

SEPTEMBER 19, 2022

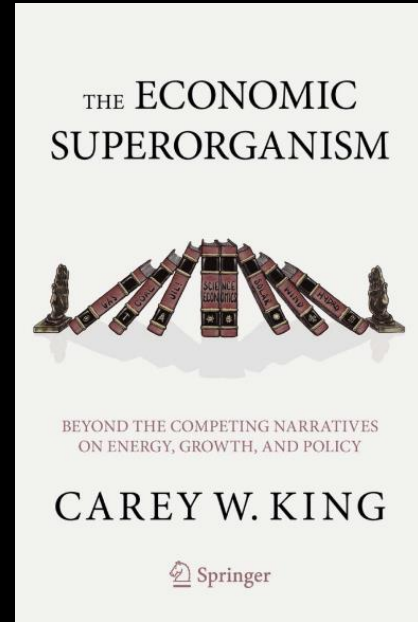


INSIGHTS AND QUESTIONS FROM HARMONEY, A BIOPHYSICAL ECONOMIC GROWTH MODEL

Fields-CFI Workshop on Impacts of Climate Change on Economics, Finance, and Insurance
Toronto, Canada, September 19-23, 2022

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Description of “HARMONEY” model

“Human And Resources with MONEY”

Biophysical Models

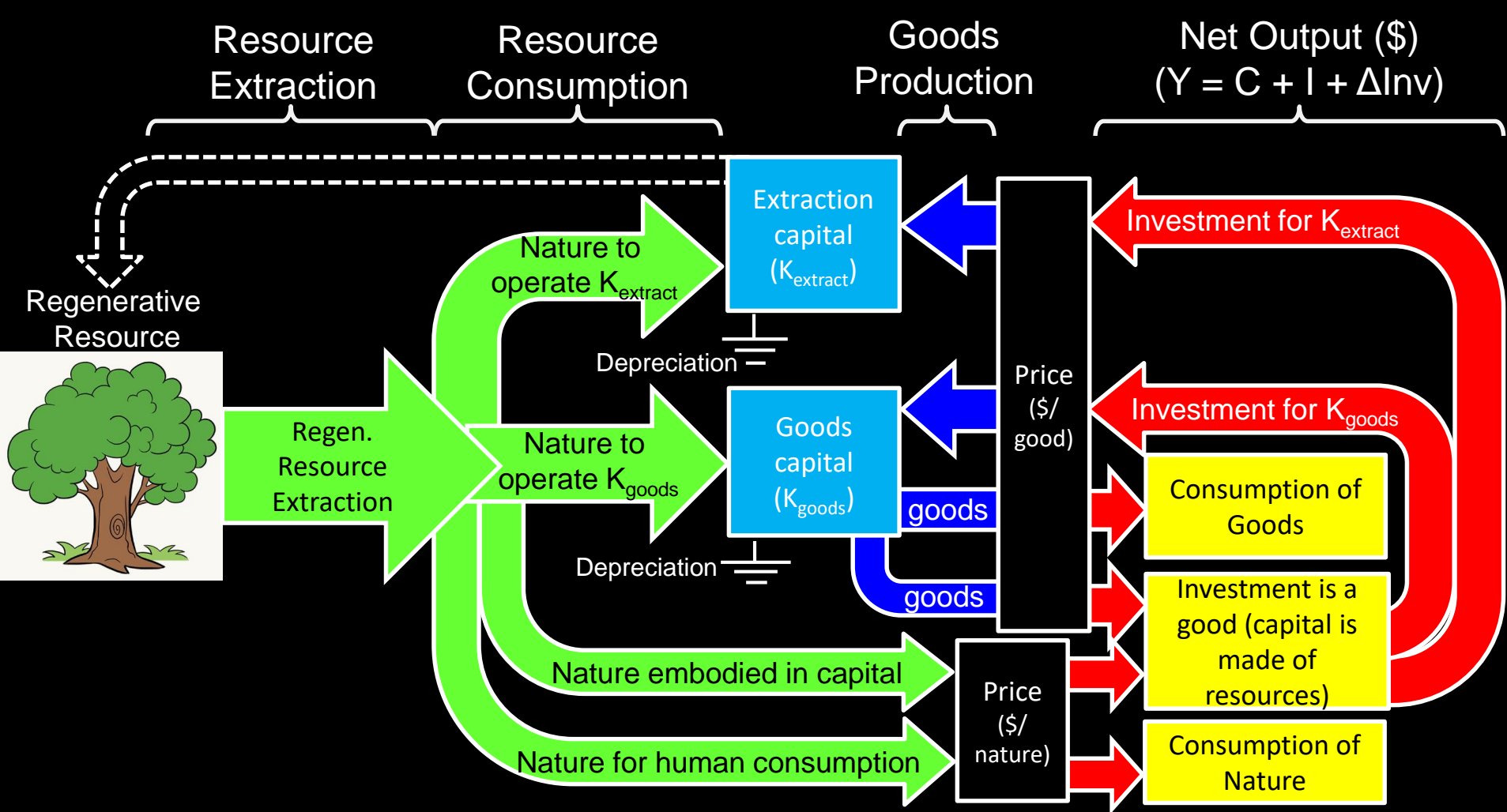
Population
 Natural Resources
 Capital (sometimes)

Macroeconomic Models

Population
 Capital
 Wages
 Employment
 Debt (sometimes)

Research Approach

Combine models: Link resource consumption
 to debt, employment, and output



Highlights of model framework

- Post-Keynesian structure
 - Uses stock and flow consistent macroeconomic accounting of money
 - Banks create money by issuing loans (as debt) to firms [Keen-Goodwin model]
- Natural resource extraction productivity declines as the resource is depleted

Input-Output representation of money flows

				Net Output			
		Goods	Extraction	Consumption	Investment	Δ Inventory	Total output
	Goods	$P_g a_{gg} X_g$	$P_g a_{ge} X_e$	C_g	$I_e + I_g$	ΔInv_g	$P_g X_g$
	Extraction	$P_e a_{eg} X_g$	$P_e a_{ee} X_e$	C_e	---	ΔInv_e	$P_e X_e$
Value Added	Profit	Π_g	Π_e				
	Wages	wL_g	wL_e				
	Interest	rD_g	rD_e				
	Depreciation	$P_g \gamma K_g$	$P_g \gamma K_e$				
	Total output	$P_g X_g$	$P_e X_e$				

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$$a_{ee} = \frac{\text{resource to operate } K_e}{\text{total resource extraction}}$$

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$$a_{ee} = \frac{\text{resource to operate } K_e}{\text{total resource extraction}}$$

$$a_{ee} = \frac{\eta_e K_e C U_e}{\delta y K_e C U_e} = \frac{\eta_e}{\delta y} = \frac{[\text{resource}]}{[\text{resource}]}$$

This a_{ee} is one key to model the feedback from “net energy”, or how much energy it takes to run the energy sector

	Goods	$P_g a_{gg} X_g$	$P_e a_{eg} X_e$	C_g	$P_e P_g$	ΔInv_g	$P_g X_g$
	Extraction	$P_e a_{eg} X_g$	$a_{ee} X_e$	C_e	---	ΔInv_e	$P_e X_e$
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Highlights of model framework

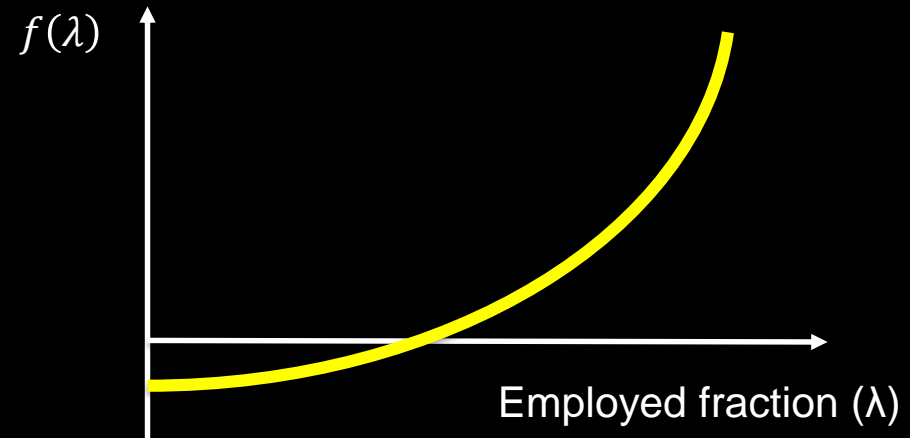
- Post-Keynesian structure
 - Uses stock and flow consistent macroeconomic accounting of money
 - Banks create money by issuing loans (as debt) to firms [Keen-Goodwin model]
- Natural resource extraction productivity declines as the resource is depleted
- Each of the following are required for “production” and can limit output
 - Capital (as machines)
 - Labor
 - Natural resource consumption: (1) as fuel to operate capital, (2) embodied in capital
- Wages change with employment and inflation

Wages per person (per Keen, 2013)

- Wage (w) is a function of employment
 - Employed fraction = λ = Labor / population

$$\frac{\dot{w}}{w} = f(\lambda) + w_1 i + w_2 \frac{1}{\lambda} \frac{d\lambda}{dt}$$

- i = inflation (based on CPI)



Highlights of model framework

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- Wages change with employment and inflation
- Investment is a function of profits (more profits, more investment)
 - Investment is curtailed if household consumption is below minimum (< 0) levels

Gross Investment

- $$\begin{aligned}
 I &= \kappa_0(\text{depreciation}) + \kappa_1(\text{net profit}) \\
 &= \kappa_0(P_g \delta K) + \kappa_1 \Pi \\
 &= 1.0(P_g \delta K) + 1.5 \Pi
 \end{aligned}$$

- Keen, S (1995) *J. of Post-Keynesian Economics*; Keen (2013) *J. of Econ. Behavior and Organization*
- Bovari et al. (2018) *Ecological Economics*

where,

Π = net profit = value added – wages – interest payments – depreciation

$P_g \delta K$ = value of capital depreciation

Highlights of model framework

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- Wages change with employment and inflation
- Investment is a function of profits (more profits, more investment)
 - Investment is curtailed if household consumption is below minimum (< 0) levels
- Consumption (household) will be defined two ways to compare results
 - As a residual of total output (after investment and intermediate consumption)
 - As a function of disposable income and deposits

Solving for prices

- Prices (P_i) are a markup (μ_i) on the costs (c_i) of production

$$P_i = (1 + \mu_i)c_i$$

- I will show results assuming a *constant markup*

Solving for prices: “full cost”

- Costs (c_i , \$/unit) are
 - Depreciation
 - Interest payments on debt
 - Labor
 - Intermediate purchases of goods and extracted resources

$$c_g = P_g a_{gg} + P_e a_{eg} + (wL_g + r_L D_g + \delta P_g K_g) / X_g$$

$$c_e = P_g a_{ge} + P_e a_{ee} + (wL_e + r_L D_e + \delta P_g K_e) / X_e$$

Solving for prices: “marginal cost”

