CSC2720: Systems Thinking for Global Problems

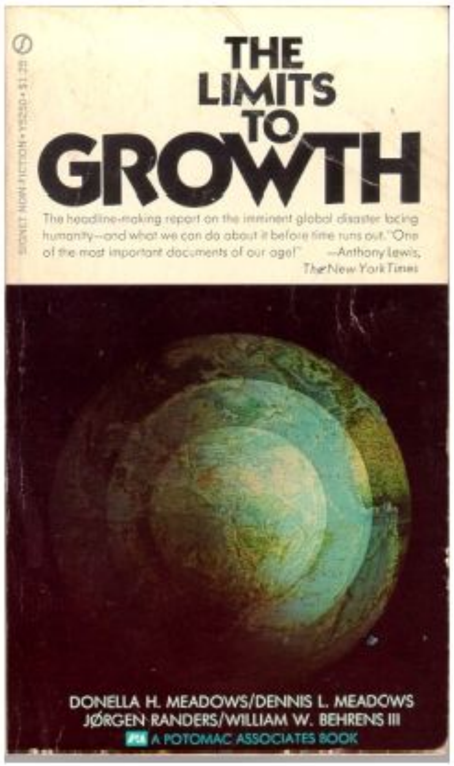
→ Last Week:

- Two types of feedback loop
- Case study: feedbacks in the climate system

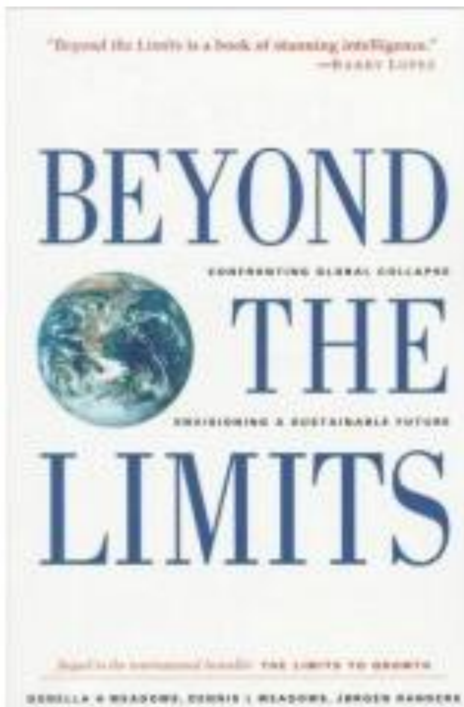
→ This Week:

- Limits to Growth and the World3 Model
- Overshoot and Collapse
- Exponential Growth
- Systems as Stocks and Flows
- Accumulation

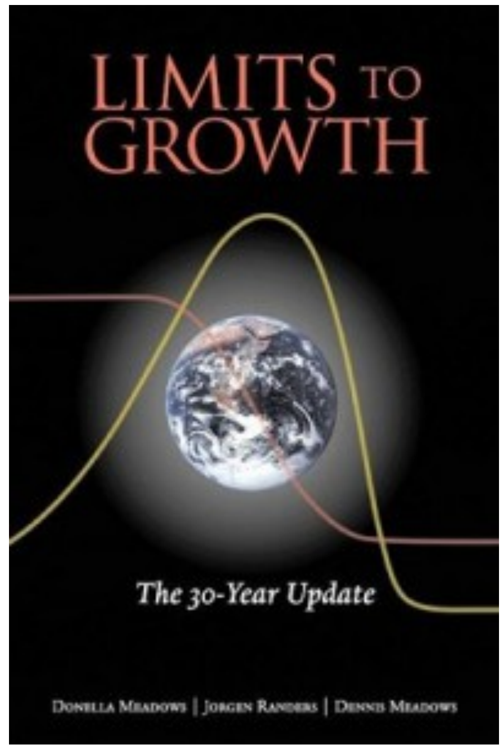
Limits to Growth



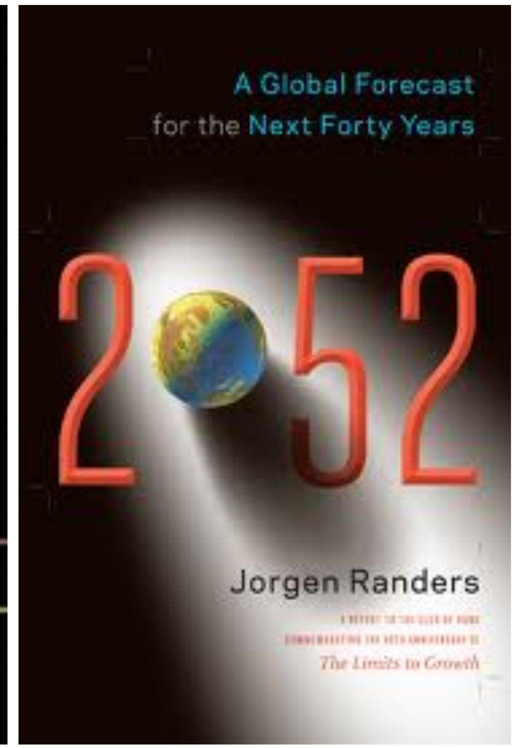
1972



1992



2002



2012

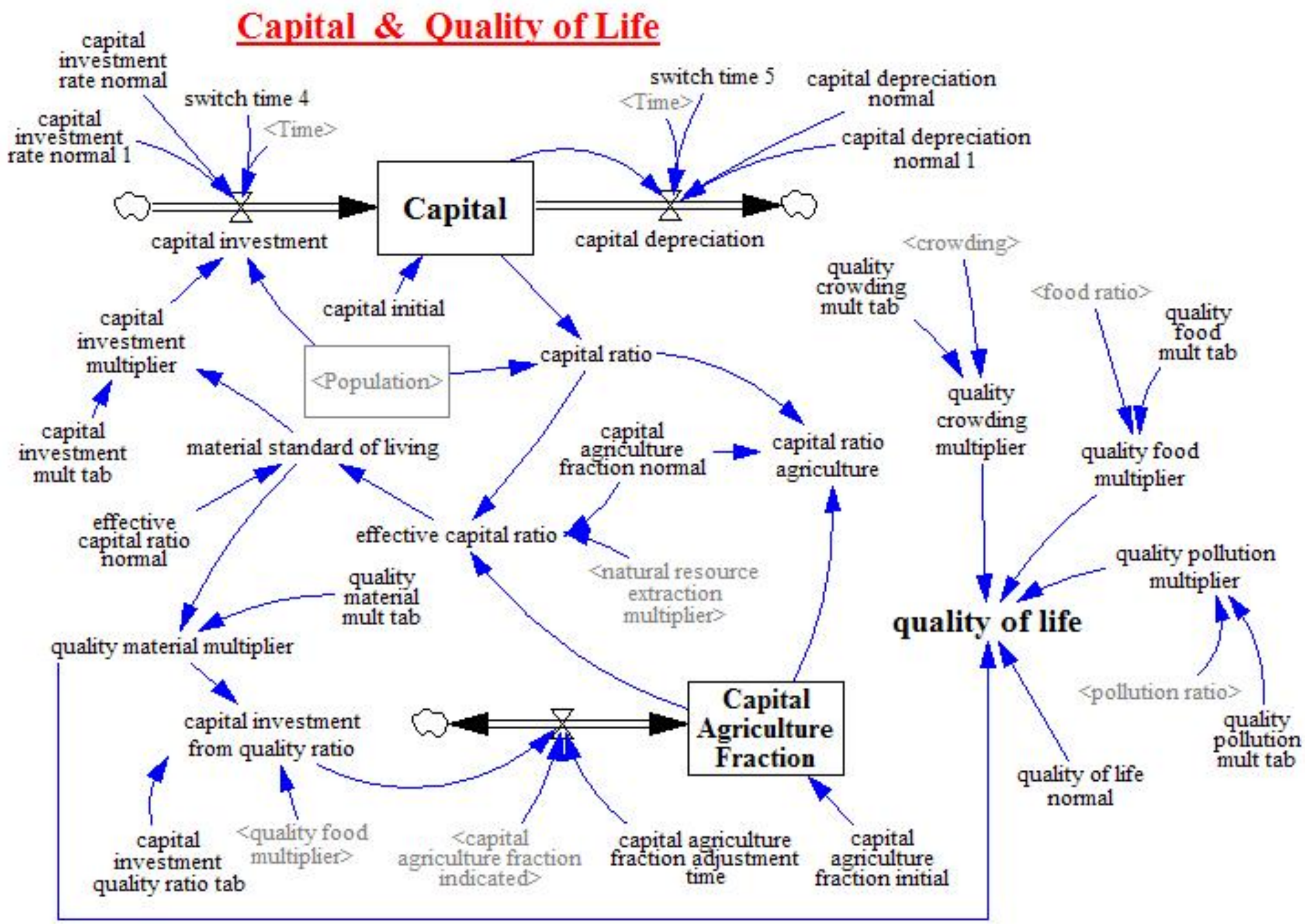
Limits to Growth

- Club of Rome formed 1968
  - Founders: Aurelio Peccei and Alexander King
- "Predicament of Mankind" -> Global Problematique
  - Concept framed by: Hasan Özbekhan, Erich Jantsch and Alexander Christakis
- "Limits to Growth" published 1972
  - Based on Jay Forrester's Systems Dynamics
  - Study by Donella Meadows, Jorgen Randers and Dennis Meadows
  - Updates:
  - "Beyond the Limits to Growth", 1992
  - "Limits to Growth: the 30-year Update" 2004

Key ideas

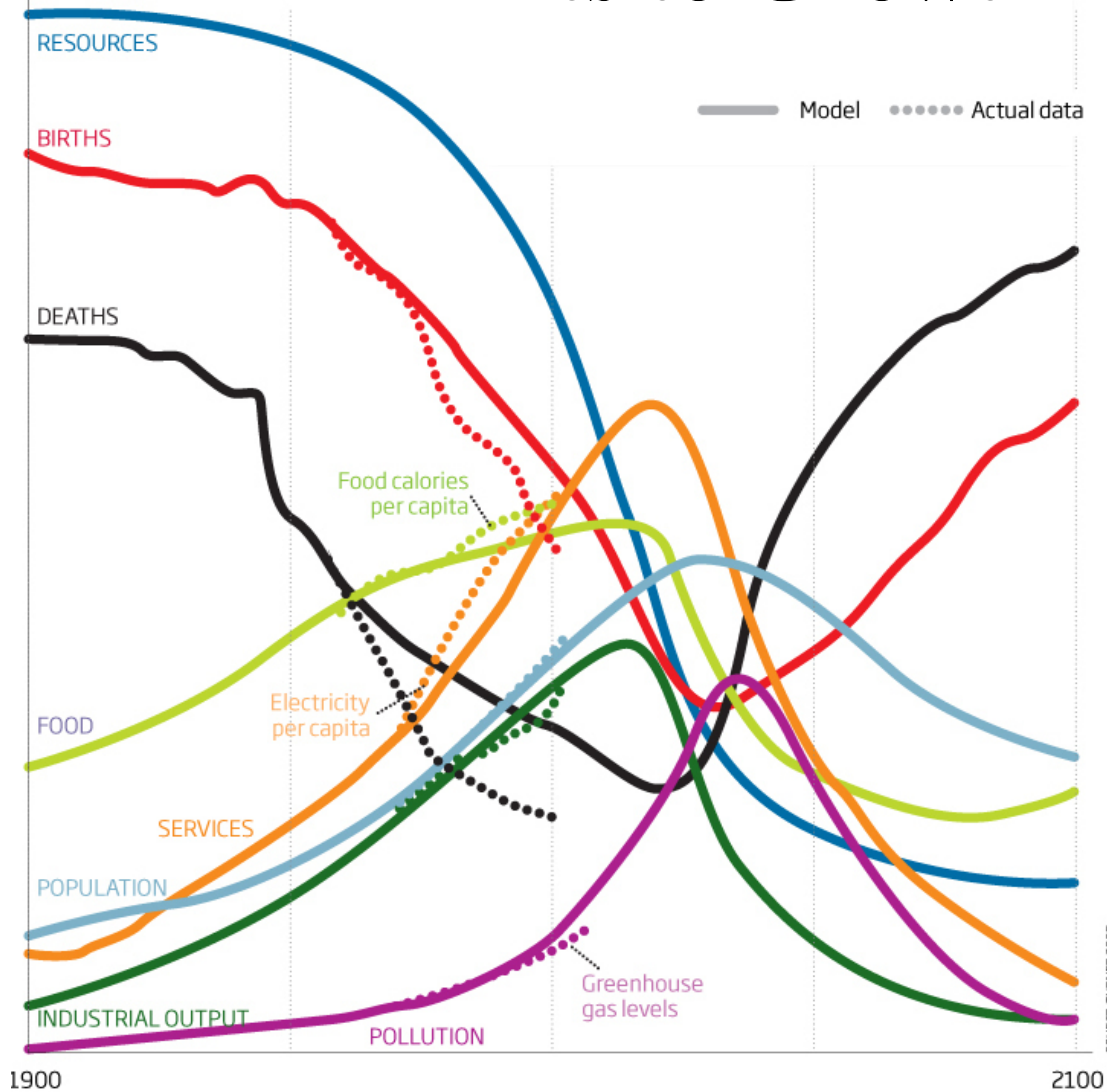
- **Finite planet has a "carrying capacity"**
  - Growth of Population x ecological footprint will exceed it
  - This happened sometime in the 1980s
  - Reduction is inevitable; can be managed or can be collapse
- **There are limits on stocks...**
  - E.g. resources such as oil, coal, scarce minerals
  - E.g. pollution sinks, such as CO_2 in the atmosphere
  - (In the past, we've been good at finding substitutions…)
- **…but the important limits are on flows**
  - E.g. Rate at which we can grow food, recycle waste, etc.
  - E.g. Rate at which we can transition to alternative technologies
  - Hence, population can overshoot carrying capacity
- **People often deny a limit has been reached until after a collapse**
  - E.g. Dotcom "bubble"; banking crisis of 2007;
  - E.g. Economic inequality? Climate change?

The World3 Model

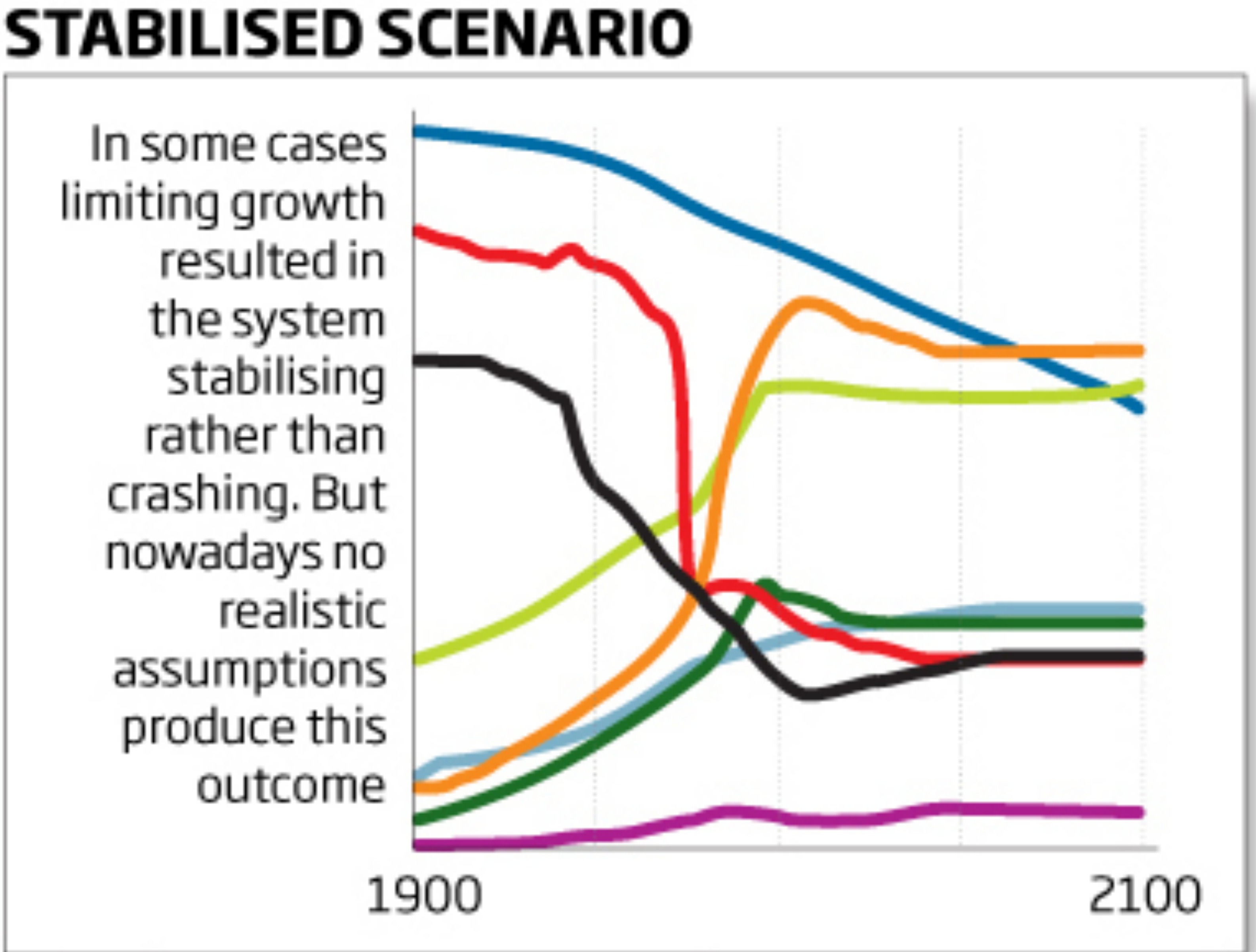


Play with it at: http://insightmaker.com/insight/1954

Limits to Growth - review



See: Turner, G. M. (2008). A comparison of The Limits to Growth with 30 years of reality. Global Environmental Change, 18(3), 397–411.


