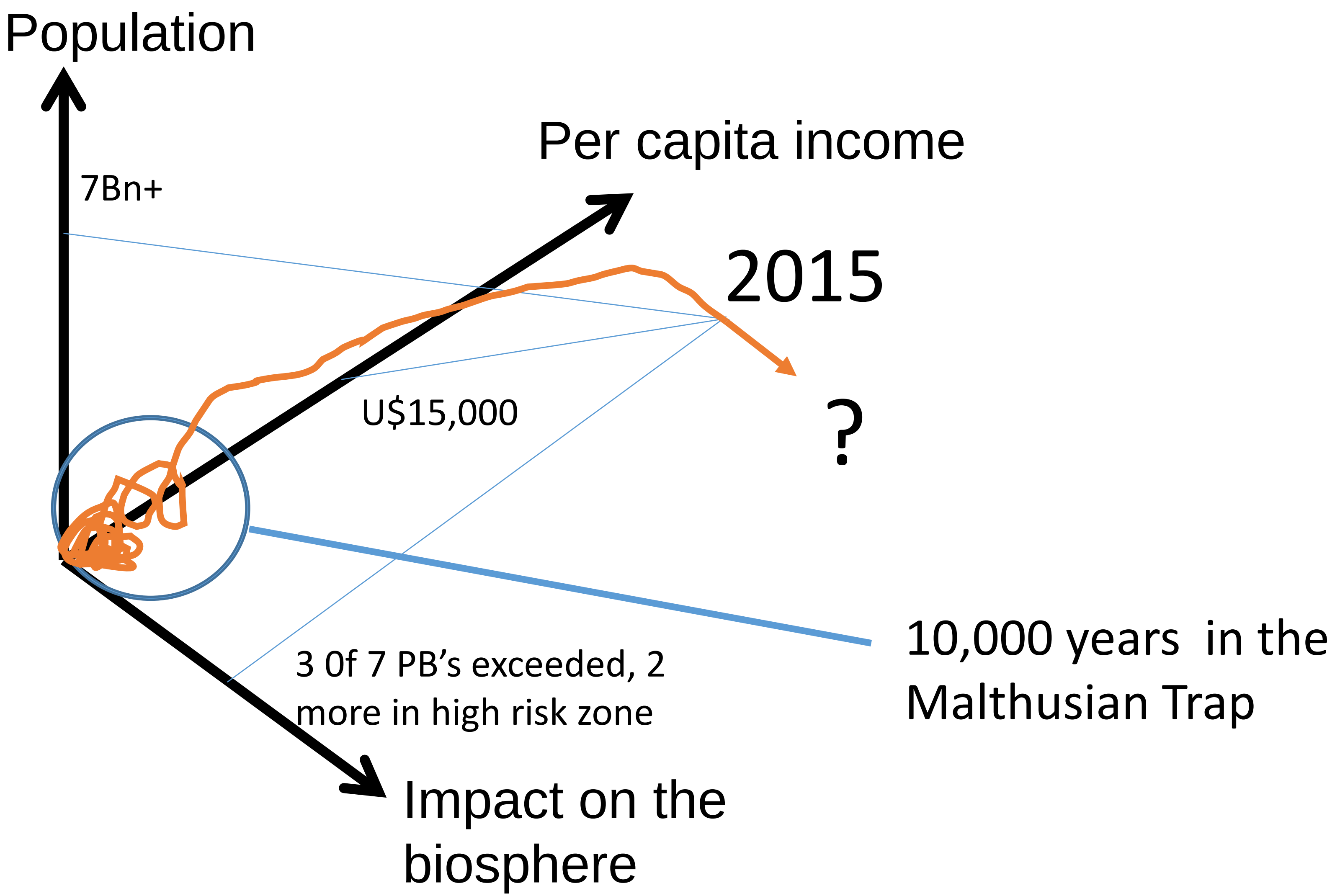


Figures from Raupach et al. (2012); data from Maddison (2010)

Attractors in the Human-Earth System



Attractors in the Human-Earth System



The Malthusian trap-a societal attractor for most of human history

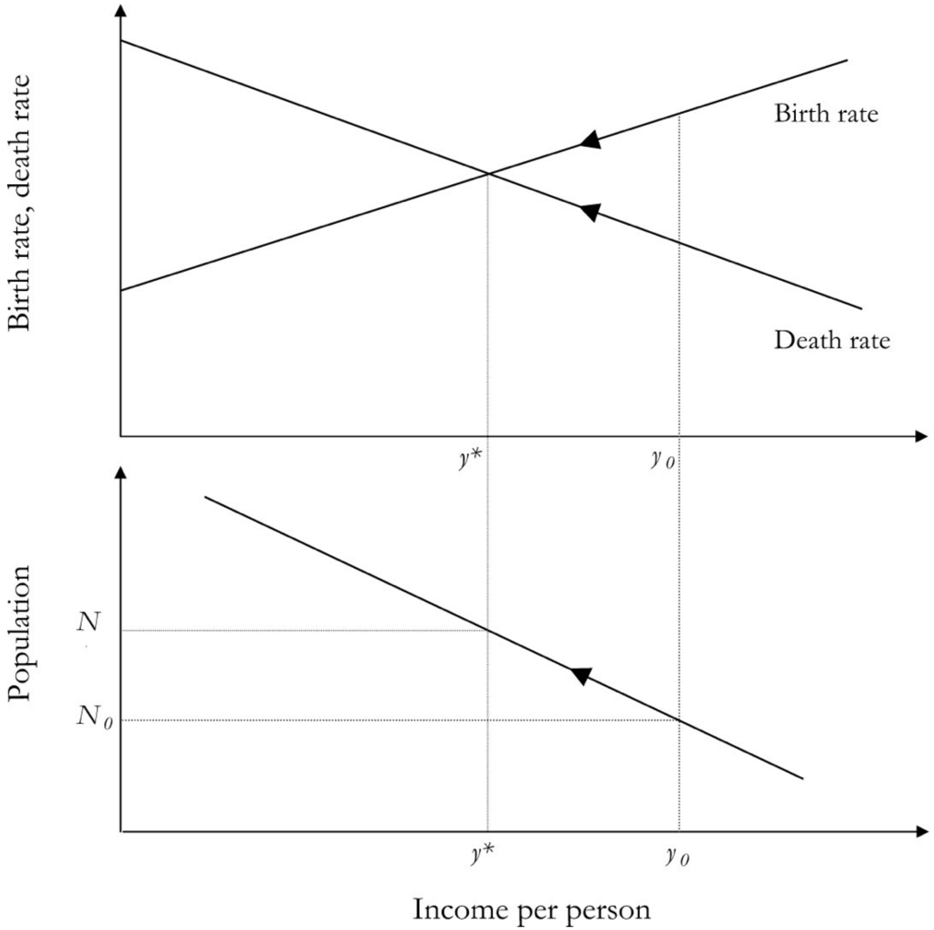
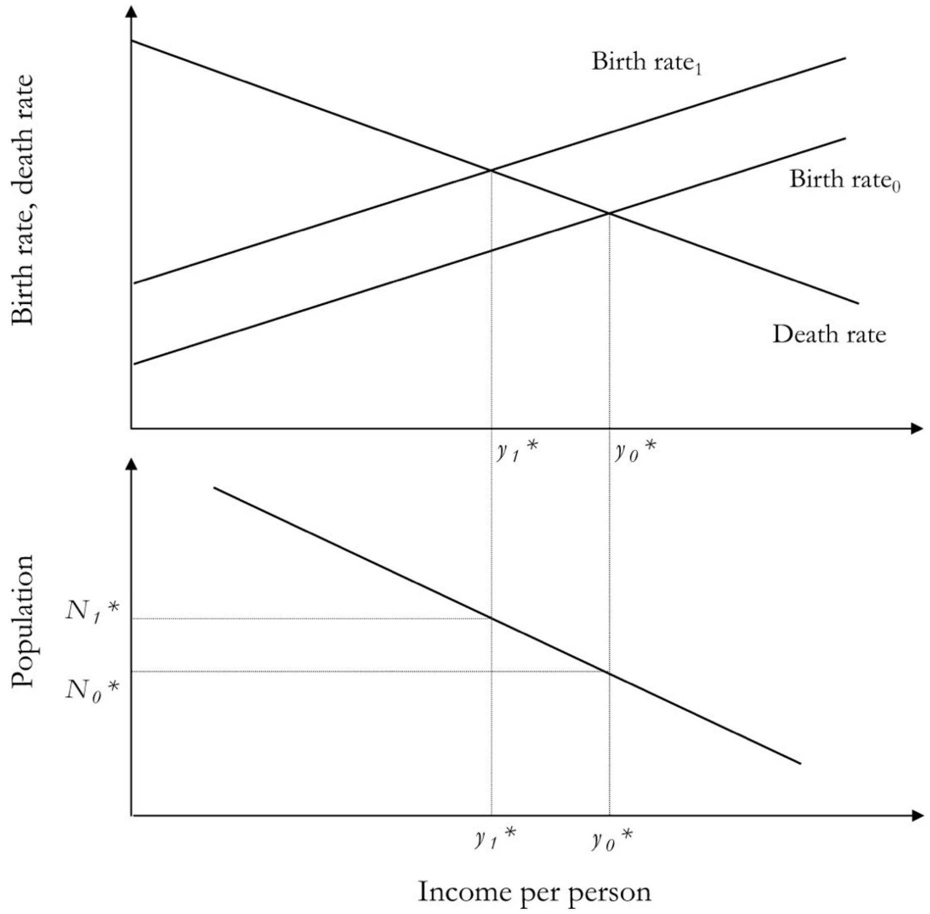


Fig. from Clark, 2007

The Malthusian trap-a societal attractor for most of human history

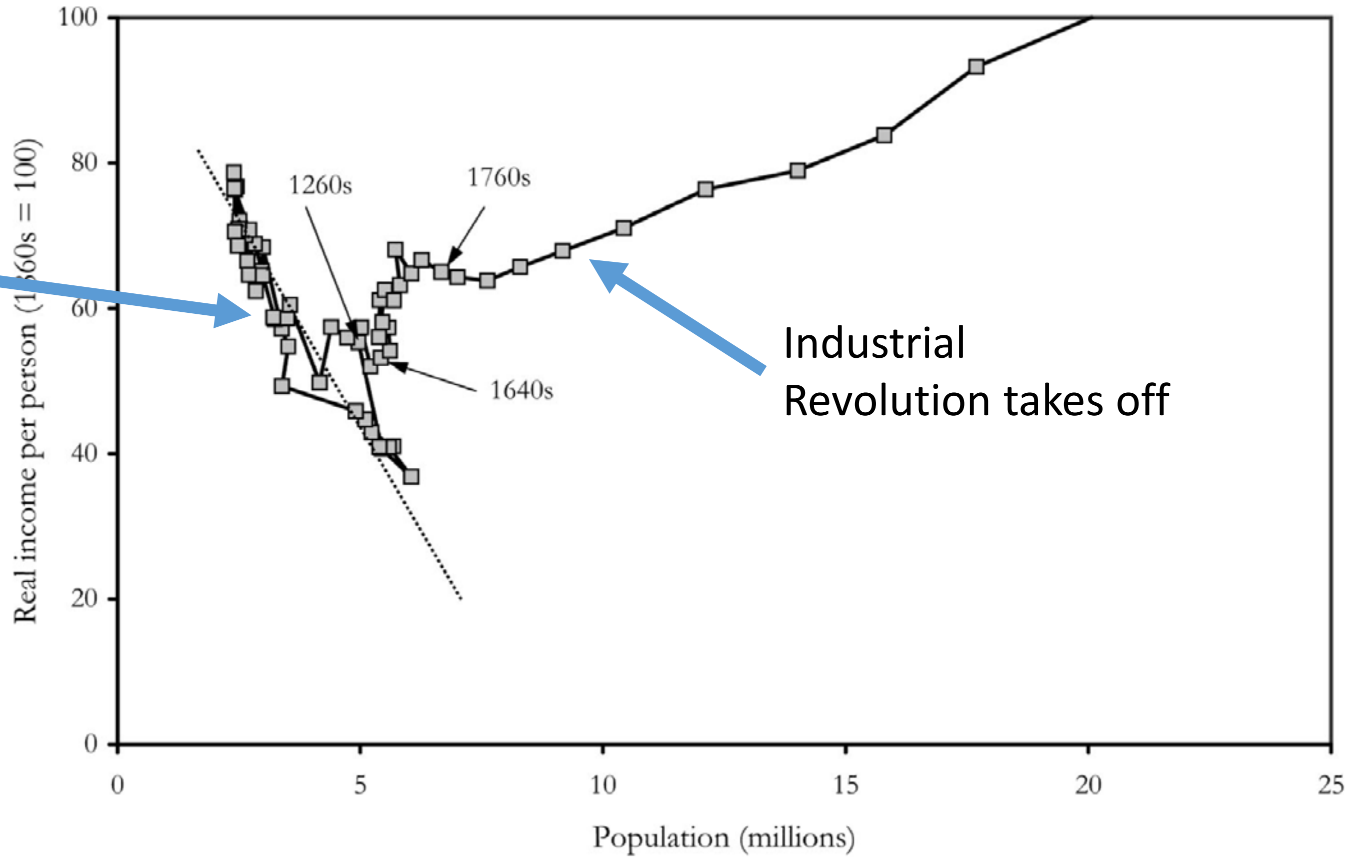


The result of an increase in the birth rate at a given income level: everyone gets poorer!

