How complexity can resolve the crisis in economics

Office of National Statistics
Newport, Wales

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Scientific method is not cast in stone

- Each discipline has its own version
- It evolves with time
- Economics is becoming more empirical
- Is this compatible with its theoretical framework?

Economics has hit problems where its solutions are inadequate

- 2008 financial crisis
  - models were abandoned during crisis
- Inequality
  - "bad economics led to bad politics"
- Climate change
  - caused by the economy. How do we fix it?

Economists are working hard on these

But are there fundamental problems?

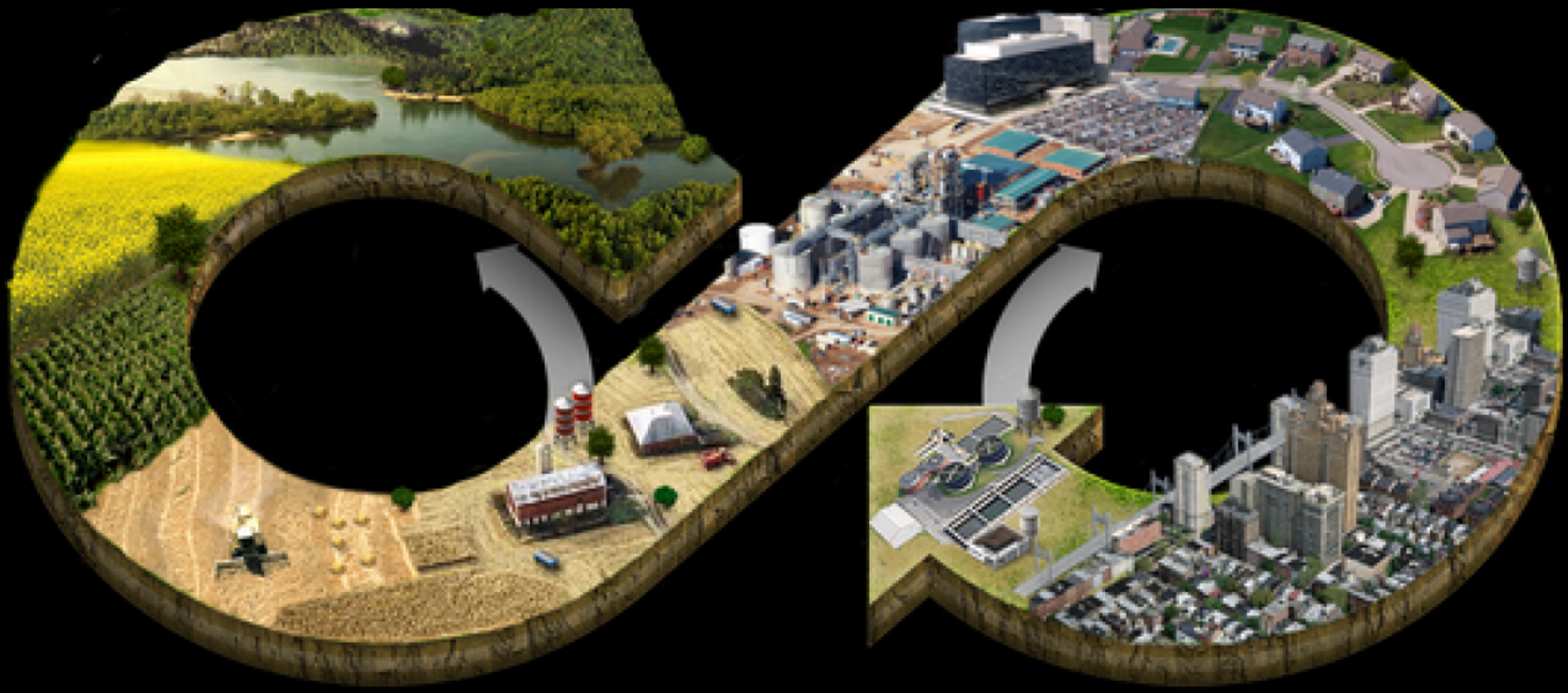
Crisis in economics

- Theoretical machinery = rational expectations
- Behavioral economics says this is wrong
- Can adding frictions save it?
- Or are bigger changes needed?

New approaches, new data

- Complexity economics revisits foundational assumptions
- Requires fine-grained microdata

What is the economy?



What is the economy?

Metabolism of civilization

- Converts natural resources and human effort into goods and services
- Coordinates and amplifies the activities of ecologies of specialists
  - allows us to do remarkable things together that we could never do on our own
  - you owe your life to it

Physical supply chain of a laptop

Imagine "google economics"

- Flows of goods and services
- Stocks and flows of capital
- Web of contracts
- Demography, occupational capabilities
- Wealth and poverty
- Ownership
- Ecology of innovation
- Physical and environmental impacts
- Regulatory constraints
- …

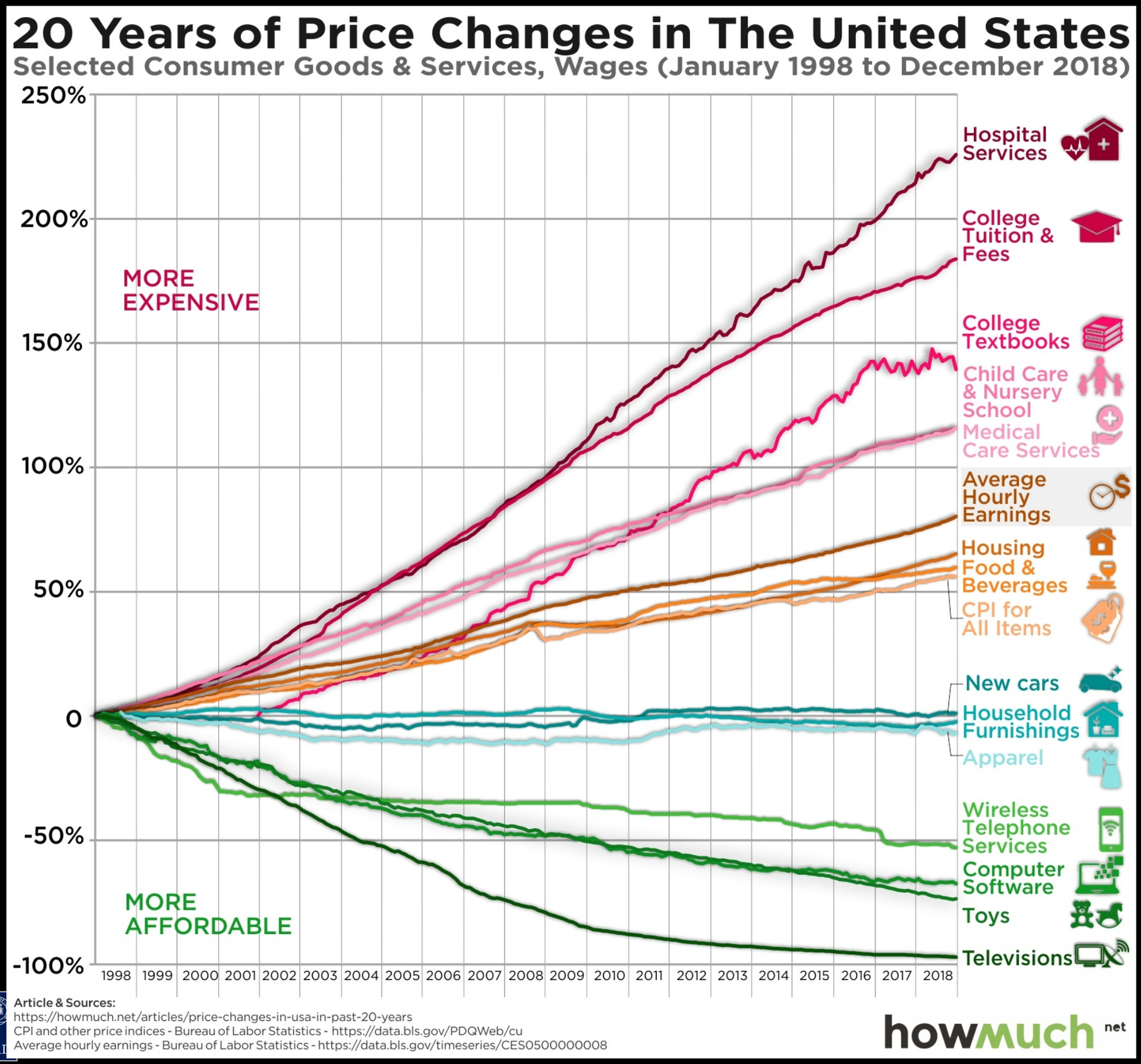
Geographically anchored
literal verisimilitude

How complicated is the economy?

- Production network
  - 50M firms with with billions of physical links
- Household network
  - 2B households, 3.3B workers, trillions of links to consumed products
- Web of contracts
  - trillions