STABILISED SCENARIO
In some cases limiting growth resulted in the system stabilising rather than crashing. But nowadays no realistic assumptions produce this outcome
1900
2100

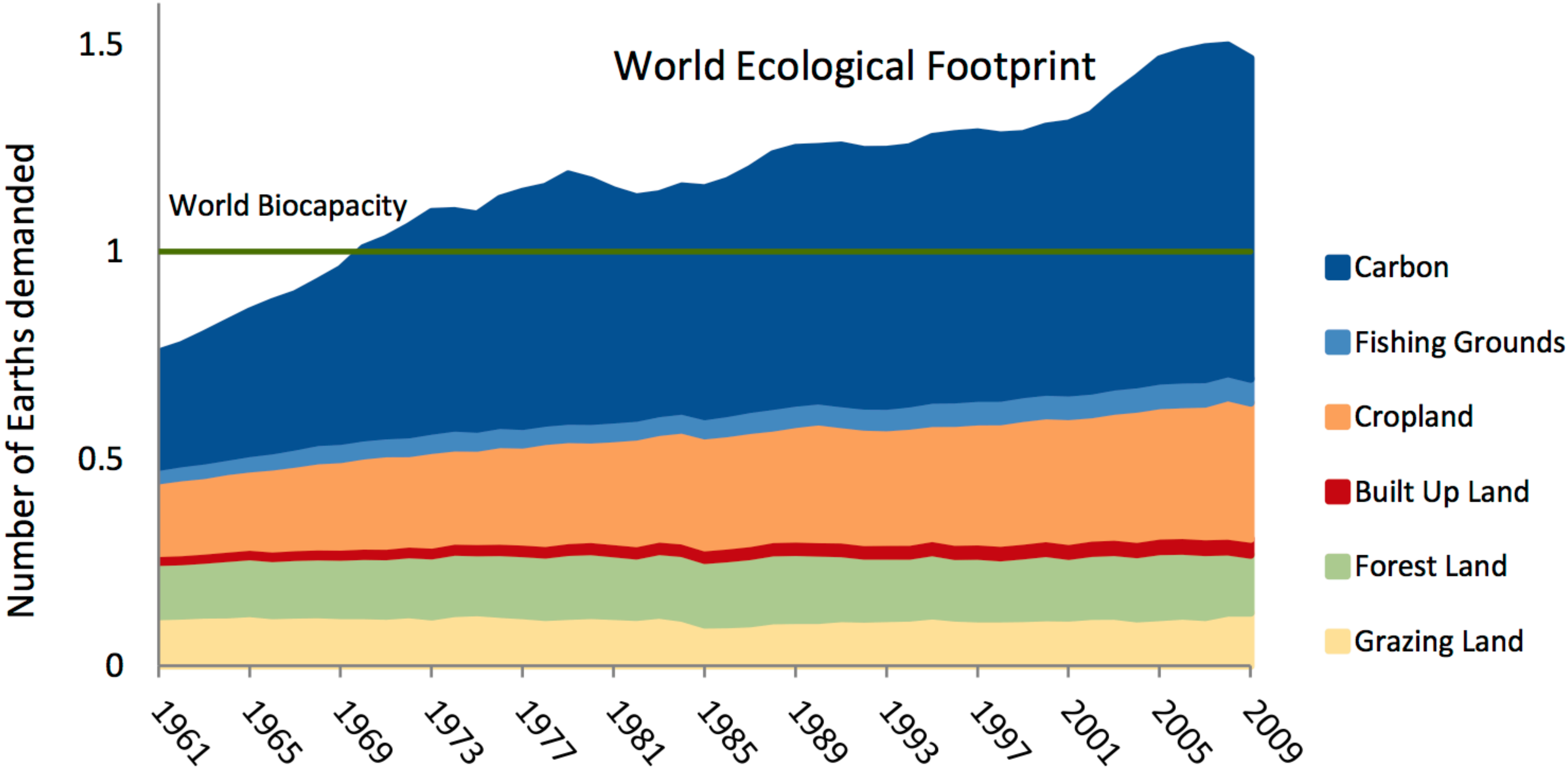
How is overshoot possible?

What happens if you spend more than you earn each year?

What happens if a farmer uses more water than falls in rain each year?

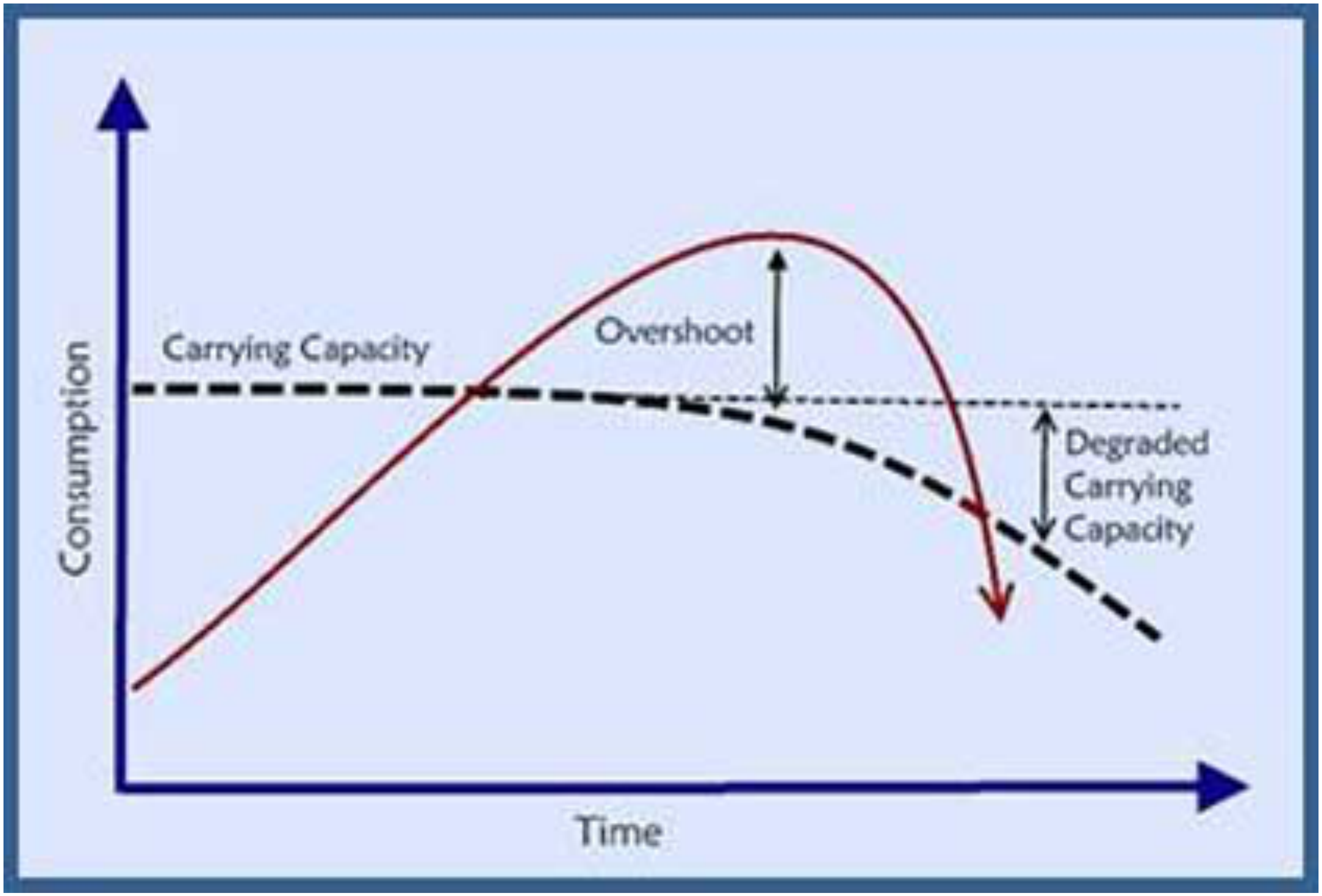
What happens if we produce more CO2 each year than the soils and oceans can absorb?

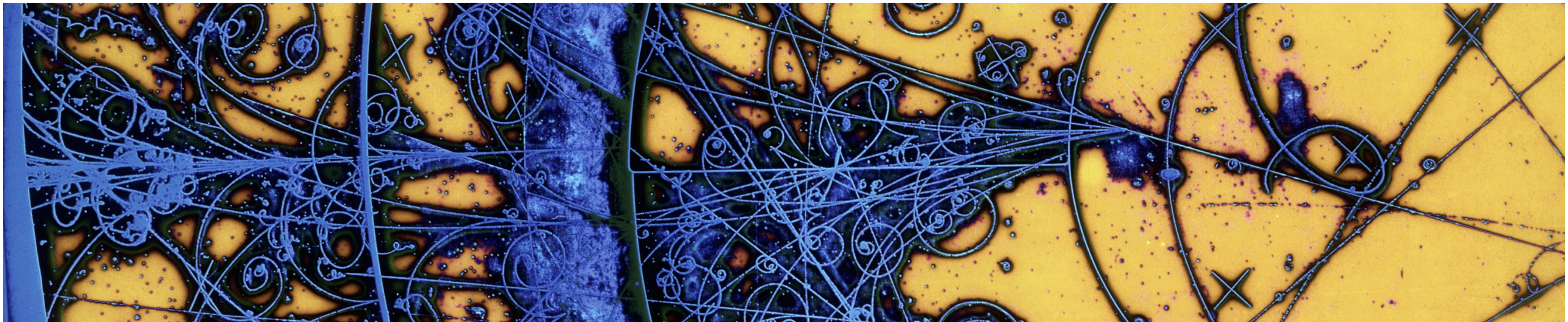
Overshoot



http://www.footprintnetwork.org/images/article_uploads/National_Footprint_Accounts_2012_Edition_Report.pdf