- Costs (c_i , \$/unit) are
 - Depreciation
 - Interest payments on debt
 - Labor
 - Intermediate purchases of goods and extracted resources

$$c_g = P_g a_{gg} + P_e a_{eg} + (wL_g + rD_g + \delta P_g K_g) / X_g$$

$$c_e = P_g a_{ge} + P_e a_{ee} + (wL_e + rD_e + \delta P_e K_e) / X_e$$

Simulation results

Note: model is not calibrated to any region in the real world

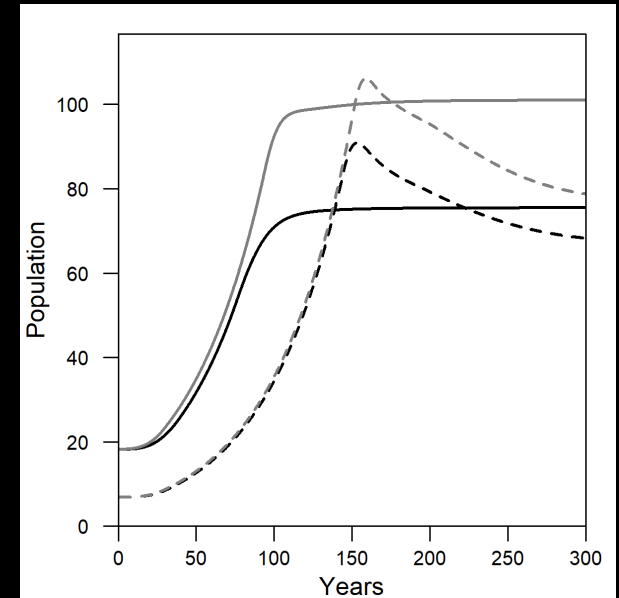
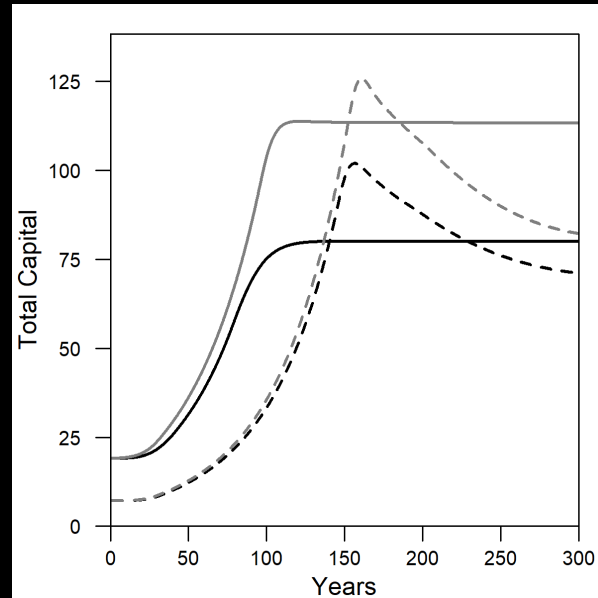
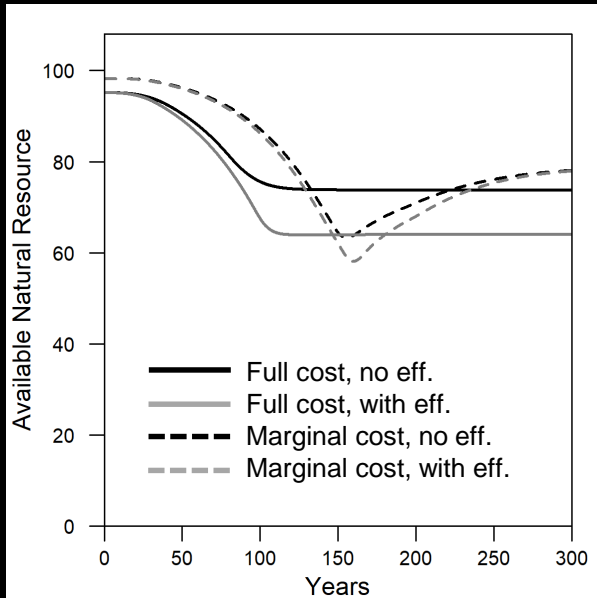
Points to keep in mind

- I vary two things to compare results
 - 1) The definition of cost (full vs. marginal)
 - 2) Efficiency: An (exogenous) increase in efficiency of capital operation (e.g., fuel input) as a function of investment in new capital

- The model grows from an equilibrium of a “small economy”
 - Resource extraction
 - $= \delta_y \times y \times K_e \times CU_e$
 - $= \delta_y \times \text{resource remaining} \times \text{capital} \times \text{capacity utilization}$
 - Small economy: extraction parameter, δ_y , is set low
 - Growing economy: extraction parameter, δ_y , is increased gradually
 - Makes it possible to extract more resources with existing capital, which enables profits for net investment and growth

Highlights of simulation of model: Resources, capital, and population

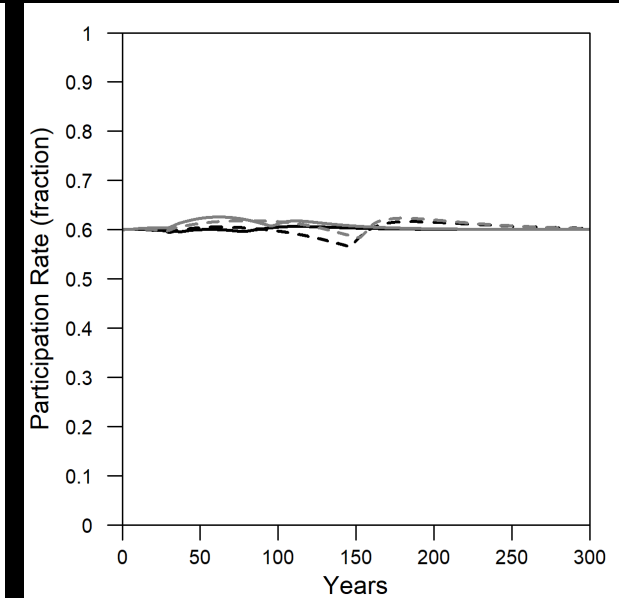
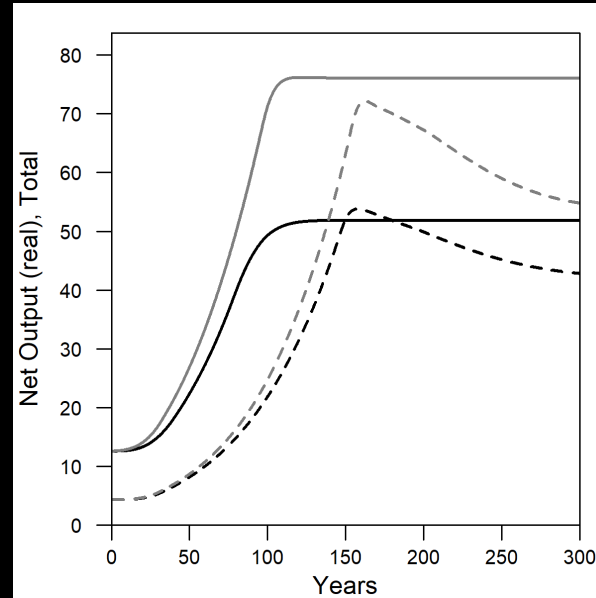
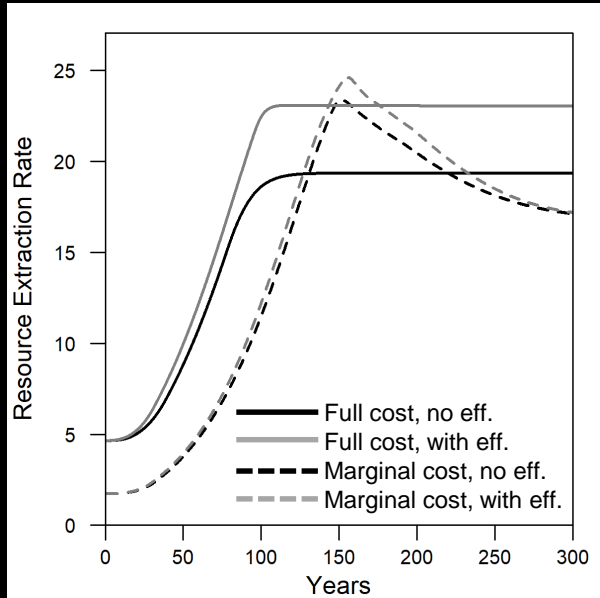
Full wage
 “bargaining power”
 = wages increase
 with inflation



Highlights of simulation of model:

Extraction rate, Net output (GDP), participation rate

Full wage
“bargaining power”
= wages increase
with inflation

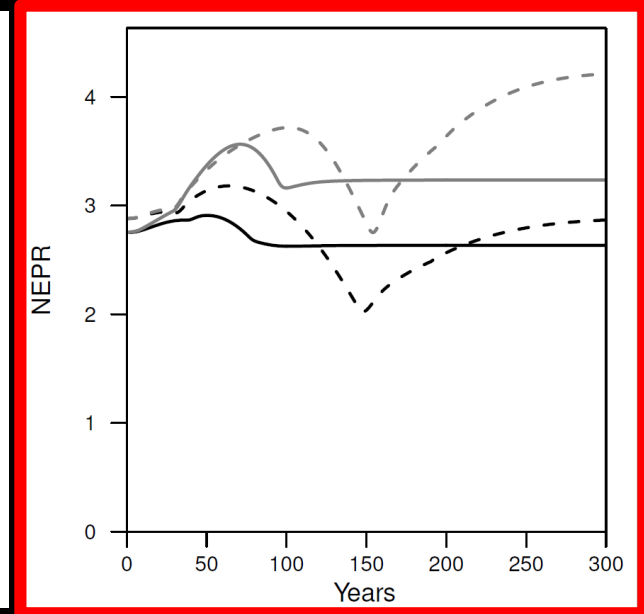
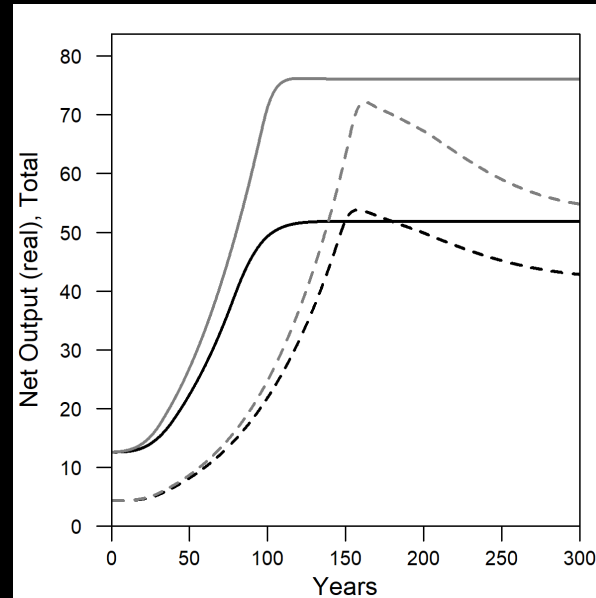
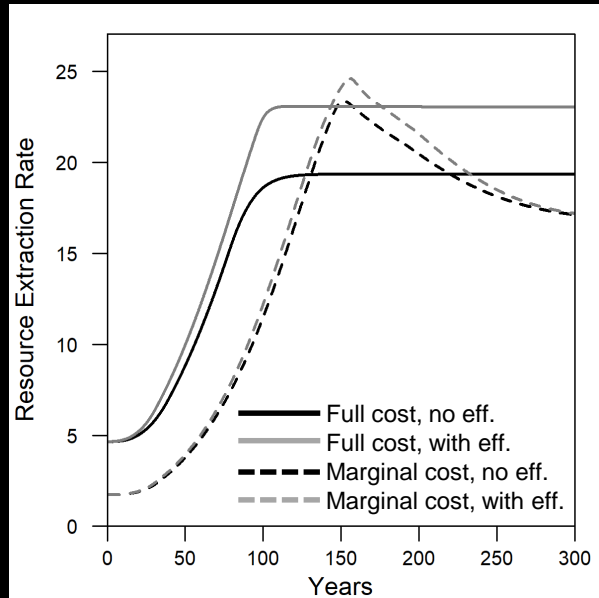