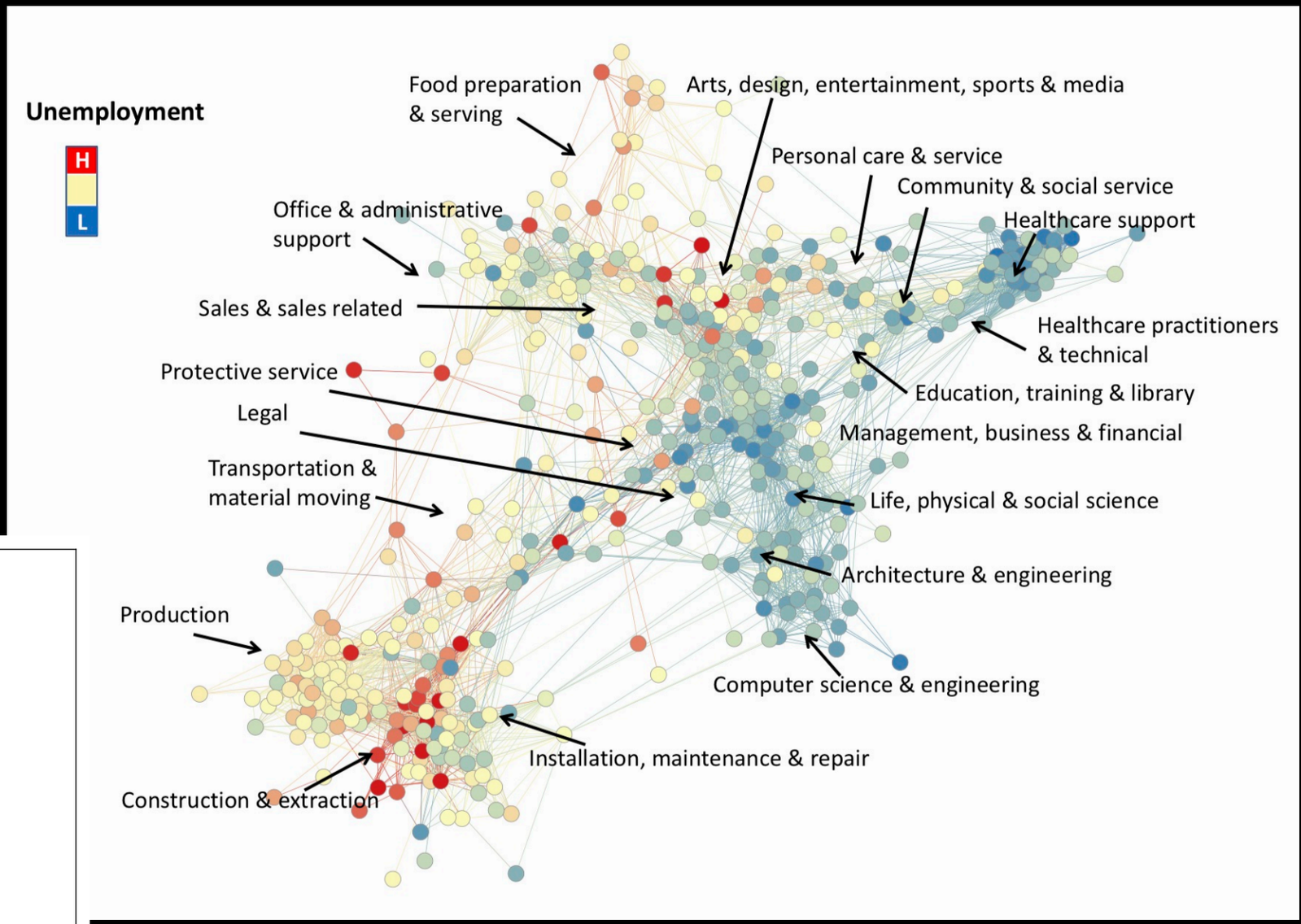
The economy is heterogeneous

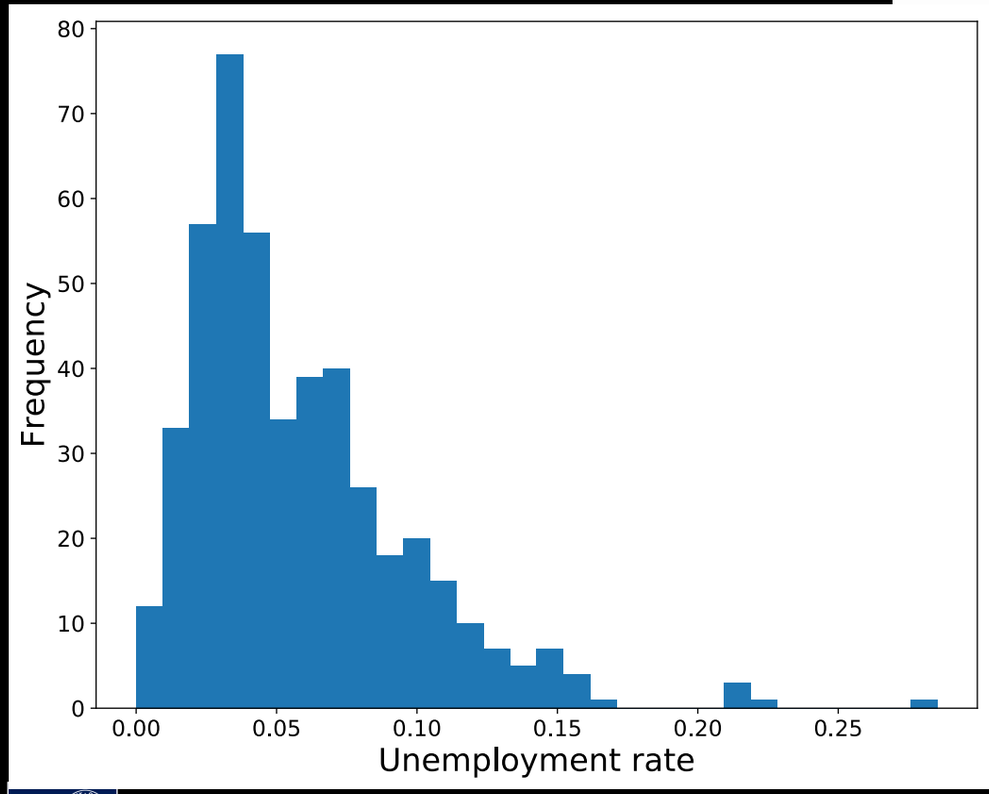
Inflation



Thanks to Jangho Yang

Unemployment





Thanks to Penny Mealy

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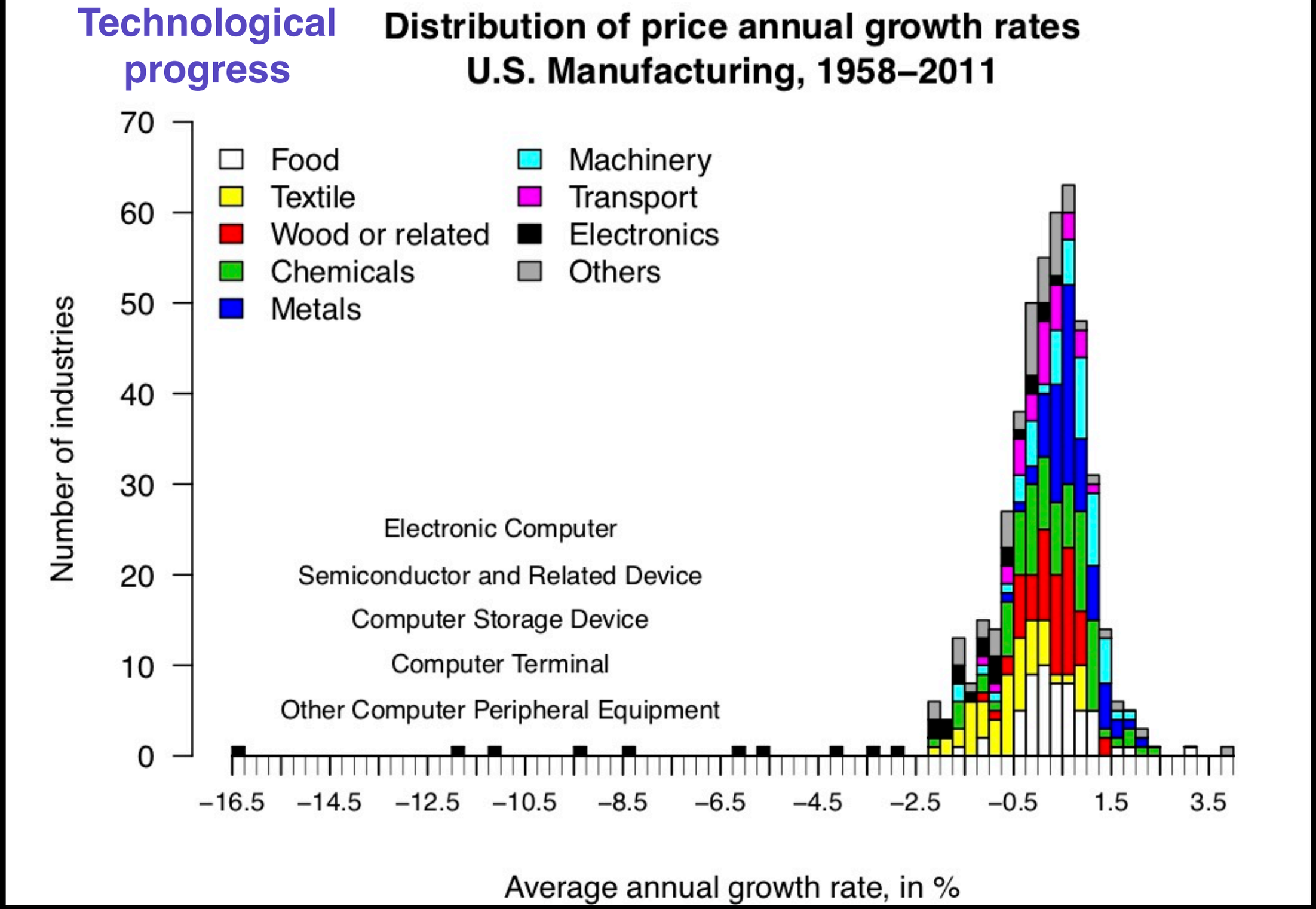
Technological progress



Thanks to Francois Lafond and Jangho Yang

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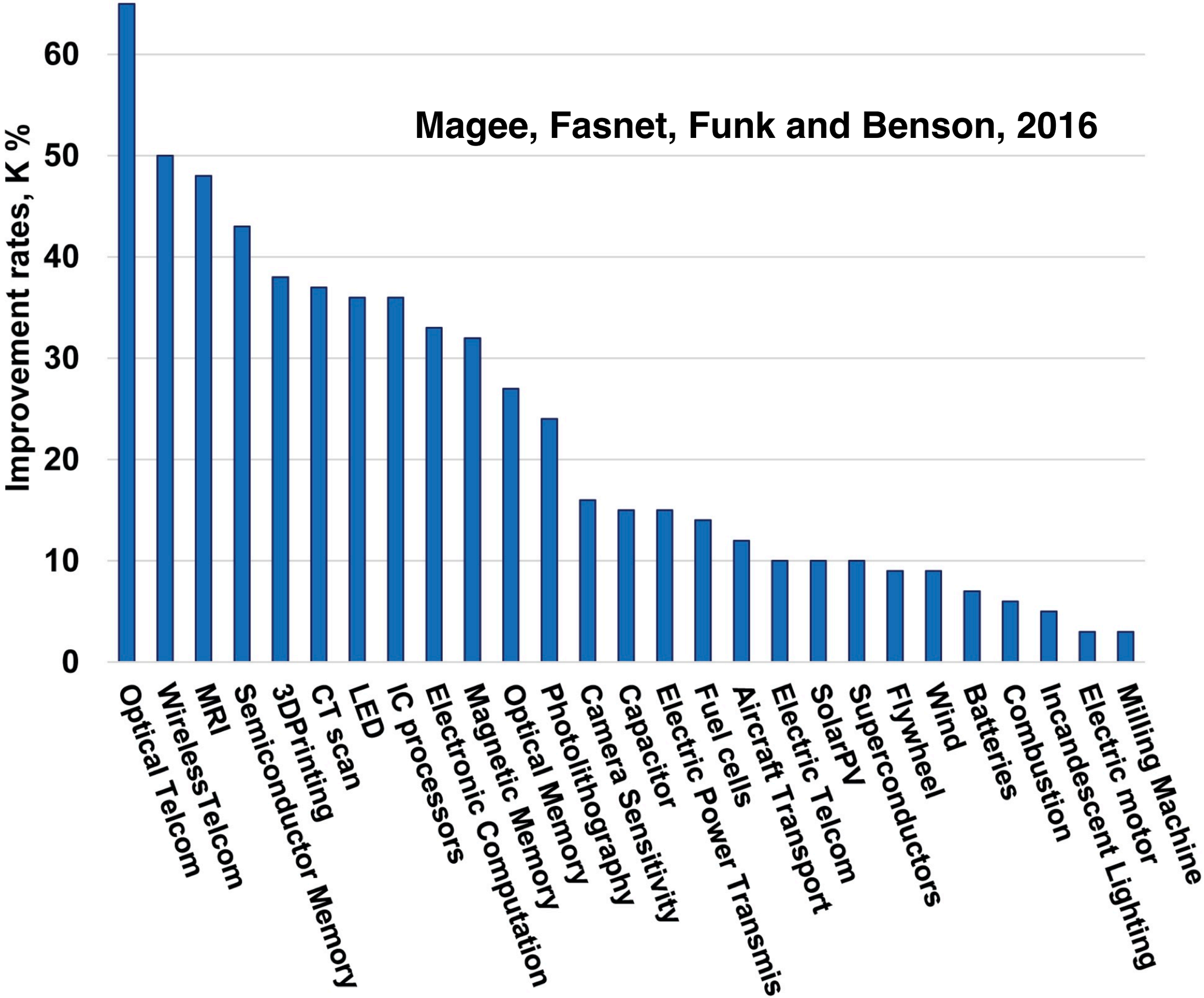

Magee, Fasnet, Funk and Benson, 2016
Improvement rates, K %
60
50
40
30
20
10
0
Optical Telcom
WirelessTelcom
MRI
Semiconductor Memory
3DPrinting
CT scan
LED
IC processors
Electronic Computation
Magnetic Memory
Optical Memory
Photolithography
Camera Sensitivity
Capacitor
Electric Power Transmis
Fuel cells
Aircraft Transport
Electric Telcom
SolarPV
Superconductors
Flywheel
Wind
Batteries
Combustion
Incandescent Lighting
Electric motor
Milling Machine

People are heterogeneous

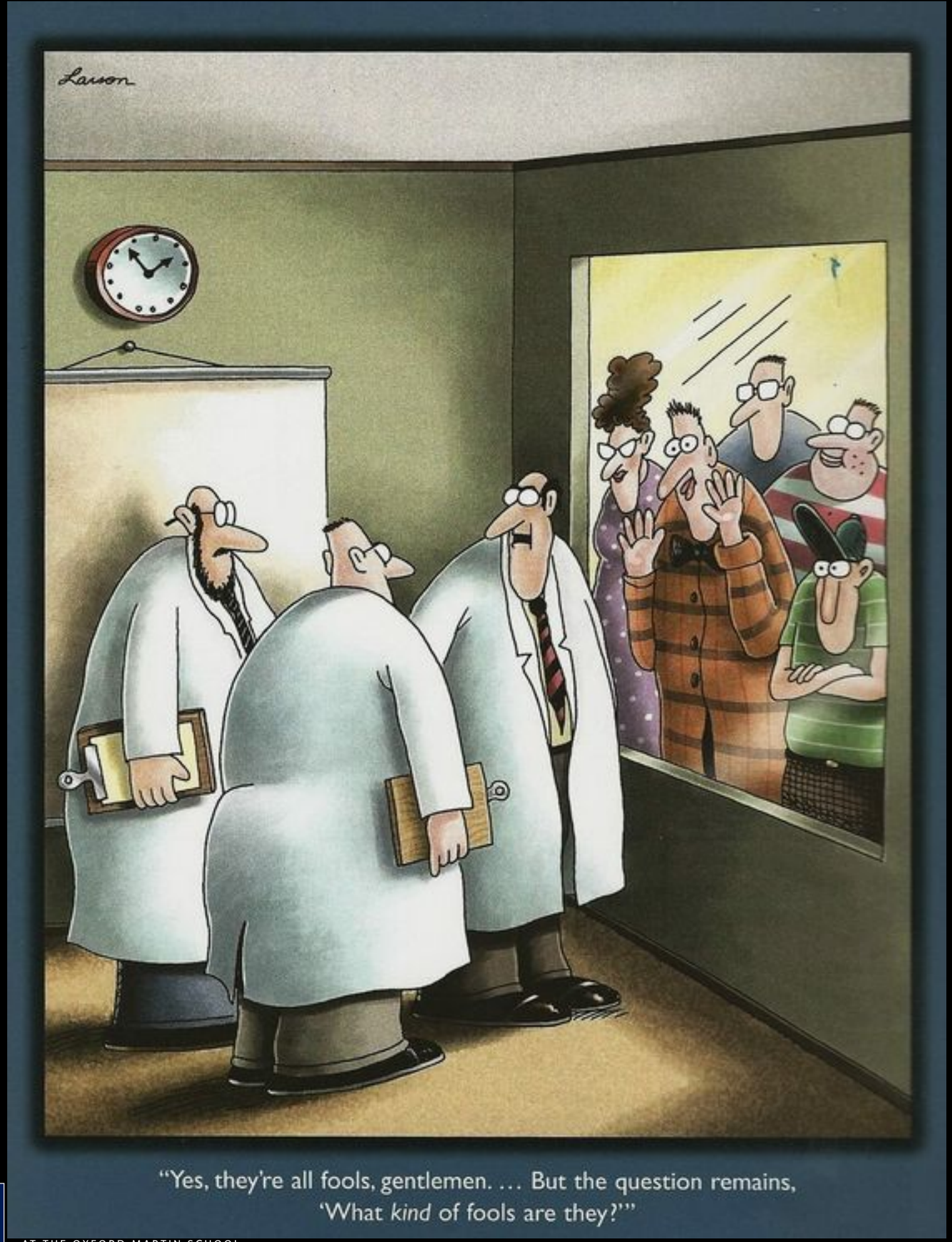
Caricature of economics as accounting + behavior

+

Accounting

- Accounting is mechanical
- Each household has balance sheet
  - assets, liabilities
- 2 billion balance sheets, thousands of entries on each, trillions of contracts
- Balance sheets are all interlinked
  - one person's liability is another's asset
- Accounting is complicated!

Behavior



How does mainstream economics model behavior?