Overshoot degrades capacity

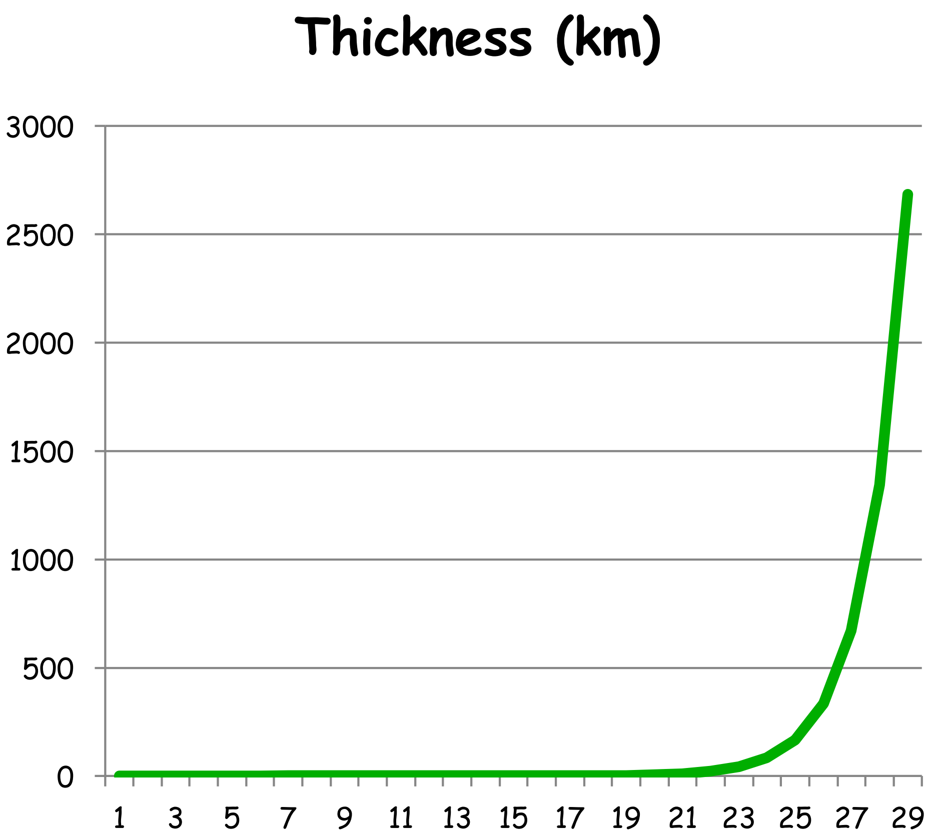


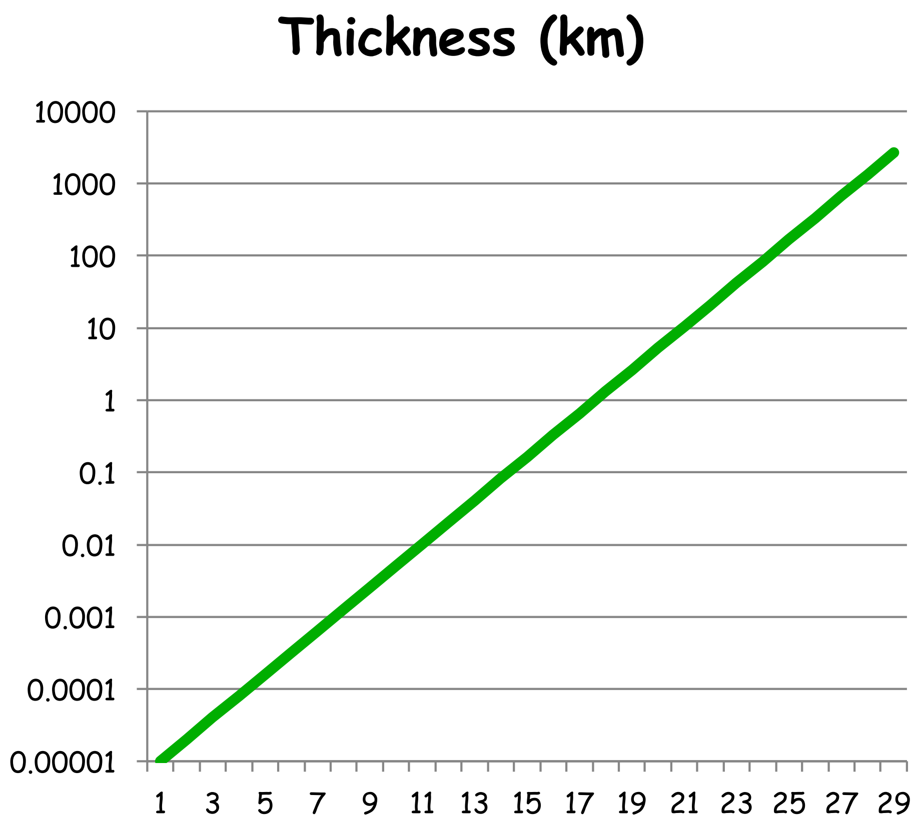


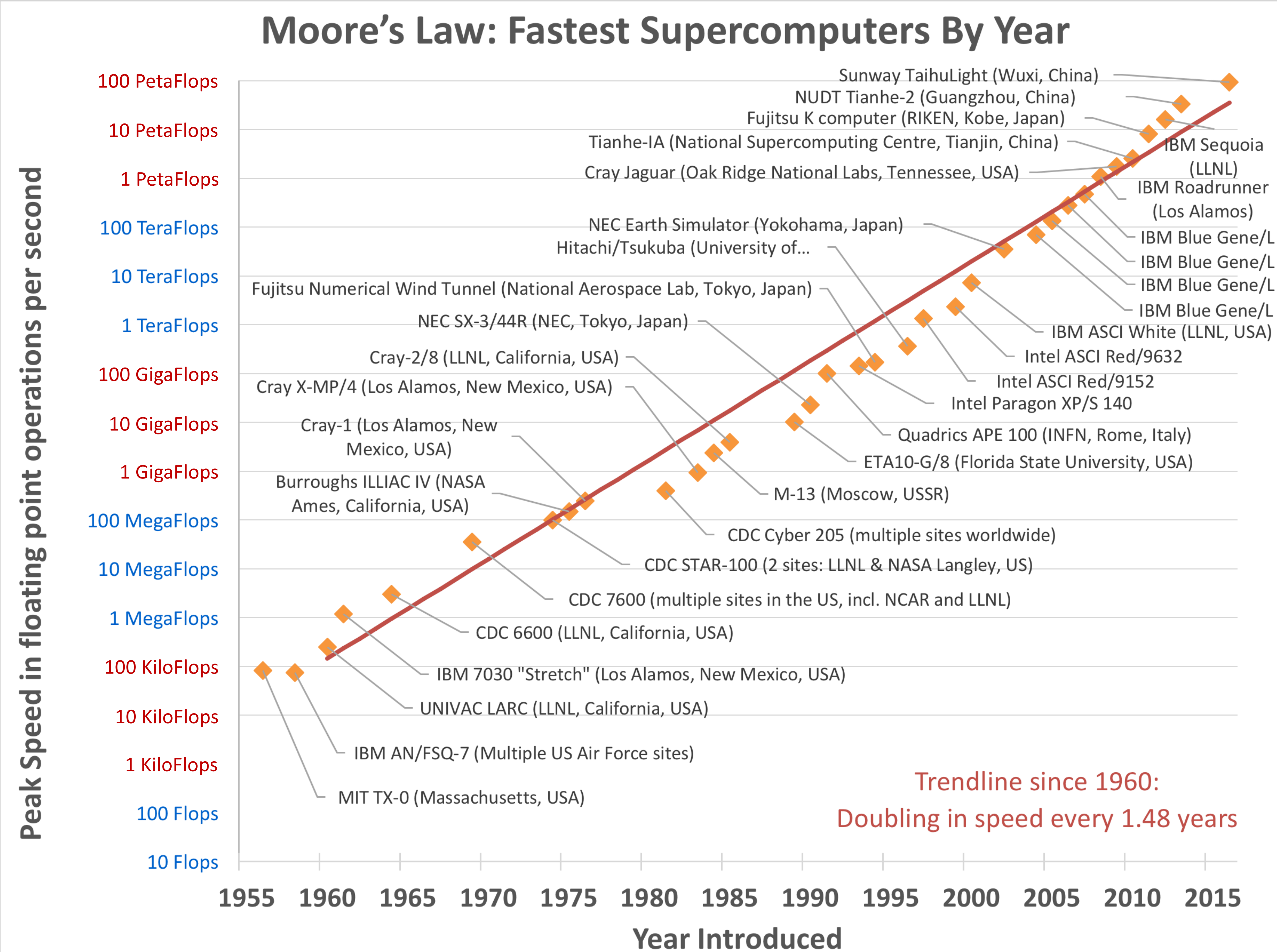
EXPONENTIAL GROWTH

Paper Folding

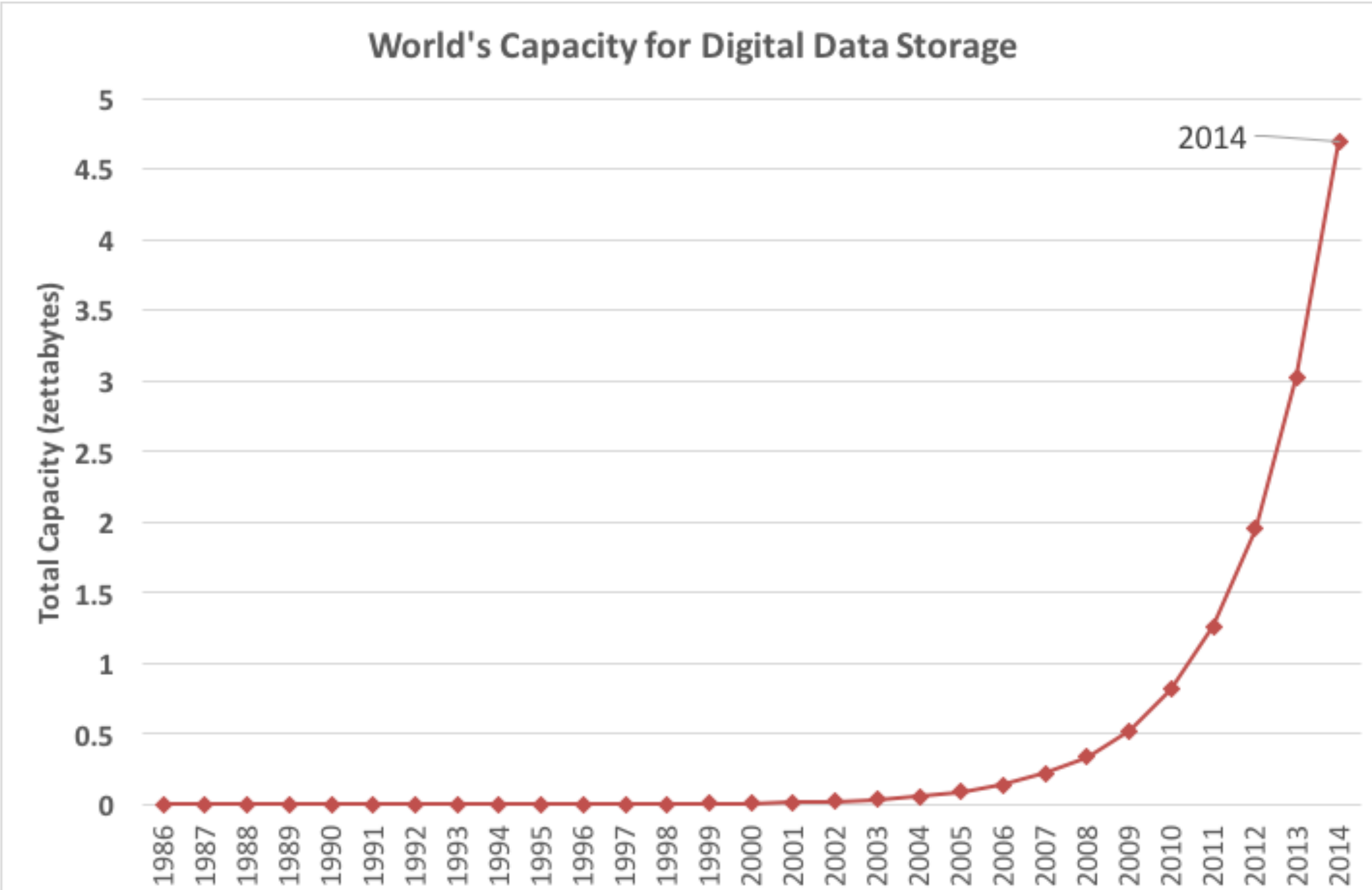
- After 4 folds, 1 cm thick
- How thick after 29 more folds?



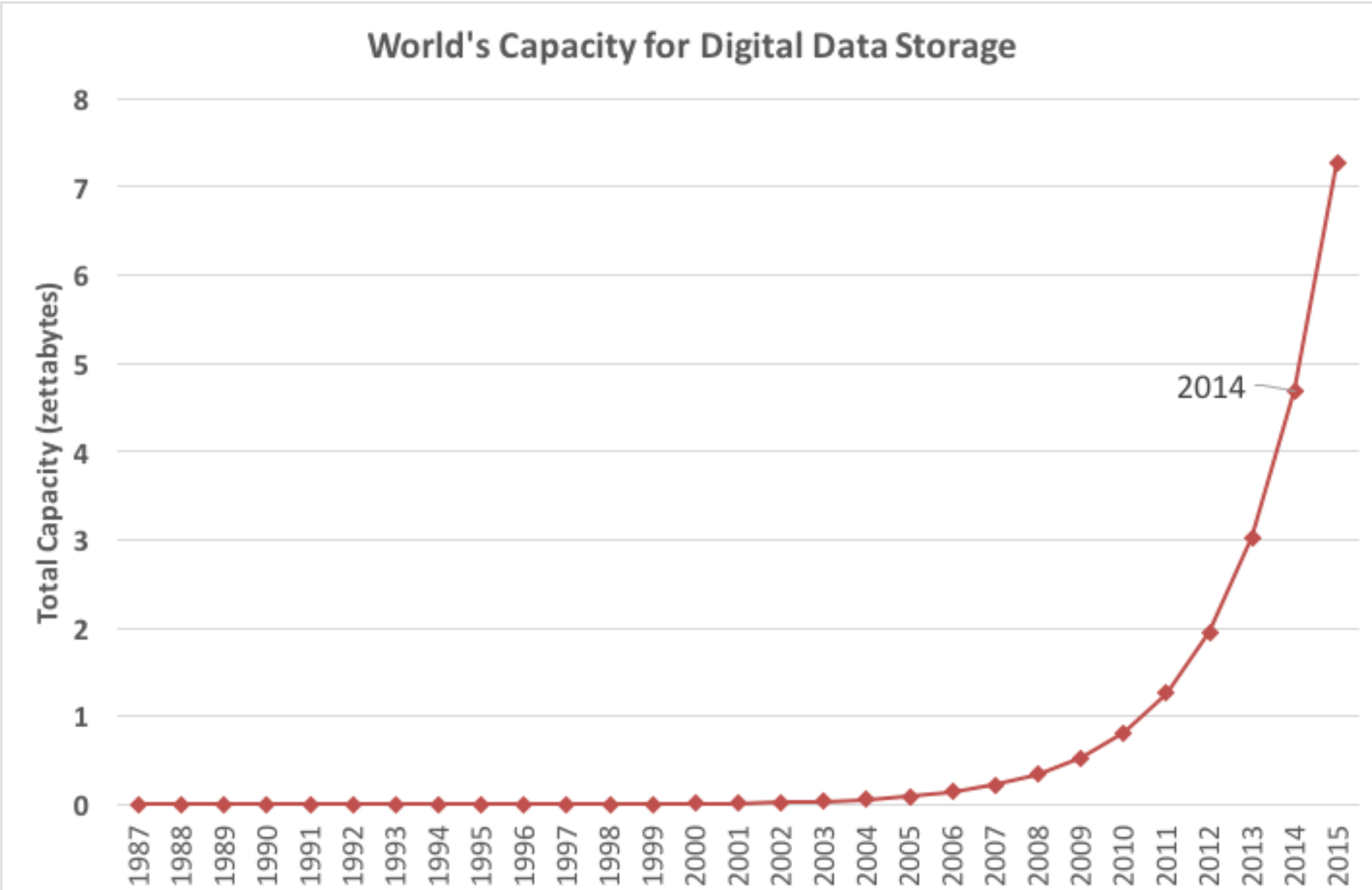



Moore's Law: Fastest Supercomputers By Year
Peak Speed in floating point operations per second
100 PetaFlops
10 PetaFlops
1 PetaFlops
100 TeraFlops
10 TeraFlops
1 TeraFlops
100 GigaFlops
10 GigaFlops
1 GigaFlops
100 MegaFlops
10 MegaFlops
1 MegaFlops
100 KiloFlops
10 KiloFlops
1 KiloFlops
100 Flops
10 Flops
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015
Year Introduced
Sunway TaihuLight (Wuxi, China)
NUDT Tianhe-2 (Guangzhou, China)
Fujitsu K computer (RIKEN, Kobe, Japan)
IBM Sequoia (LLNL)
Tianhe-IA (National Supercomputing Centre, Tianjin, China)
Cray Jaguar (Oak Ridge National Labs, Tennessee, USA)
IBM Roadrunner (Los Alamos)
NEC Earth Simulator (Yokohama, Japan)
IBM Blue Gene/L
Hitachi/Tsukuba (University of...
IBM Blue Gene/L
IBM Blue Gene/L
Fujitsu Numerical Wind Tunnel (National Aerospace Lab, Tokyo, Japan)
IBM Blue Gene/L
NEC SX-3/44R (NEC, Tokyo, Japan)
IBM ASCI White (LLNL, USA)
Cray-2/8 (LLNL, California, USA)
Intel ASCI Red/9632
Intel ASCI Red/9152
Cray X-MP/4 (Los Alamos, New Mexico, USA)
Intel Paragon XP/S 140
Cray-1 (Los Alamos, New Mexico, USA)
Quadrics APE 100 (INFN, Rome, Italy)
ETA10-G/8 (Florida State University, USA)
Burroughs ILLIAC IV (NASA Ames, California, USA)
M-13 (Moscow, USSR)
CDC Cyber 205 (multiple sites worldwide)
CDC STAR-100 (2 sites: LLNL & NASA Langley, US)
CDC 7600 (multiple sites in the US, incl. NCAR and LLNL)
CDC 6600 (LLNL, California, USA)
IBM 7030 "Stretch" (Los Alamos, New Mexico, USA)
UNIVAC LARC (LLNL, California, USA)
IBM AN/FSQ-7 (Multiple US Air Force sites)
MIT TX-0 (Massachusetts, USA)
Trendline since 1960:
Doubling in speed every 1.48 years