Highlights of simulation of model:

Extraction rate, Net output (GDP), NEPR

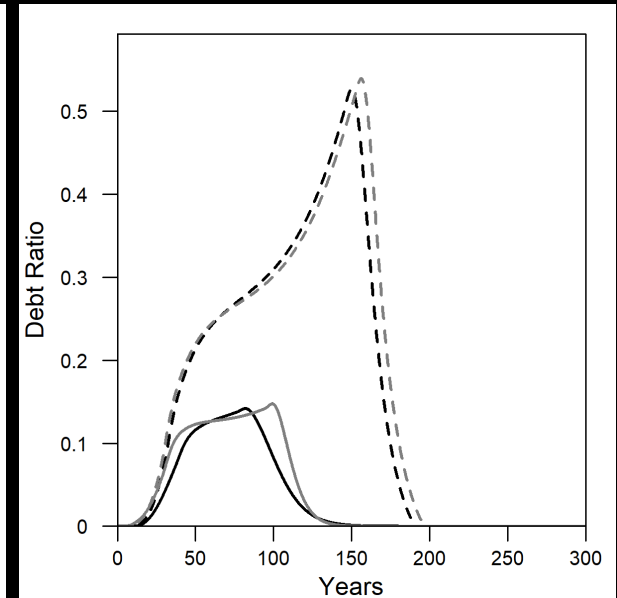
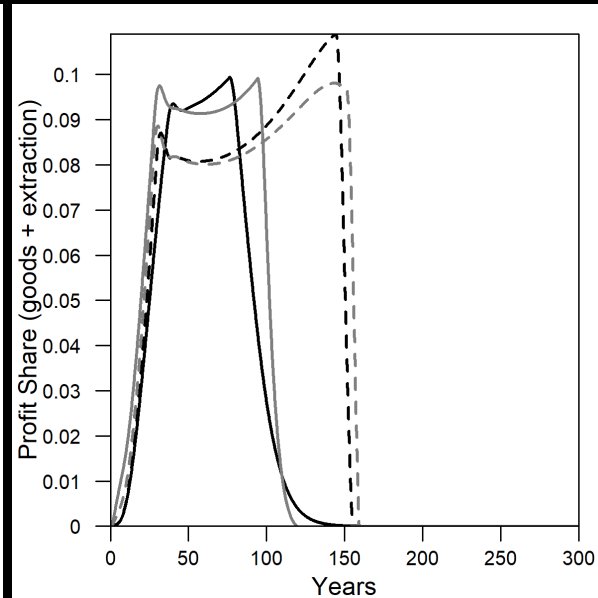
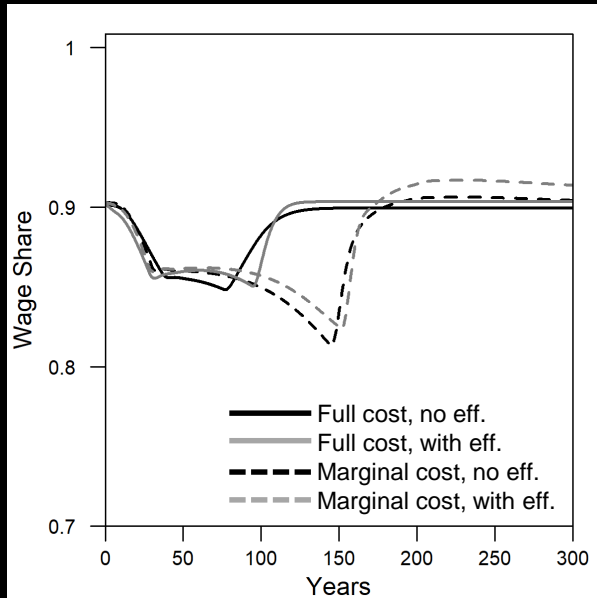
NEPR: Net External Power Ratio = PROI ~ dynamic EROI

Full wage
 “bargaining power”
 = wages increase
 with inflation



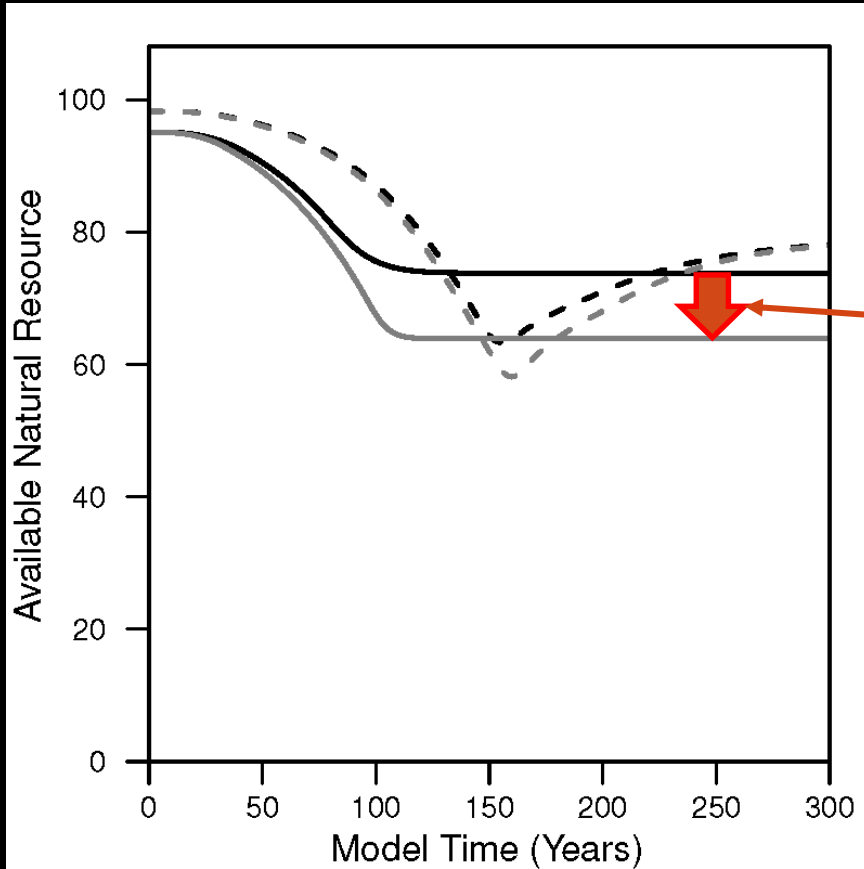
Highlights of simulation of model: wage share, profit share, debt ratio

Full wage
 “bargaining power”
 = wages increase
 with inflation



Insight #1:

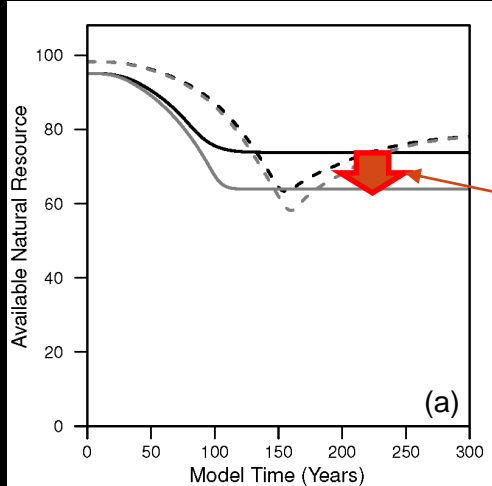
Efficiency begets more
consumption and accumulation,
not less (Jevons Paradox)



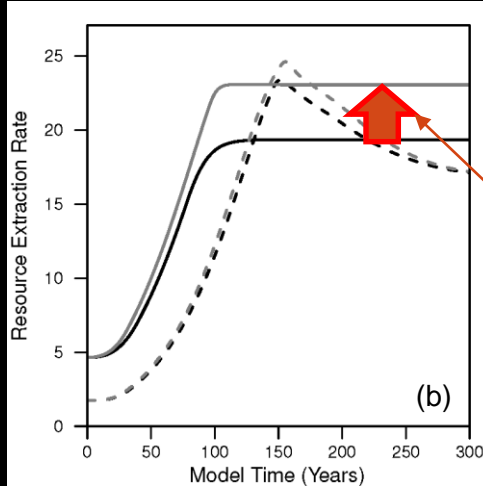
The \uparrow in efficiency allows higher resource depletion

Legend:

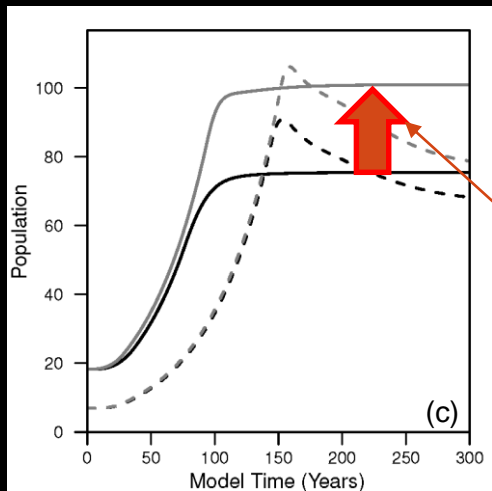
- Full Cost, with \uparrow in efficiency
- Full Cost, no \uparrow in efficiency
- - - Marginal Cost, with \uparrow in efficiency
- - - Marginal Cost, no \uparrow in efficiency



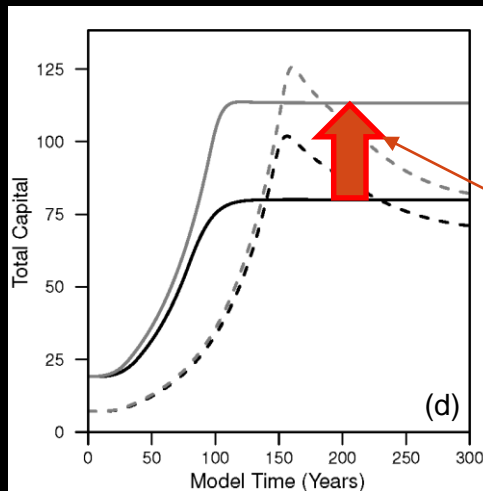
The \uparrow in efficiency allows higher resource depletion



The \uparrow in efficiency allows higher resource extraction rate



The \uparrow in efficiency allows higher accumulation of population



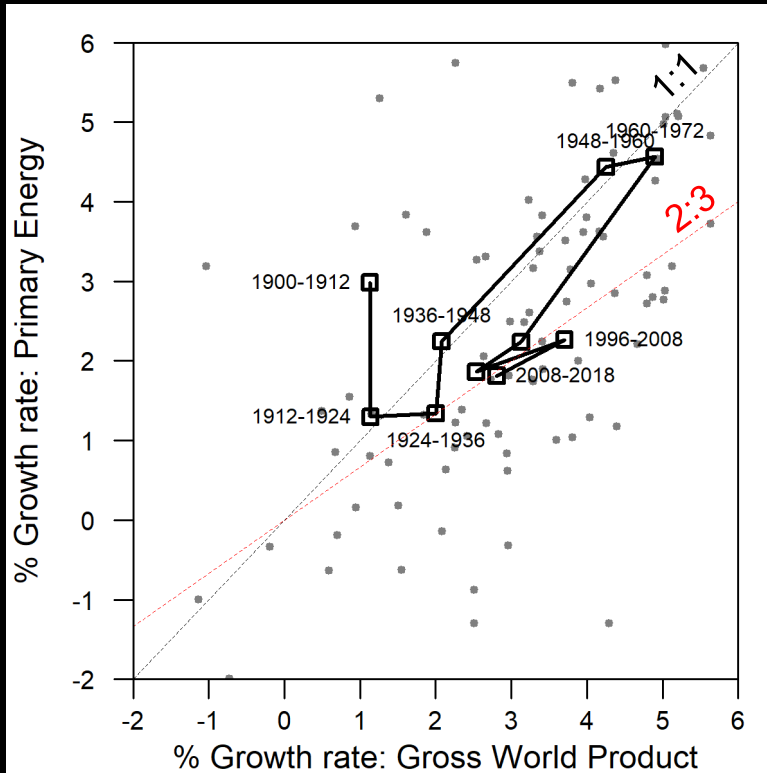
The \uparrow in efficiency allows higher accumulation of capital (machines)