Fig. from Clark, 2007

Escaping the Malthusian Trap: output became directly rather than inversely proportional to population through increases in the efficiency with which economic inputs were converted to outputs

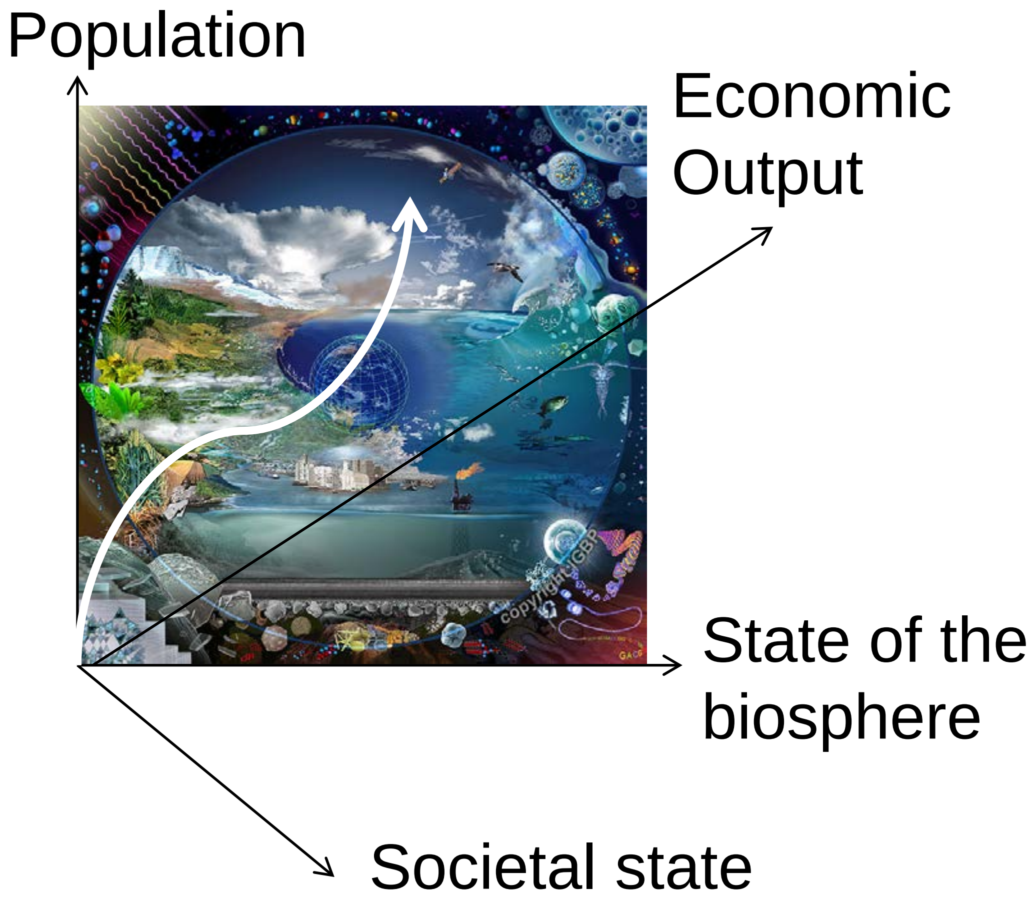
Britain in the plague years 1350-1700. Incomes rose after epidemics, fell with recovery



Industrial Revolution takes off

Fig. from Clark, 2007

In the Post-Industrial World, a minimal description of the Human-Earth System must include societal dynamics



We will try to construct a systems description based on four ‘state’ variables and three key linking processes

State variables:

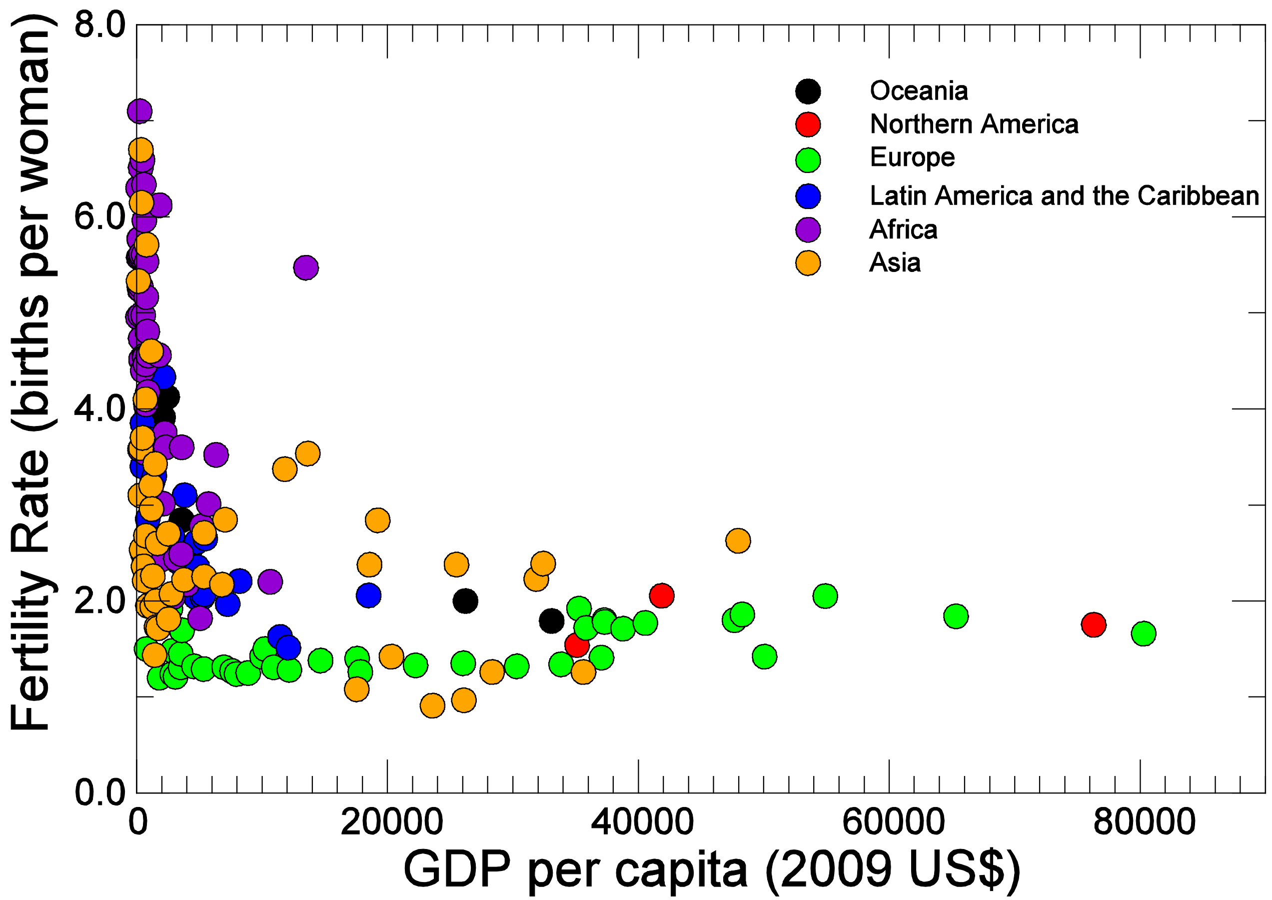
1. Population
2. Economic output
3. Societal State
4. Impact on the biosphere

Linking processes:

1. Inequality
2. Urbanisation
3. Energy Provision

Population: the Fertility-mortality balance and its link with wealth

Total fertility rate (TFR) vs GDP per capita; World Bank 2010

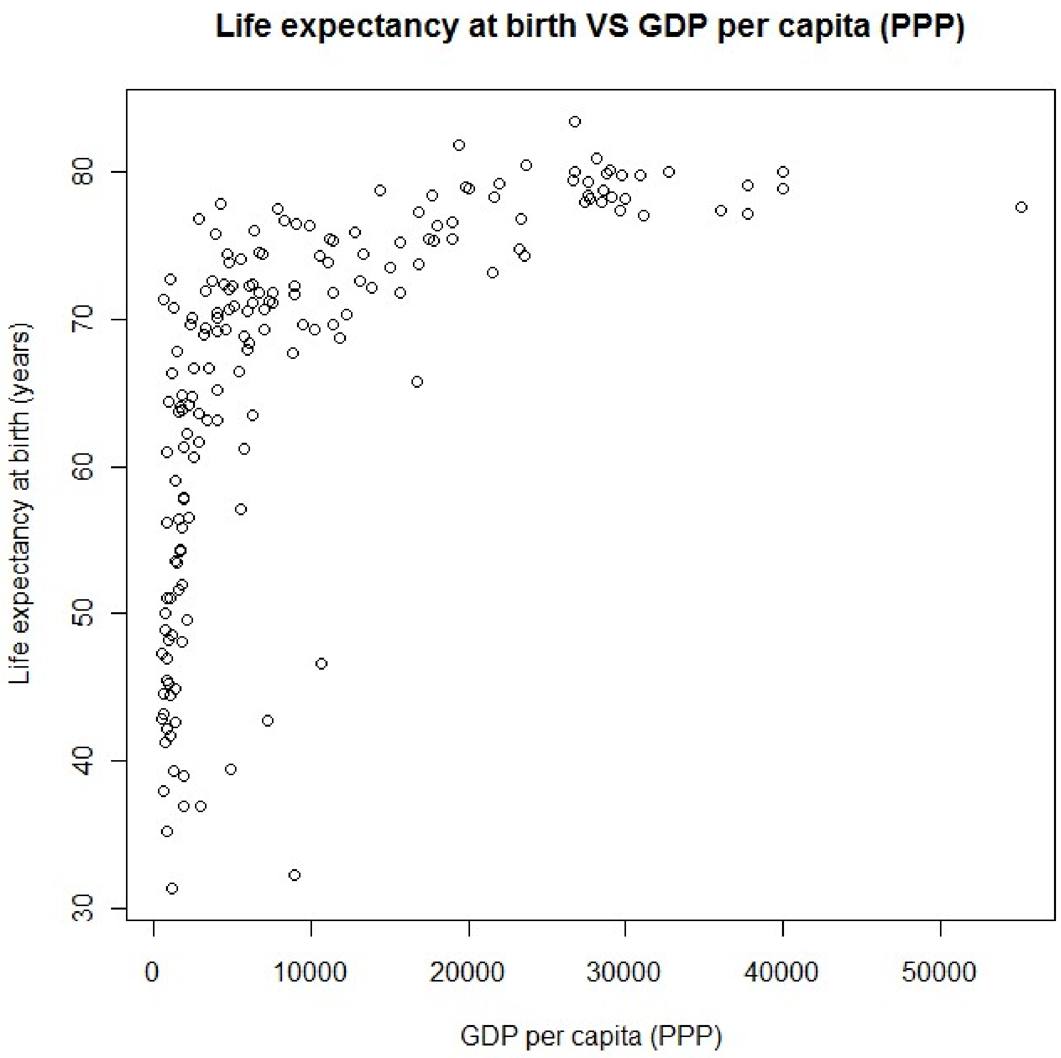


The strongest correlate with fertility/mortality is per capita wealth. Per capita GDP or GNI is usually used as a surrogate

The causal relationships are both complicated and not fully understood.

Culture, societal state and factors like urban vs rural location are very important

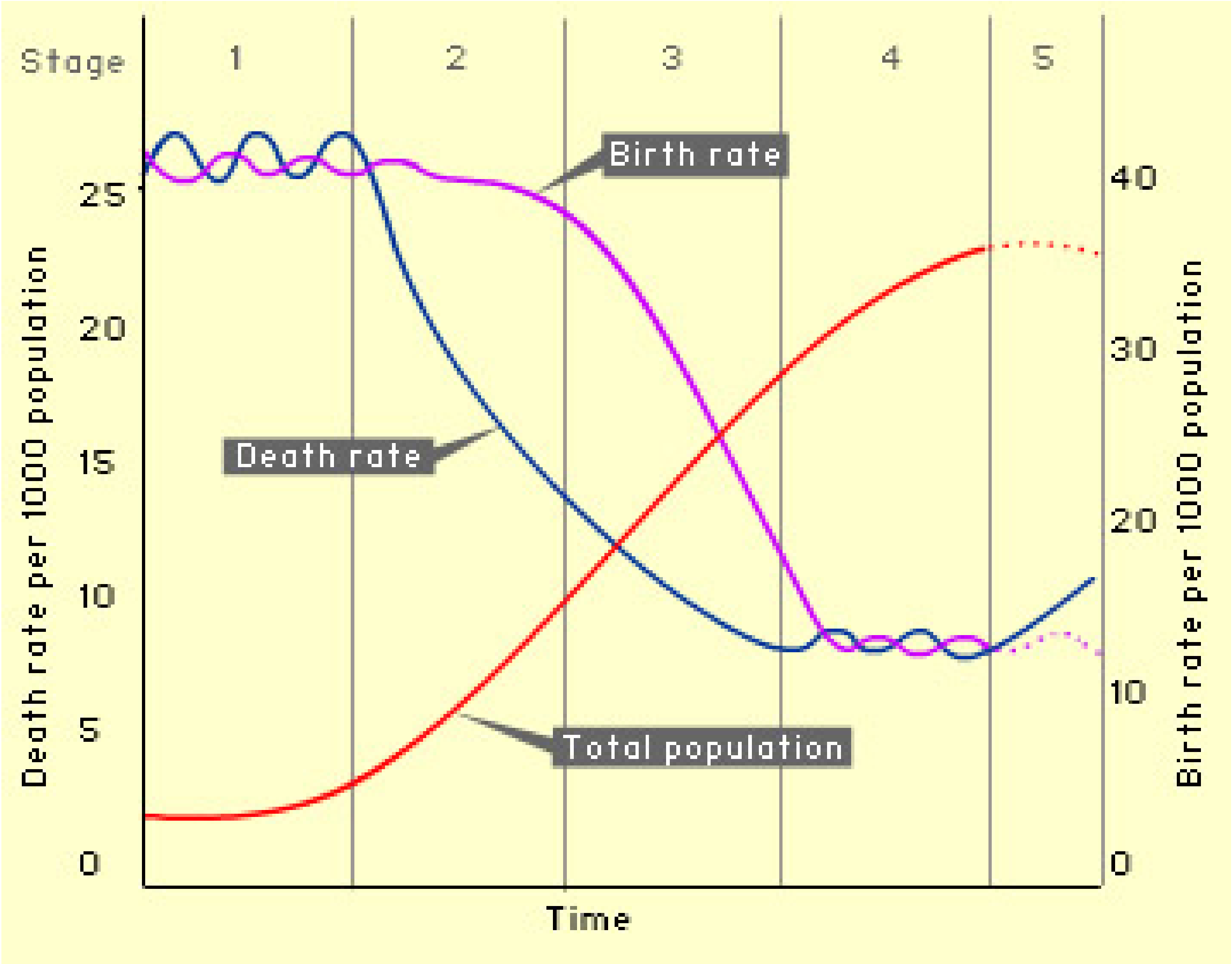
Population: the Fertility-mortality balance and its link with wealth



The mortality or life expectancy relationship with GDP per capita is the inverse of that of TFR

Data from Index Mundi website

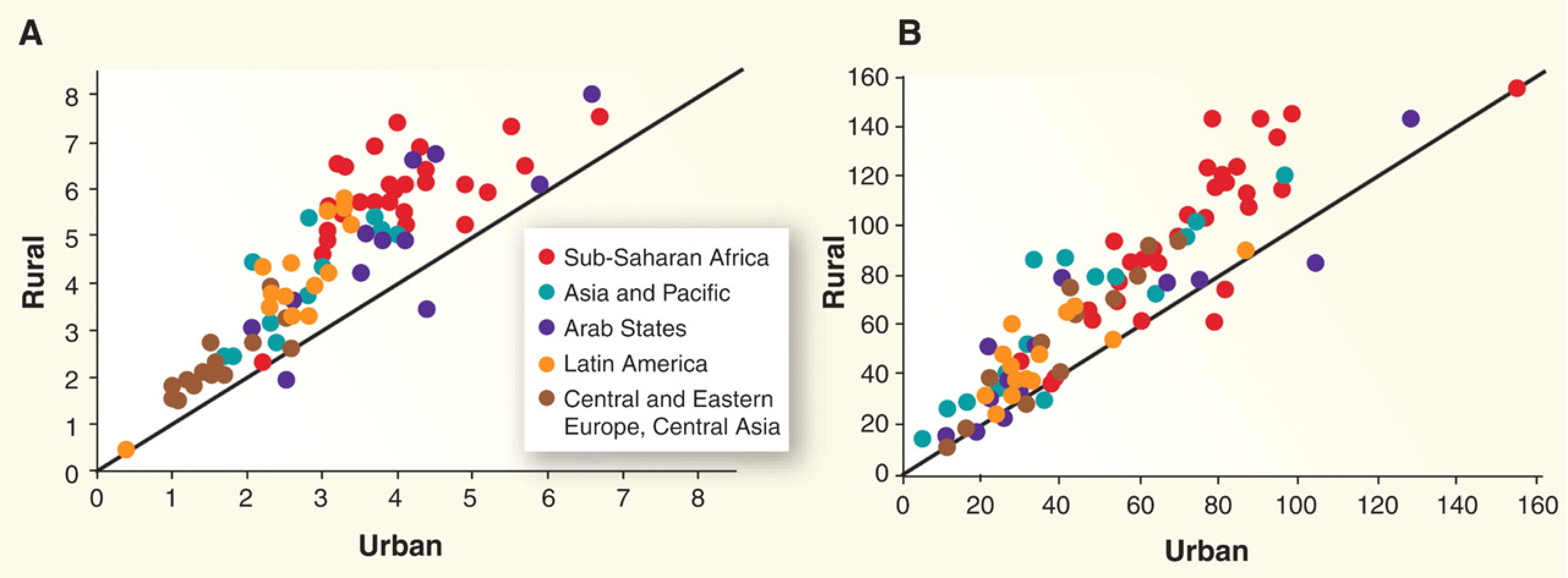
The Key Feedback from Mortality to Fertility: the Demographic Transition