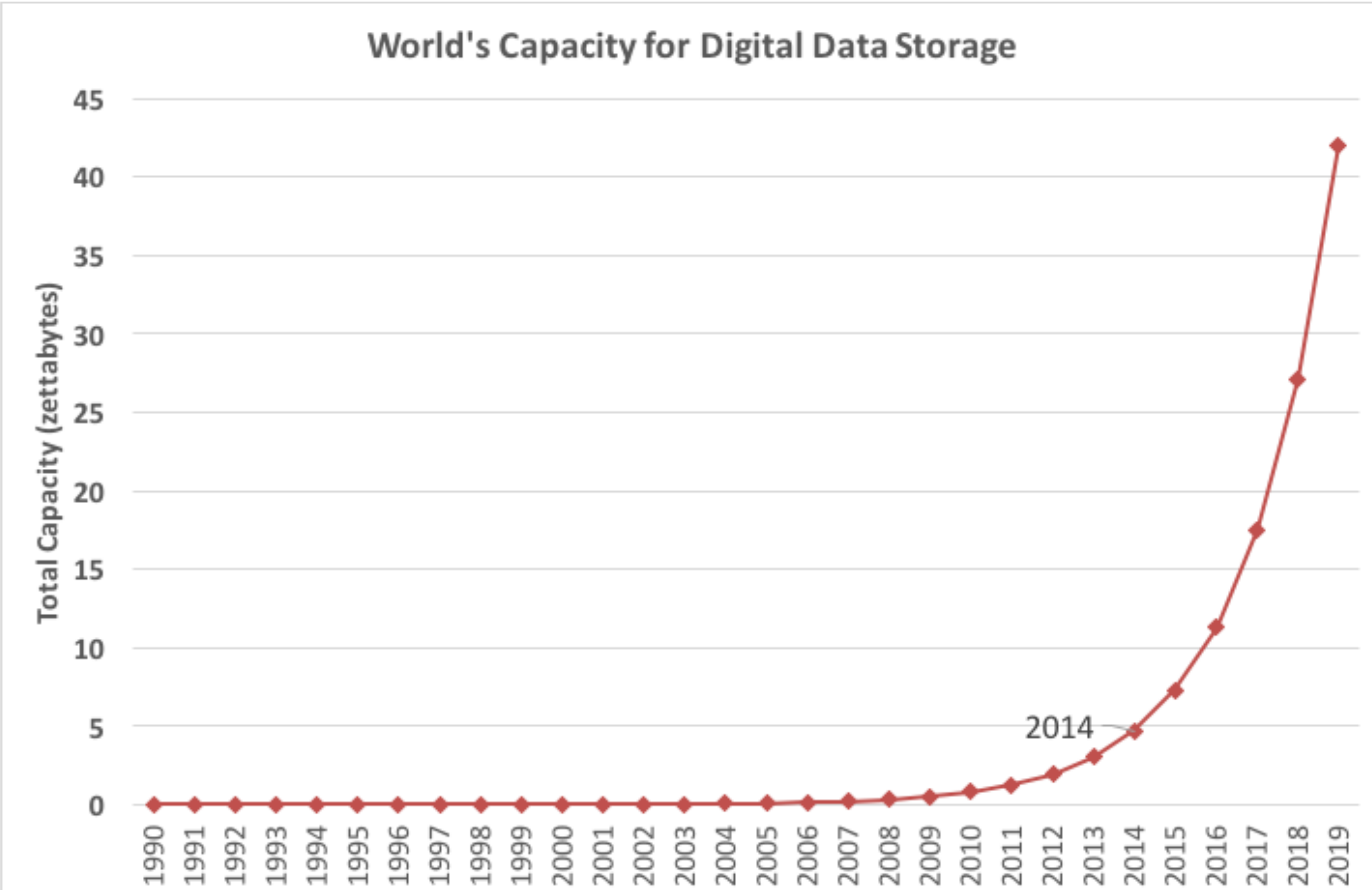
Understanding Exponential Growth



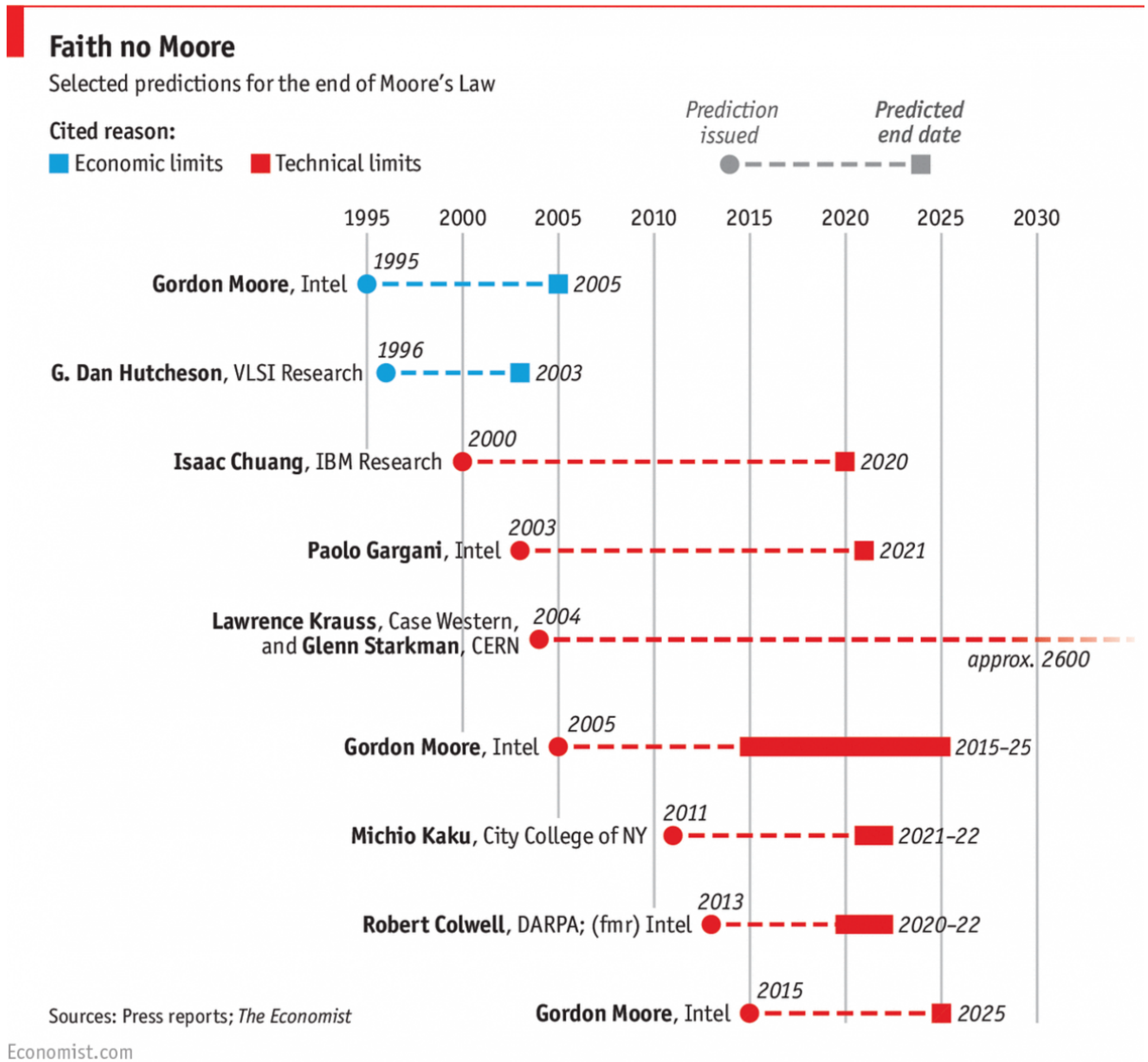
Understanding Exponential Growth



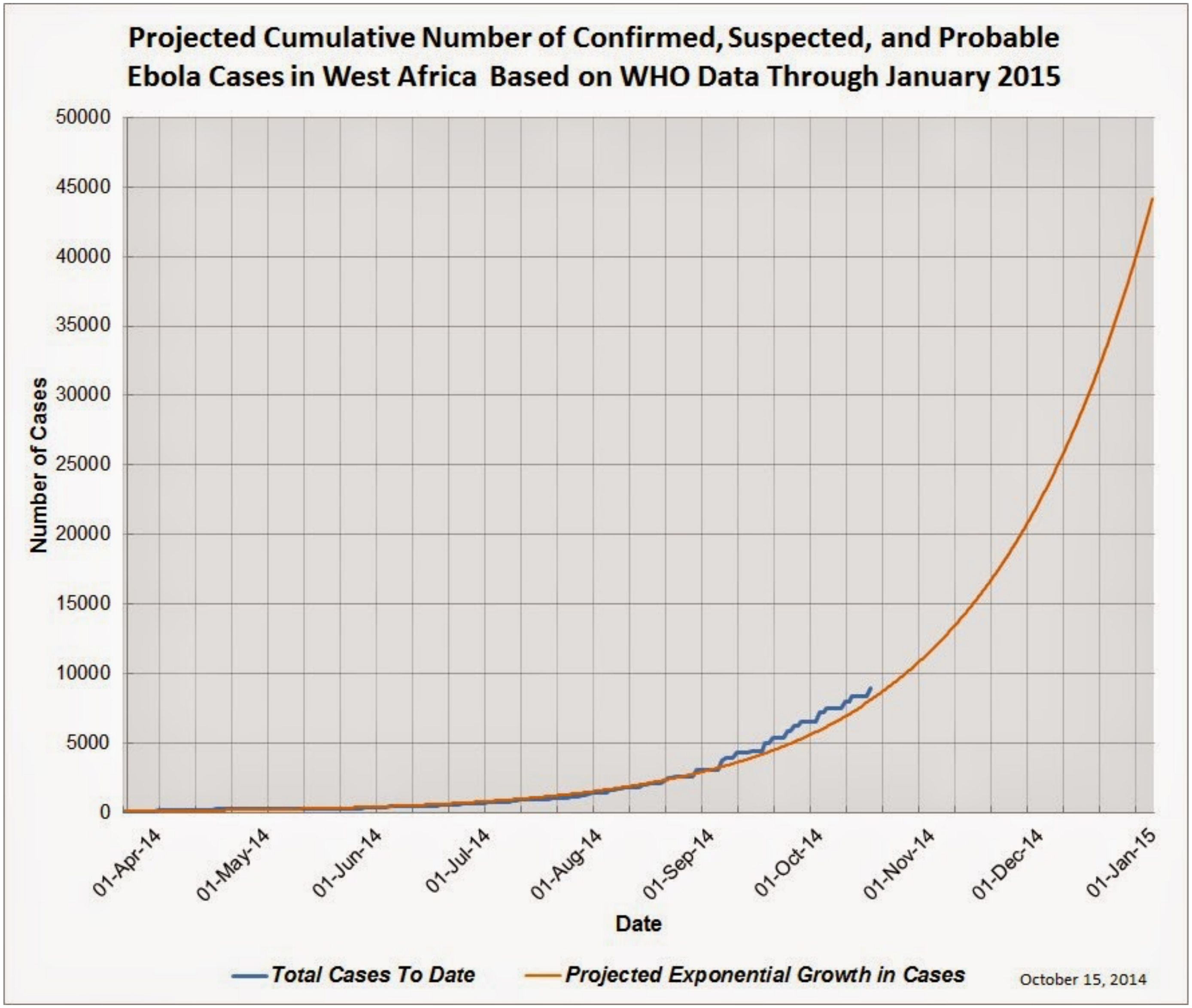
Understanding Exponential Growth



Can Moore's Law continue forever?

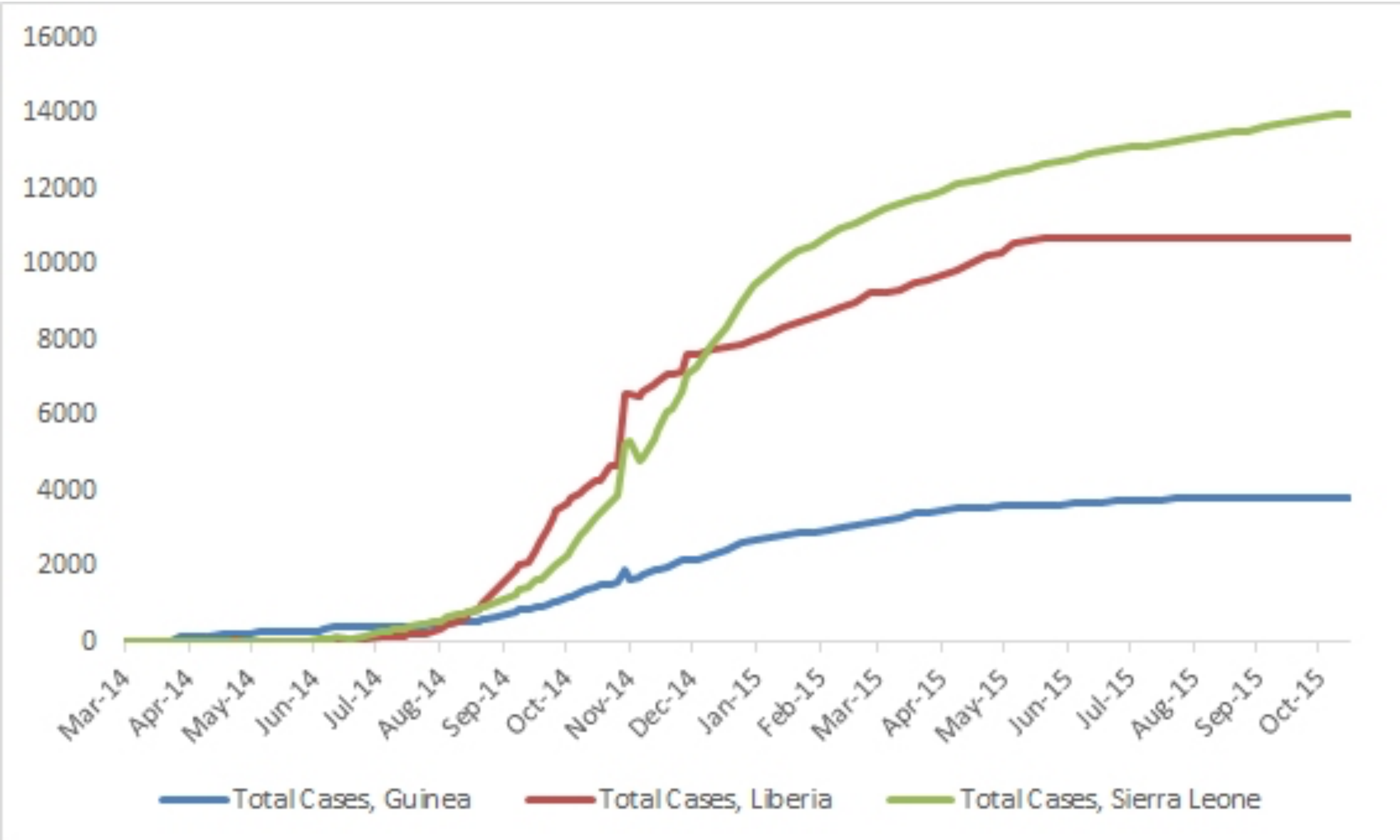


Why does this graph have this shape?

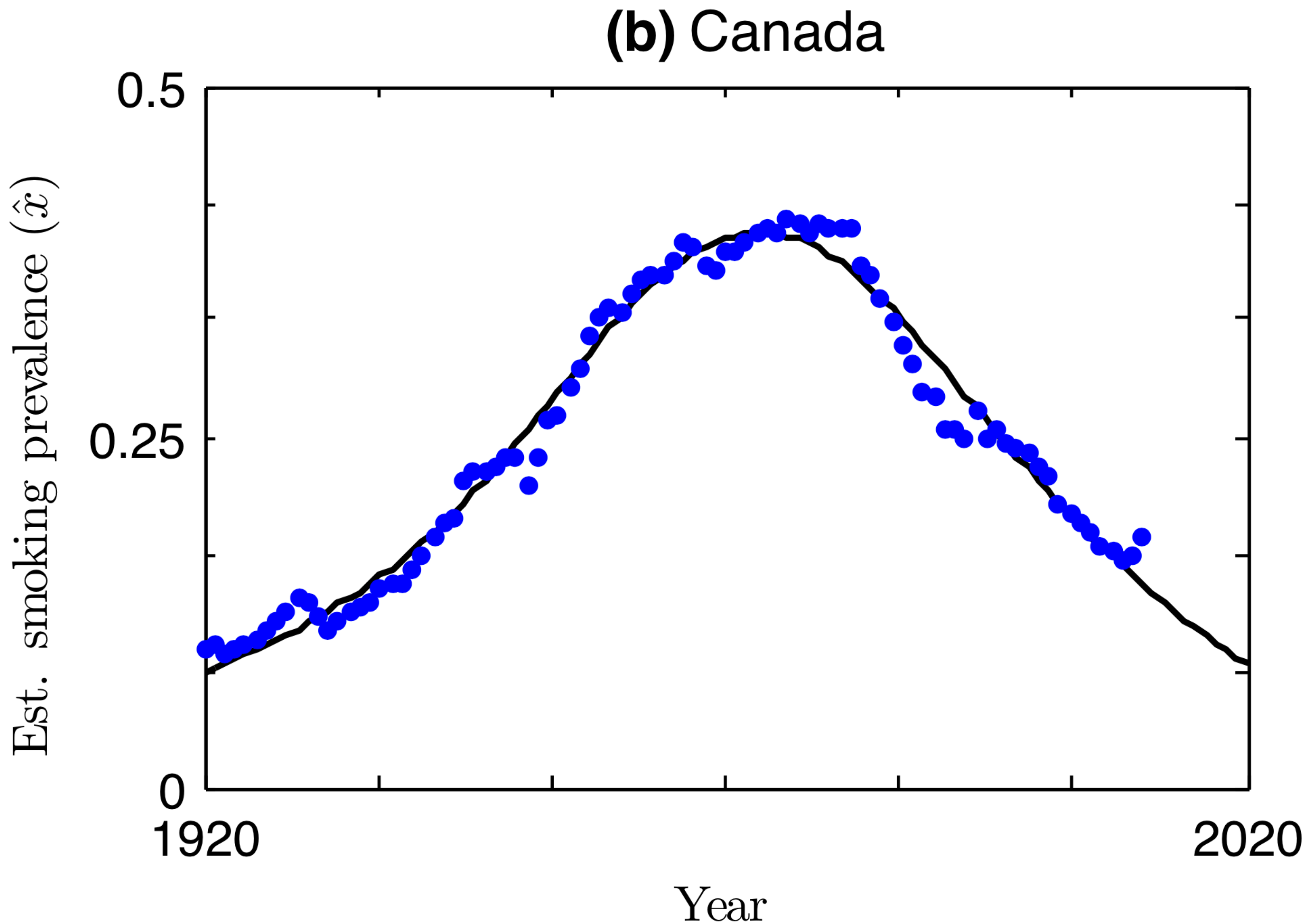


http://novel-infectious-diseases.blogspot.ca/2014/10/comparing-who-and-cdc-projections-of.html