Legend:

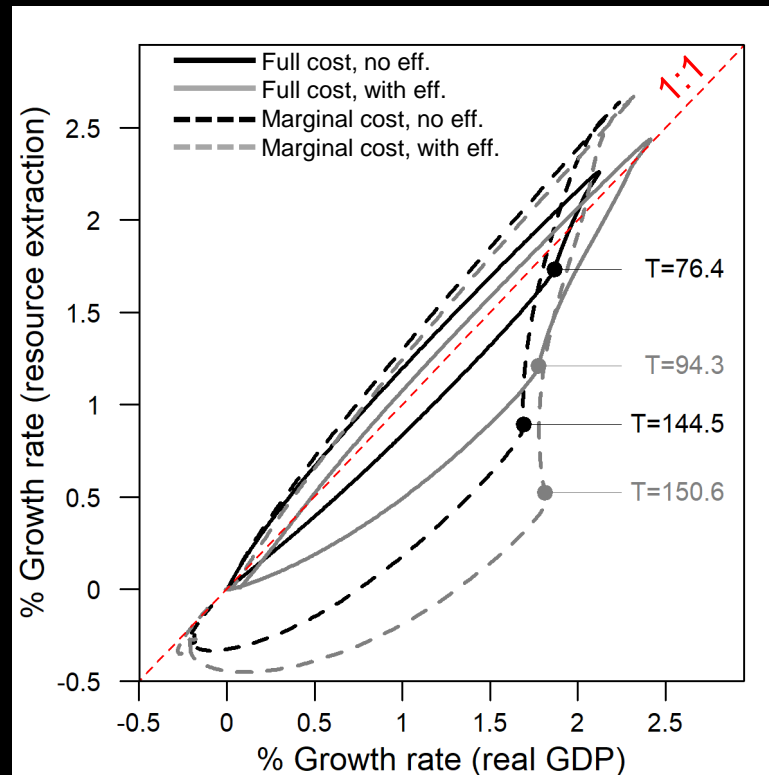
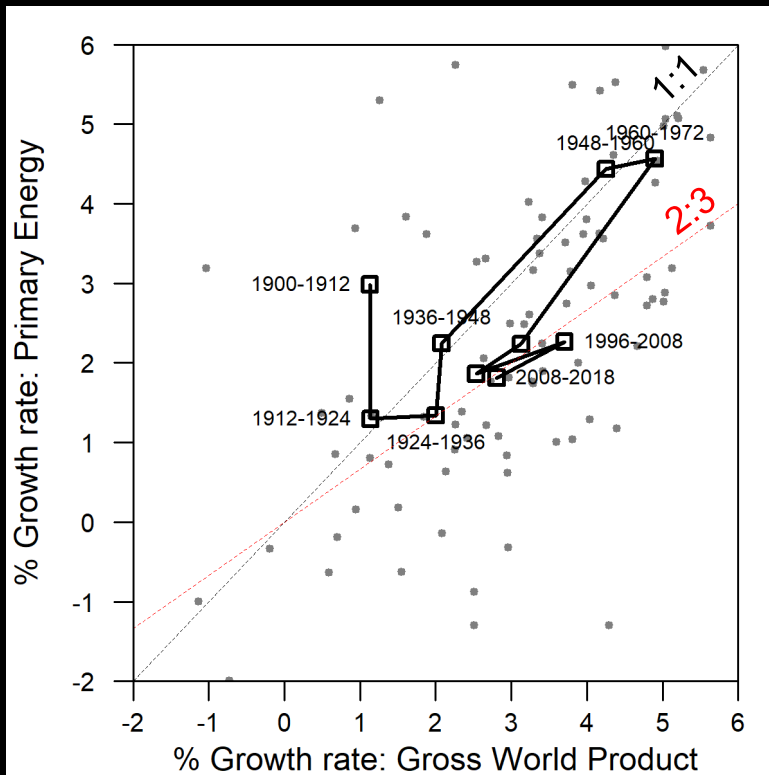
- Full Cost, with \uparrow in efficiency
- Full Cost, no \uparrow in efficiency
- - - Marginal Cost, with \uparrow in efficiency
- - - Marginal Cost, no \uparrow in efficiency

Insight #3: Enhanced Interpretation of Decoupling Resource Consumption from GDP

Viewing relative decoupling: growth rate of resource consumption vs. growth rate of GDP

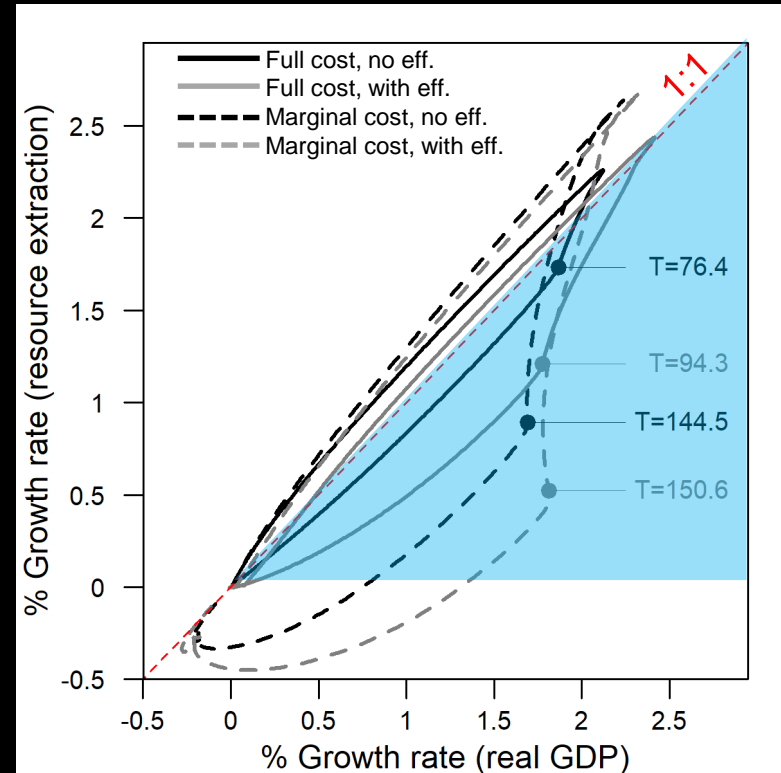
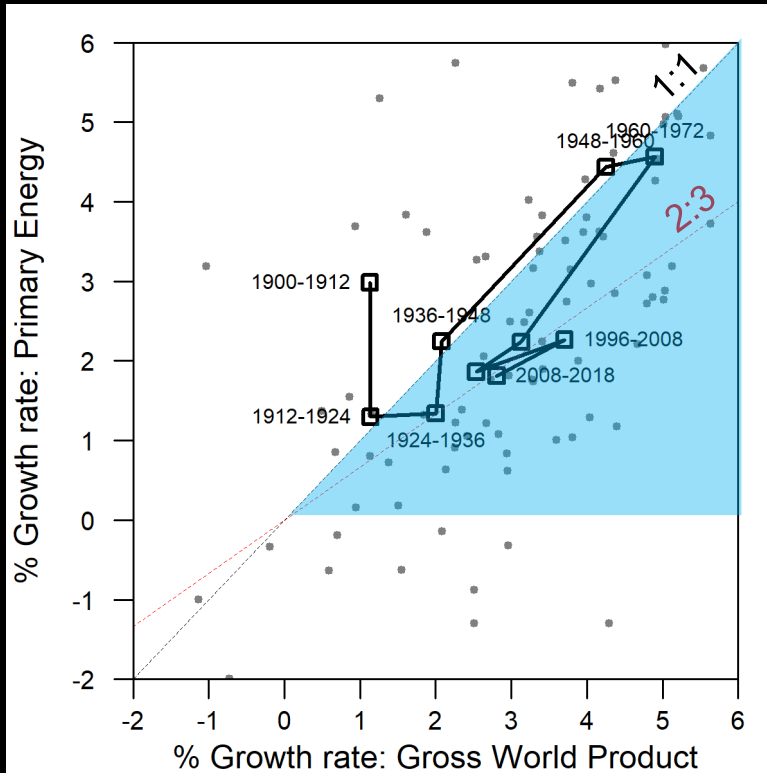


Viewing relative decoupling: growth rate of resource consumption vs. growth rate of GDP



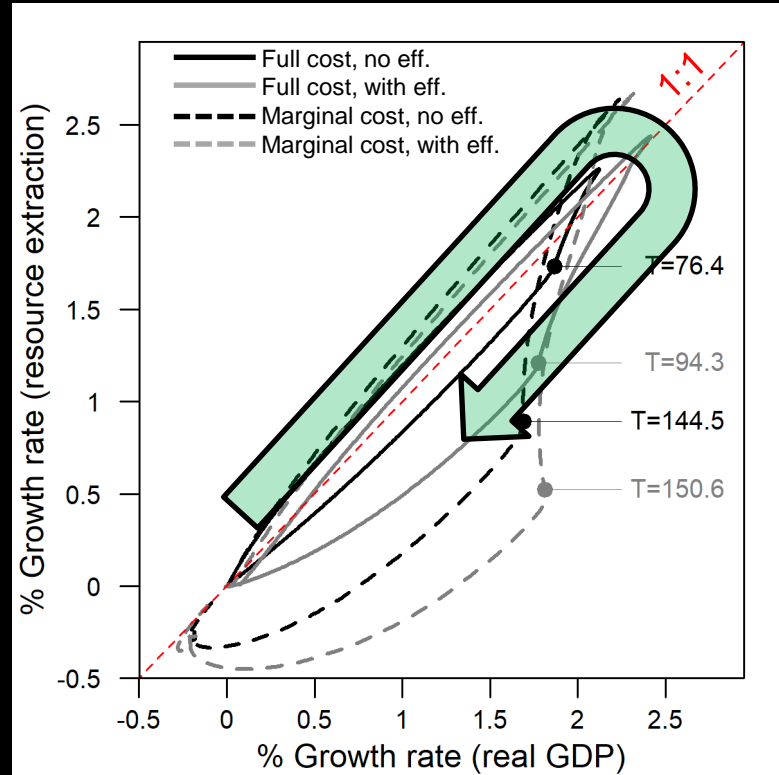
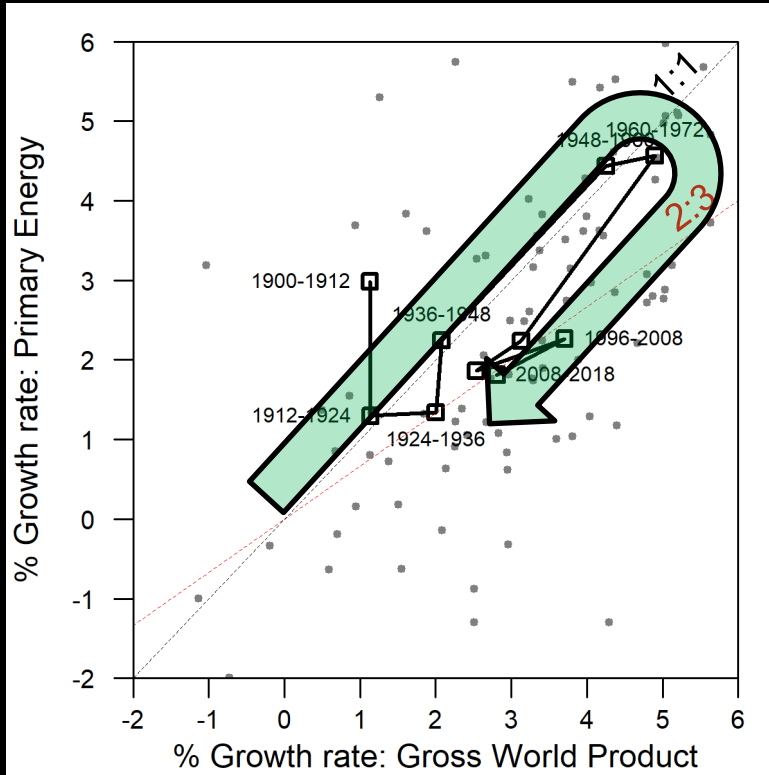
Times
are ~
peak
profit
shares