Rational expectations

A rational agent can compute anything

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Rational expectations with frictions (*constrained rationality*)

- Each agent has a utility function
  - macroeconomics: discounted consumption
- Rational agent maximizes utility
  - takes others into account
- World imposes constraints (*frictions*)
- Equilibrium
  - state where everyone maximizes utility

Research program of mainstream macroeconomics

- Add new friction
- Solve model
- Test: Improved match to empirical facts?
- Repeat

Problems with constrained rationality

- Experiments do not support it
- Difficult to match empirical facts
- Hard to solve
  - leads to drastic simplifications
  - heterogeneity is difficult to incorporate
- Rationality suppresses endogenous dynamics
- Does not take advantage of 21st century tech

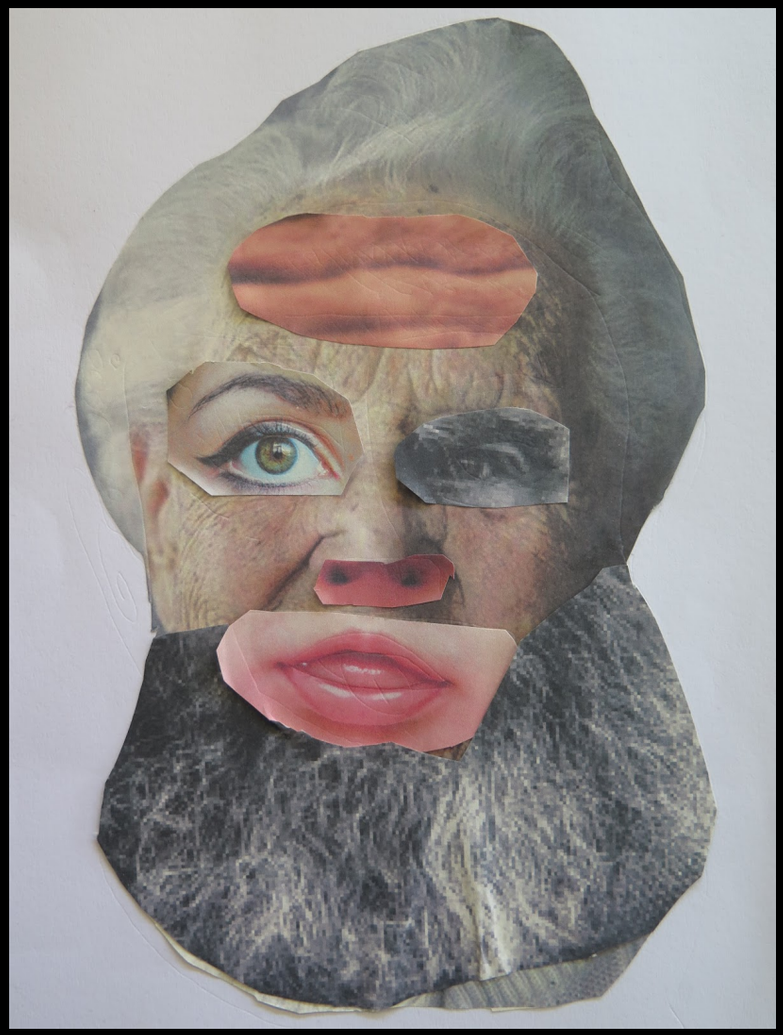
Making models with rational expectations is hard

Makes it difficult to do justice to the complexity of all the interactions between real world balance sheets

Representative agent

of aggregate macro

=



Frontier of modern macro is to replace representative agent by heterogeneous agents

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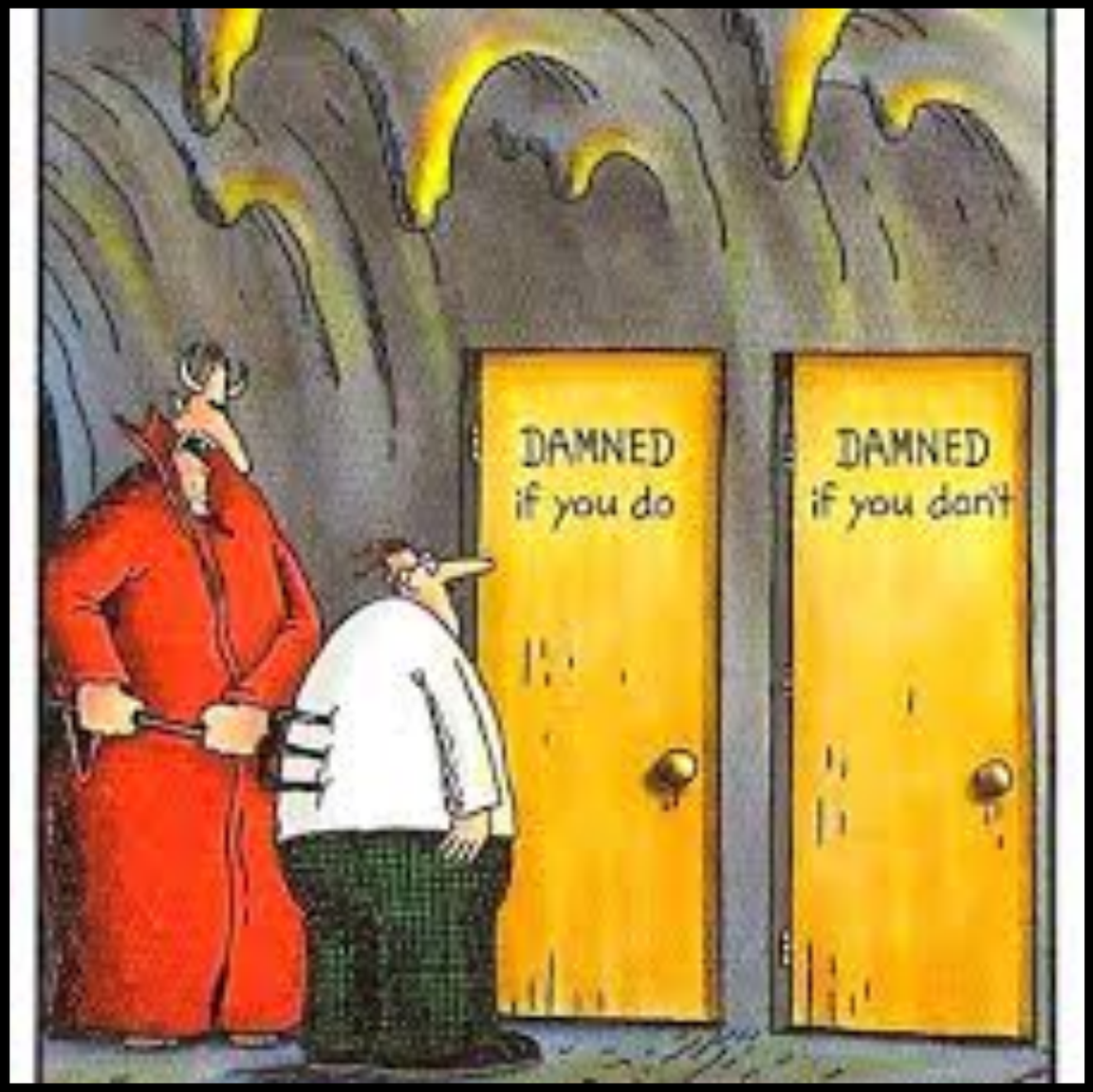
Dynamics are exogenously driven

- Economy sits at equilibrium
- Shock knocks it away
- Moves toward equilibrium
- Another shock knocks it away
- …
- E.g. Smets-Wouters model has 7 shocks: changes in labor productivity, risk perception, technologies, wages, prices, spending and monetary policy

Catch 22 of aggregate macro



- Economy is complex
- Economy evolves
  - data from distant past is not very useful
  - historical time series are short
  - only simple models can be estimated
- But economy is complex — Catch 22

Standard macro is based on old technology

- National accounting: mid-20th century
- Official macro models: small scale computing
  - most computing time is spent on optimization
- 21st century technologies:
  - Big Data
  - large scale computing

What is the alternative?

Complex system

- Emergent behavior: Qualitatively different than that of individual components.
- Nonlinear behavior: Whole not equal to the sum of its parts
- Emergence depends on nonlinearity
- Must model at fine scale

Complexity economics

Applying complex systems thinking and methods to economics

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Bounded rationality

Reasoning capabilities are limited

Very different than constrained rationality!

Heuristics
(rules of thumb)

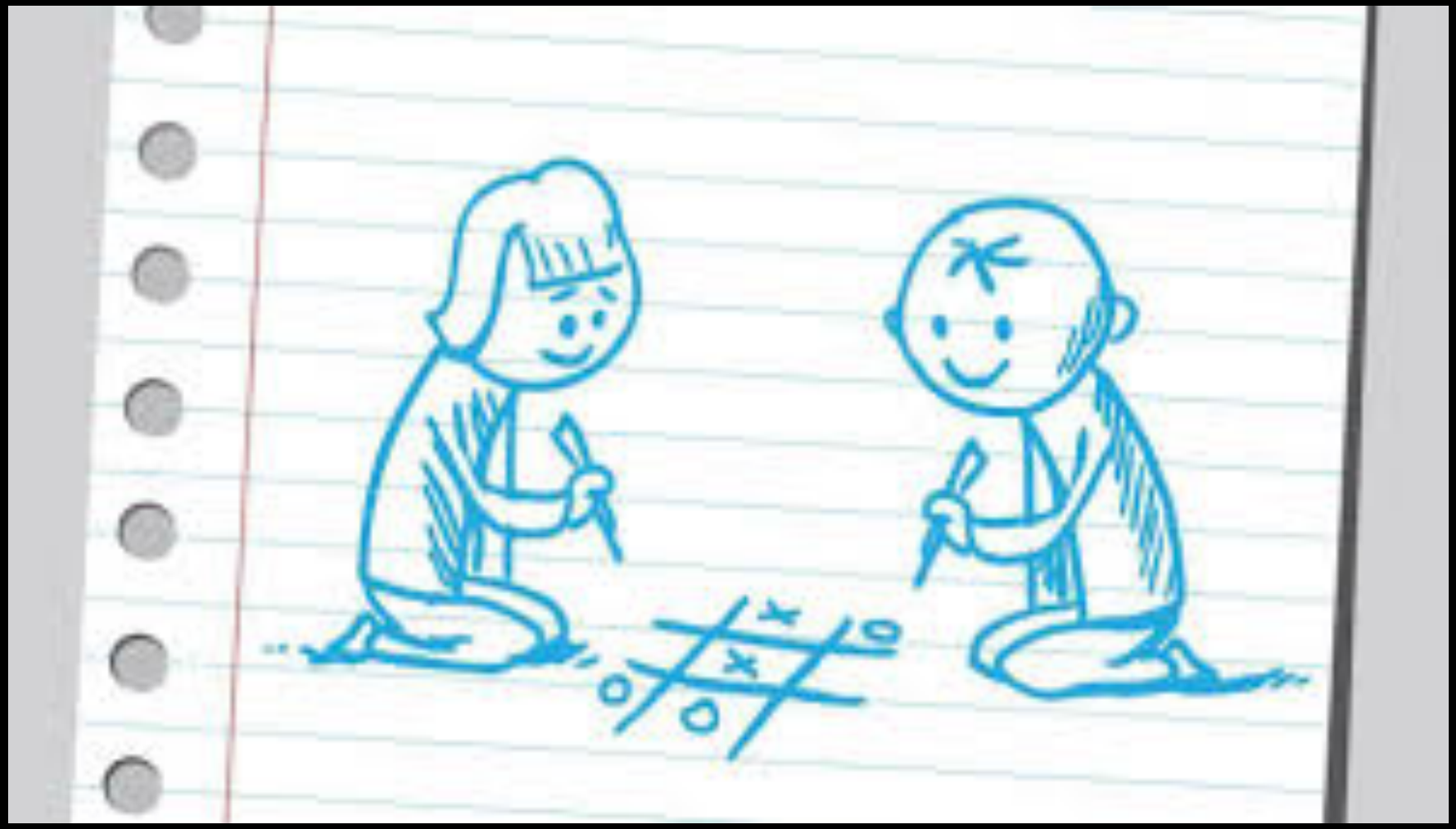
Myopic reasoning

Herbert Simon

Chess players are boundedly rational

Not even Bobby Fisher can compute every possible outcome

but older children playing naughts and crosses become rational



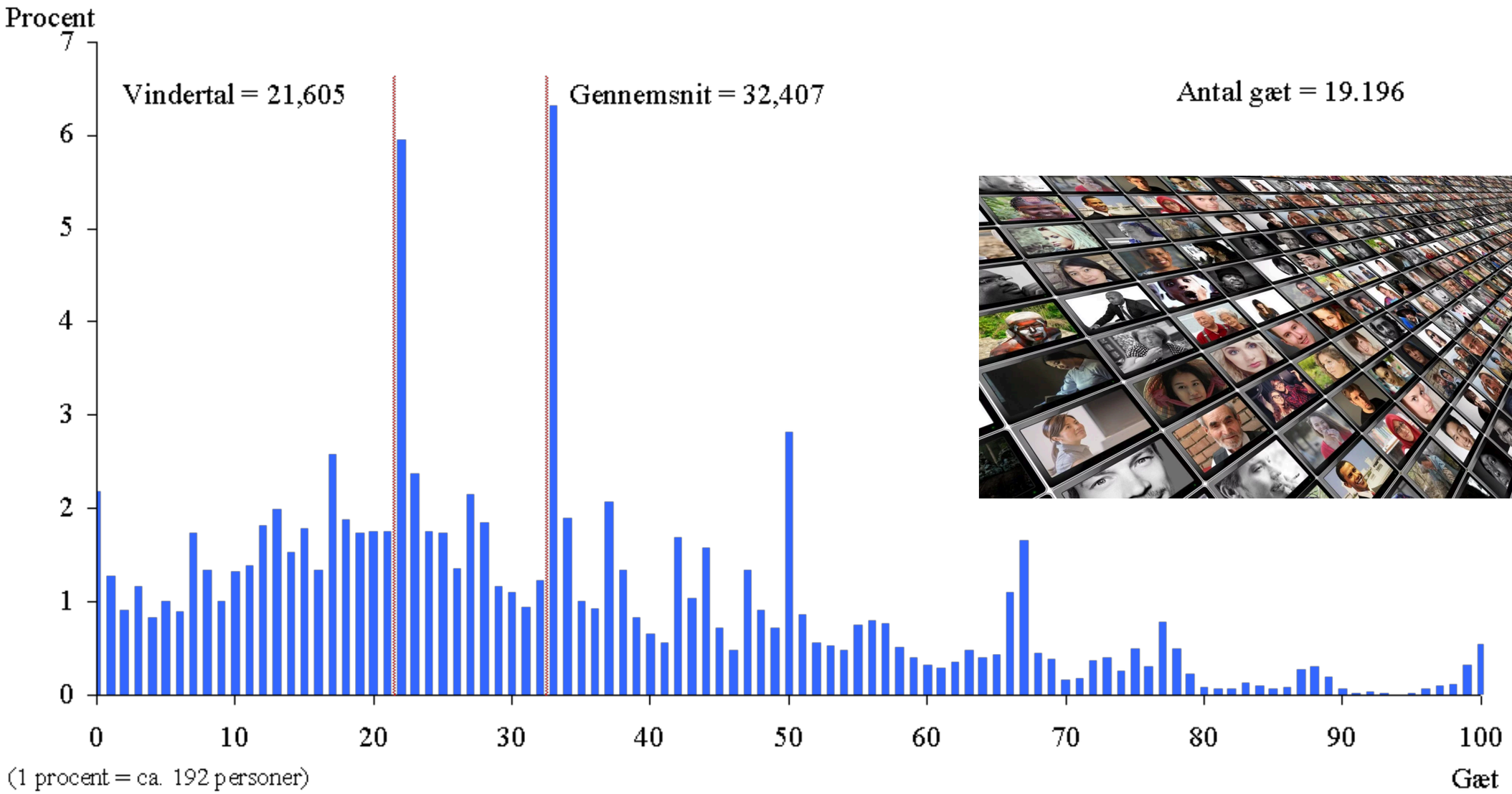
Success of rationality approximation depends more on the problem than the player

Empirical test

Beauty contest game

Guess the number between 0 and 100 that is 2/3 of the average guess.