Fertility-mortality balance-the effect of urban living

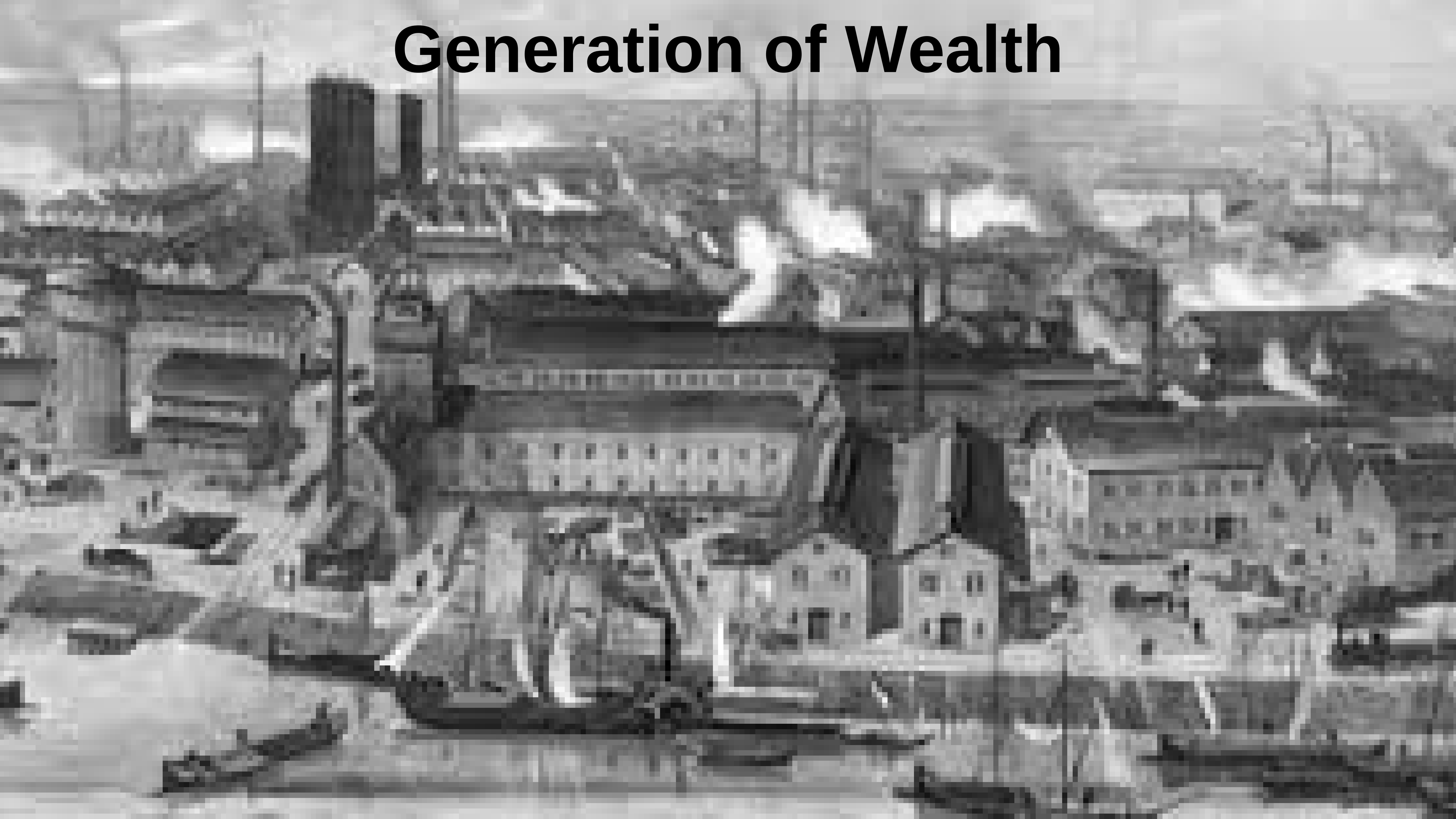
TFR: births per woman aged between 15 and 49

Infant mortality rates per 1000 births



Dye, Science, 2008

Generation of Wealth



Generation of wealth-economic output

y is economic output, k is capital, z is land or natural resources and A is the efficiency with which inputs are converted into output. g's are growth rates, all in per capita terms

$$y = AF(k,z) \qquad g_y = ag_k + cg_z + g_A$$

The Malthusian age: growth in output and capital is effectively zero; growth in efficiency of production is no faster than growth in population, *N*.

$$g_y = g_k = 0 \qquad g_z = -g_N \qquad g_A = -cg_z = cg_N$$

Industrial and modern age: growth in output is mainly the result of improvements in economic efficiency

$$g_y \;\square\; ag_k + g_A \qquad a \simeq 0.25$$

Societal State

- The Foraging Order   (Hunter-gatherer societies)-pre neolithic revolution
- The Limited Access Order or Natural State-most of society for most of history
- Open Access Orders-modern liberal democracies

North, Wallis and Weingast (2009)

Fukayama (2011, 2014)

Societal State

- The Natural or ‘Limited Access’ Order (10,000BCE-Now)
    - **Fragile** limited access order (early and more primitive societies)
    - **Basic** limited access order (kingdoms and empires up to present day)
    - **Mature** limited access order (modern polities lacking some or many basic personal or collective freedoms; eg. China, USSR, modern Russia)

Societal State

- The Natural or 'Limited Access' Order (10,000BCE-Now) is characterised by:
  - Slowly growing economies, vulnerable to shocks
  - Government without the general consent of the governed
  - Relatively small numbers of organizations
  - Smaller and more centralized governments
  - Social relationships organized predominantly along personal lines including privileges, social hierarchies, laws enforced unequally, insecure property rights, and a pervasive sense that not all individuals were created or are equal.

Societal State

- The Open Access Order (~1850-now; modern liberal democracies such as UK, Denmark, Australia) are characterized by:
  - Political and economic development
  - Economies that experience positive growth on average
  - Rich and vibrant civil societies with lots of organizations
  - Bigger, more decentralized governments
  - Widespread impersonal social relationships, including rule of law, secure property rights, fairness and equality.

Transitioning between Natural State and Open Access Order

- First need to move out of the Malthusian state
- requires quantum increase in production efficiency and breakdown of existing social norms by urbanisation or other dislocation?

- Given this, the role of inequality is central

- Mechanism of transition is a tension between the ‘masses’ who, faced with evident and sufficient inequality, are capable of seizing de facto power (revolution) and ‘elites’ who may cede de jure power to forestall revolution (or not). The goal of the ‘masses’ is redistributive taxation to reduce inequality.

(Acemoglu and Robinson, 2006-or Plutarch, 100AD)

Societal State

Stable transition from the natural state to an open access order requires three 'doorstep' conditions to be met:

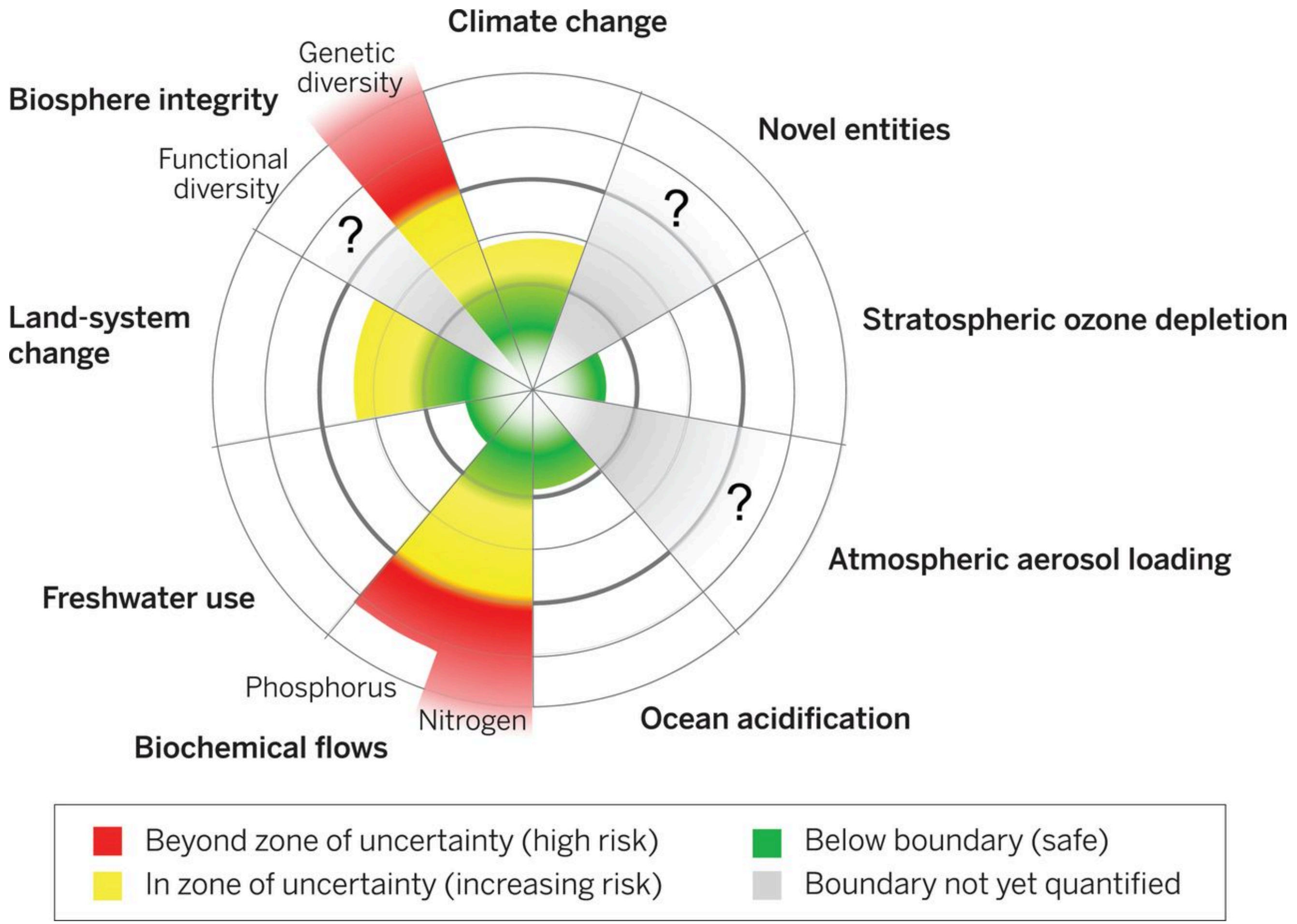
- Rule of law for elites
- Perpetual organisations
- Centralised control of the military

NB. If doorstep conditions are not in place, the transition will not be successful or lasting-eg. Arab Spring.

[North et al, 2009; Fukayama, 2011, 2014]

Biospheric State

Current status of the control variables for seven of the planetary boundaries. The green zone is the safe operating space, the yellow represents the zone of uncertainty (increasing risk), and the red is a high-risk zone.