Blue shaded area is often considered a state of “relative decoupling” (declining energy intensity)



Times are ~ peak profit shares

Initially the global economy increased growth rates (linearly) and decreased them to the “relatively decoupled” regime today: a clockwise pattern



Times are ~ peak profit shares

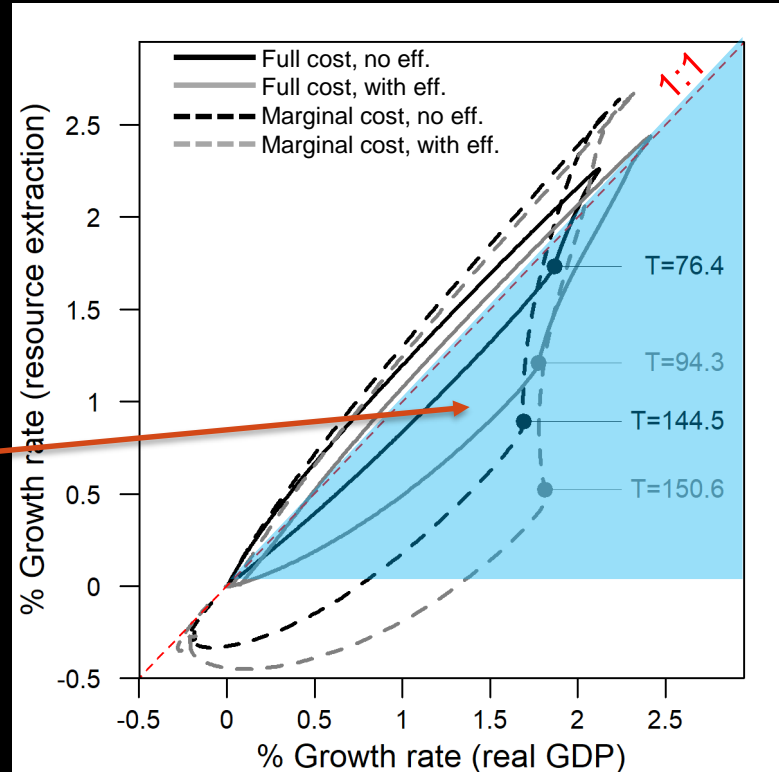
Consider the concept of “relative decoupling”

- Relative decoupling:

growth rate resource
extraction

<

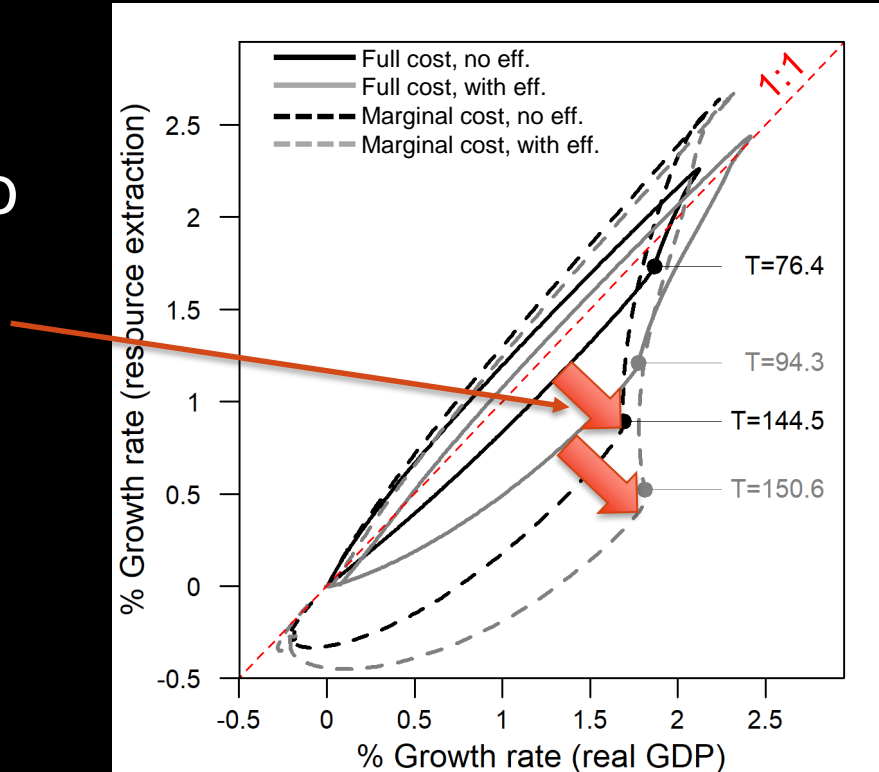
growth rate GDP



Times
are ~
peak
profit
shares

The “metabolic growth rate” of the economy

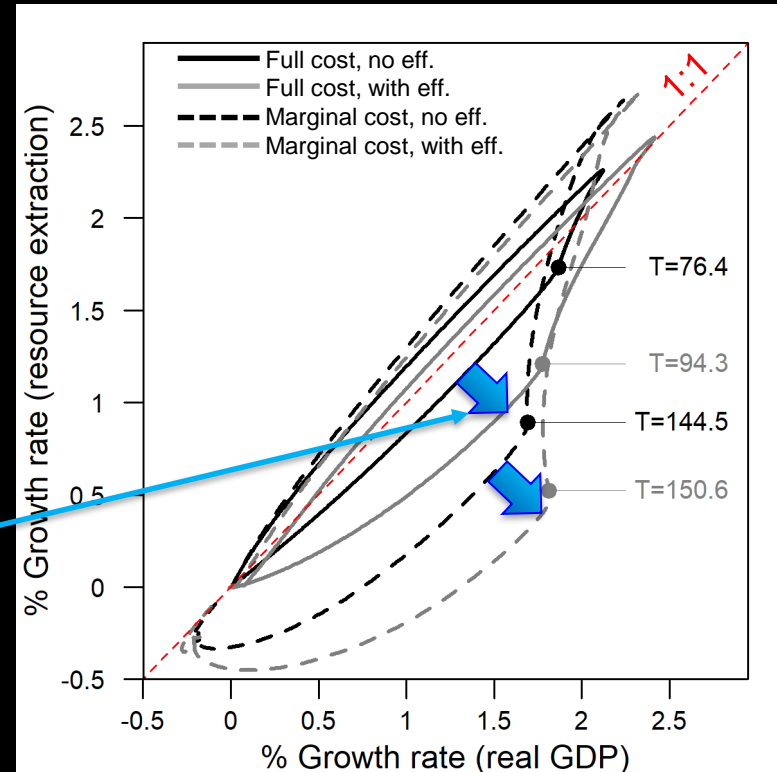
- More “decoupling” seems apparent due to
 - Using marginal rather than full costs



Times
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The “metabolic growth rate” of the economy

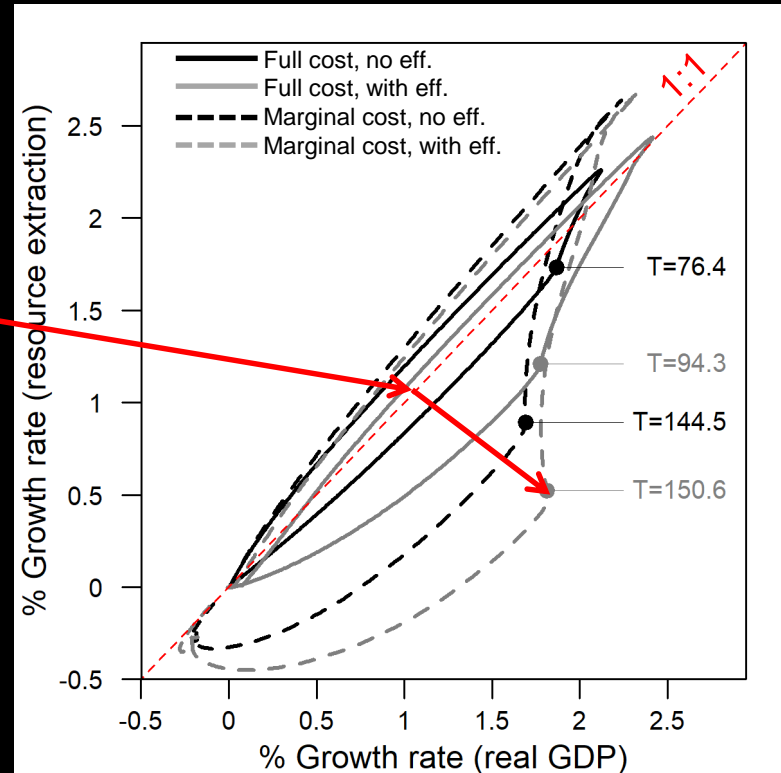
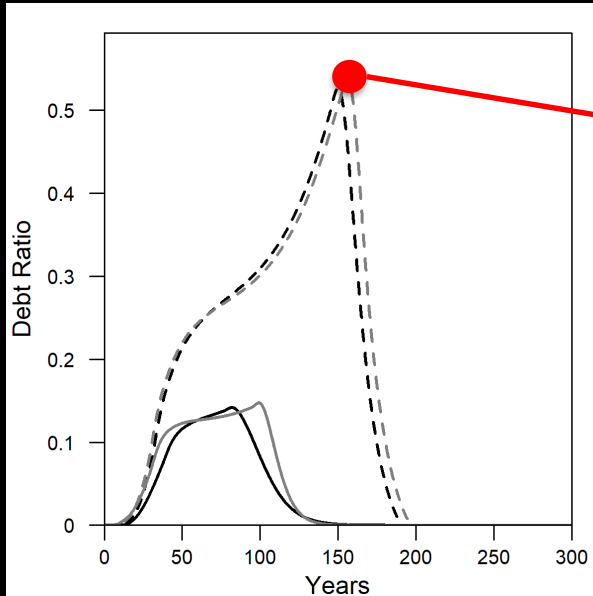
- More “decoupling” seems apparent due to
 - Using marginal rather than full costs
 - Actually increasing resource consumption efficiency of capital (e.g., fuel efficiency)