Fordeling af gæt i "Gæt Et Tal"s første runde i september 2005



Hvis du har spørgsmål til konkurrencen er du velkommen til at kontakte os via e-mail (konkurrence@econ.ku.dk) eller på telefon 35 32 30 51.

Denne konkurrence er en del af et videnskabeligt studie under ledelse af prof. dr. Tyran.

Nash equilibrium

Set of decisions such that no player can improve on her own

John Nash

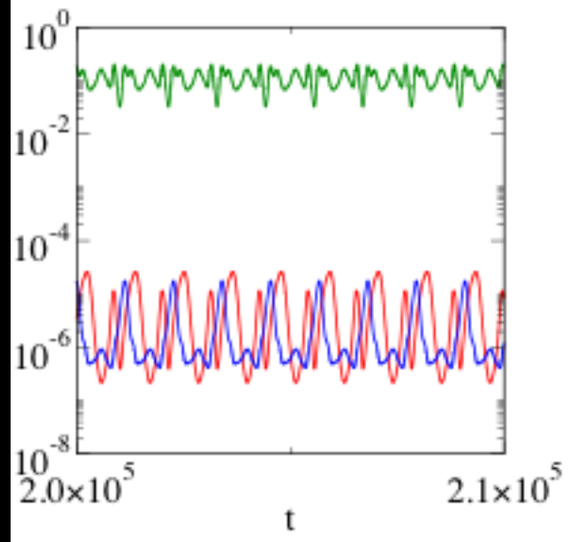
What if we play the game repeatedly?

- This game will converge to equilibrium
- But what about other games?

What does this imply about equilibrium?

- Work with Marco Pangallo, Tobias Galla, Torsten Heinrich, James Sanders
- Exhaustively studied normal form games using empirically valid learning algorithms
- Equilibrium is unlikely when games are complicated and competitive
  - more than 2 players
  - more than a few possible actions
  - incentives not lined up

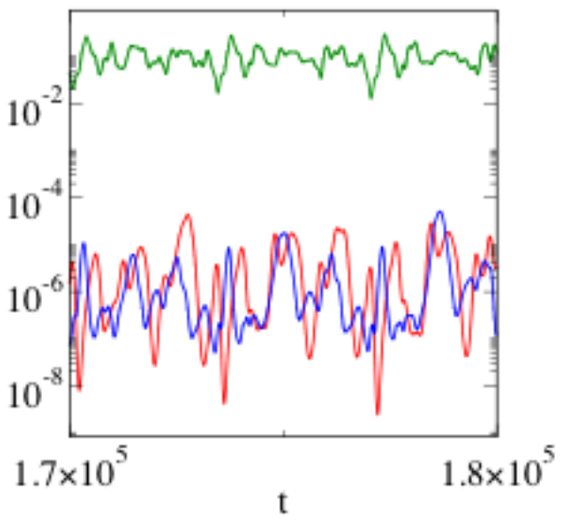
$D = 1.1$



$\Gamma = -0.5$

$\alpha = 4.8 \times 10^{-3}$

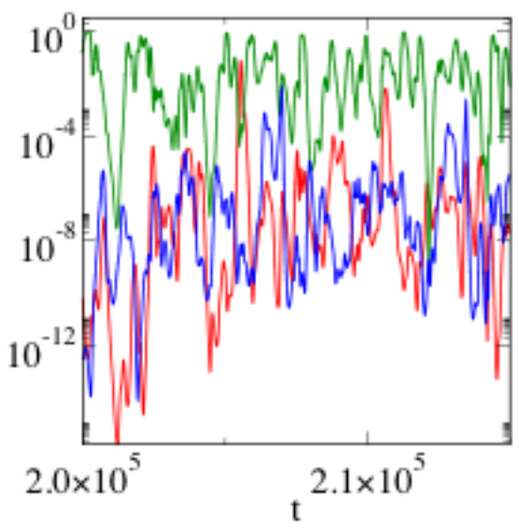
$D = 3.1$



$\Gamma = -0.5$

$\alpha = 4.5 \times 10^{-3}$

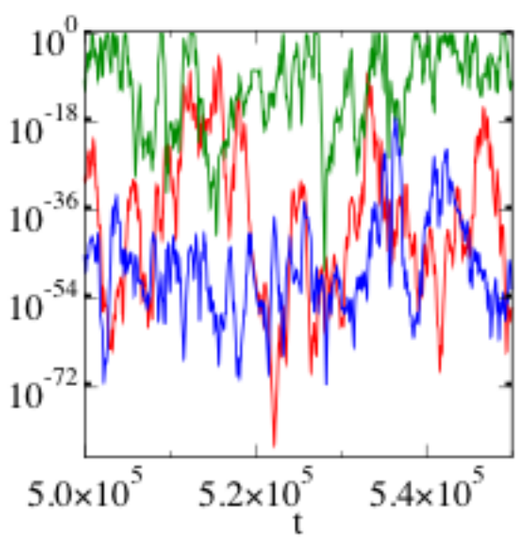
$D = 9.8$



$\Gamma = -0.4$

$\alpha = 3.5 \times 10^{-3}$

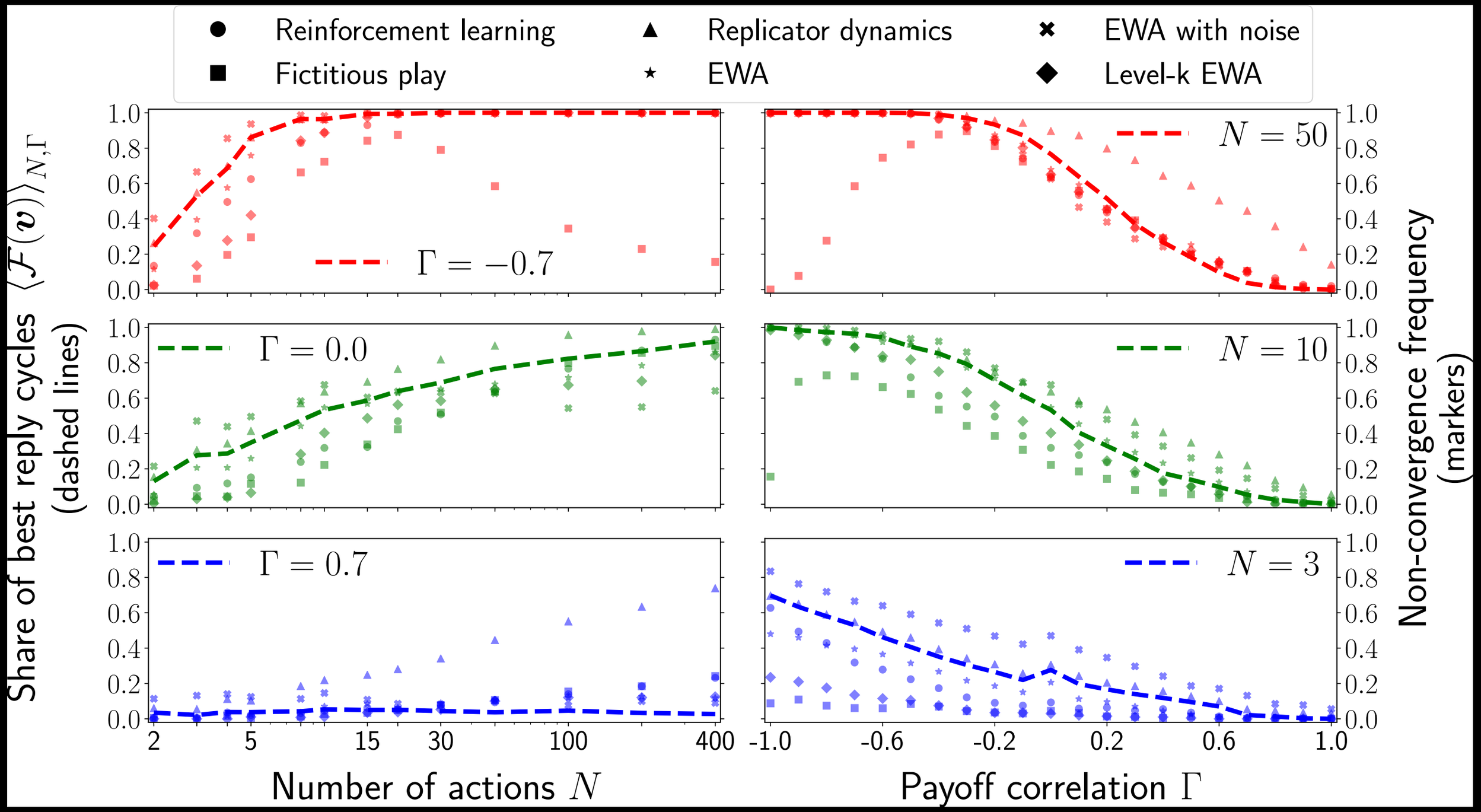
$D = 65.5$



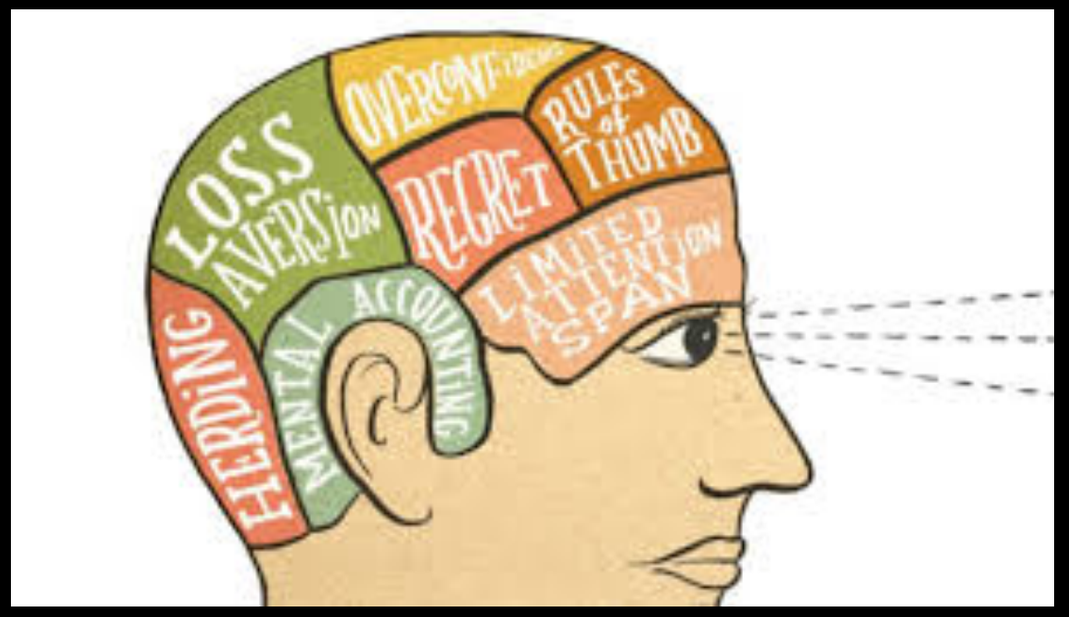
$\Gamma = -0.7$

$\alpha = 5 \times 10^{-4}$

Probability of non-convergence

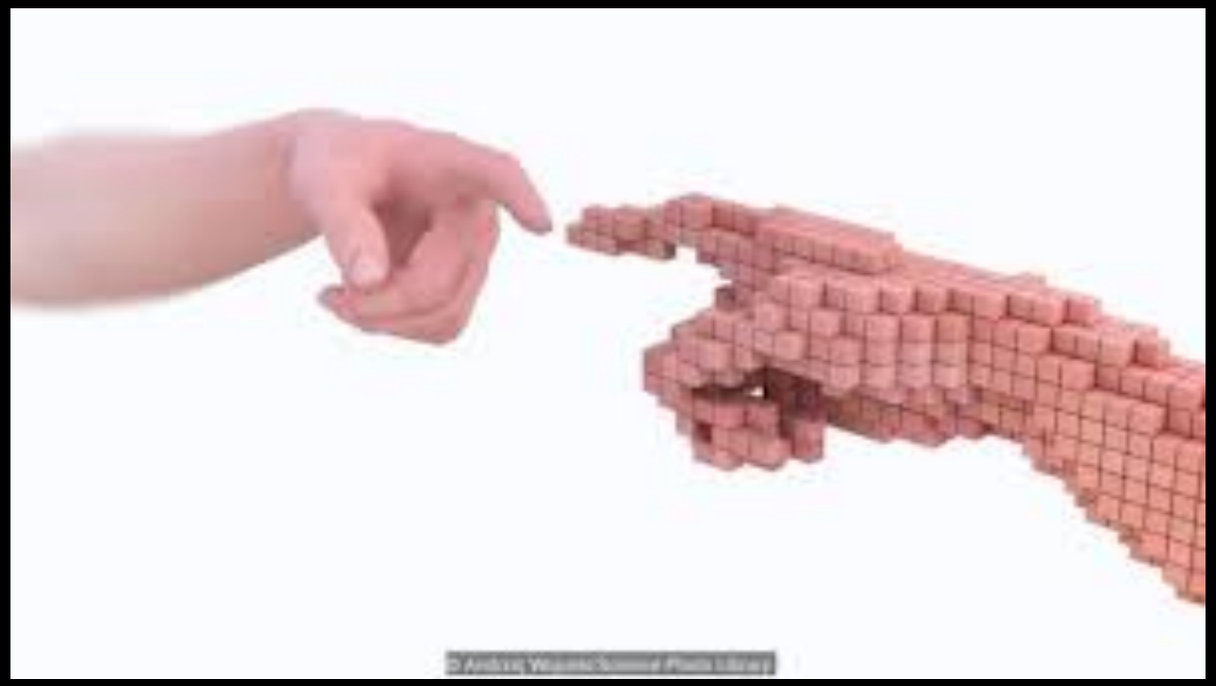


Complexity economics takes behavioral economics seriously



- Embraces bounded rationality
- Agents follow heuristics, myopic reasoning
- Update heuristics that currently work well
- Well supported in behavioral experiments
- Nonequilibrium
  - may or may not converge to equilibrium

Simulation



- ABM = simulation of decision makers
- Simulation: Mimic system on computer
- Simulation of bounded rationality is feasible
  - not true for constrained rationality

Rational expectations: dynamics are exogenously driven

What happens under bounded rationality?