But the prediction was wrong…

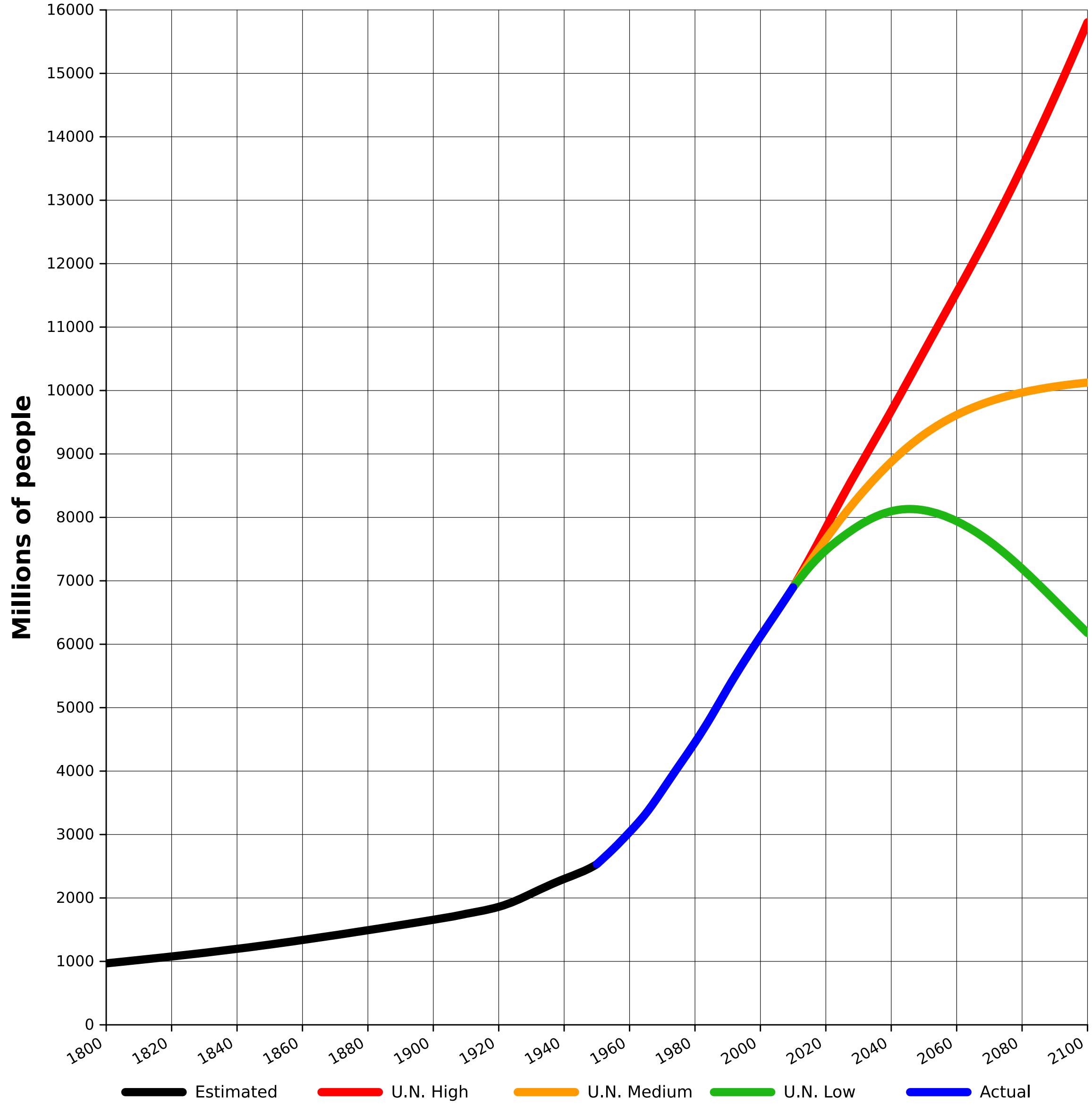


http://www.cdc.gov/vhf/ebola/outbreaks/2014-west-africa/cumulative-cases-graphs.html

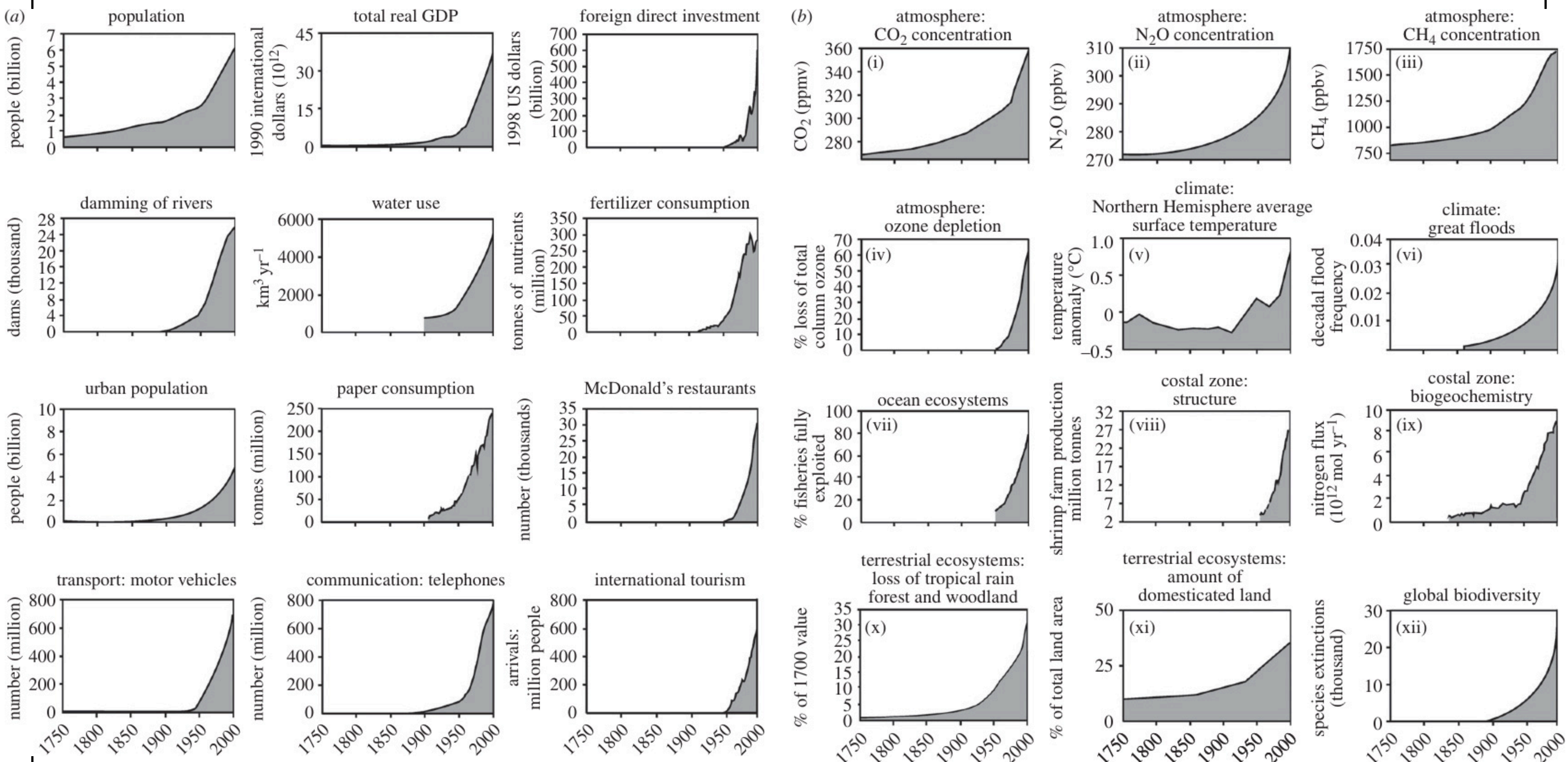


Lang et al (2014). The influence of societal individualism on a century of tobacco use: modelling the prevalence of smoking, 1–20. Dynamical Systems; Physics and Society.

Population Growth and Projections



Exponentials Everywhere!



Steffen, W., Grinevald, J., Crutzen, P., & McNeill, J. (2011). The Anthropocene: conceptual and historical perspectives. DOI: 10.1098/rsta.2010.0327

Environmental Footprint of Progress

Impact = Population x Affluence x Technology

$$I = P \times A \times T$$

P: # persons

A: $\frac{\text{consumption}}{\text{person}}$

T: $\frac{\text{emissions}}{\text{consumption}}$

Kaya Identity:

Emissions = Population × Wealth per capita × Energy Intensity × Carbon Intensity

Total emissions = population X GDP /population X Energy /GDP X Emissions /energy

Impossible Hamster!

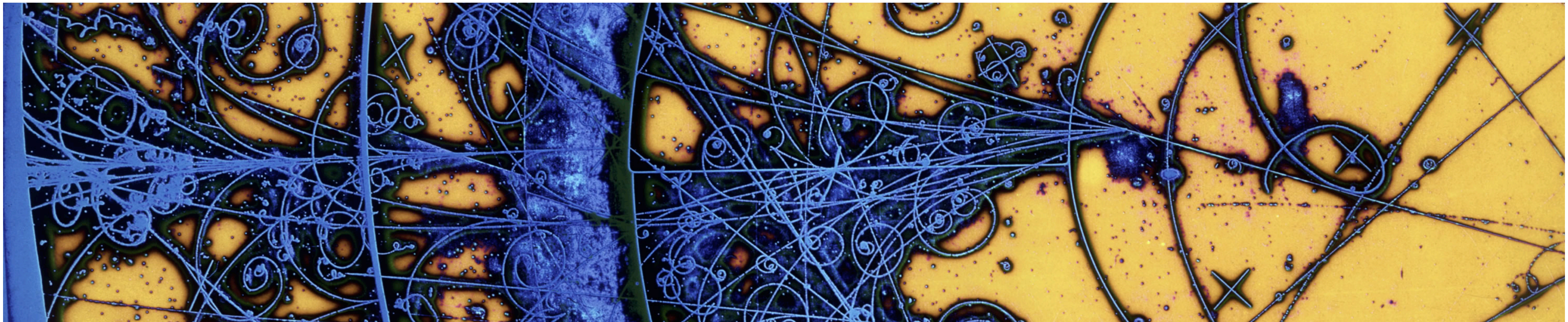
https://www.youtube.com/watch?v=Sqwd_u6HkMo

1) Some curves that look exponential are not!

2) Exponential growth cannot continue forever

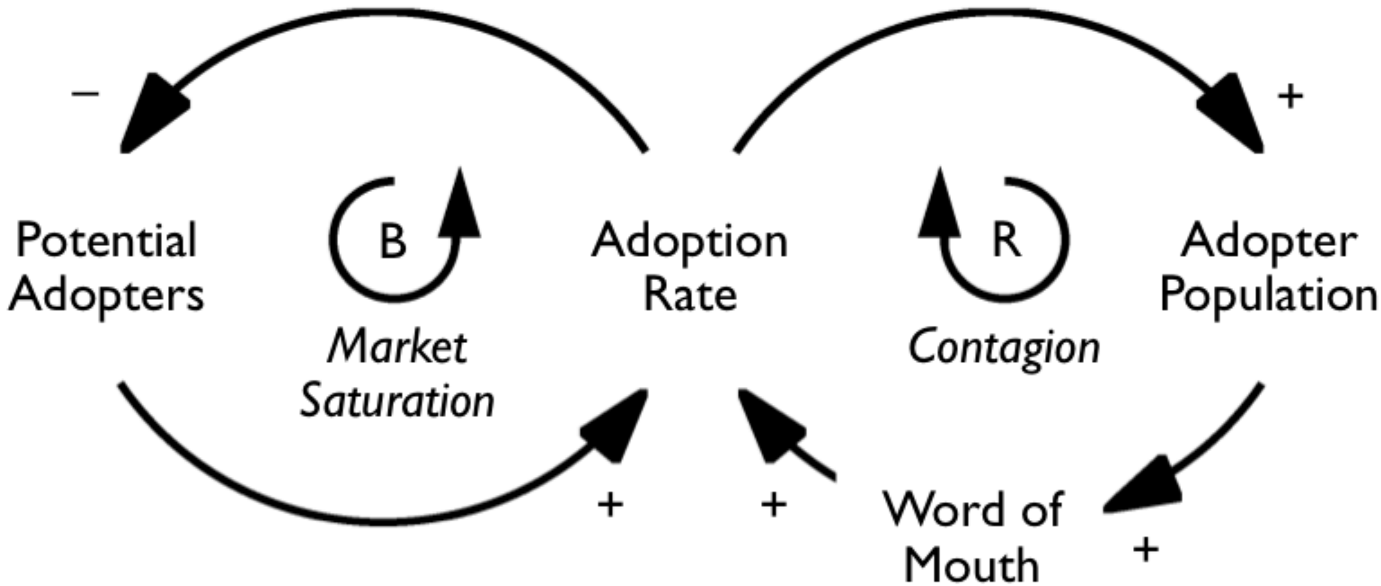
3) Predicting the peak of a growth curve is really hard

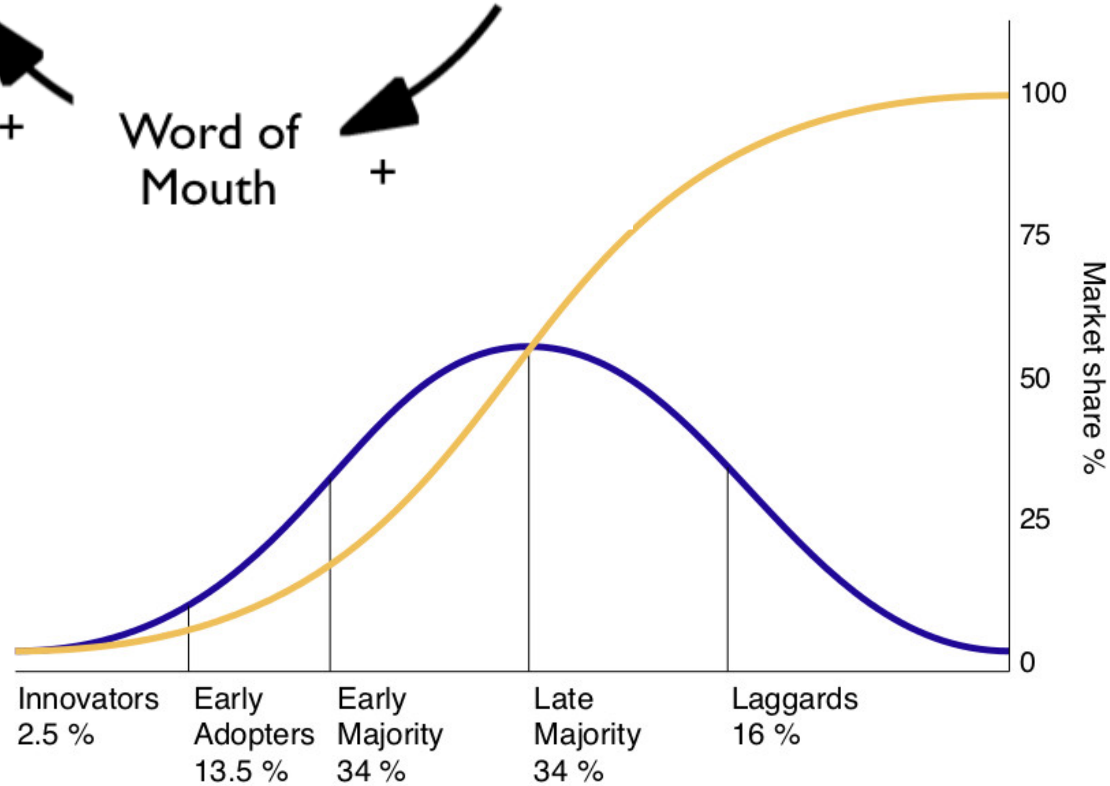
(be suspicious of any precise predictions)