Times are ~ peak profit shares

The “metabolic growth rate” of the economy

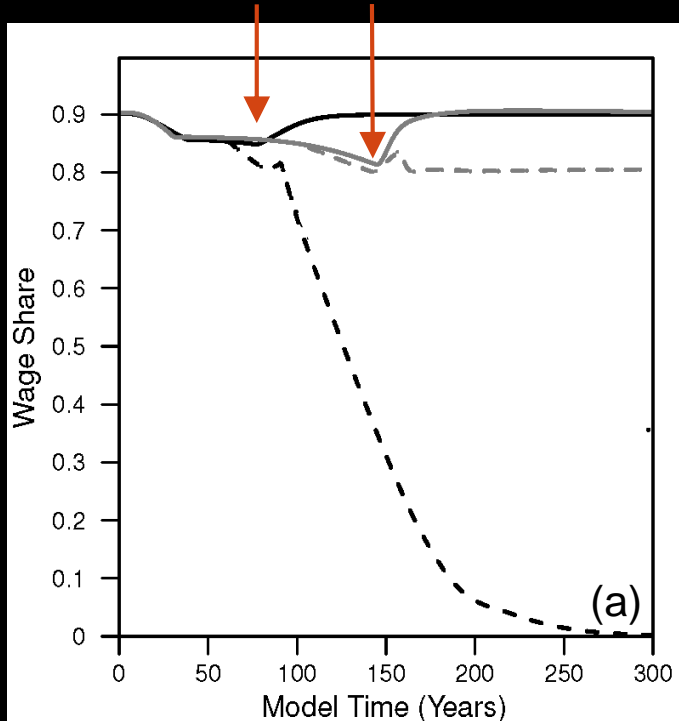
- Most “decoupling” occurs near highest debt ratio



Times
are ~
peak
profit
shares

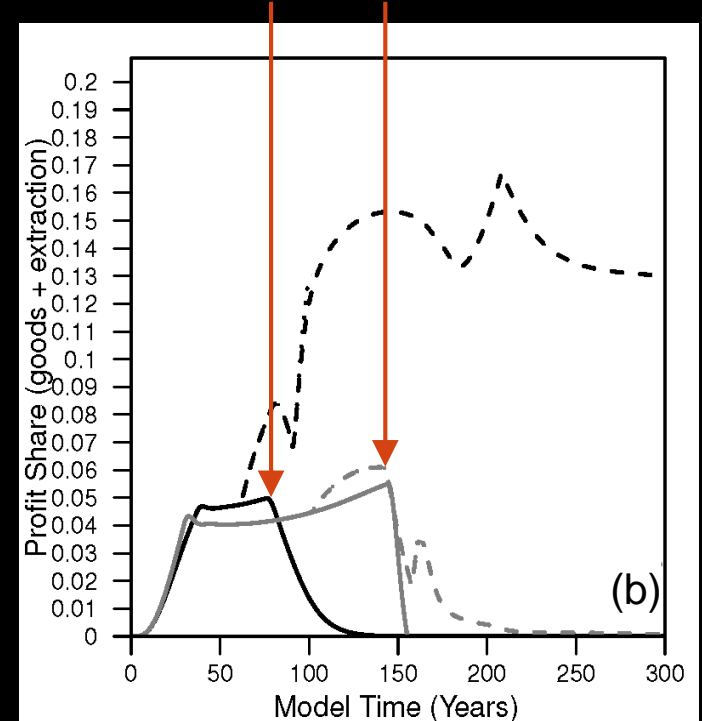
Insight #4: Labor (wage share)
vs. Capital (capital share) vs.
Resource Consumption Tradeoff

If workers wages increase with inflation:
wage share increases after resource consumption peaks.

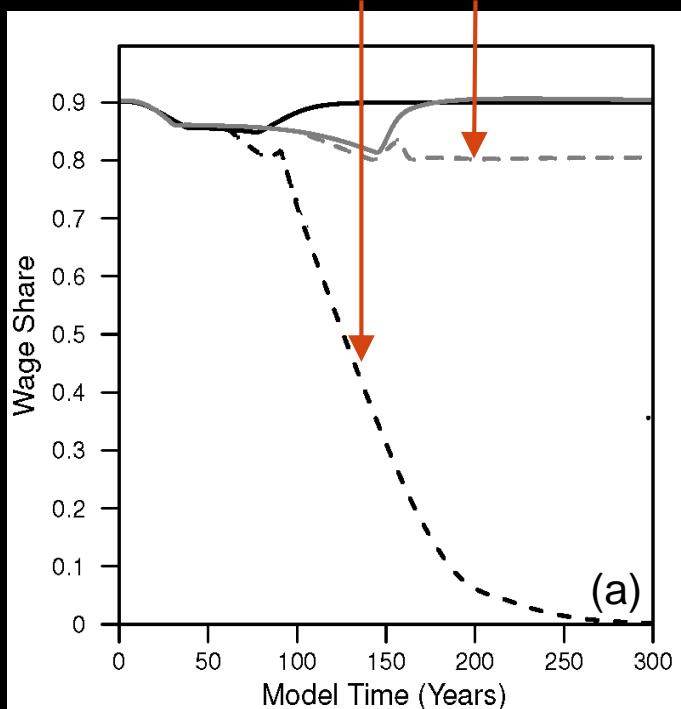


- Legend:
- Full cost, wages increase with inflation
 - - Full cost, wages do not increase with inflation
 - Marginal cost, wages increase with inflation
 - - Marginal cost, wages do not increase with inflation

If workers wages increase with inflation:
profit share decreases to zero after resource consumption peaks.



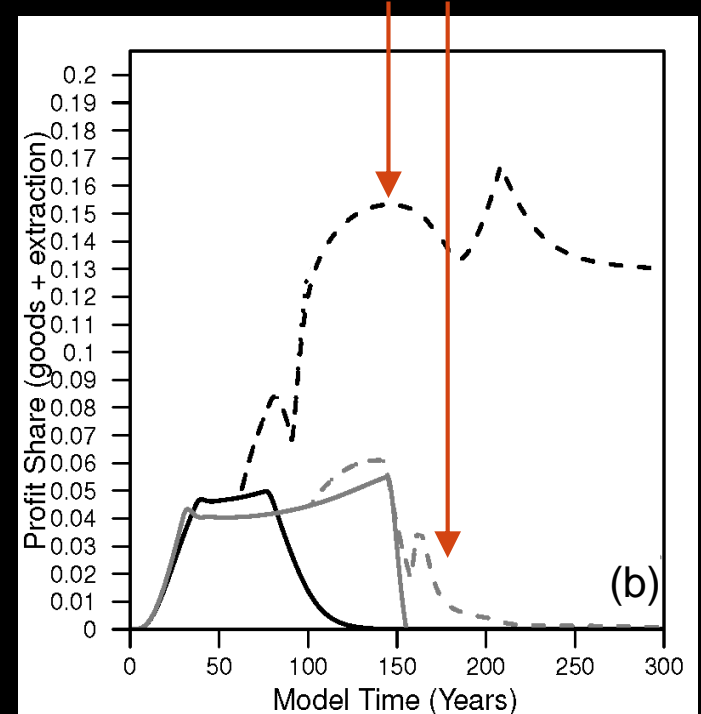
If workers wages no longer increase with inflation:
wage share decreases after resource consumption peaks.



Legend:

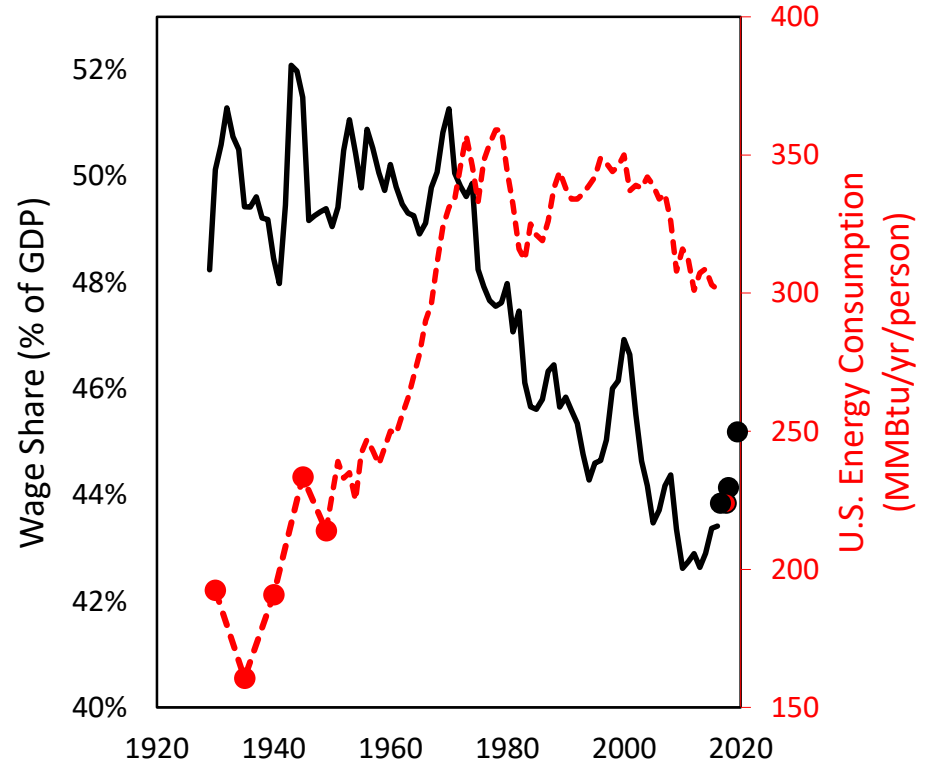
- Full cost, wages increase with inflation
- - Full cost, wages do not increase with inflation
- Marginal cost, wages increase with inflation
- - Marginal cost, wages do not increase with inflation

If workers wages no longer increase with inflation:
profit share remains positive after resource consumption peaks.



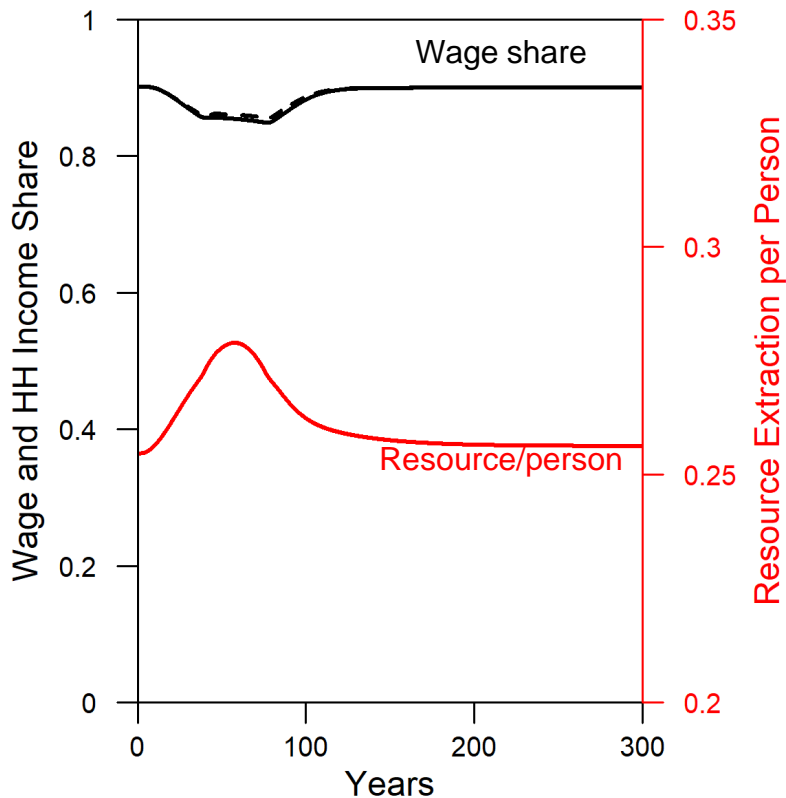
U.S. Data (1929-2020)

(2017-2020 as black dots)