Standard macro model with bounded rationality

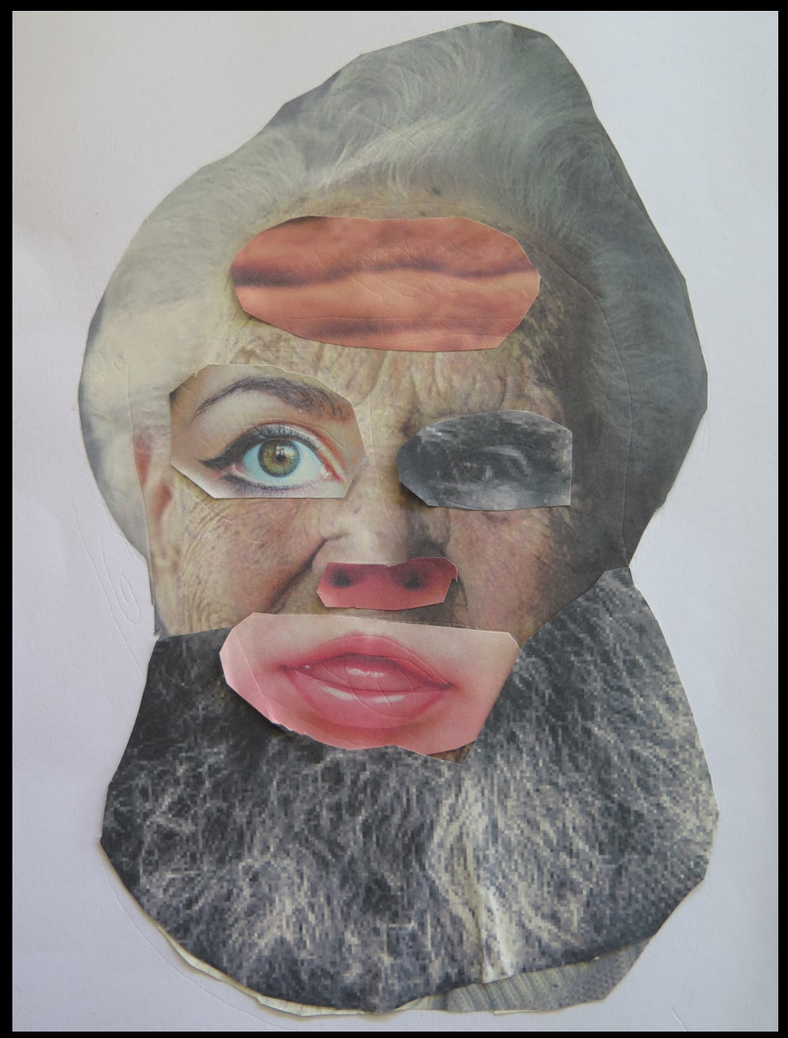
Yuki Asano, Jakob Kolb, JDF, Jobst Heitzig

- Based on Ramsey-Cass-Koopmans model

Representative household chooses savings rate

Goal is to maximize discounted consumption

Compromise between investment and consumption



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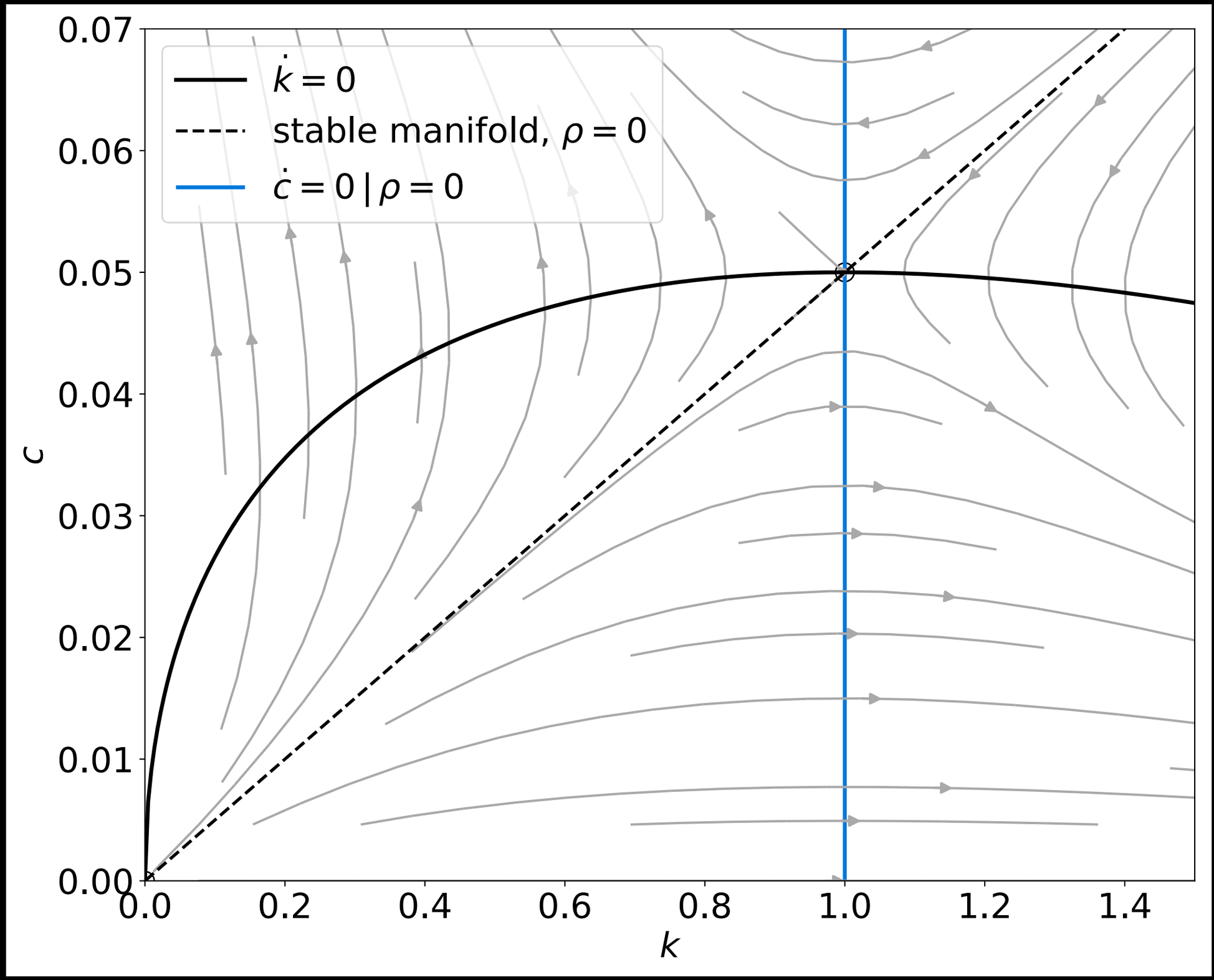

Standard macro model with bounded rationality

Yuki Asano, Jakob Kolb, JDF, Jobst Heitzig

Our version: Each household copies savings rate of neighbor with highest consumption

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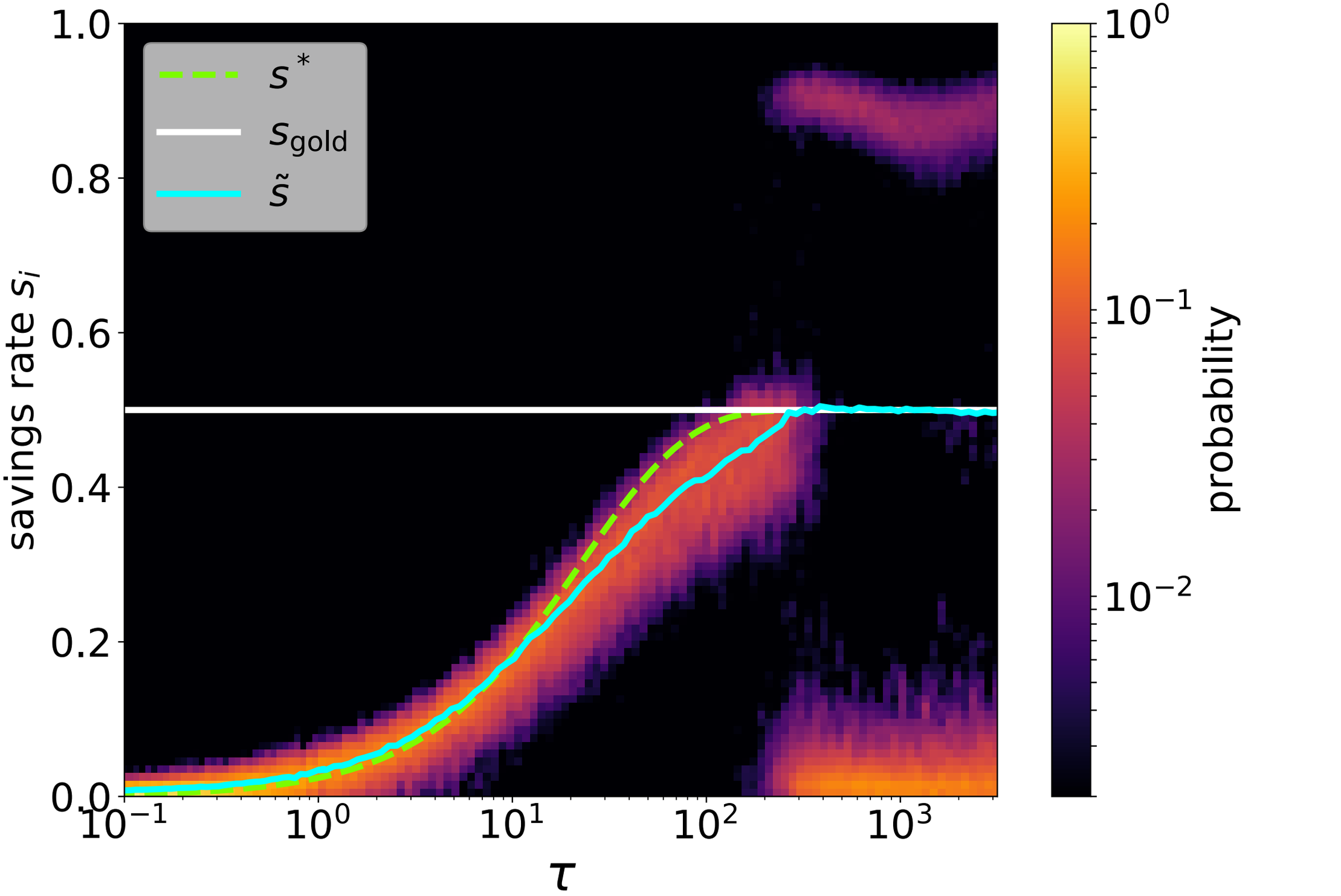
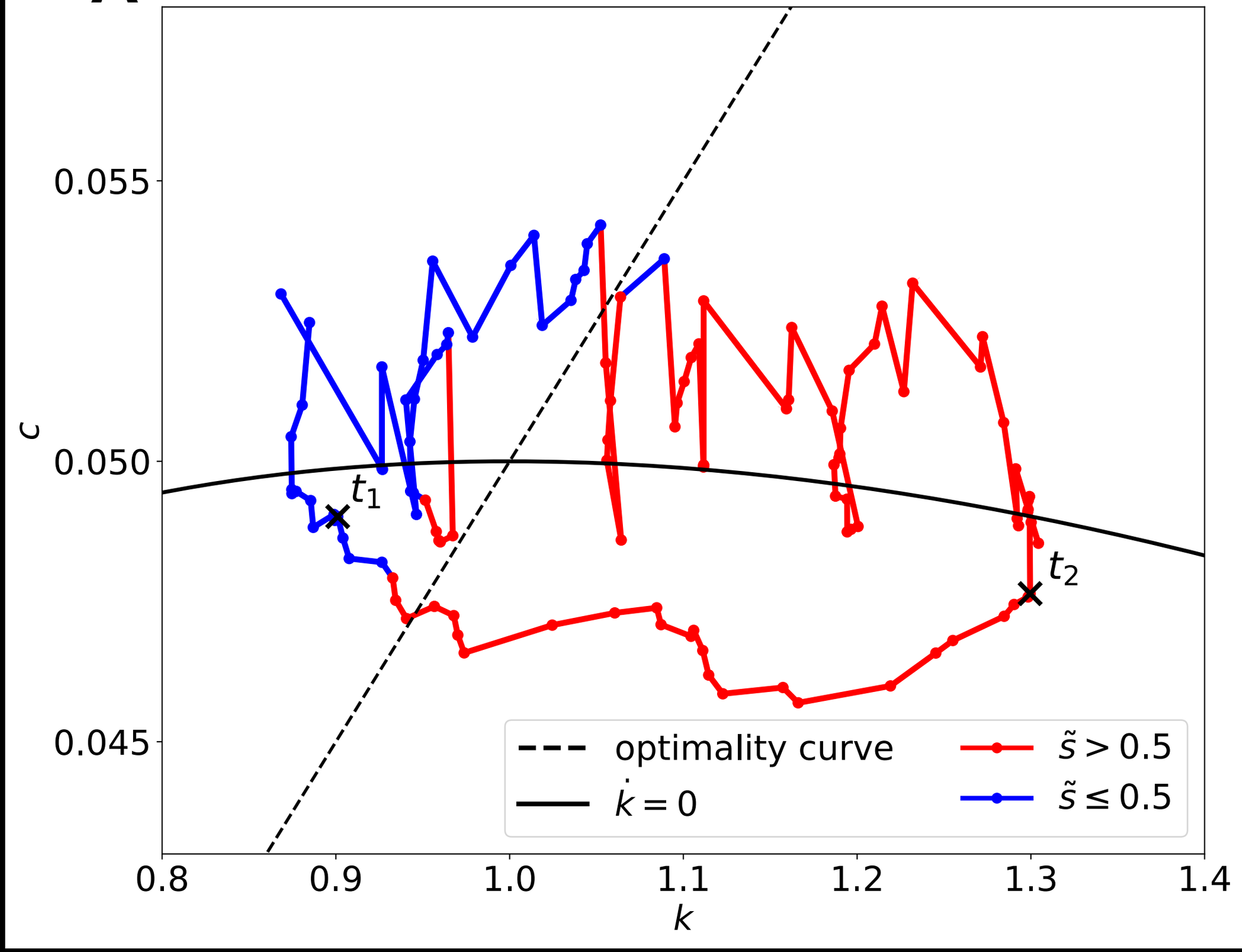
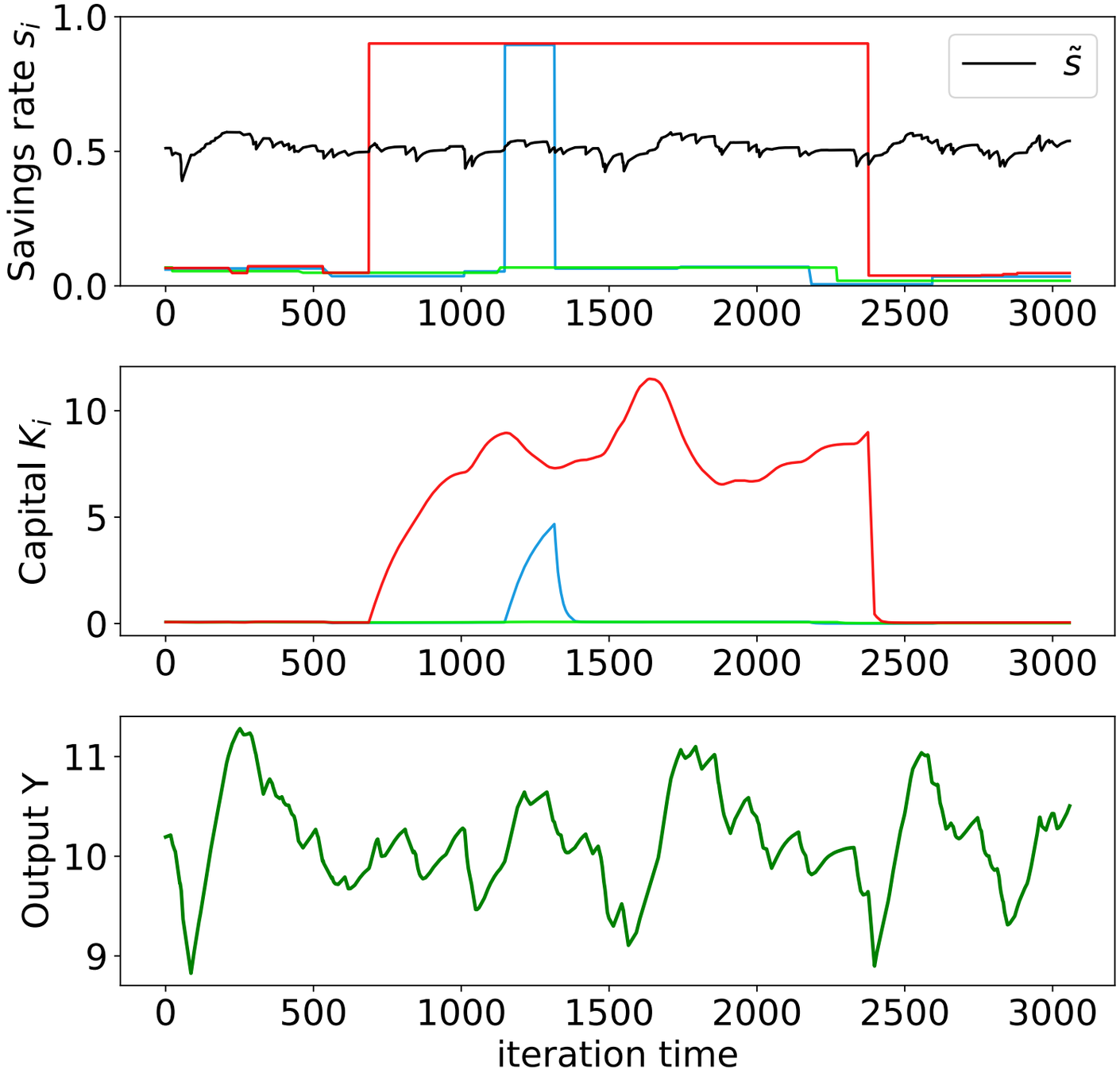