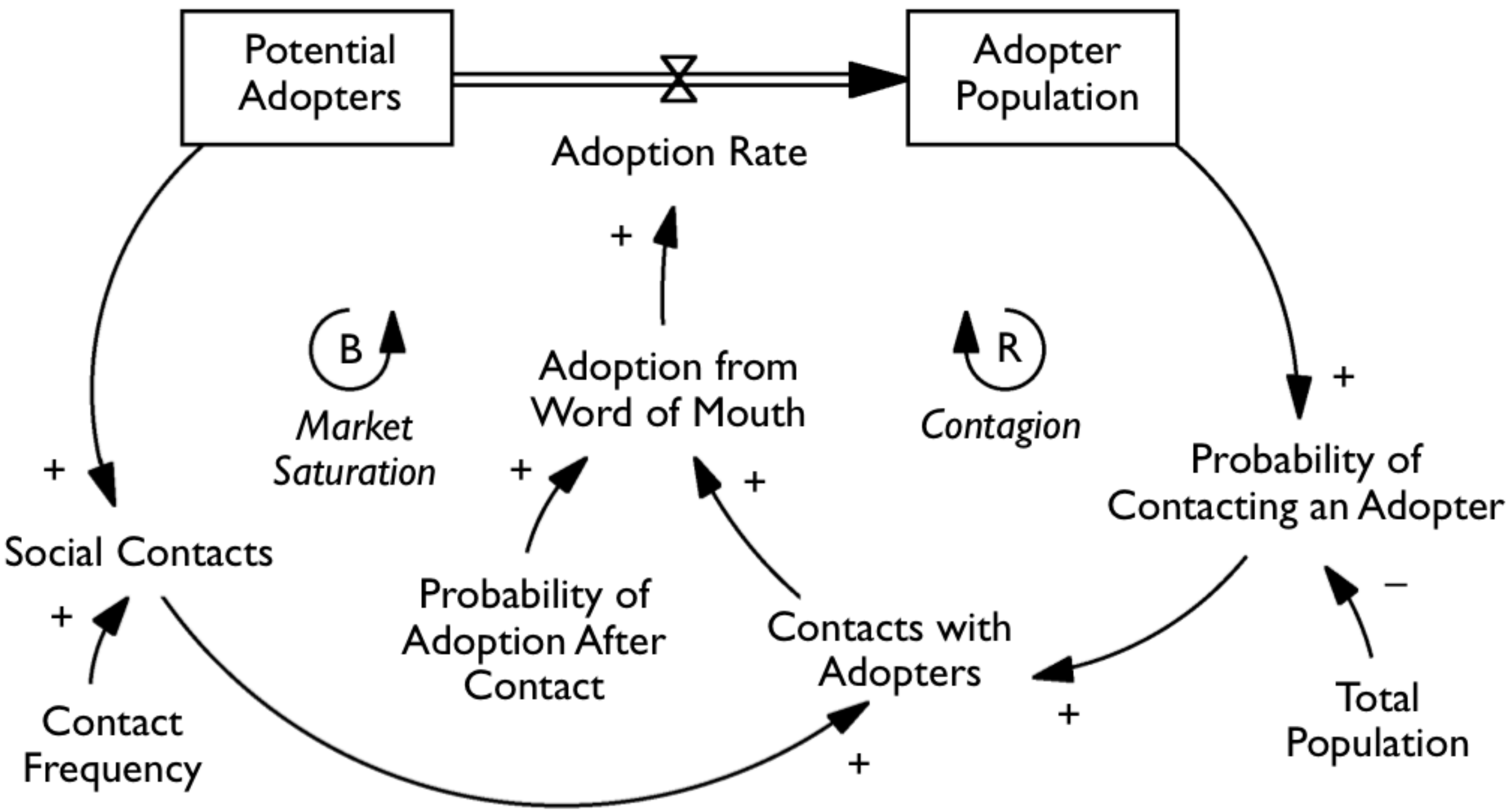
STOCK AND FLOW MODELS

Multi-loop systems





As a Stock'n'Flow Diagram…



Source: Sterman, "Systems Dynamics Modeling: Tools for Learning in a Complex World"

Why we need to think about flows

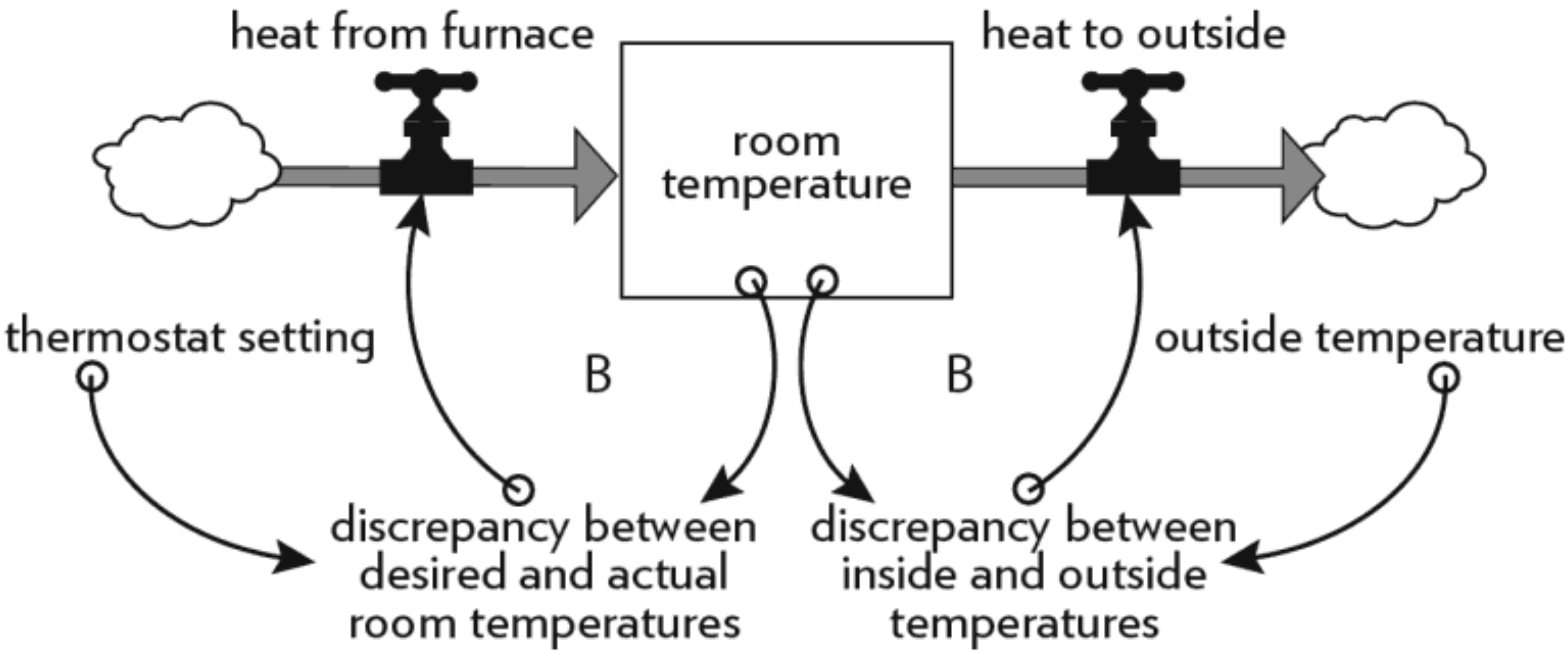


Figure 15. Room temperature regulated by a thermostat and furnace.

Image Source: Meadows, Thinking in Systems

But the room doesn't stay warm!

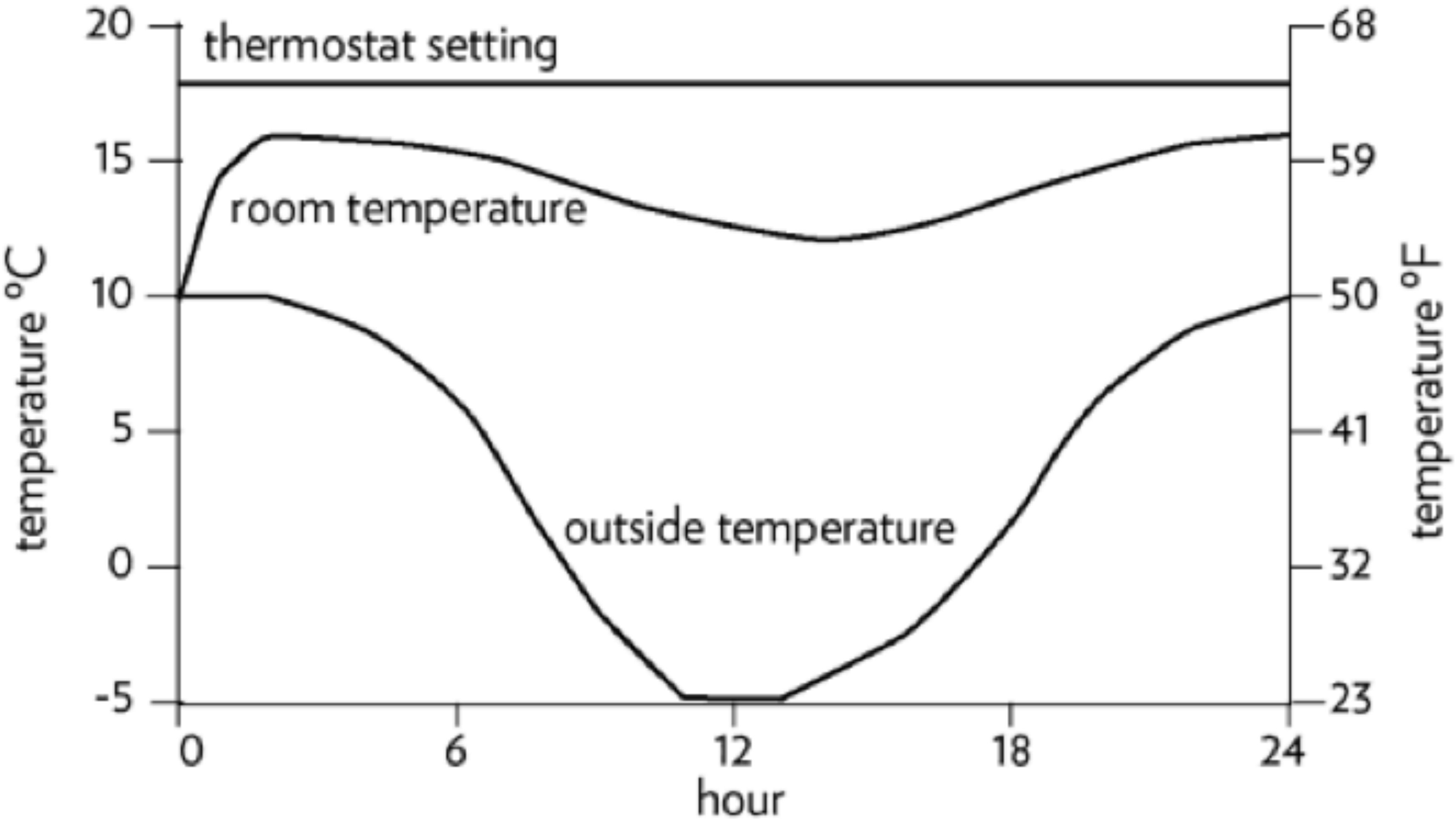
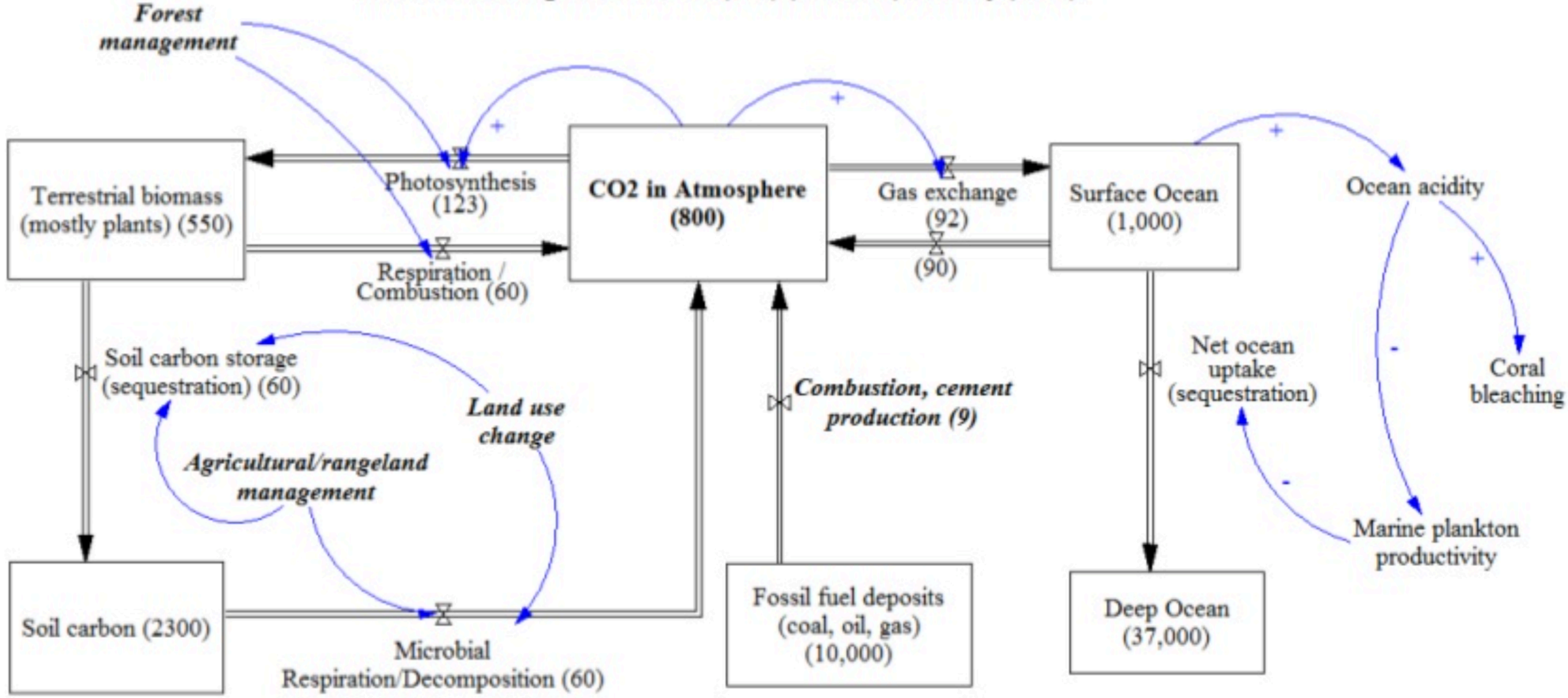


Figure 20. On a cold day, the furnace can't keep the room warm in this leaky house!