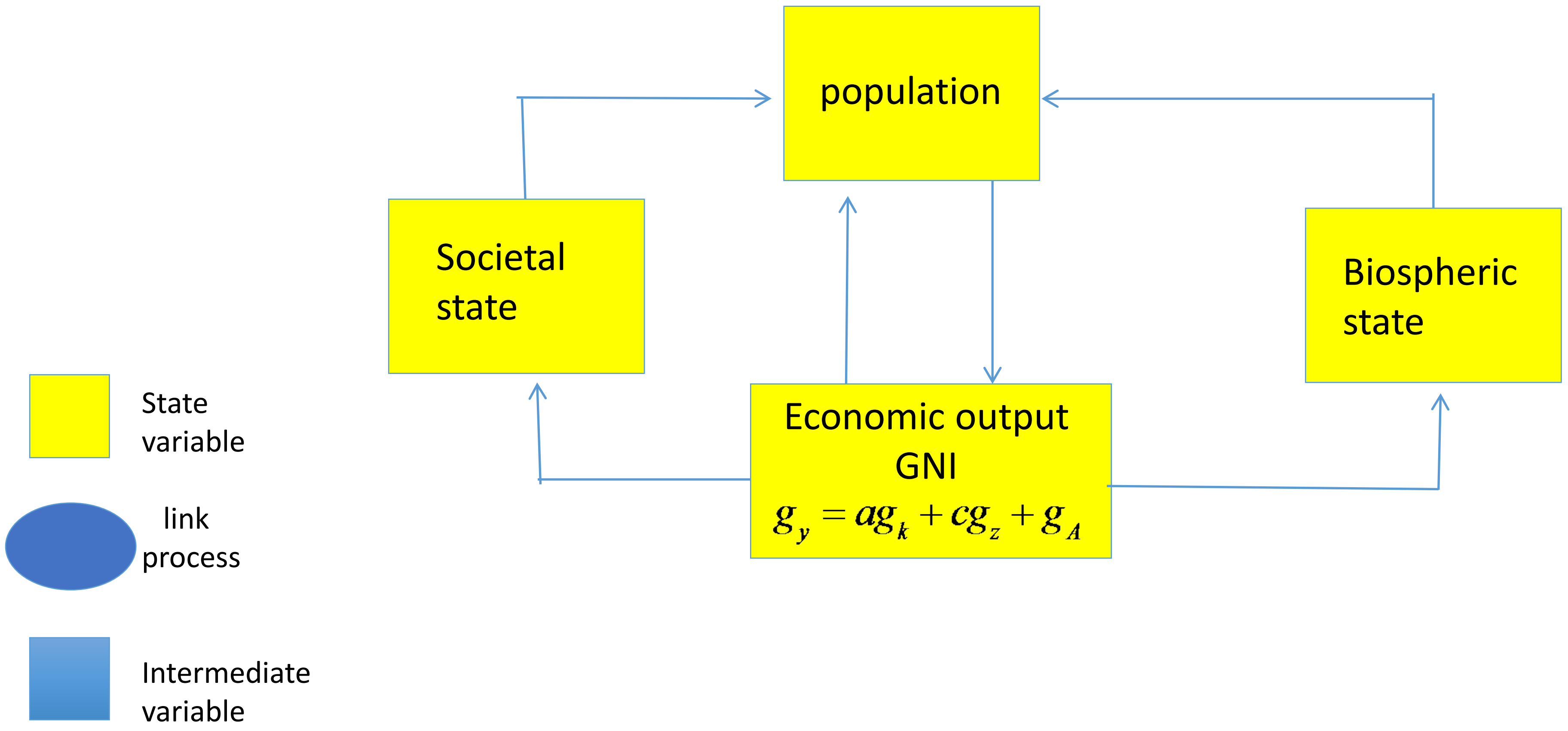


Will Steffen et al. Science 2015;347:1259855

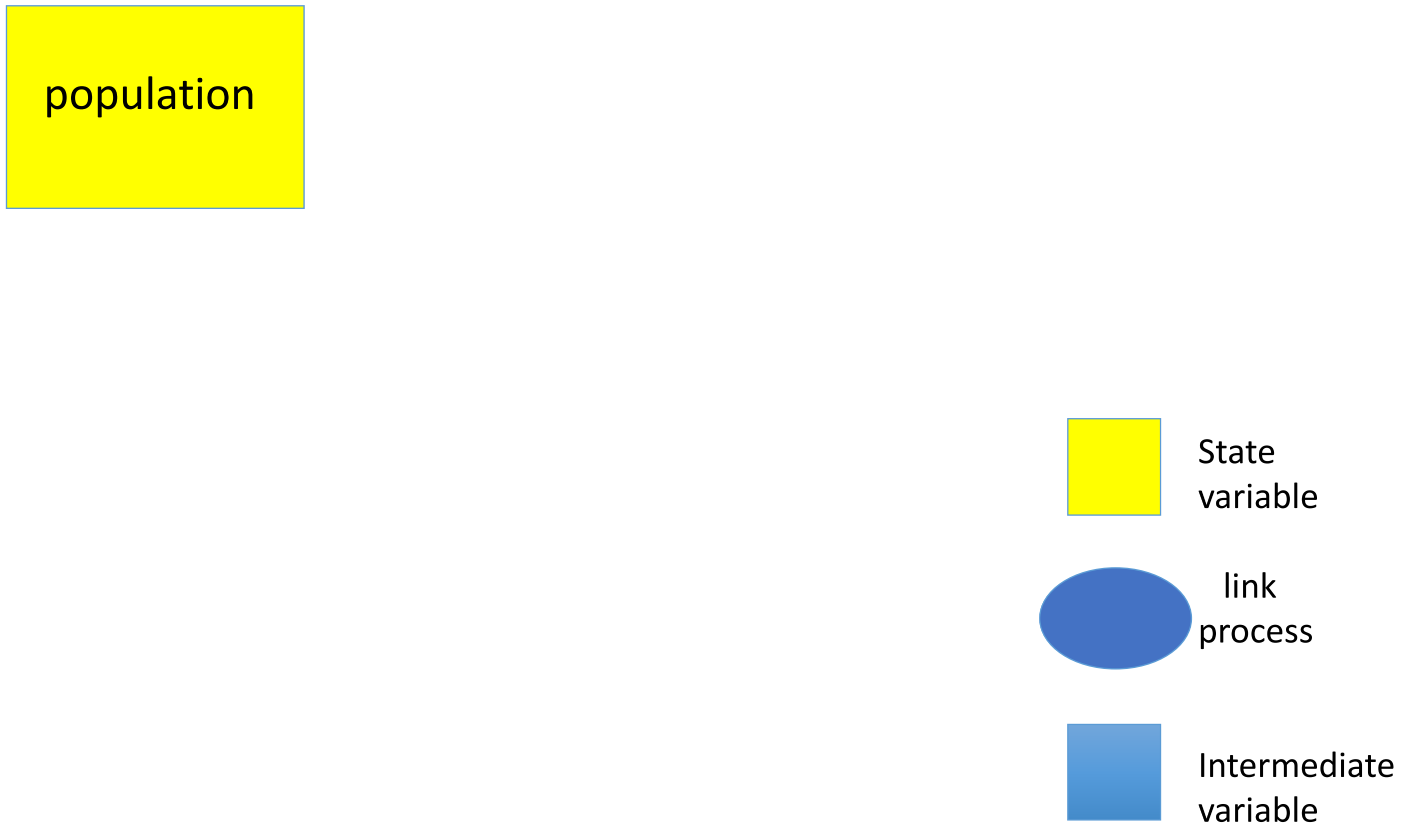
Science AAAS

Published by AAAS

Tracing the links and feedbacks between the four state variables

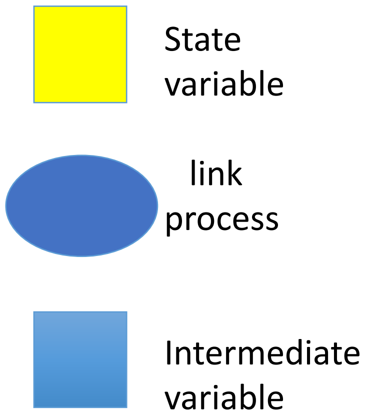


population

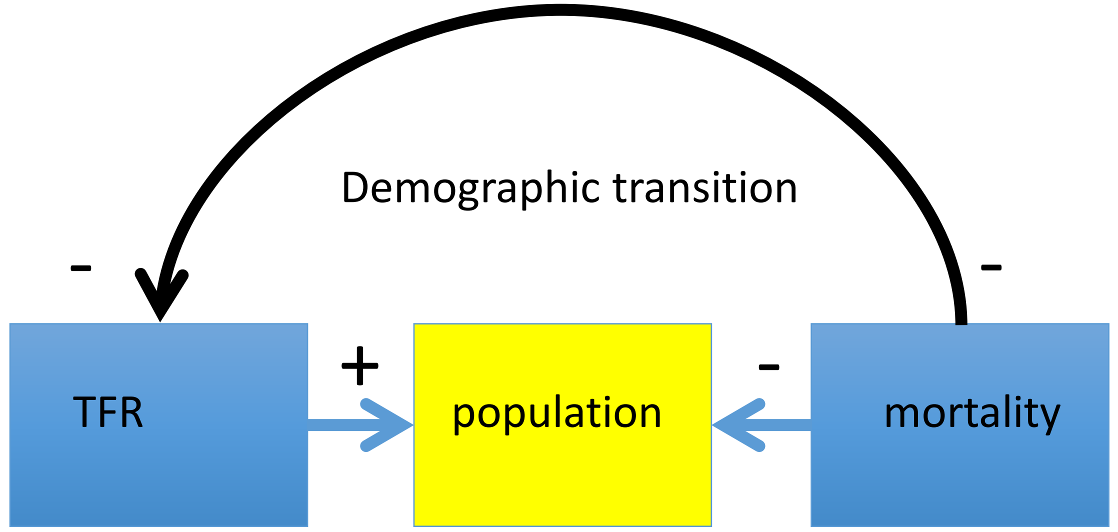

population
State variable
link process
Intermediate variable

population

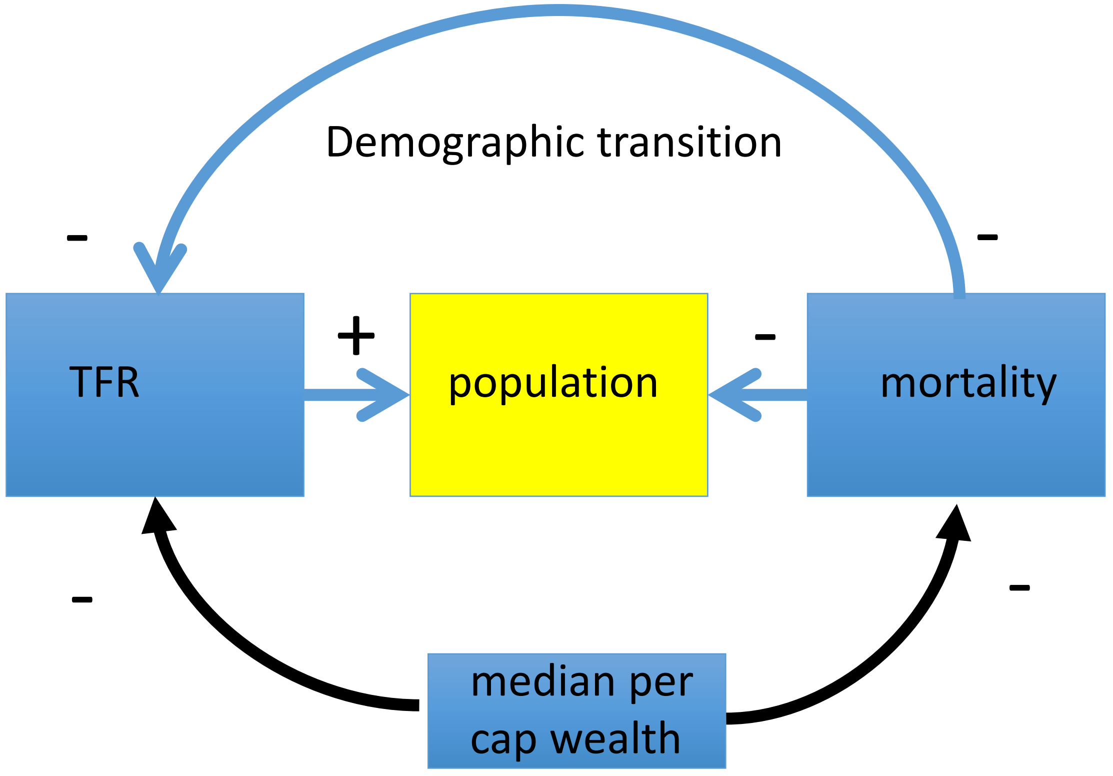

TFR
+
population
-
mortality


State variable
link process
Intermediate variable

population

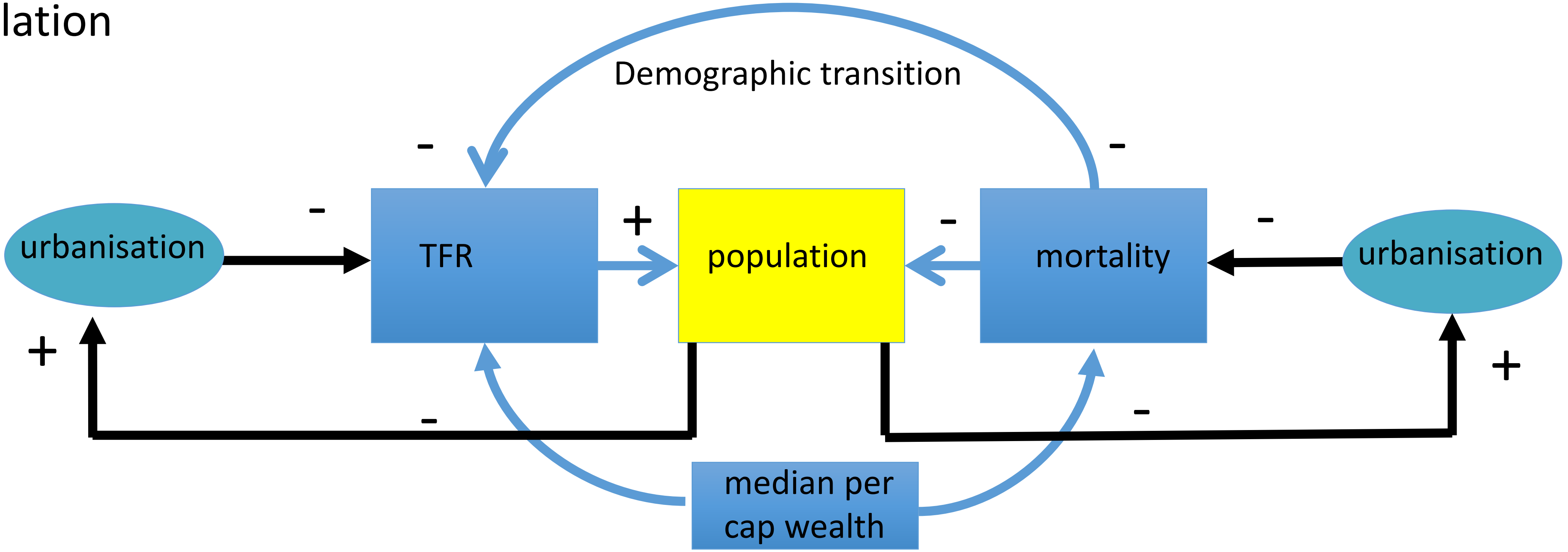


population

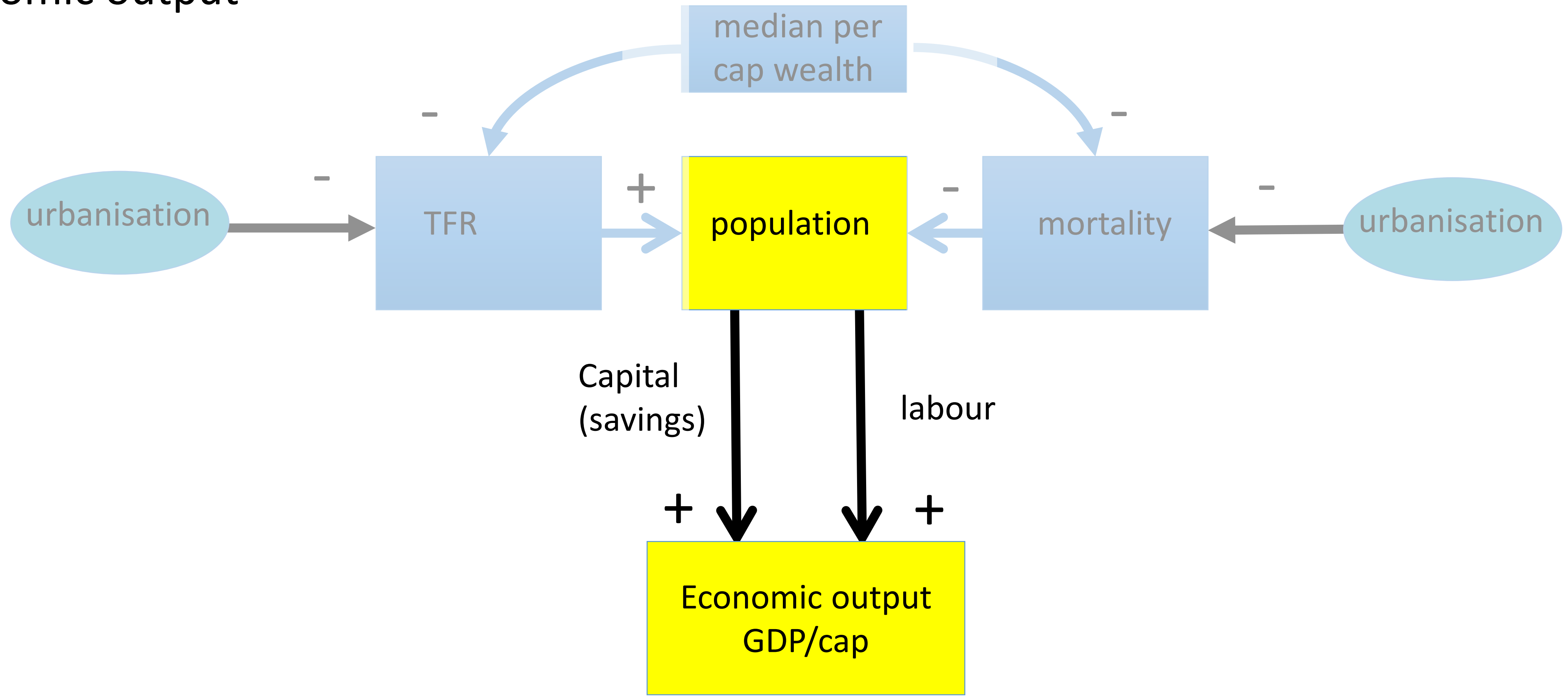


Demographic transition
-
-
TFR
+
population
-
mortality
-
-
median per
cap wealth