1.0
0.8
0.6
0.4
0.2
0.0
savings rate s_i
s^*
s_{gold}
$\tilde{s}$
10^{-1}
10^{0}
10^{1}
10^{2}
10^{3}
τ
10^{0}
10^{-1}
10^{-2}
probability

A





Equilibrium <=> pole balancing

Business cycles naturally emerge under bounded rationality, without need for external shocks

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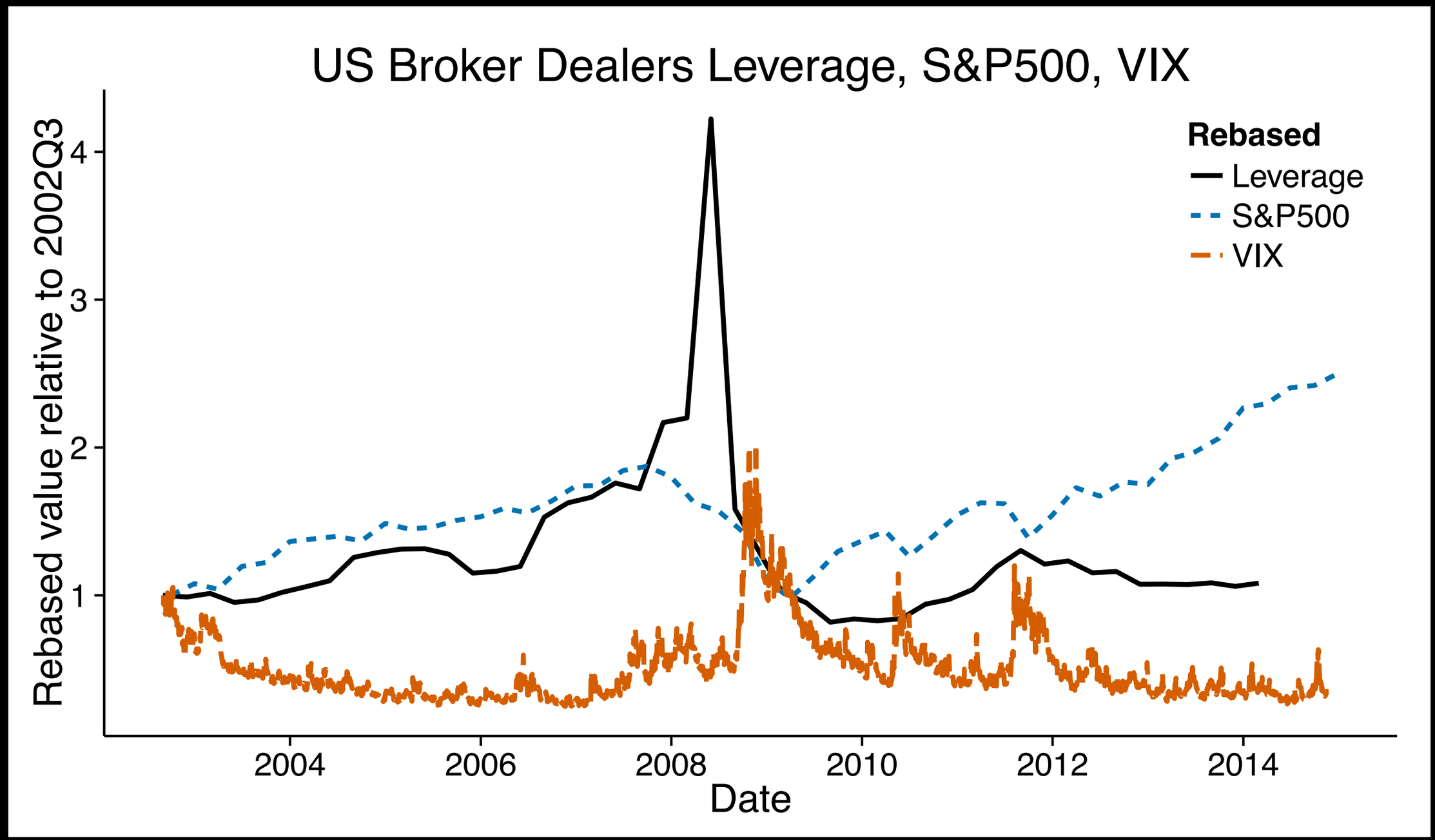
Economics can be done without assuming equilibrium!

- No utility functions
- No rational agents
- No perfect maximizers

Run up to crisis of 2008



The Basel Leverage Cycle Model

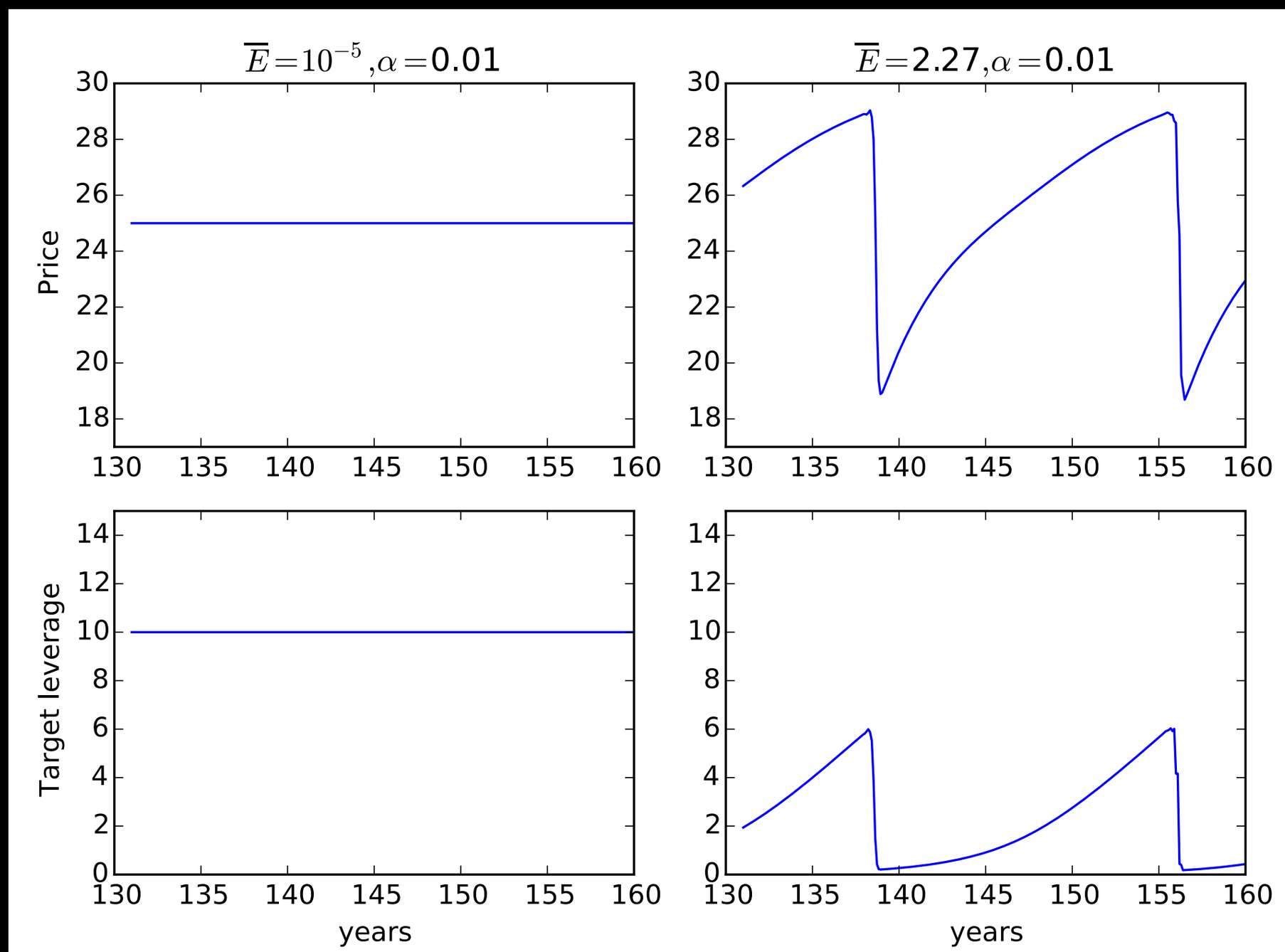
(Dynamics of the leverage cycle, Aymanns and Farmer, 2015)
(Taming the Leverage Cycle, Aymanns, Caccioli, Farmer, Tan, 2016)

- Two agents: bank and fundamentalist
- One risky asset + cash
- Four assumptions:
  - Bank uses exponential moving average of historical volatility to estimate expected volatility
  - Basel II risk management (VaR) sets leverage target
  - Price formation (supply = demand) (Increasing leverage target => buying => price of asset rises)
  - Fundamentalist buys undervalued asset & v.v.

Price and leverage vs. time

Small banking sector

Large banking sector



Financial stability of European banking system

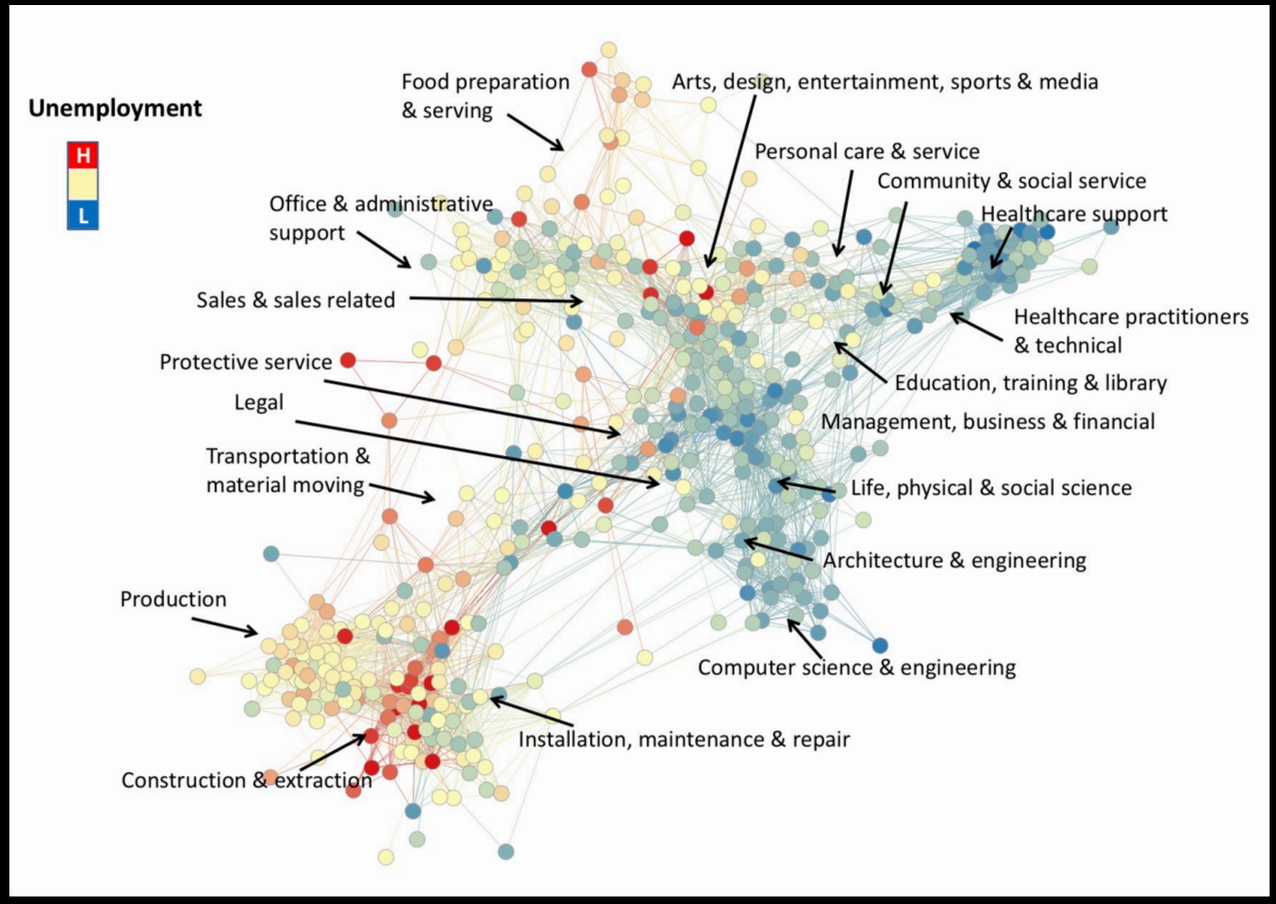
Alissa Kleinnijenhuis, Paul Nahai-Williamson, Thom Wetzer, JDF

- Can track every systemically important financial institution in Europe
- Simulate propagation of financial contagion
- Can show that stress tests are dramatically amplified by systemic interactions
- More realistic evaluation of financial stability

Unemployment

Maria del Rio Chanona, Penny Mealy,
Francois Lafond, Mariano Berguerisse, JDF

- Agent-based model of job transitions
- Can predict effect of automation shock
  - what professions are safest?