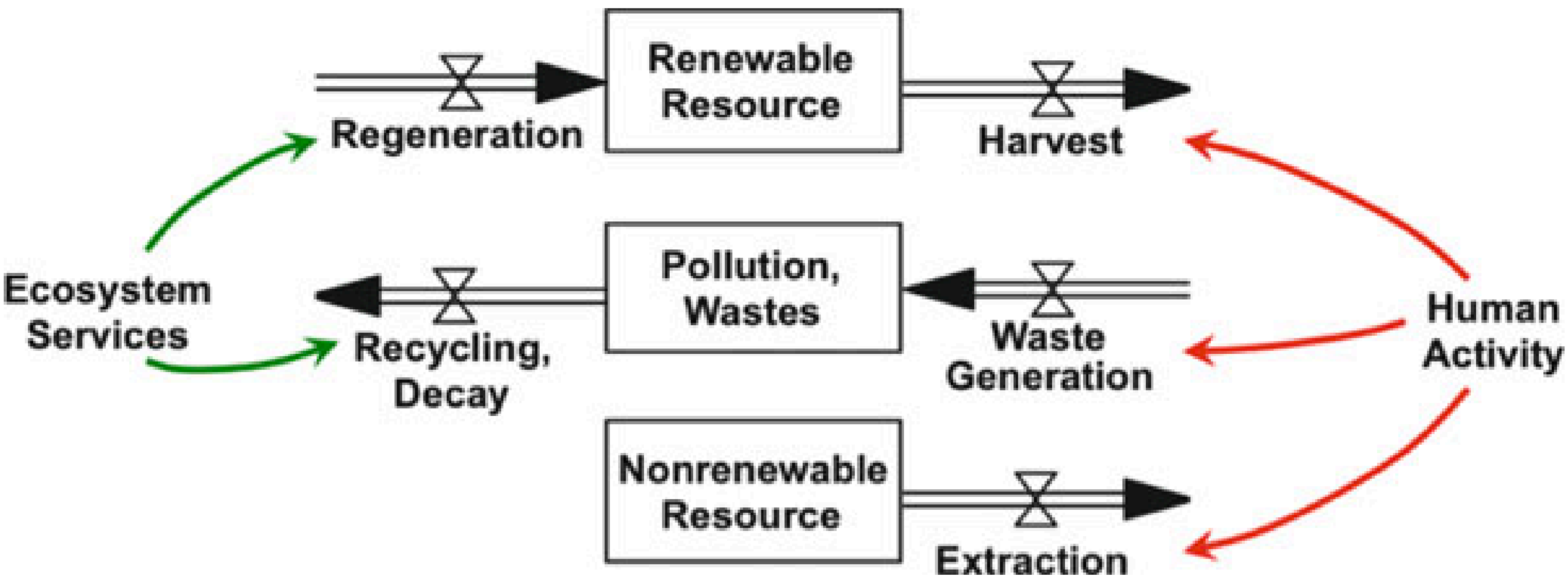
Image Source: Meadows, Thinking in Systems

Stock-flow diagram of the Global Carbon Cycle

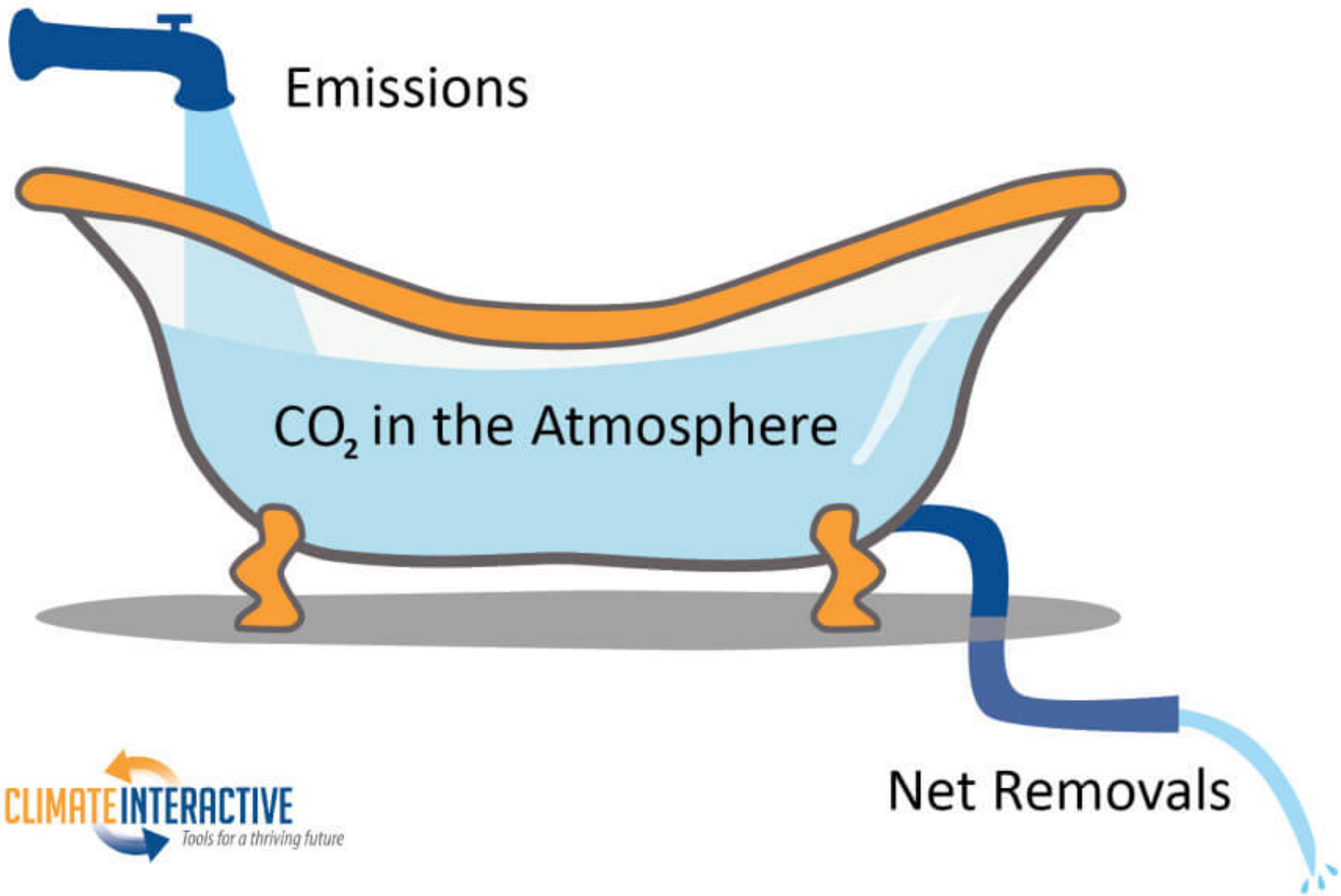
Numbers are in Gigatons of carbon (GtC) (reservoirs) or GtC/y (flows)



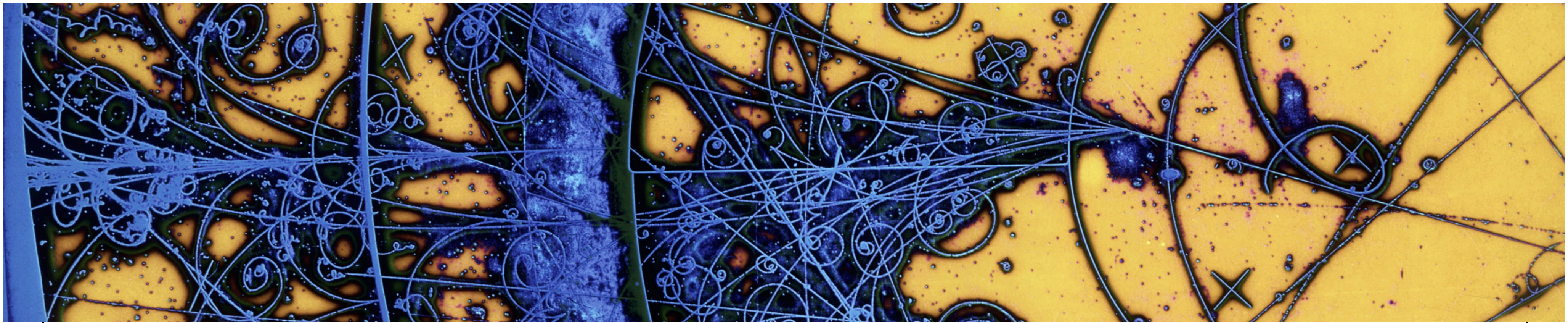
Daly's Sustainability Conditions



The Climate Bathtub



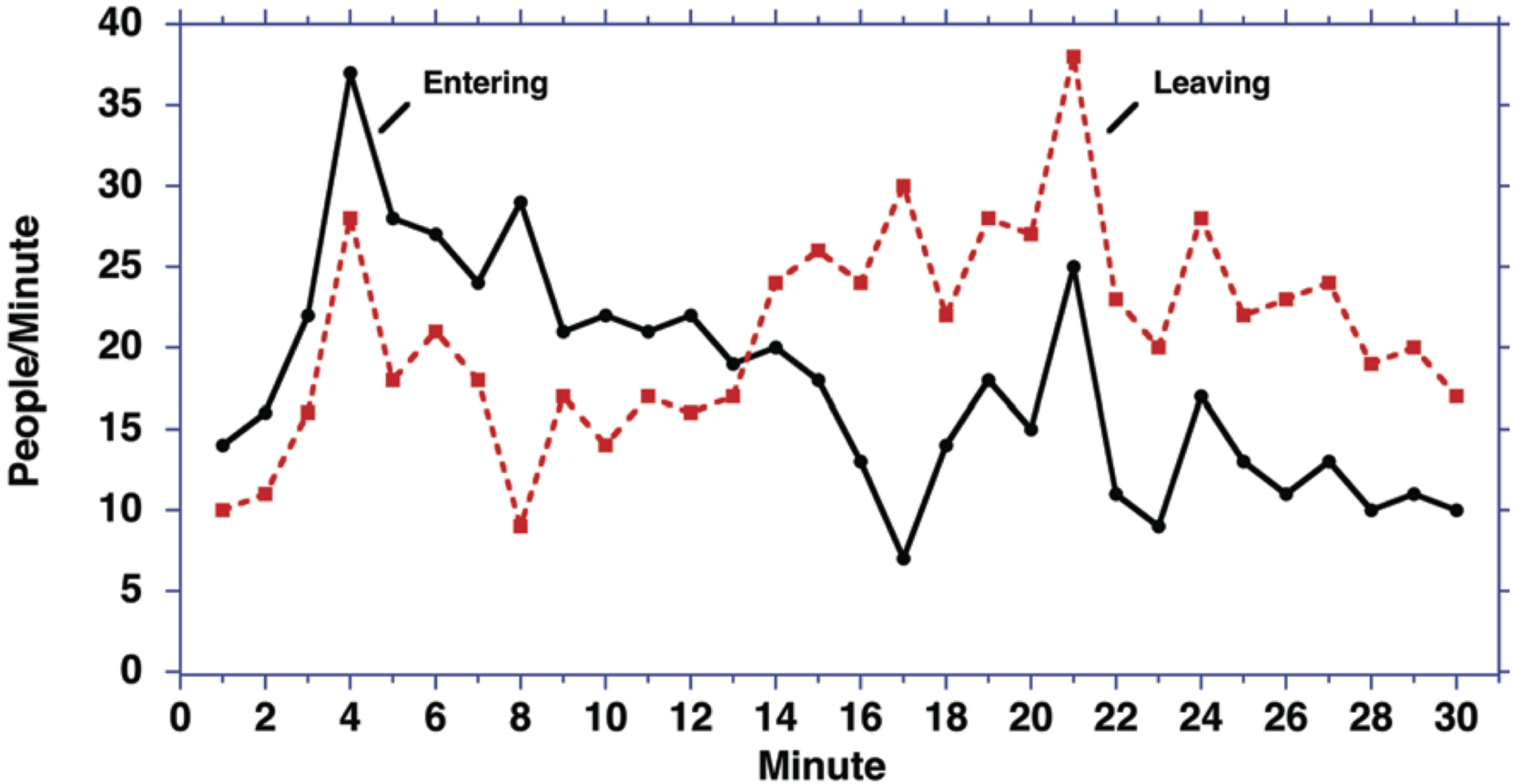
Overall framing by Dr. John Sterman, MIT Sloan



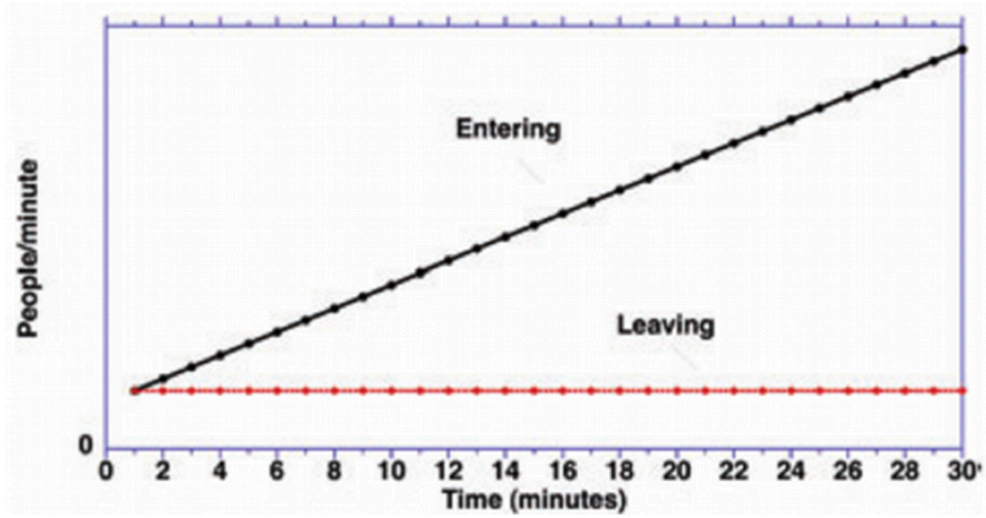
Systems Activity:

ACCUMULATE!

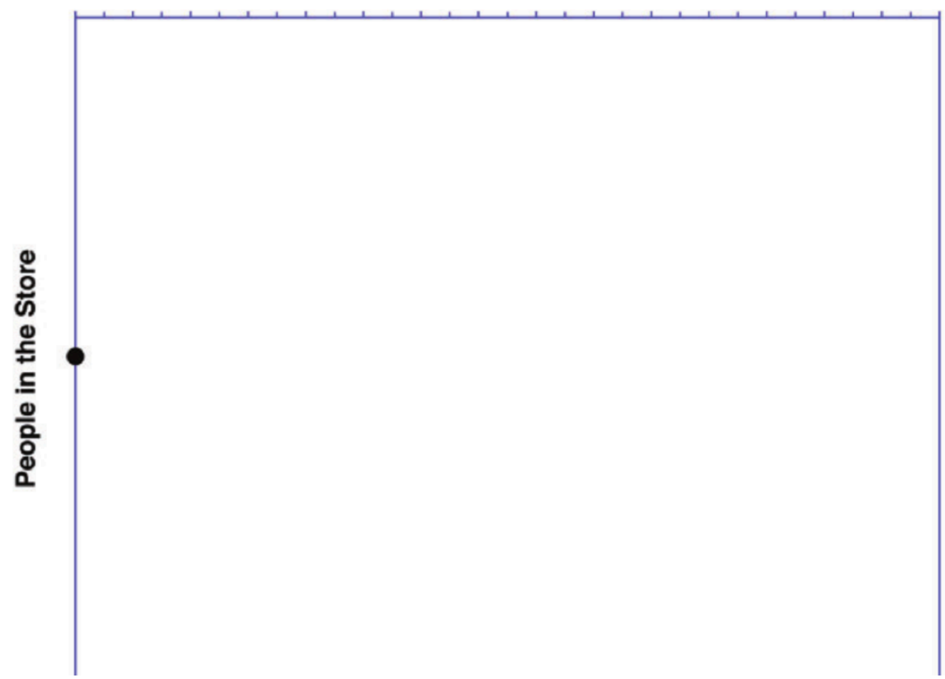
Here's the data



Cronin, M., et al. (2009). Why don't well-educated adults understand accumulation? A challenge to researchers, educators, and citizens. Organizational Behavior & Human Decision Processes, 108(1), 116–130.



In the space below, graph the number of people in the store over the 30 minute interval. You do not need to specify numerical values. The dot at time zero shows the initial number of people in the store.