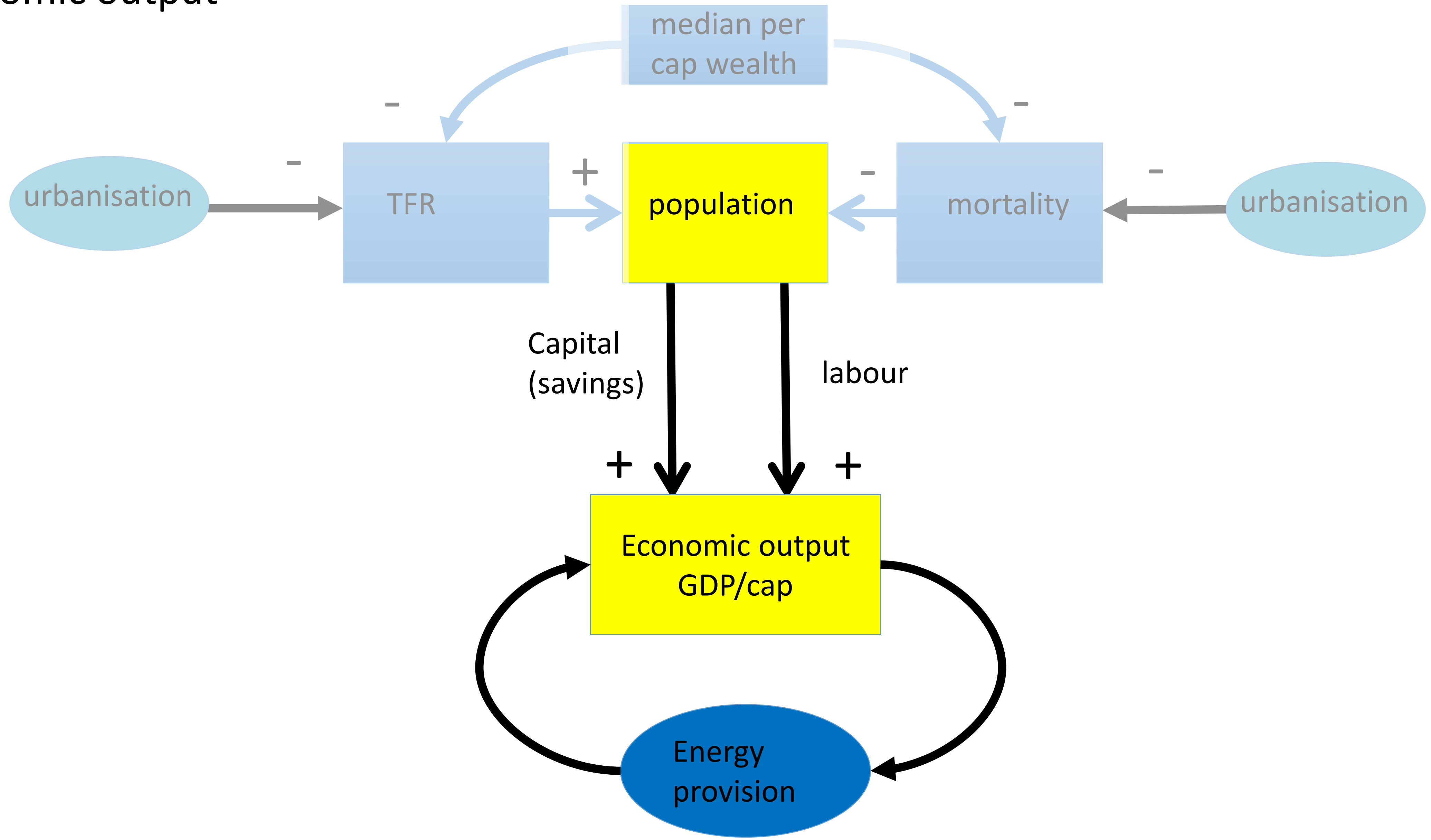
population


Demographic transition
-
-
-
urbanisation
TFR
+
population
-
mortality
-
urbanisation
+
-
-
+
median per cap wealth