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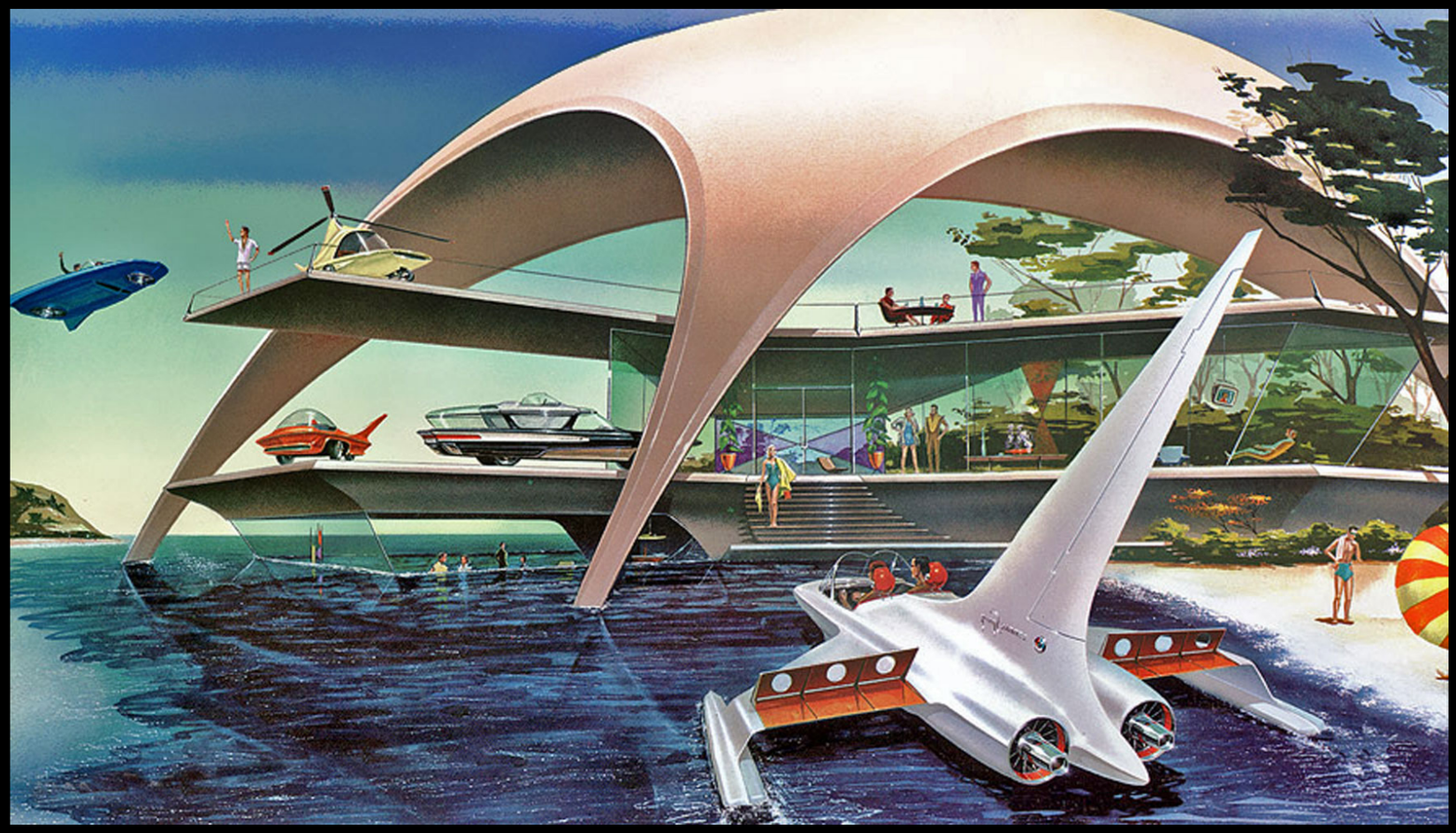
Technological change



Technologies improve at very different rates

The rates are highly persistent

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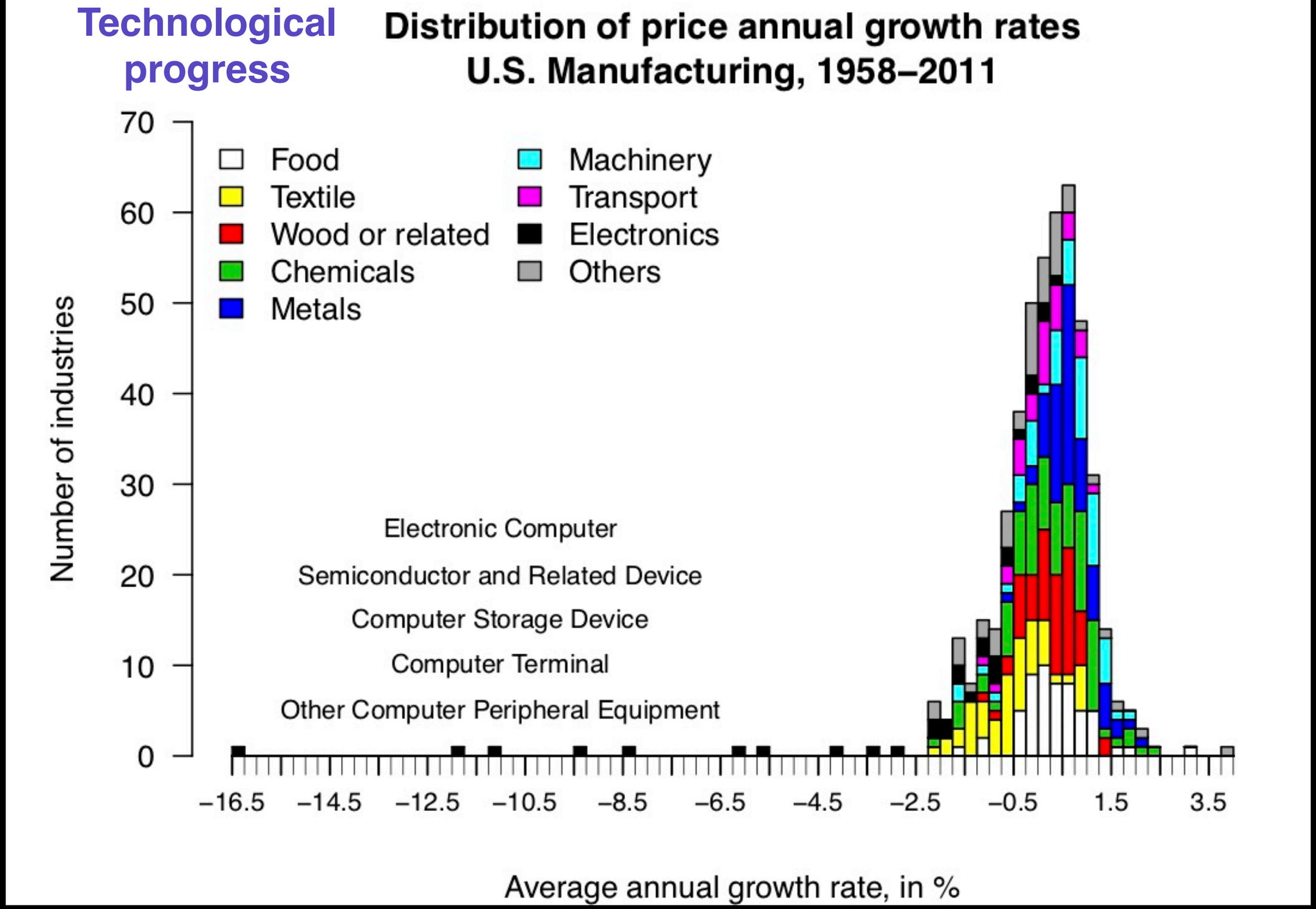
Technological progress



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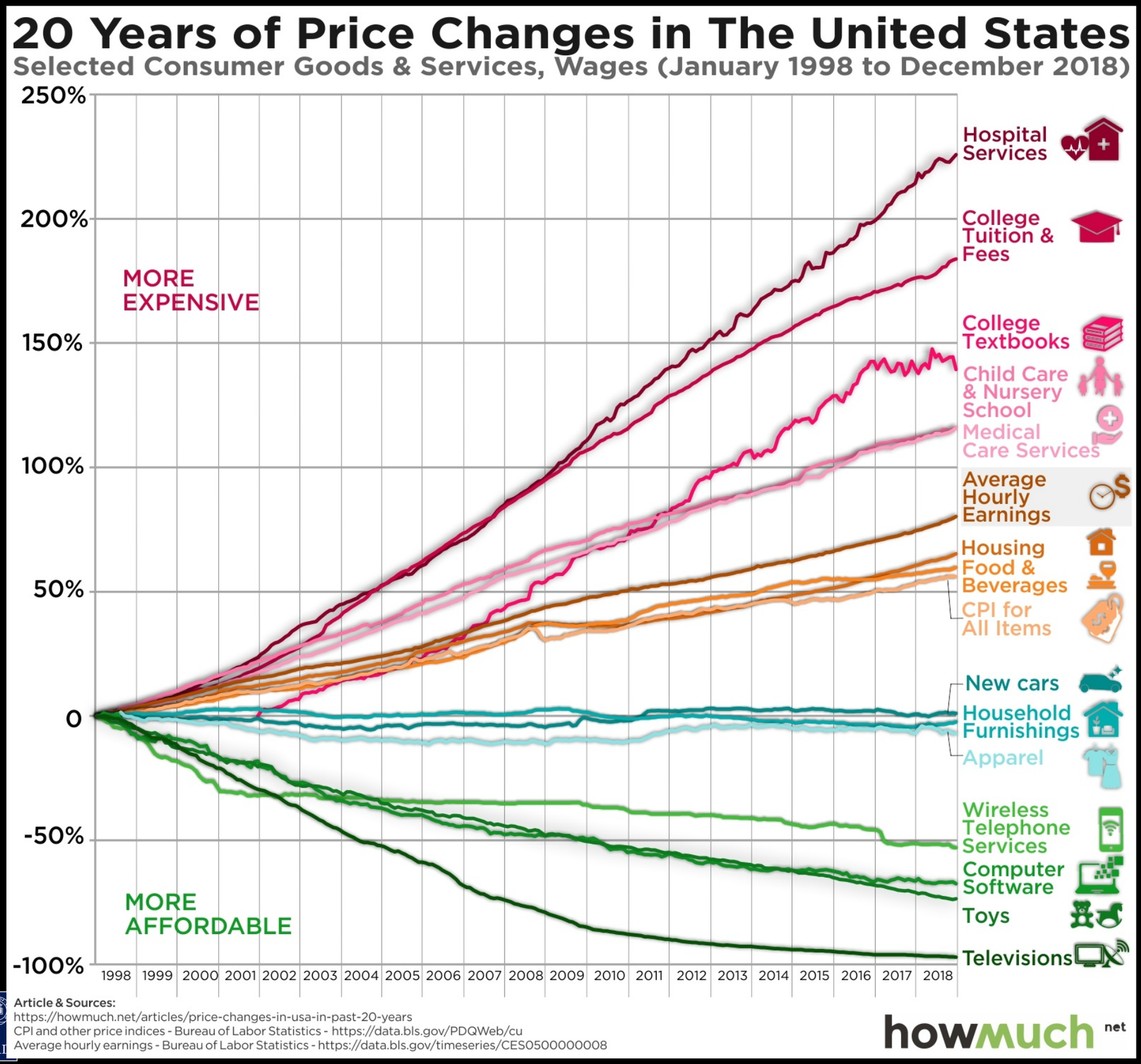
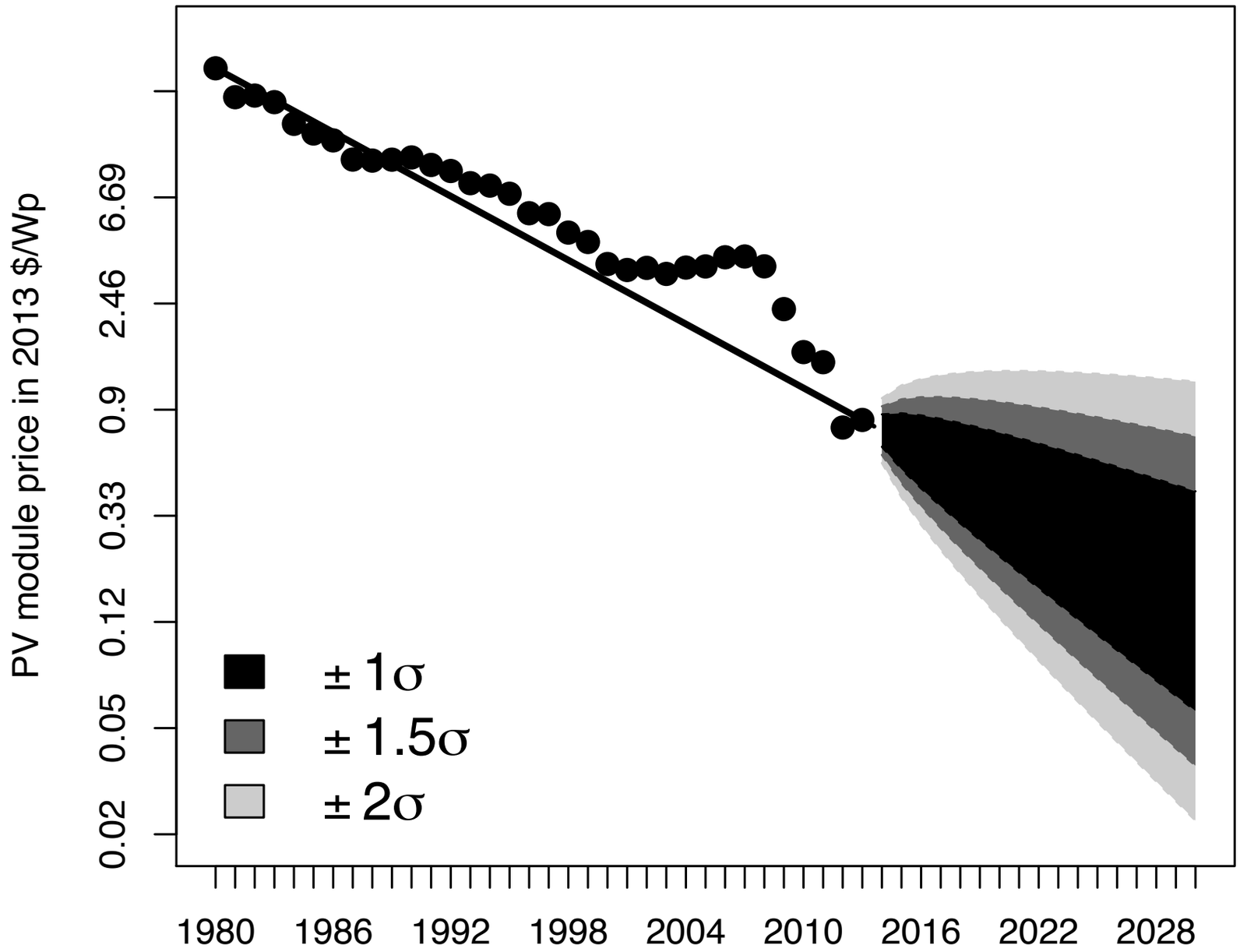
Inflation