Model

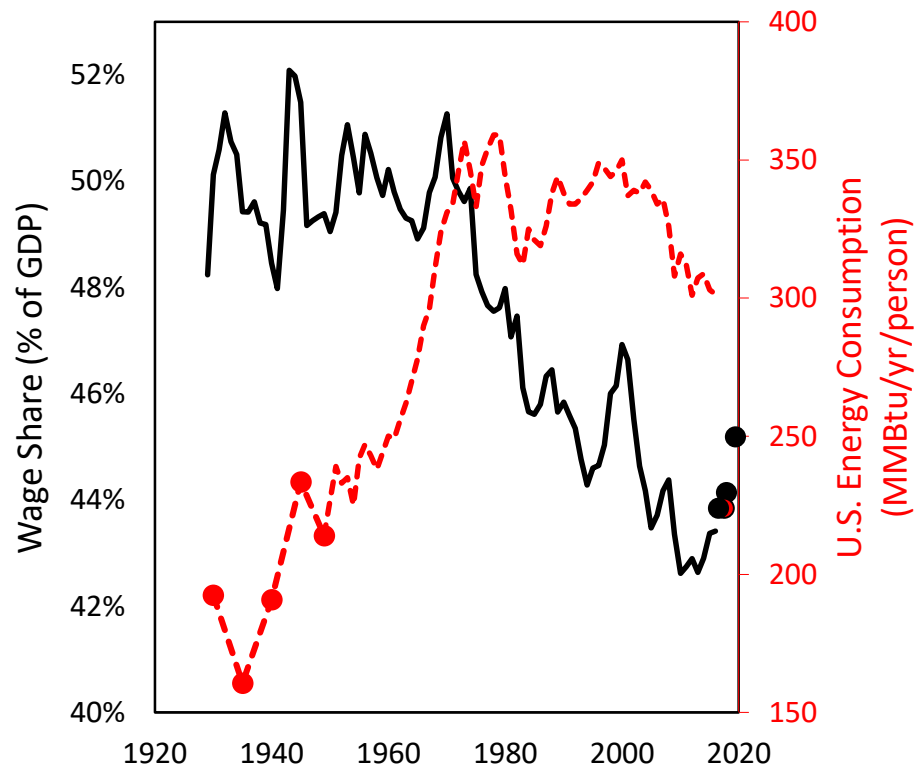
(full cost, full wage bargaining power)



WHAT STARTS HERE CHANGES THE WORLD

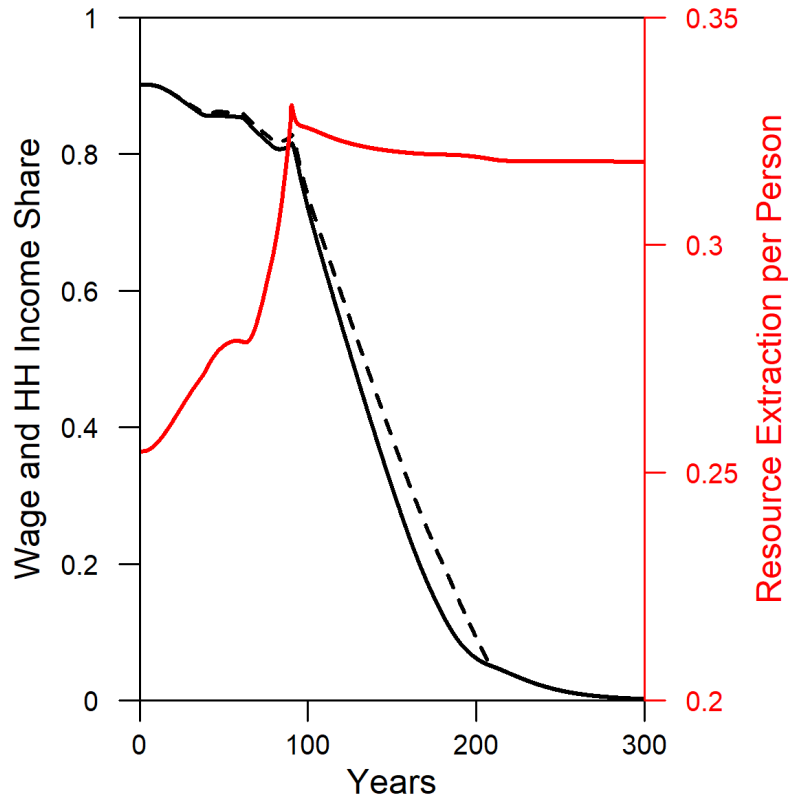
U.S. Data (1929-2020)

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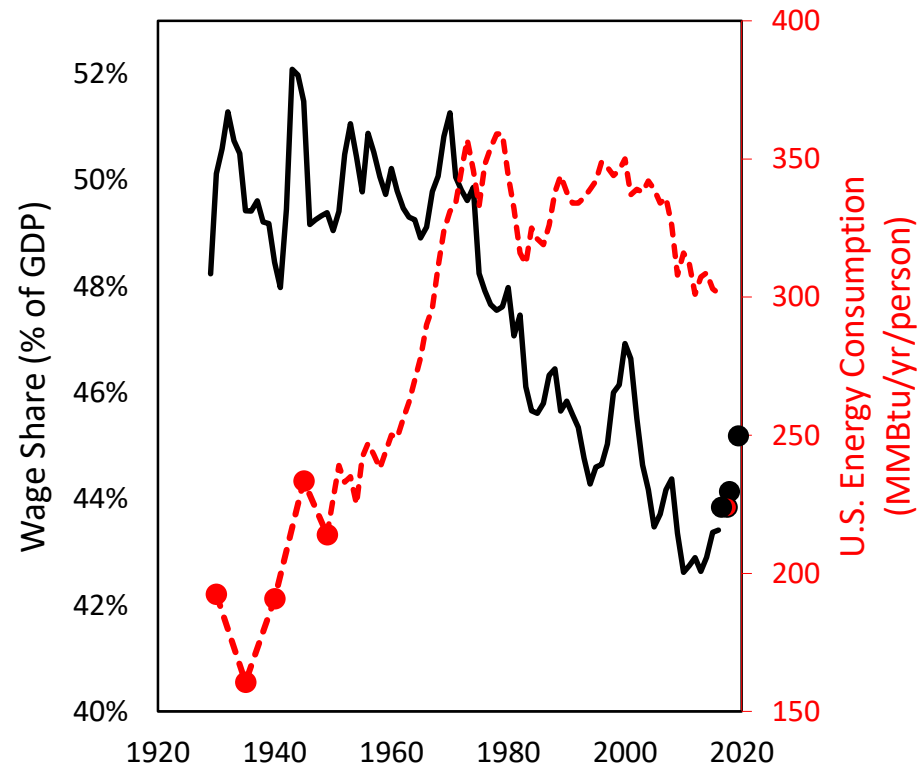
Model

(full cost, loss of wage bargaining power from T=60 to T=160)



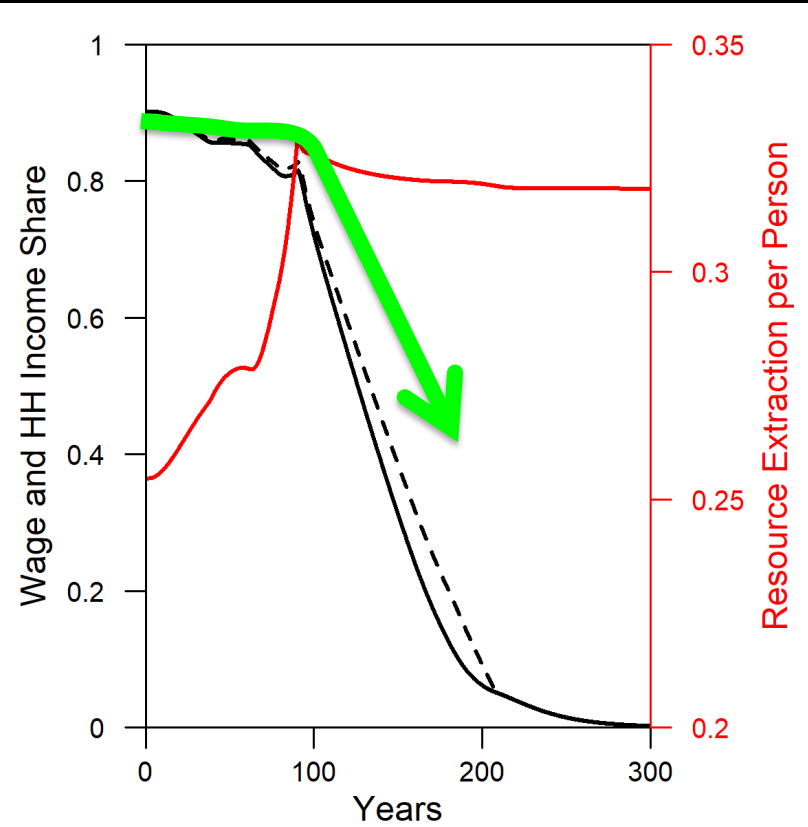
U.S. Data (1929-2020)

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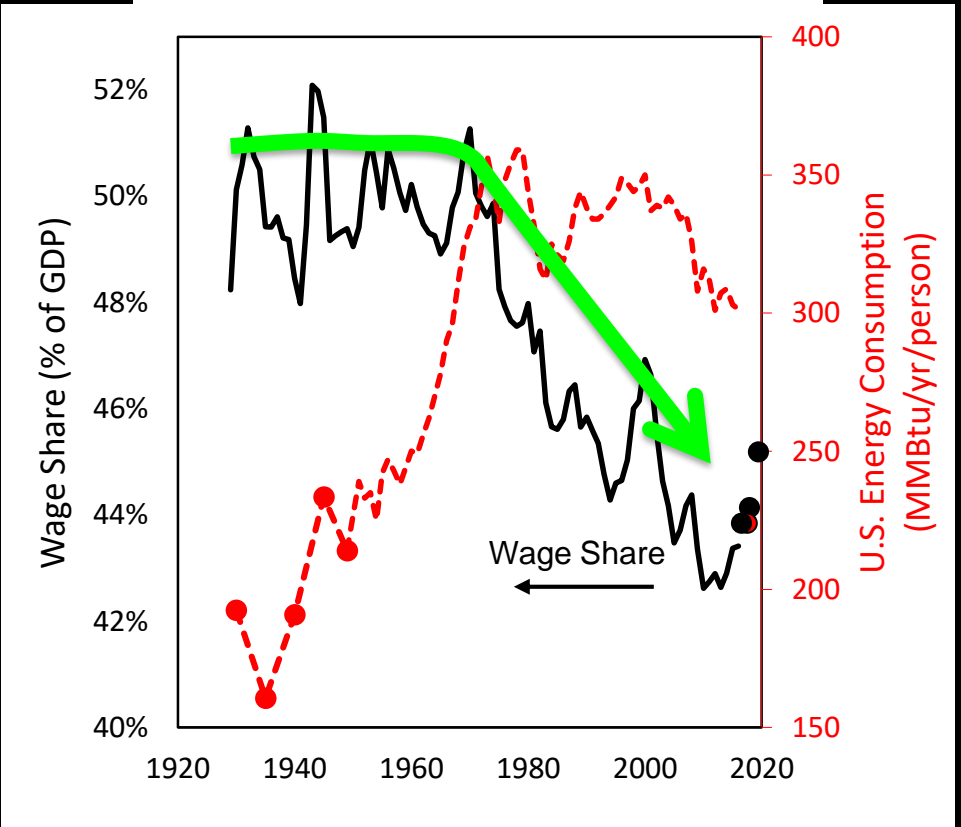
Model

(full cost, loss of wage bargaining
Power from T=60 to T=160)