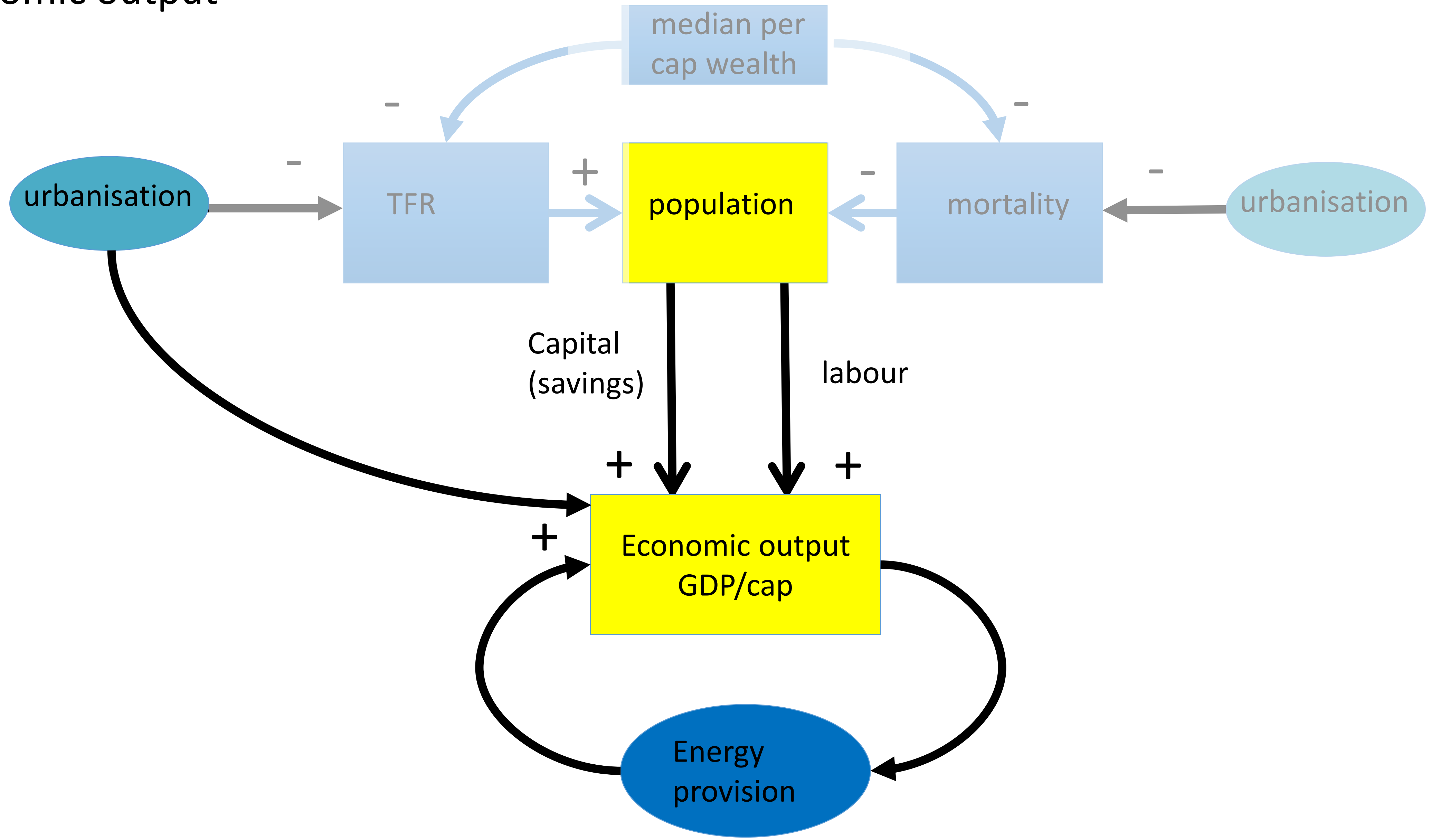
Economic output



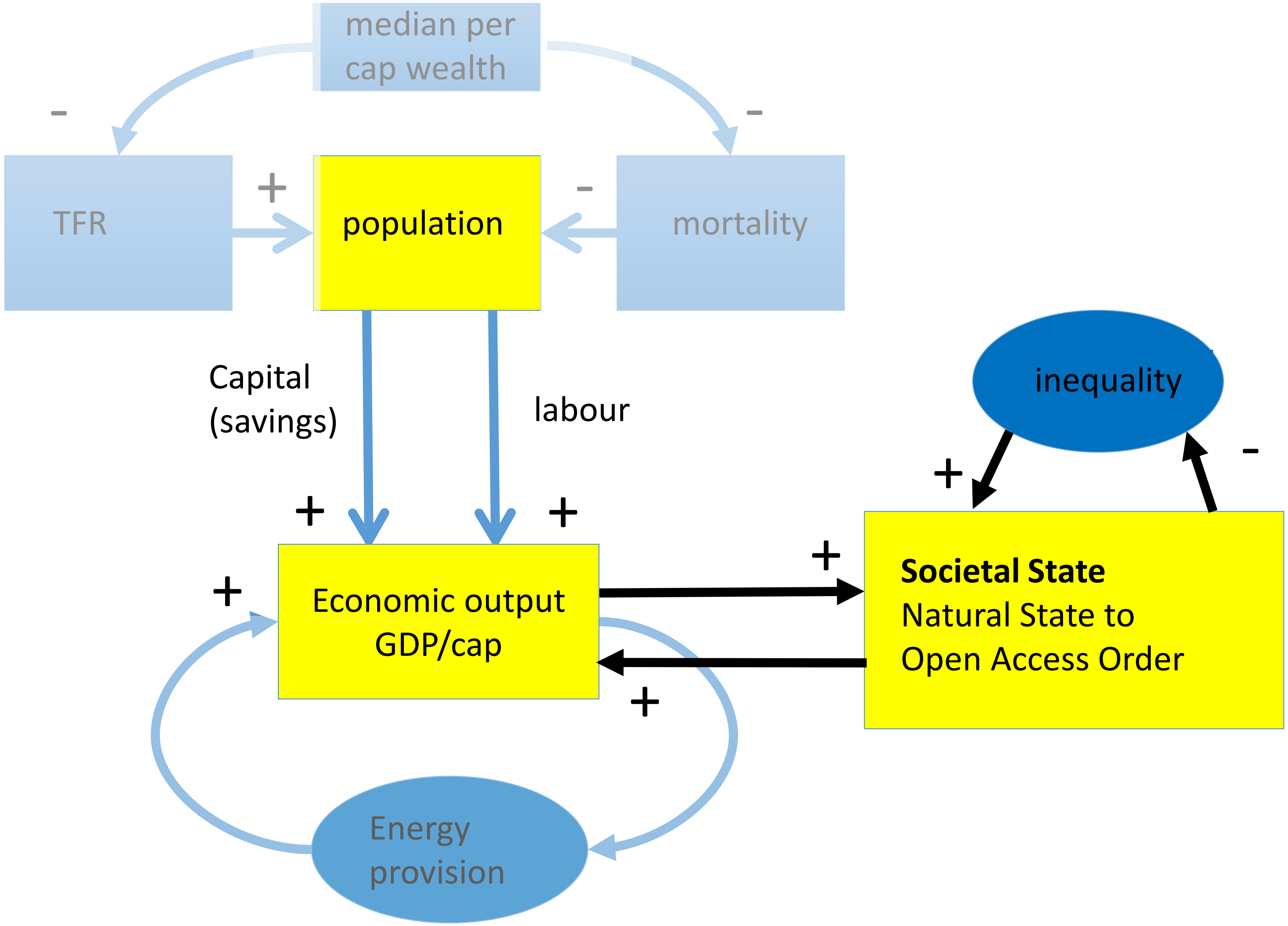
Economic output



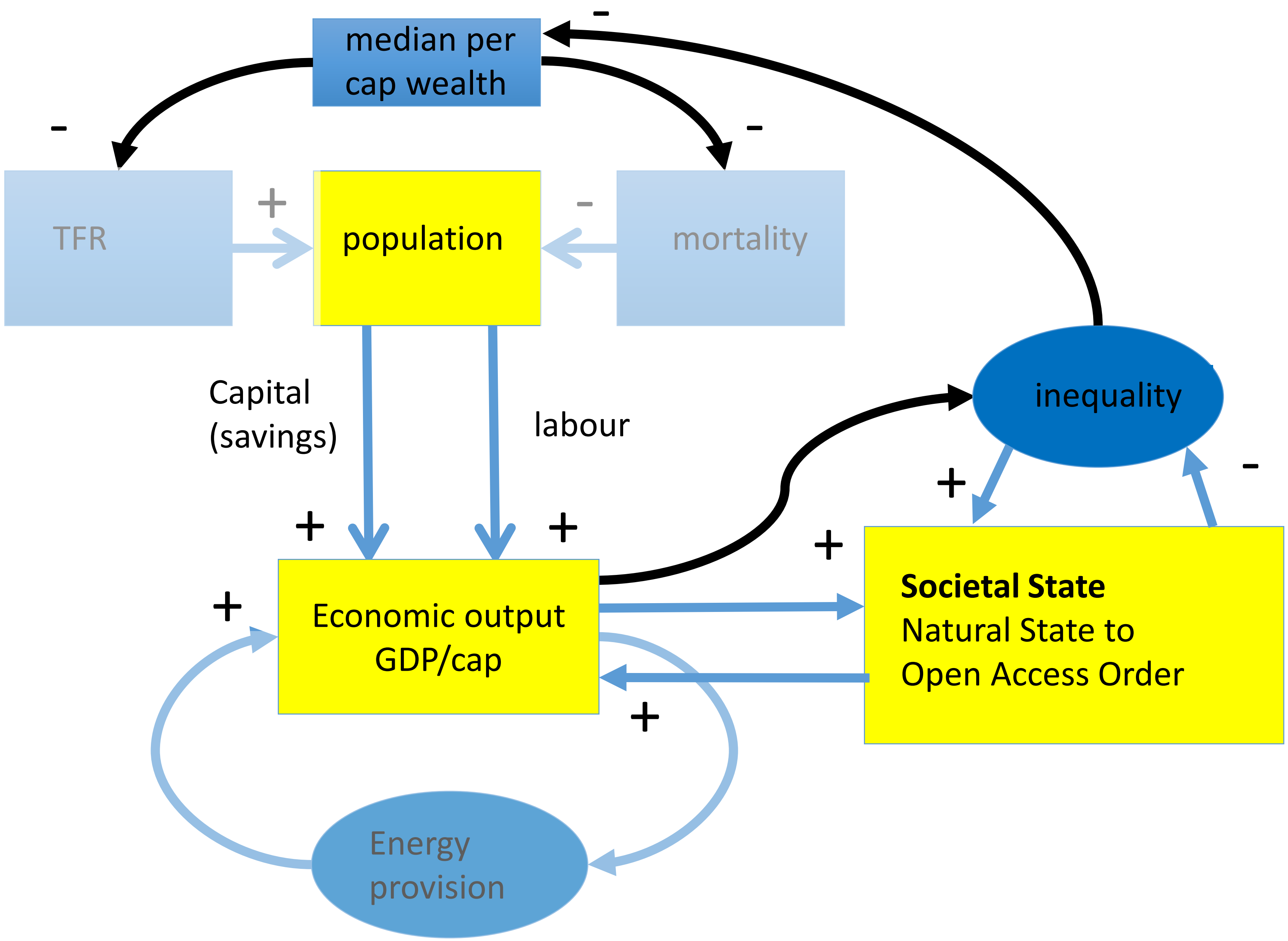
Economic output



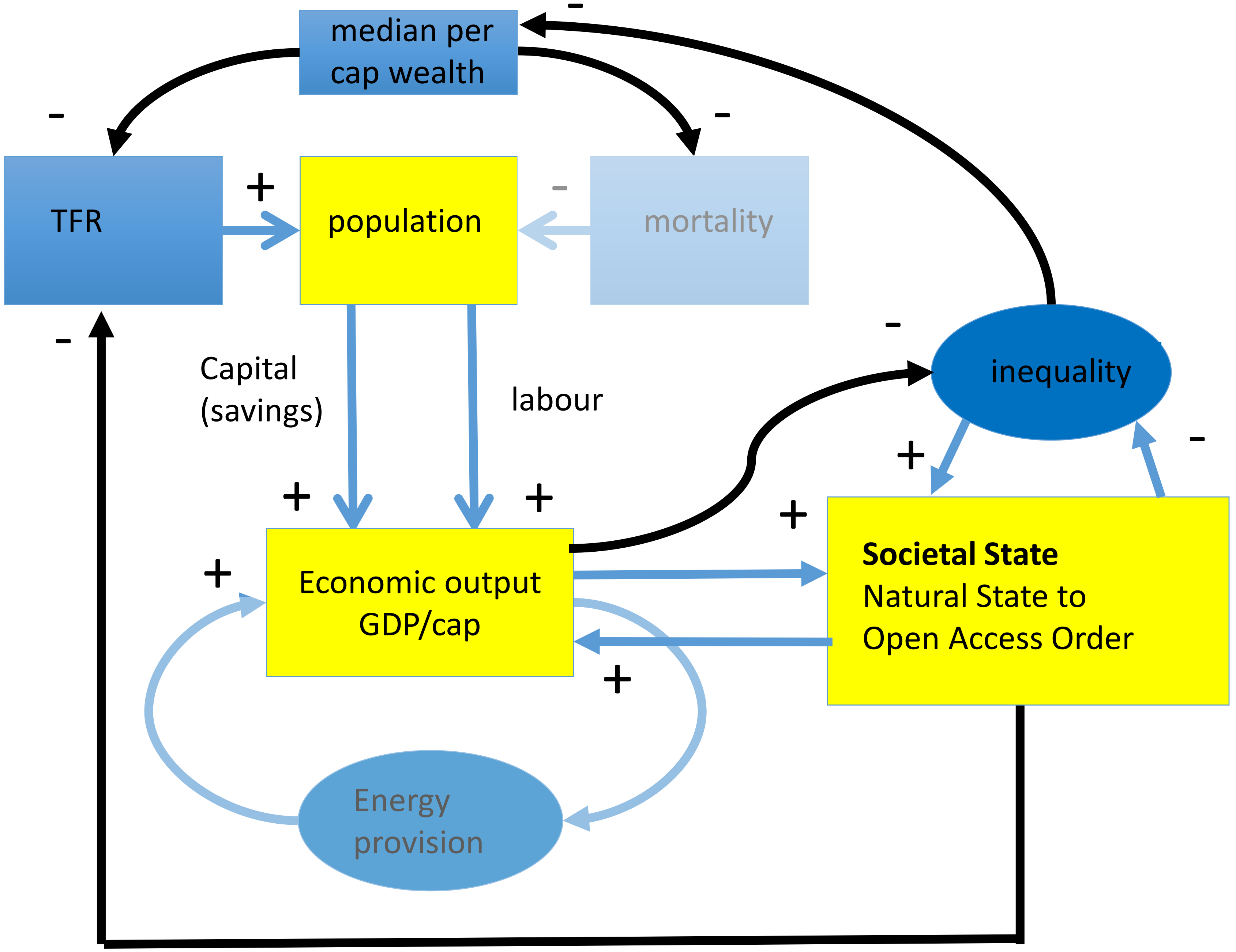
Societal State



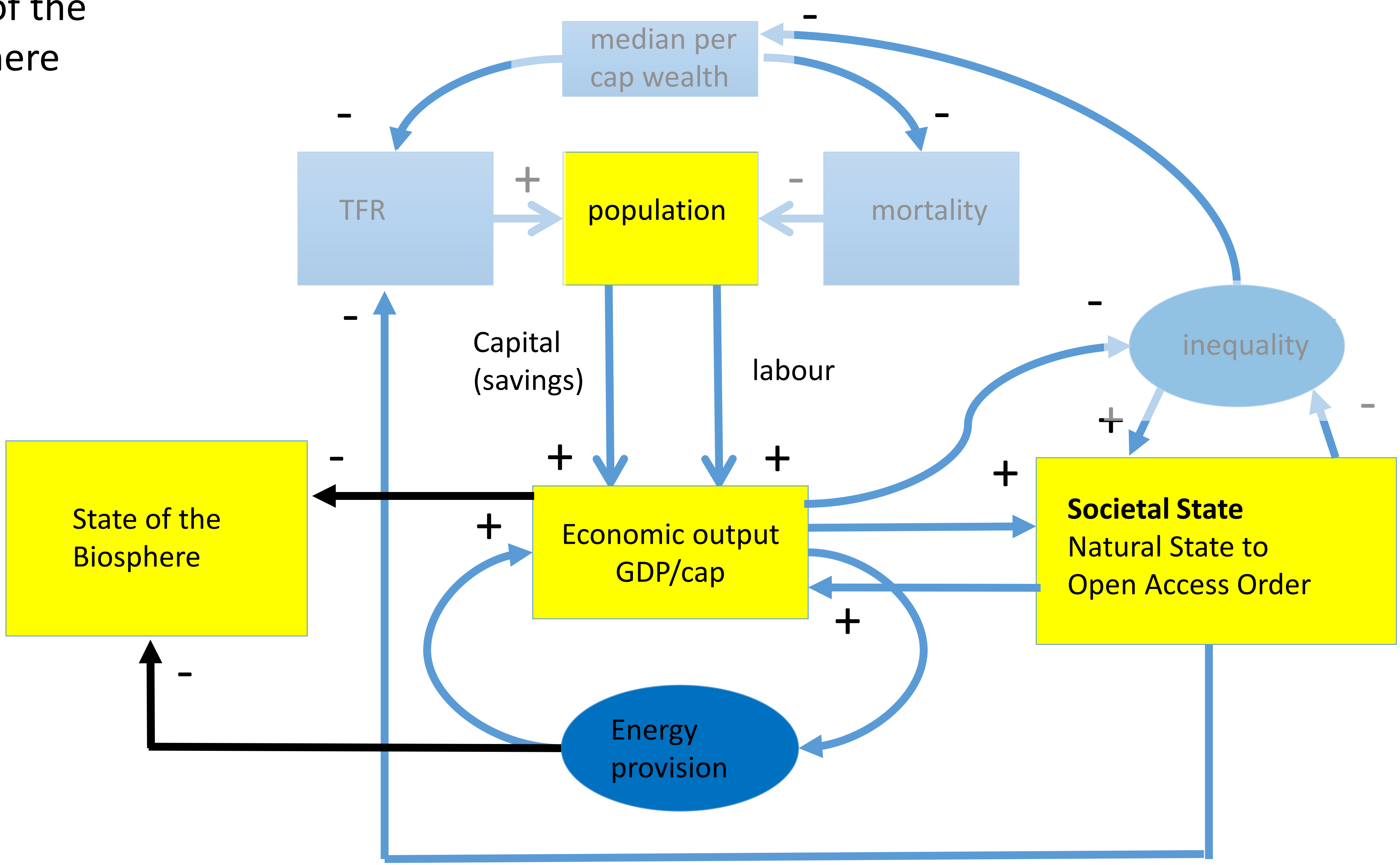
Societal State



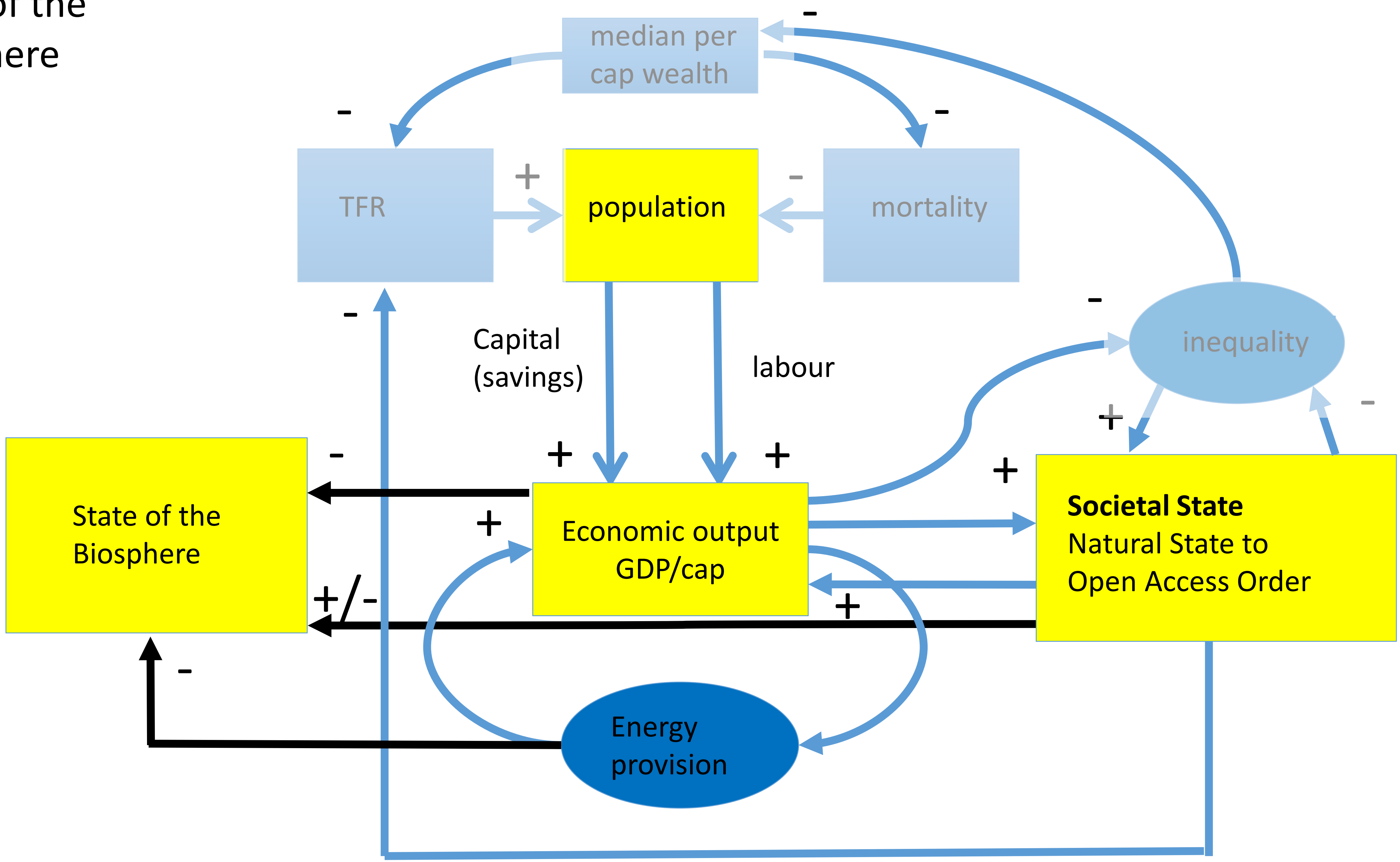
Societal State



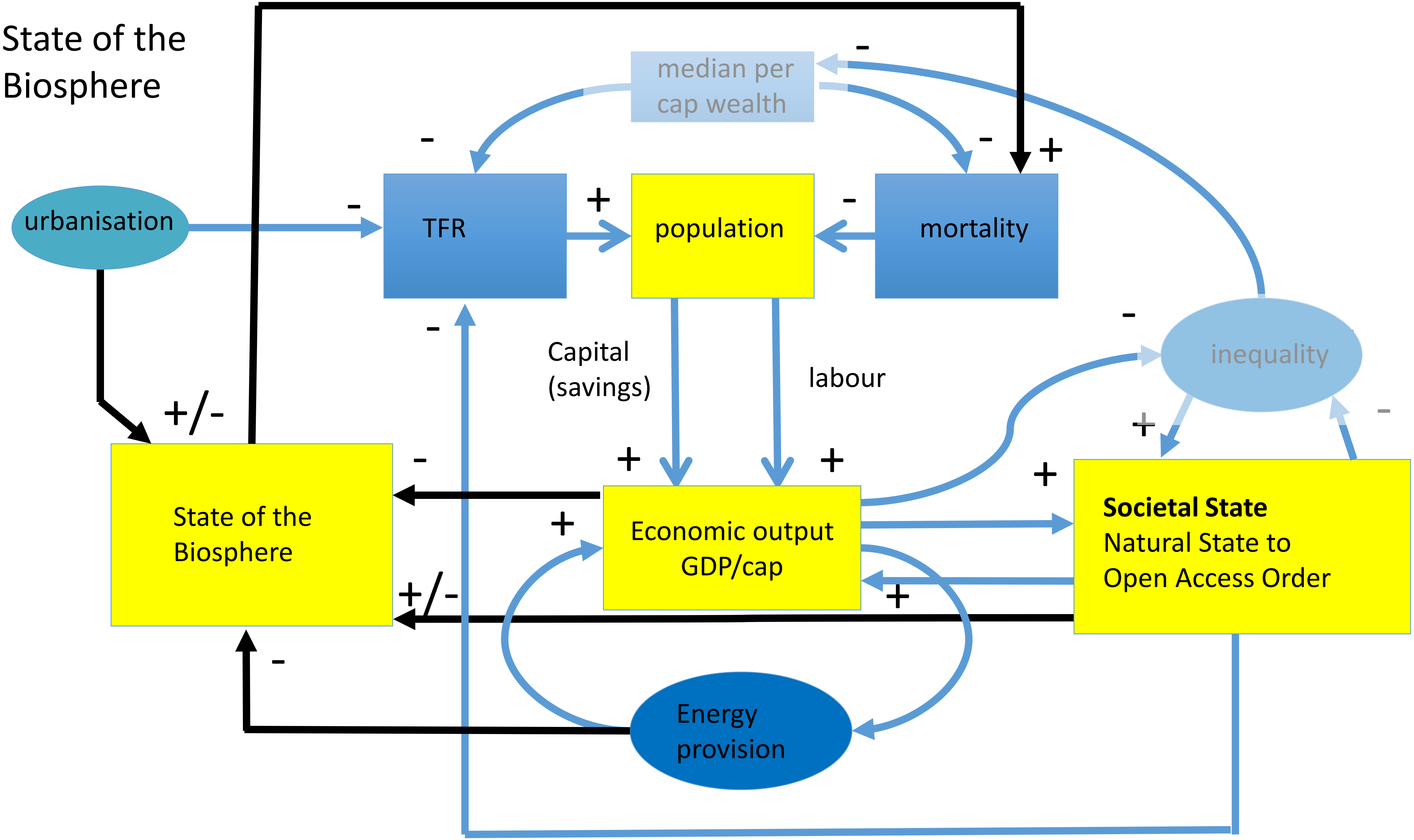
State of the Biosphere



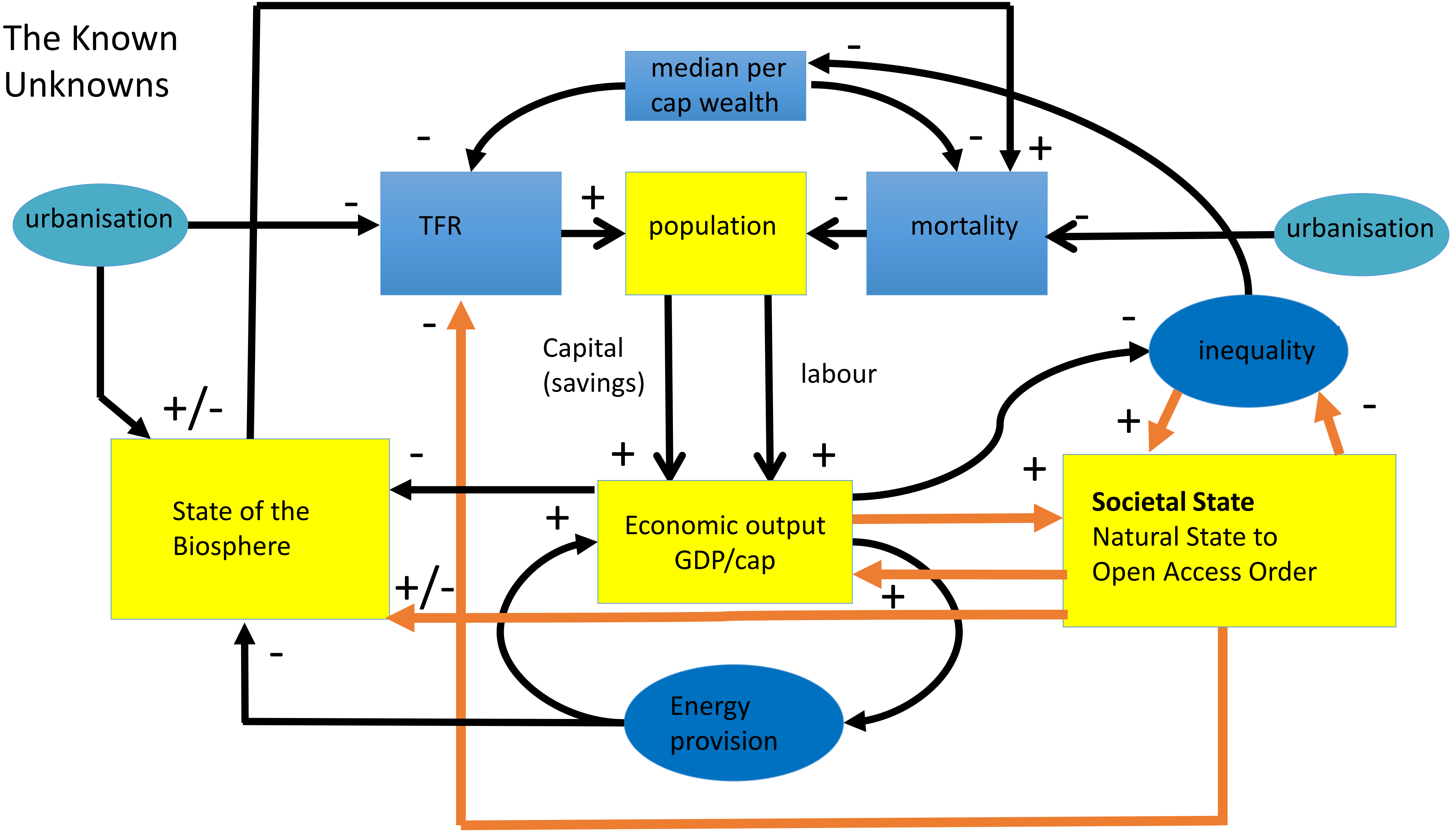
State of the Biosphere



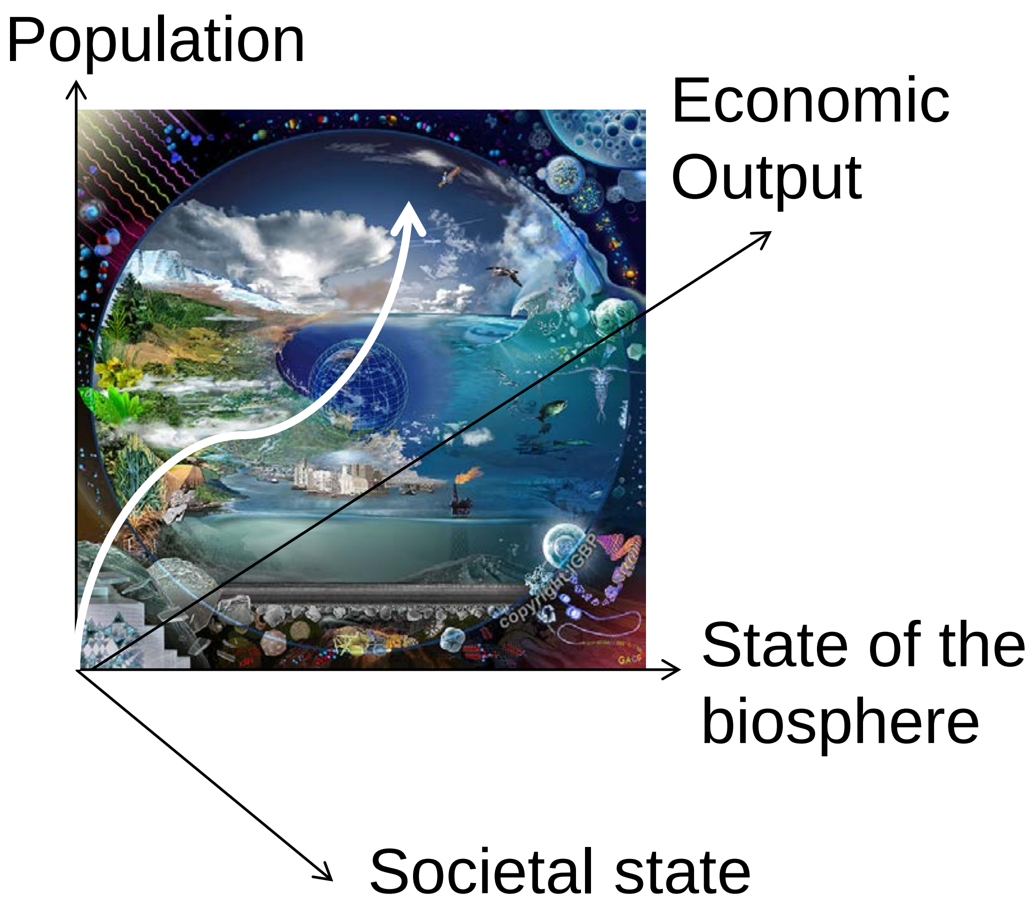
State of the Biosphere



The Known Unknowns



We can examine the system description for instabilities-tipping points and bifurcations-even though our knowledge of the functional relationships may be limited



$$P(t) = F_p(p,y,b,s;I,U,E;t)$$

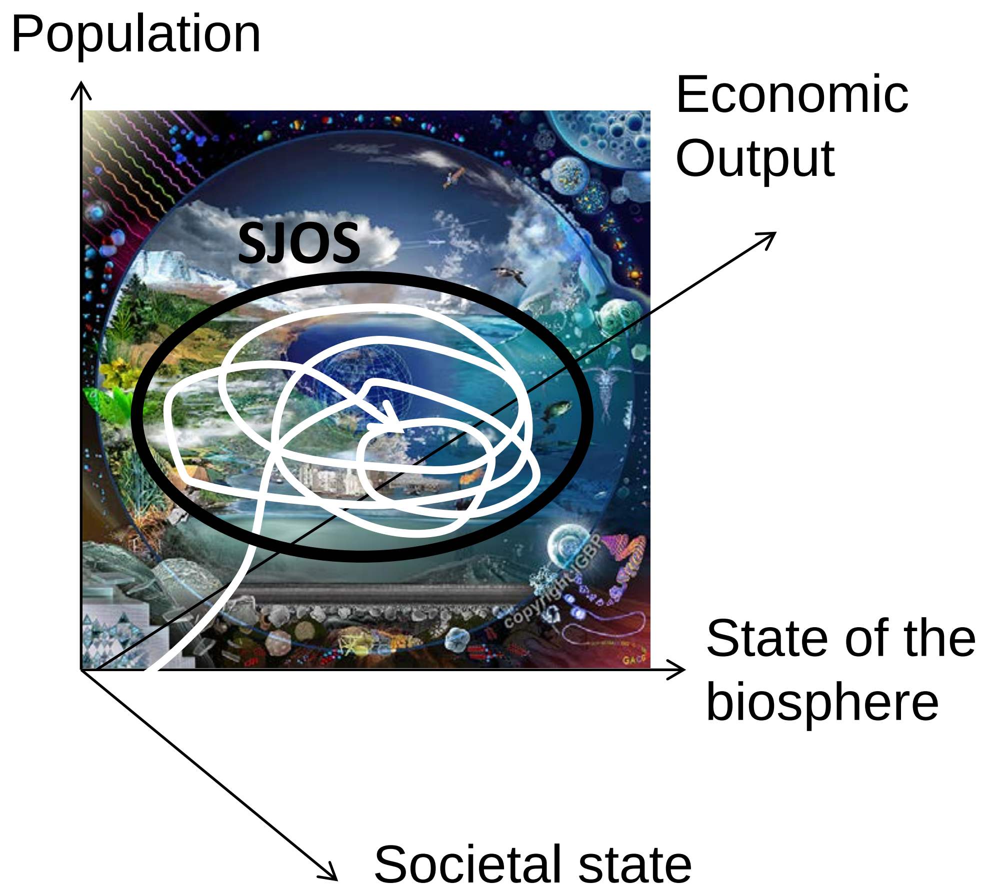
$$Y(t) = F_y(p,y,b,s;I,U,E;t)$$

$$B(t) = F_b(p,y,b,s;\ I,U,E;t)$$

$$S(t) = F_s(p,y,b,s;\ I,U,E;t)$$

$$\frac{d}{dt}\begin{pmatrix} p \\ y \\ b \\ s \end{pmatrix} = \begin{pmatrix} \partial F_p/\partial p & \partial F_p/\partial y & \partial F_p/\partial b & \partial F_p/\partial s \\ \partial F_y/\partial p & \partial F_y/\partial y & \partial F_y/\partial b & \partial F_y/\partial s \\ \partial F_b/\partial p & \partial F_b/\partial y & \partial F_b/\partial b & \partial F_b/\partial s \\ \partial F_s/\partial p & \partial F_s/\partial y & \partial F_s/\partial b & \partial F_s/\partial s \end{pmatrix} \begin{pmatrix} dp \\ dy \\ db \\ ds \end{pmatrix}$$