Thanks to Jangho Yang

Distributional forecast of solar PV assuming business as usual

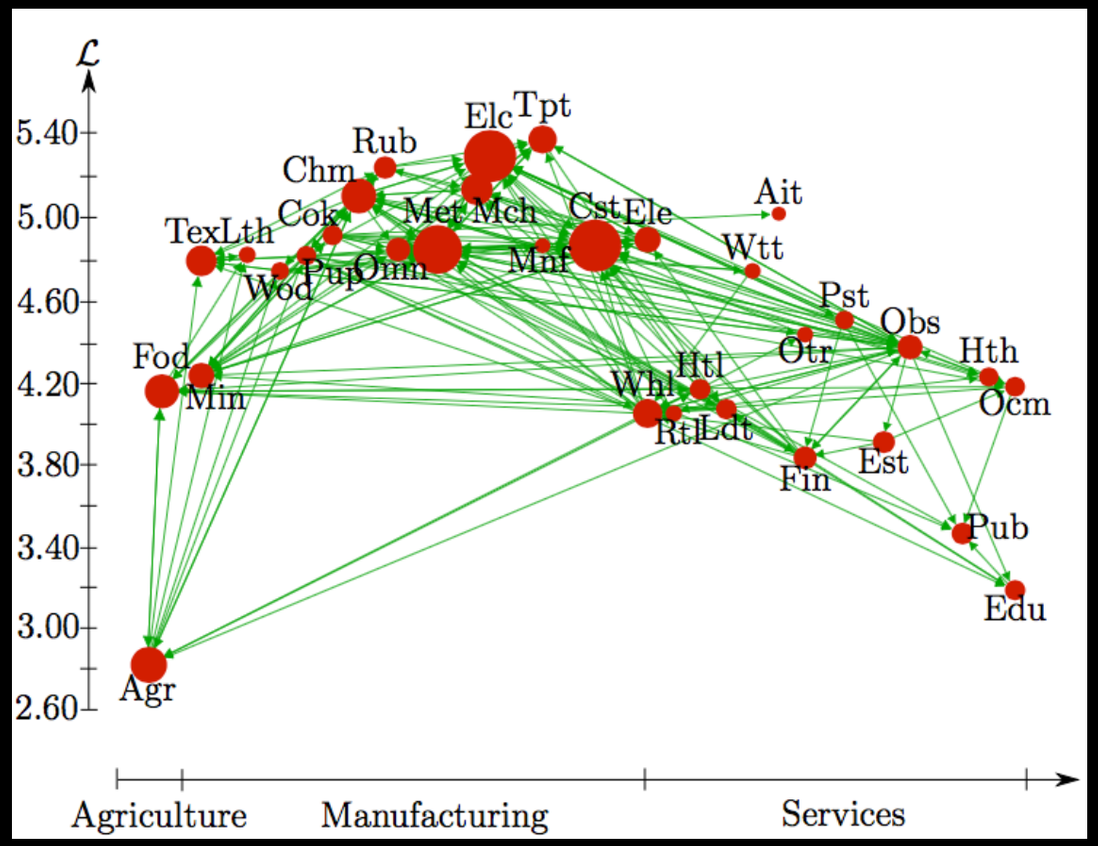


Farmer and Lafond, 2016

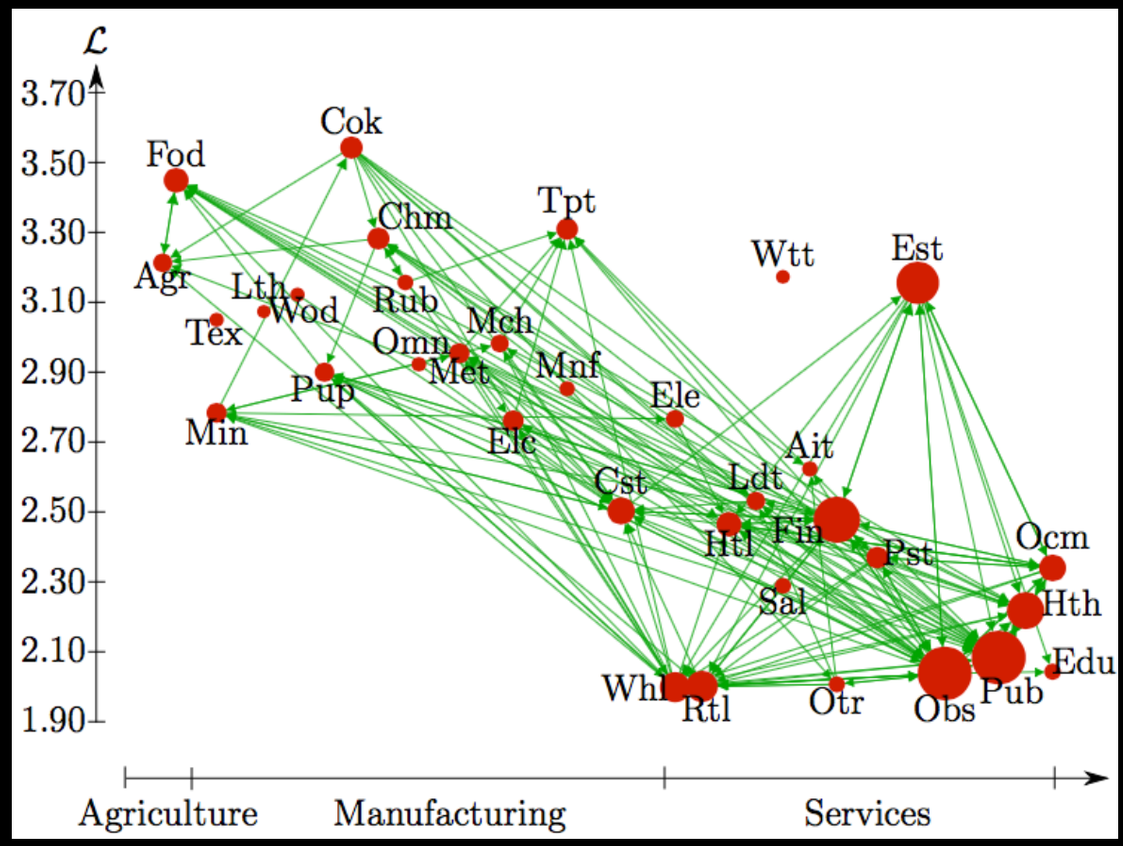
- Technological change drives economic growth
- The economy rewires itself toward rapidly improving technologies
- Can take advantage of ecological relationships to understand and predict growth

Ecological relationships predict growth

The U.S. and China

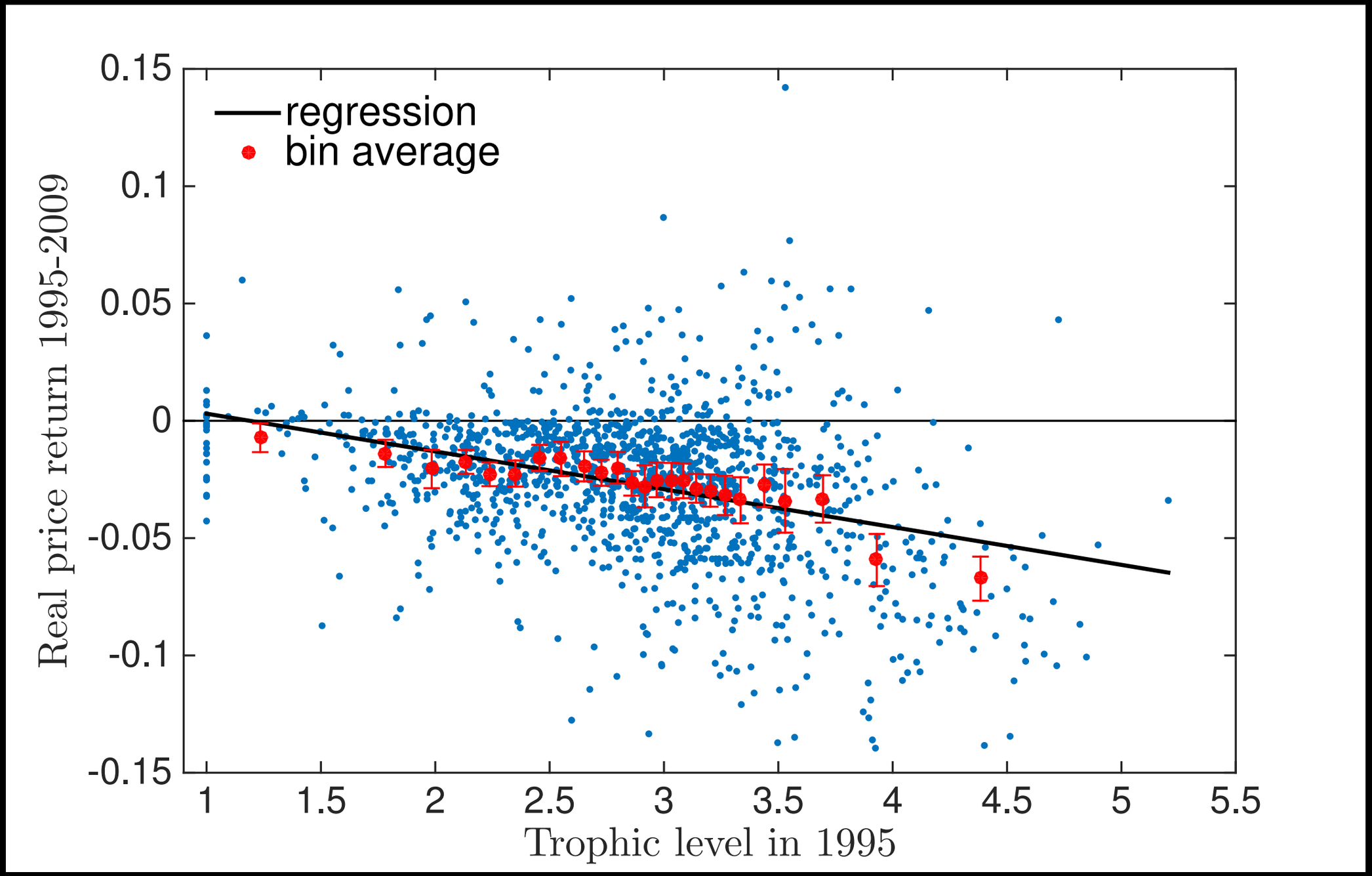


China



U.S.

Future industry price return vs. trophic level of industry



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McNerney, Savoie, Caravelli and Farmer, 2018

What is the cost of the green energy transition?

Rupert Way, Penny Mealy, JDF

- Commonly assumed that green energy transition will be really expensive
- But wind, solar have dropped in price for many decades, in contrast to coal, oil, gas, nuclear, …
- Converting to wind and solar quickly is likely to be a net savings, above and beyond reducing climate change.

Catch 22 of macro

- Economy is complex
- Economy evolves
  - limited aggregate data
  - only simple models can be estimated
- But economy is complex — Catch 22

Global microeconomics

Let macro emerge from micro

Takes advantage of heterogeneity
Much more data at microscale
Better statistical significance
Endogenous dynamics
Can model emergence
Predicts more things

Conceptual debate

- "As if" reasoning

vs.

- Principle of verisimilitude
  - models should match key aspects of reality They should "feel" true
  - Einstein's dictum: Everything should be made as simple as possible, but no more

Very different data needs!

Complex systems models require
fine grained micro data for calibration

Complexity economics is young

500 person-years vs. 50,000 person years

- Need to develop new methods
  - fitting models to time series data
  - parallelism
- Standard software libraries
- Better data sets

Much to be done!

Why does mainstream resist complexity economics?

- Requires abandoning foundational assumptions in use since mid 20th century
- Requires very different toolkit
  - large scale software simulation
- Different attitude toward doing science

http://www.doynefarmer.com/book

https://www.inet.ox.ac.uk/programmes/complexity/

Additional slides