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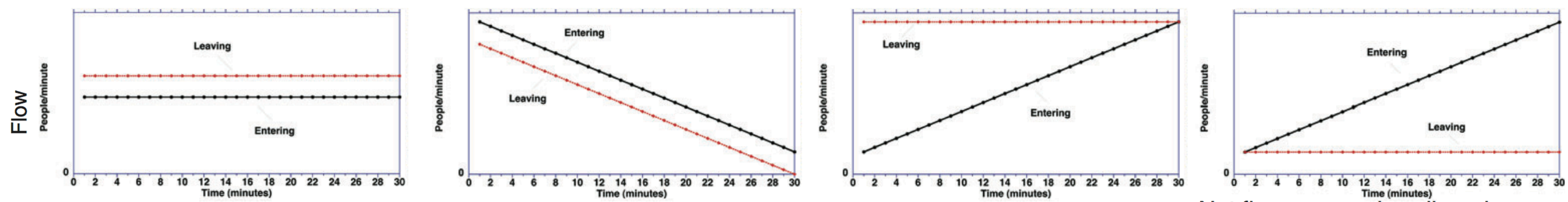
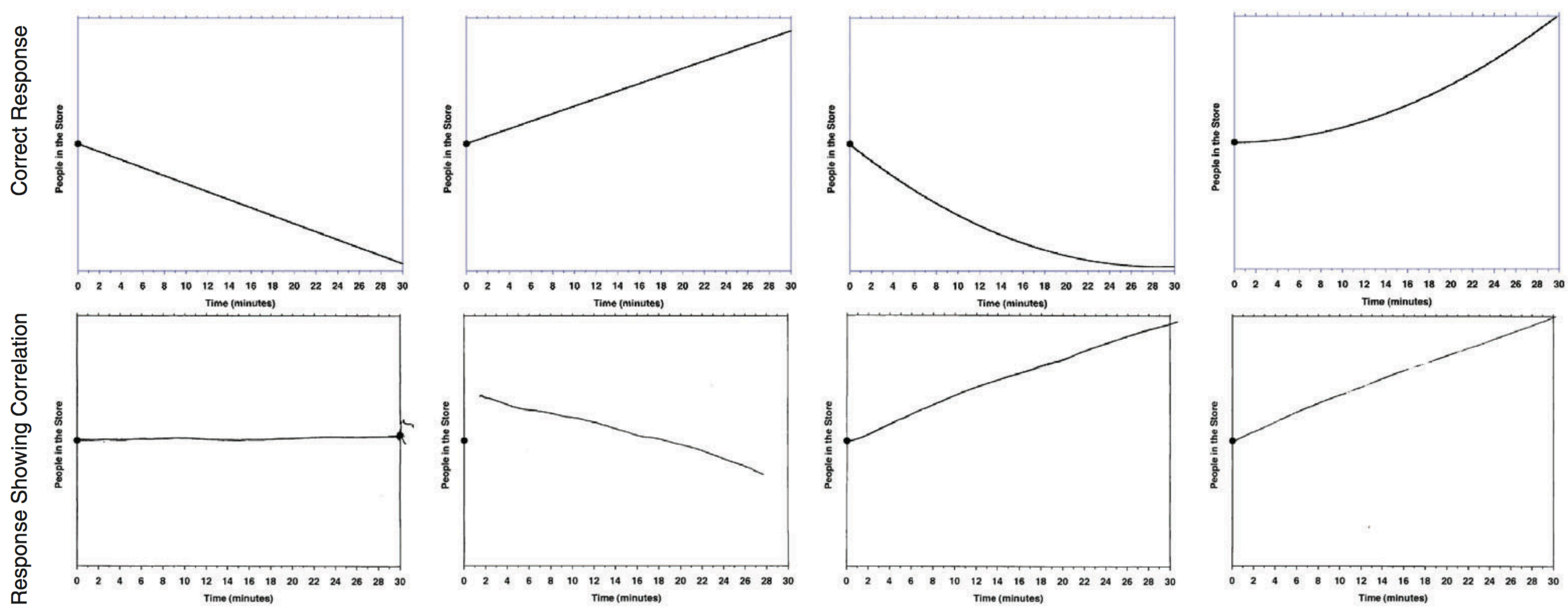


Net flow is constant and < 0. Stock falls linearly.

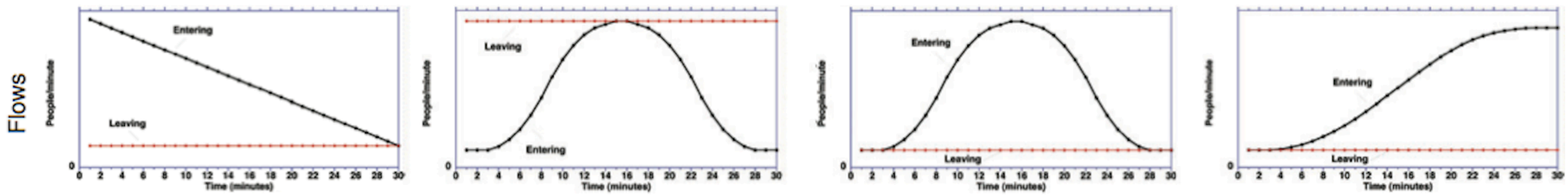
Net flow is constant and > 0. Stock rises linearly.

Net flow ≤ 0, rises linearly to 0 by time 30. Stock falls at decreasing rate, is constant at t=30

Net flow ≥ zero, rises linearly throughout. Stock rises at increasing rate from initial equilibrium.



Cronin, M., et al. (2009). Why don't well-educated adults understand accumulation? A challenge to researchers, educators, and citizens. Organizational Behavior & Human Decision Processes, 108(1), 116–130.

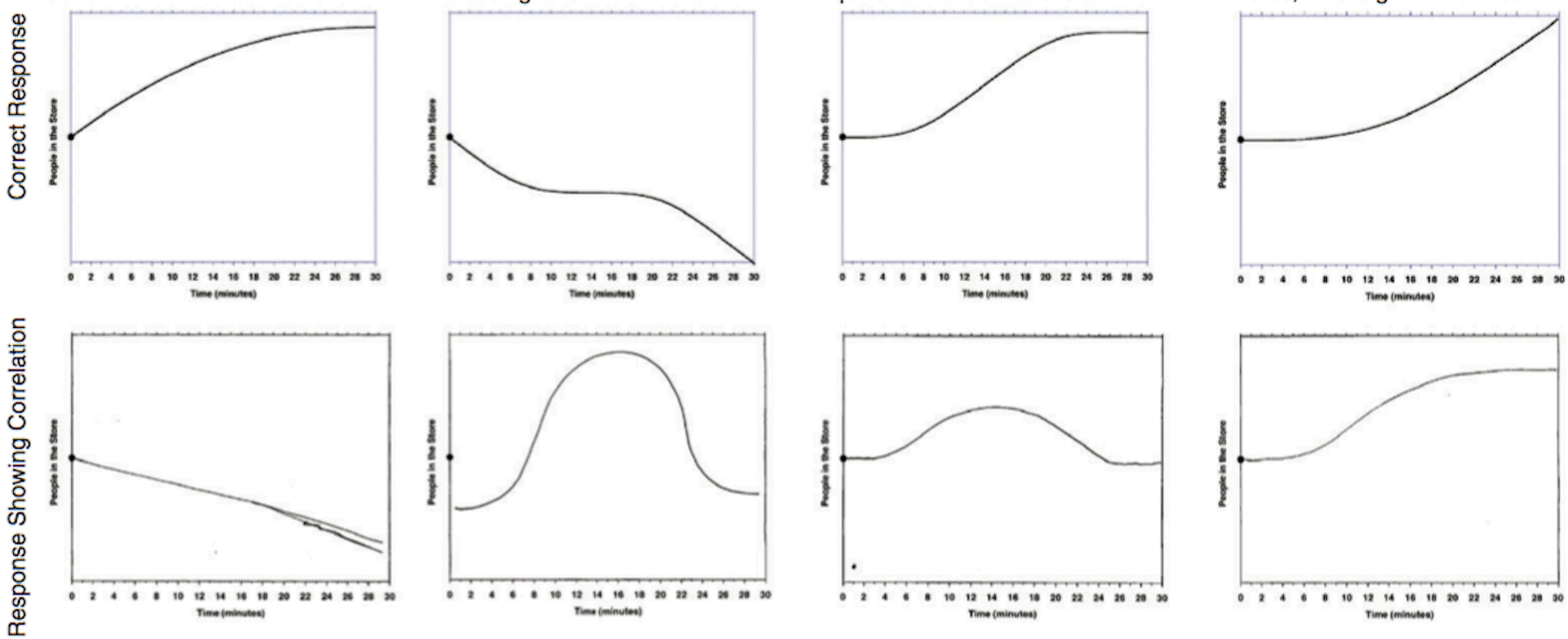


Net flow ≥ 0, falls linearly to 0 by t = 30. Stock rises at decreasing rate, reaches equilibrium at t = 30.

Net flow ≤0, rises to 0 at midpoint, then falls. Stock falls at decreasing rate, is flat at midpoint, then falls at increasing rate.

Initially zero, net flow rises to max, then falls. Stock follows s-shape with inflection point at midpoint and equilibrium at start and end.

Net flow ≥0, follows S-shape. Stock starts in equilibrium, rises at increasing rate until last few minutes, where growth is linear.



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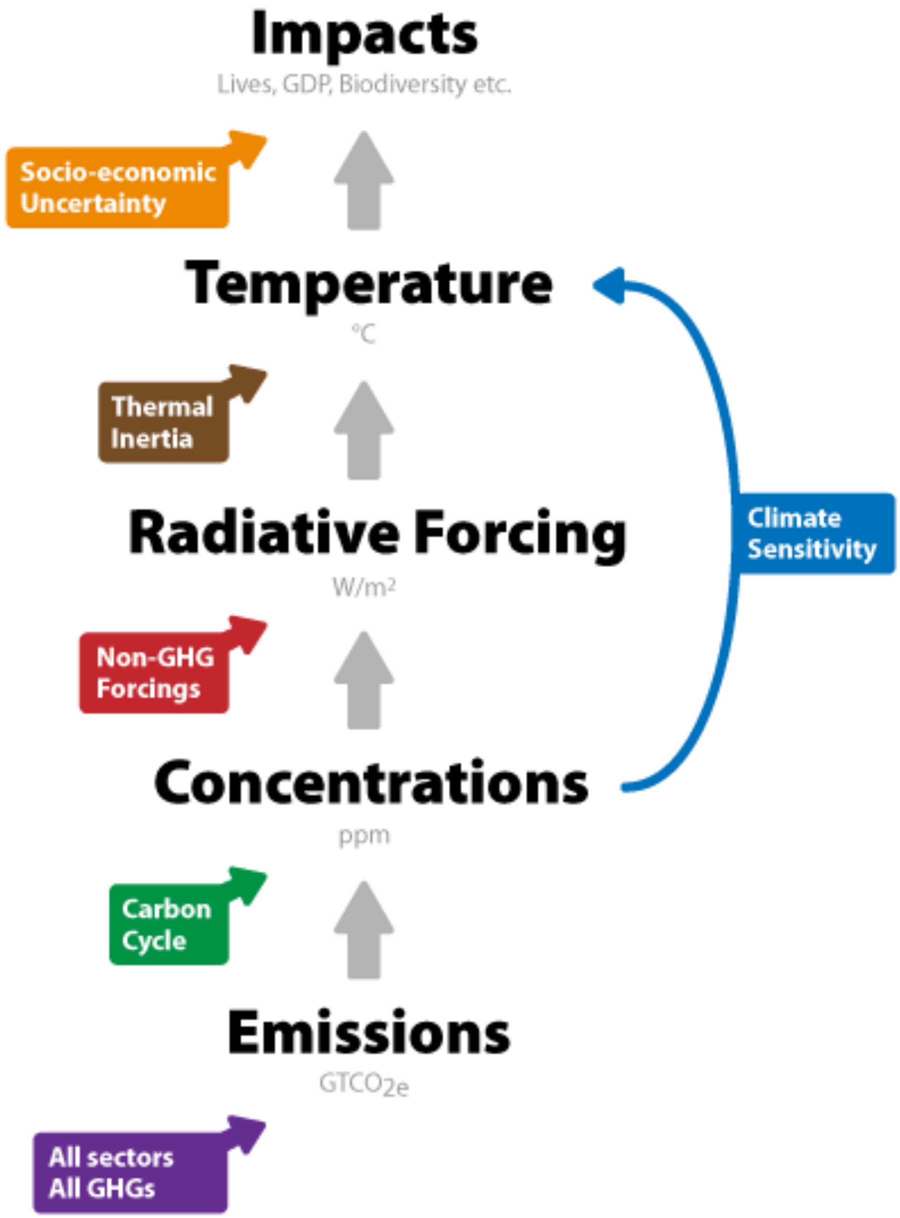
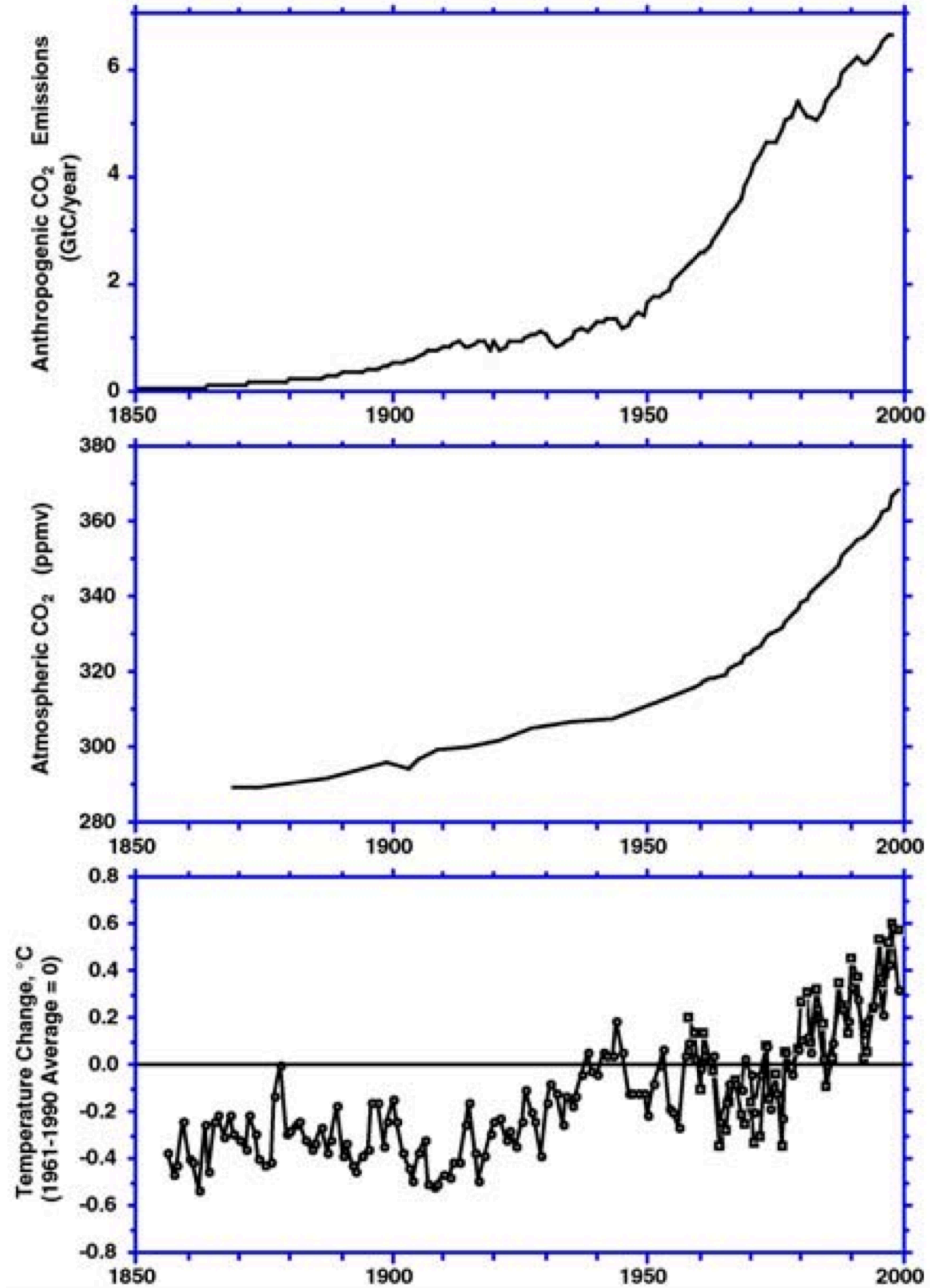

Impacts
Lives, GDP, Biodiversity etc.
Socio-economic Uncertainty
Temperature
°C
Thermal Inertia
Radiative Forcing
W/m²
Climate Sensitivity
Non-GHG Forcings
Concentrations
ppm
Carbon Cycle
Emissions
GTCO2e
All sectors All GHGs


Anthropogenic CO2 Emissions (GtC/year)
0
2
4
6
1850
1900
1950
2000
Atmospheric CO2 (ppmv)
280
300
320
340
360
380
Temperature Change, °C (1961-1990 Average = 0)
-0.8
-0.6
-0.4
-0.2
0.0
0.2
0.4
0.6
0.8