Can the trajectory of the human-earth system be understood and modelled well enough to provide useful guidance on human development goals like the SDG's?



Quality Survival or a SJOS means that the trajectory of the human-earth system has to dwell in a part of the state space where population is bounded, wealth is sufficient and sufficiently spread to satisfy aspirations, adverse biogeochemical change is limited and society in the main attains open access orders

Cocks, 2010, Global Overshoot

Some first conclusions

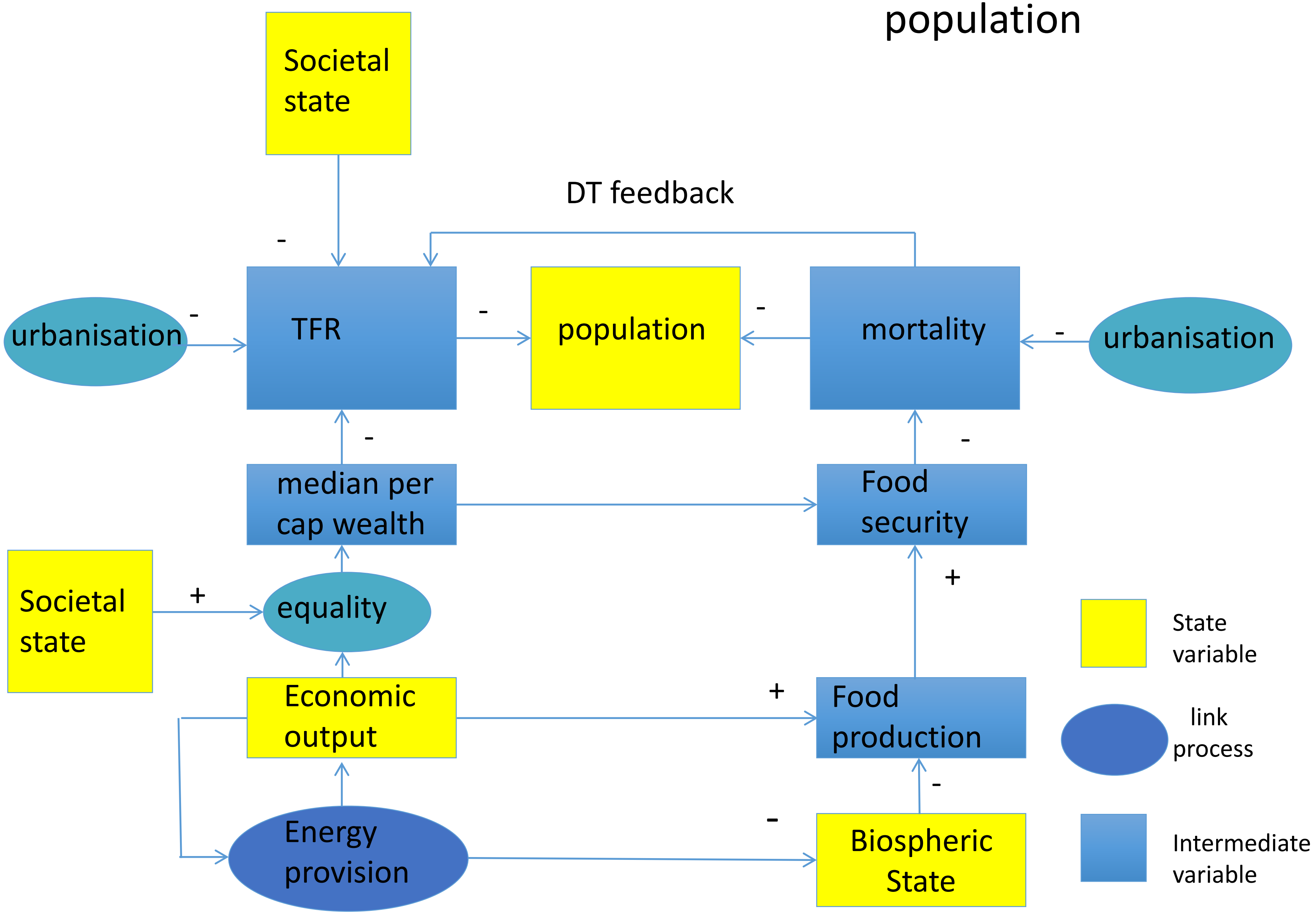
- World population can plateau at 9-11Bn then decline after 2100 (UN, IIASA)
- This implies, however, that most people have an income that exceeds ~U$5000 pa. Even if the massive skewness of wealth today is mitigated, this will require considerable economic growth
- Industry, especially the energy production required to drive the economy, and agriculture impact the biosphere negatively-vide climate change and ocean/soil acidification. This impacts mortality via food security and public health.
- It is possible to decarbonise the world economy using current technology at a cost-but also with many benefits (eg. Jobs).
- However, political actions and choices are pushing the trajectory of the HE system in the direction of continued high carbon use and increased inequality.
- So currently a SJOS is not an attractor for the HES.

Can understanding society or the human-earth system as a complex system help?

- Complex causality warns against simplistic solutions
- Goals like the SDGs could be self defeating if the underlying drivers are strongly coupled
- Even teasing out the key links and processes at a conceptual level is illuminating
- Formal modelling can tell us much more about where we could go if the wrong levers are pulled-and which might be the right ones.

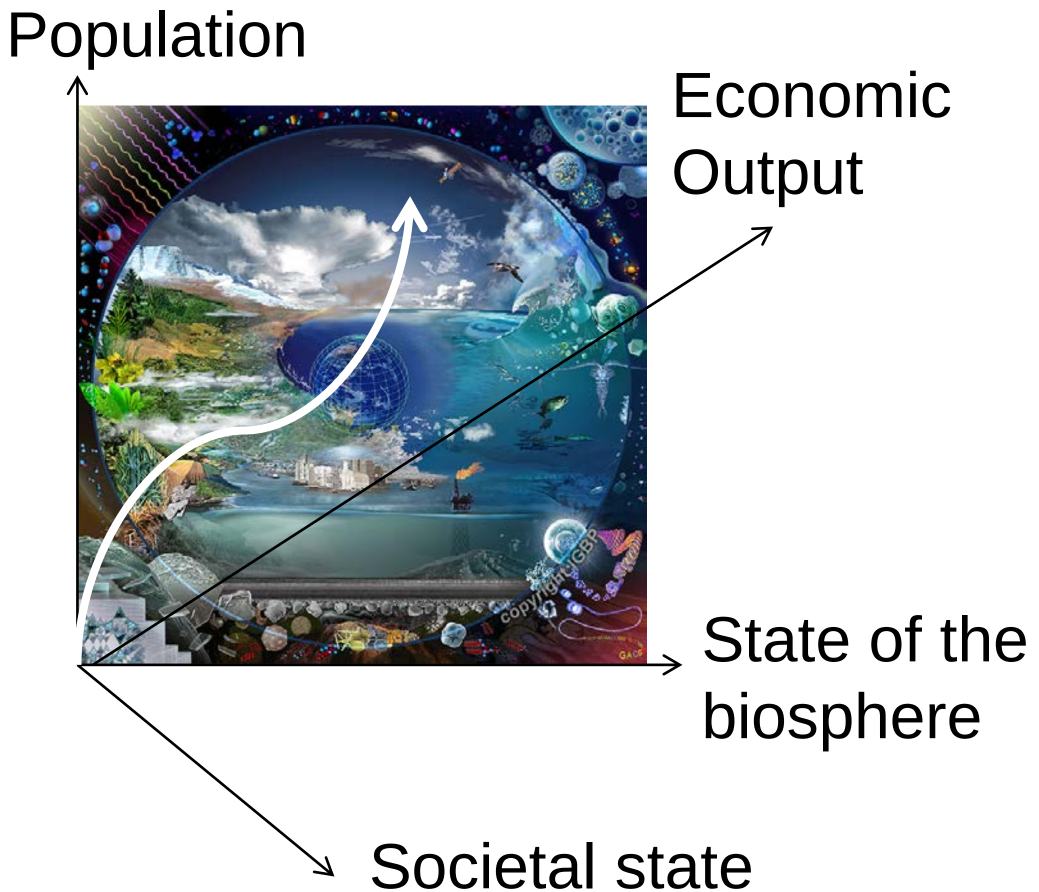

1960
1965
1975
1980
1985
1990
1995
2000
2005
2010

population

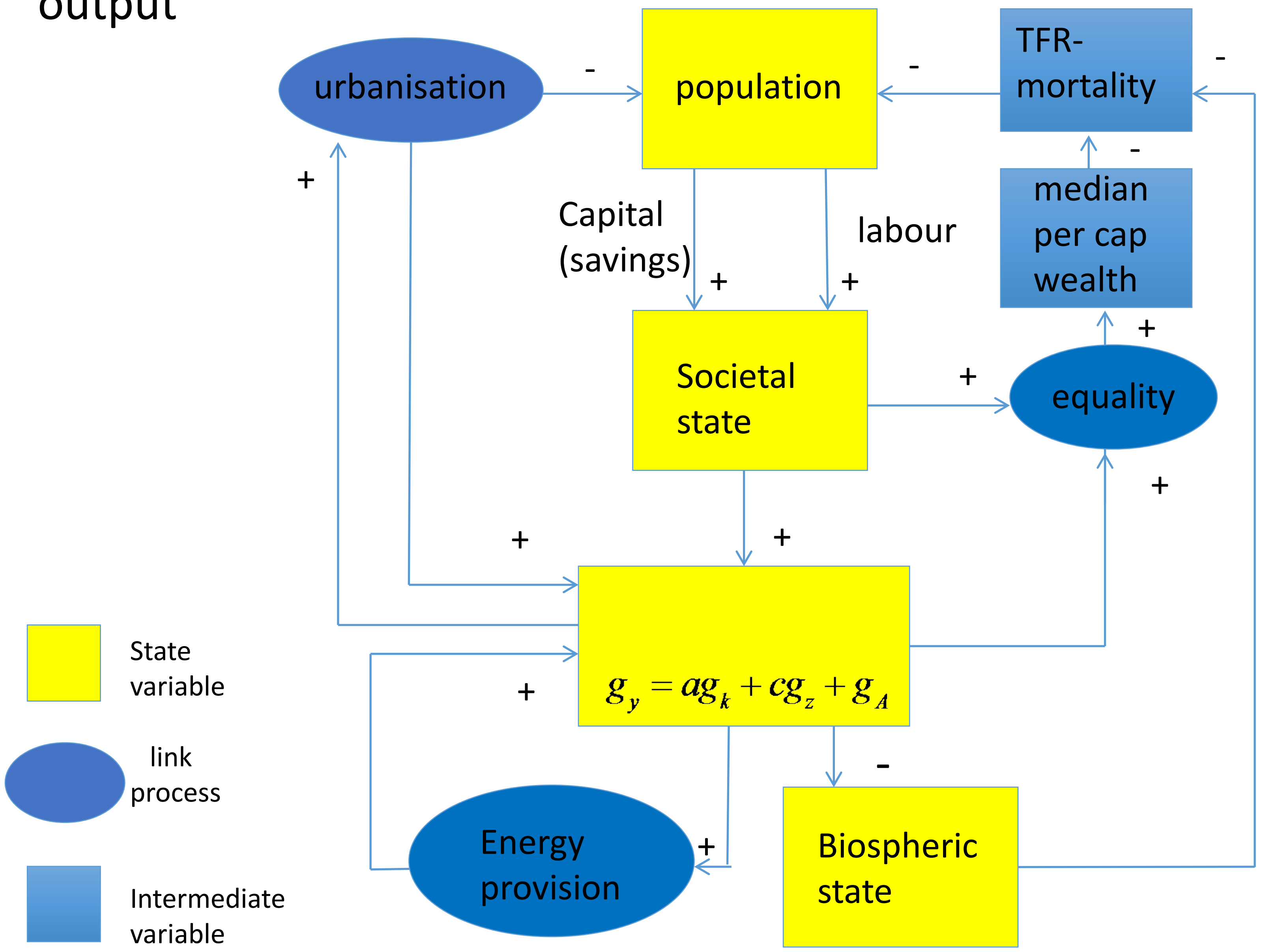


Societal state
DT feedback
-
urbanisation
-
TFR
-
population
-
mortality
-
urbanisation
-
median per cap wealth
-
Food security
Societal state
+
equality
+
Economic output
+
Food production
-
Energy provision
-
Biospheric State
State variable
link process
Intermediate variable

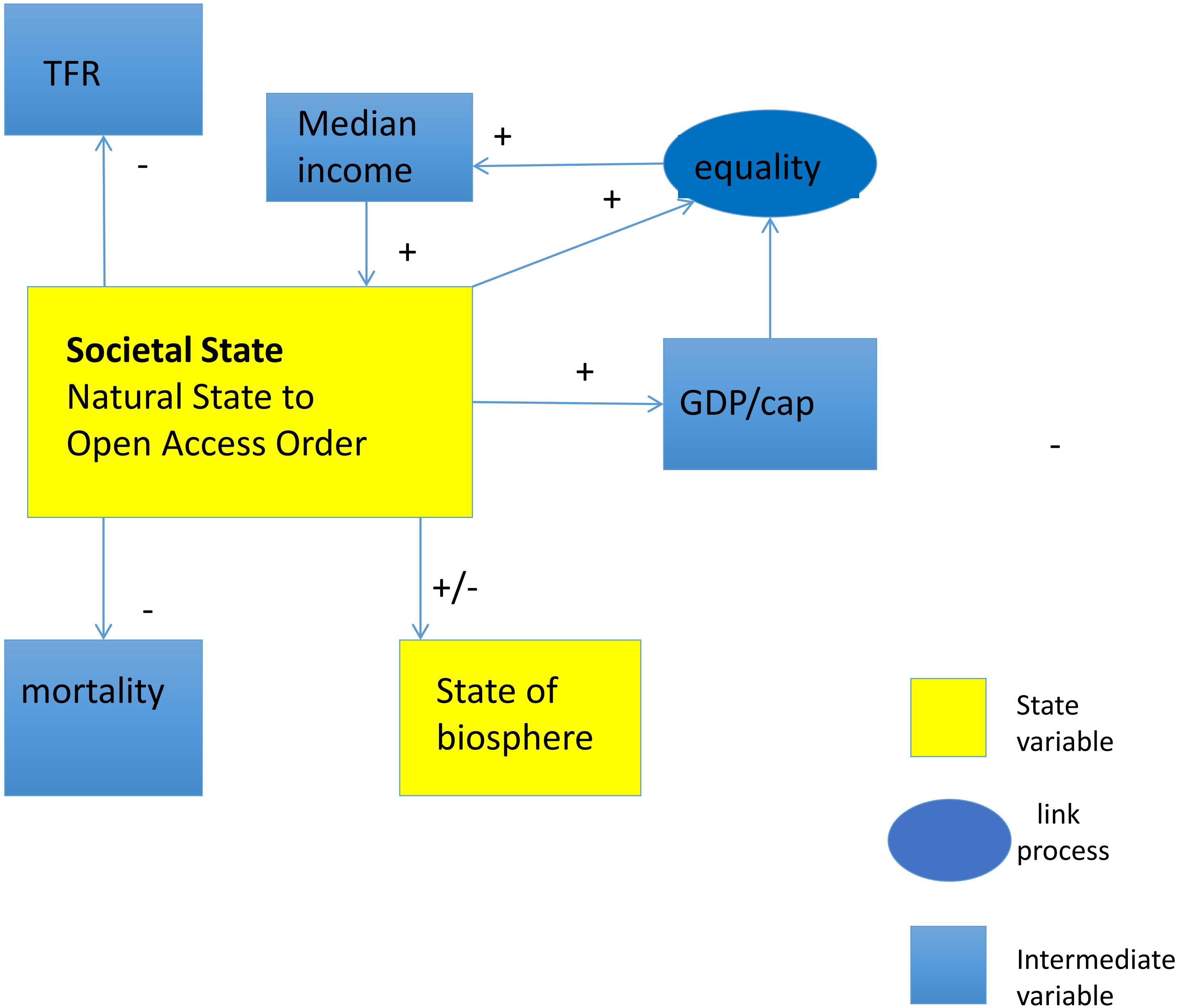
Can we define a minimal set of variables and relationships to describe the Human-Earth System as a dynamical system?



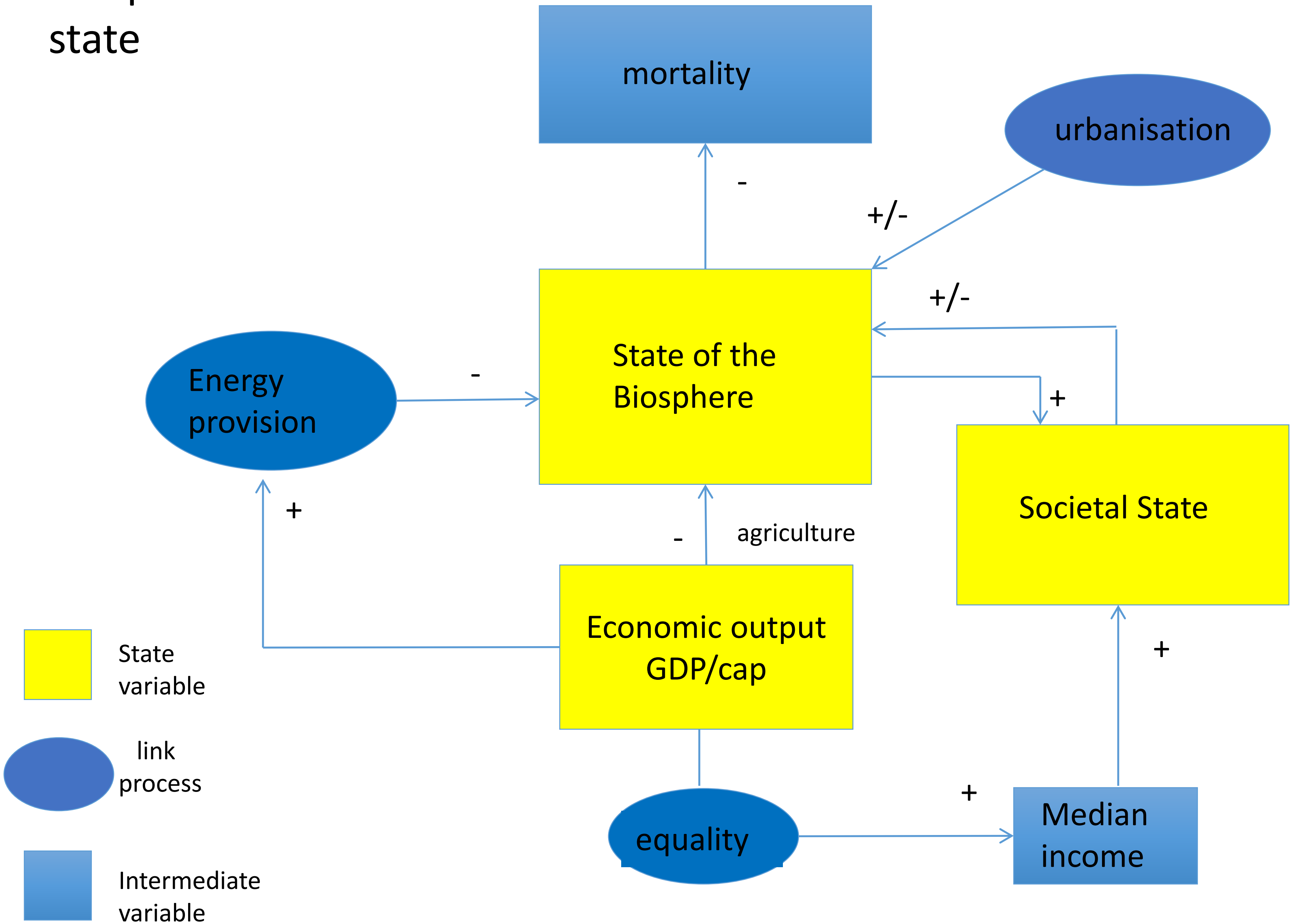
Economic output



Societal state



Biospheric state



The Human-Earth System as a dynamical system?