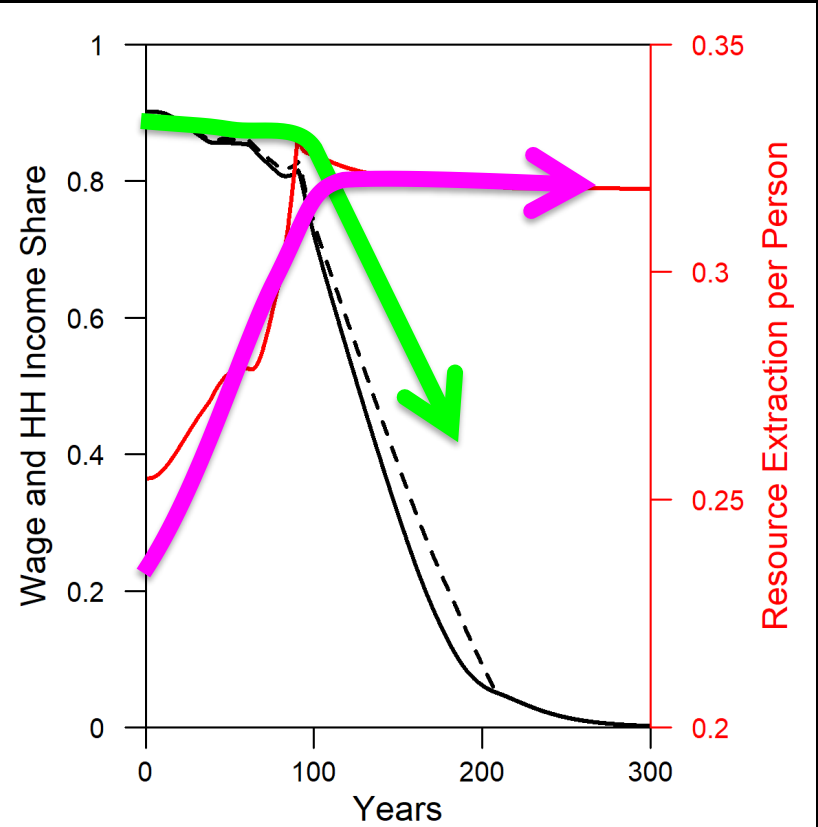
U.S. Data (1929-2020)

(2017-2020 as black dots)



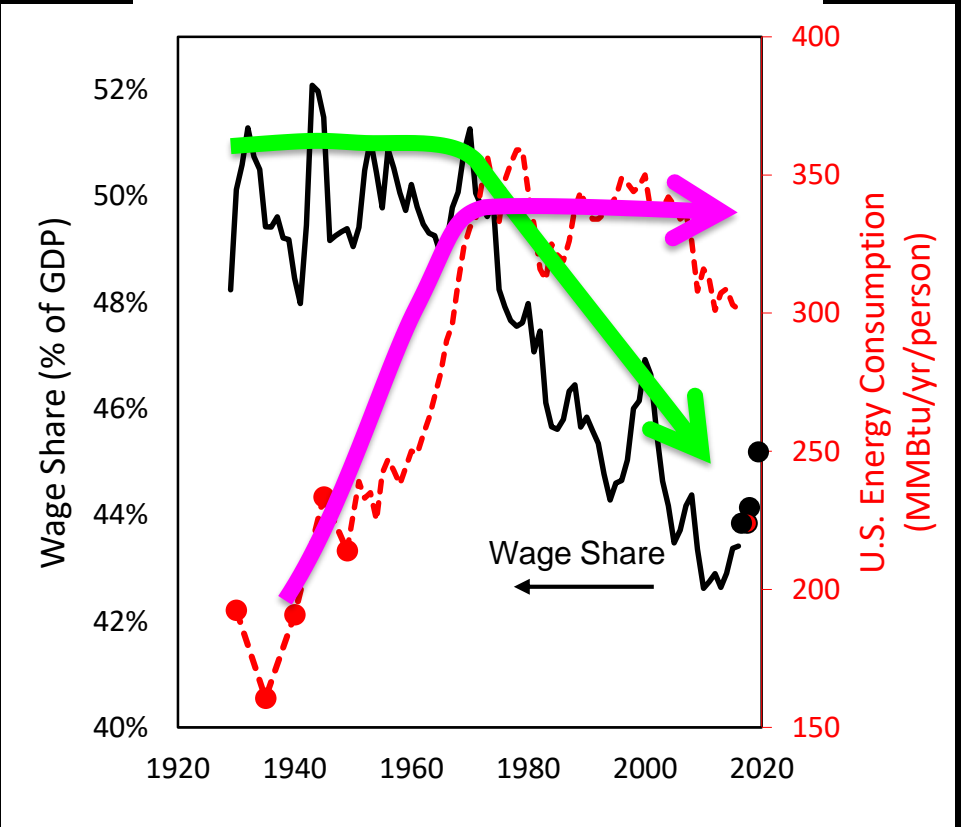
Model

(full cost, loss of wage bargaining
Power from T=60 to T=160)



U.S. Data (1929-2020)

(2017-2020 as black dots)



Insight #5: Evolution of Economic Structure and Complexity

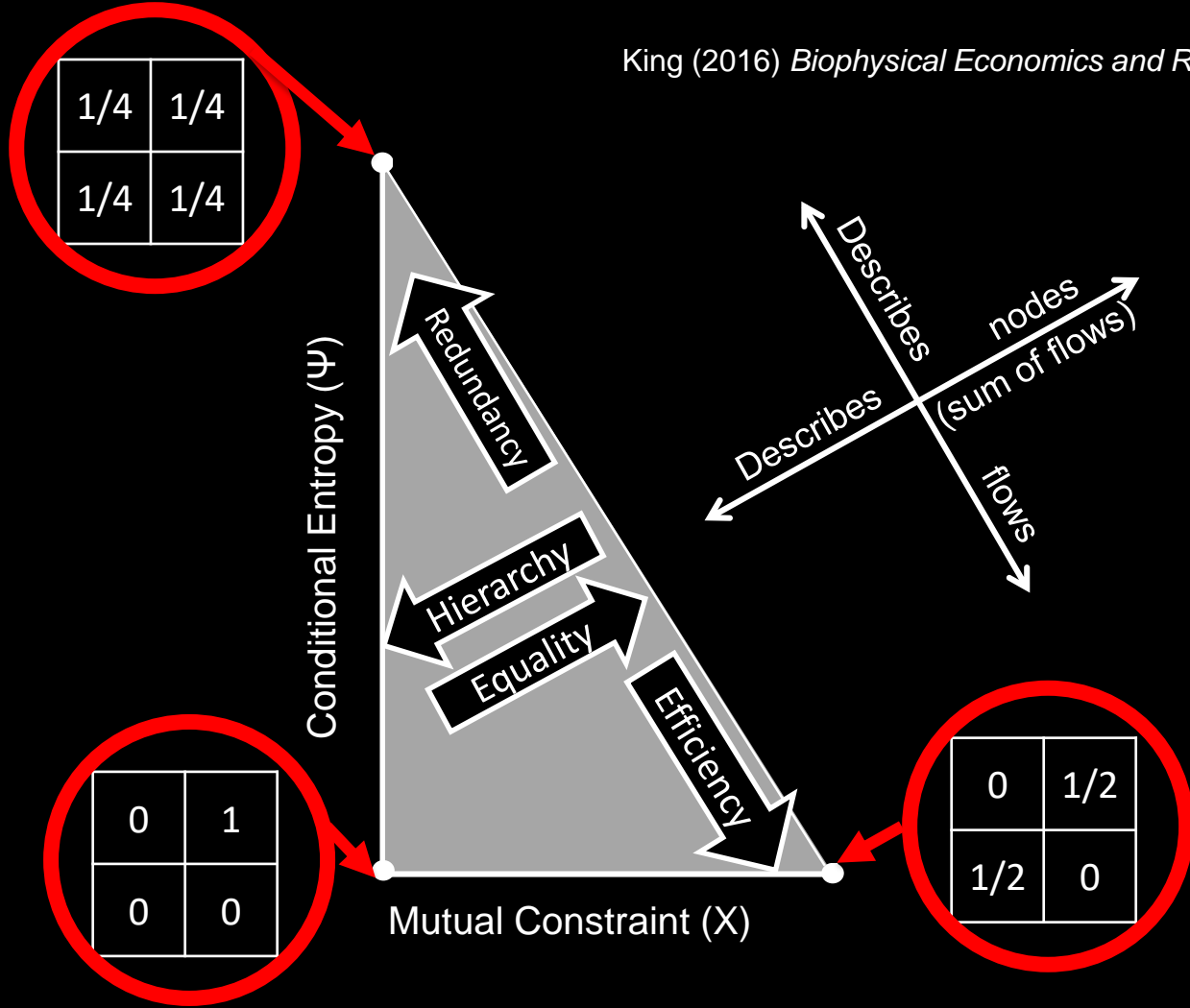
			Net Output				
		Goods	Extraction	Consumption	Investment	Δ Inventory	Total output
	Goods	$P_g a_{gg} X_g$	$P_g a_{ge} X_e$	C_g	$I_e + I_g$	ΔInv_g	$P_g X_g$
	Extraction	$P_e a_{eg} X_g$	$P_e a_{ee} X_e$	C_e	---	ΔInv_e	$P_e X_e$
Value Added	Profit	Π_g	Π_e				
	Wages	wL_g	wL_e				
	Interest	rD_g	rD_e				
	Depreciation	$P_g \gamma K_g$	$P_g \gamma K_e$				
	Total output	$P_g X_g$	$P_e X_e$				

Structural (information theory) metrics use relative (fraction of total) intersectoral \$ flows

		Goods	Extraction			
Goods		$\$_{gg}/\$_{tot}$	$\$_{ge}/\$_{tot}$			
Extraction		$\$_{eg}/\$_{tot}$	$\$_{ee}/\$_{tot}$			

Total intermediate \$ flows:

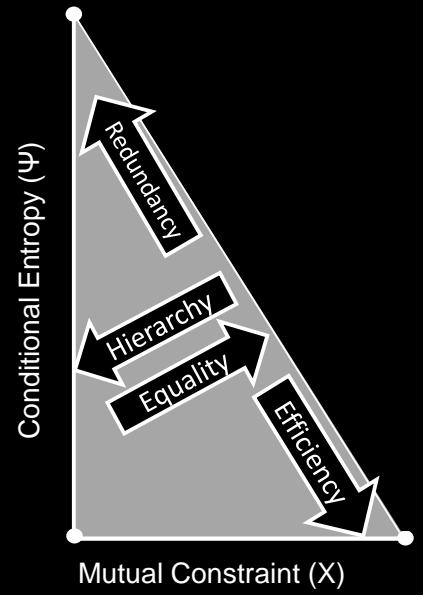
$$\$_{tot} = \$_{gg} + \$_{ge} + \$_{eg} + \$_{ee}$$



The U.S. shows a clockwise “structural” trend since 1947

(tracking money flows in input-output tables)

1/4	1/4
1/4	1/4



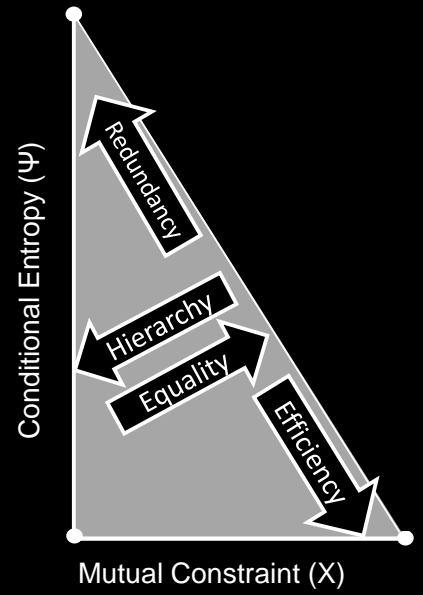
0	1/2
1/2	0

0	1
0	0

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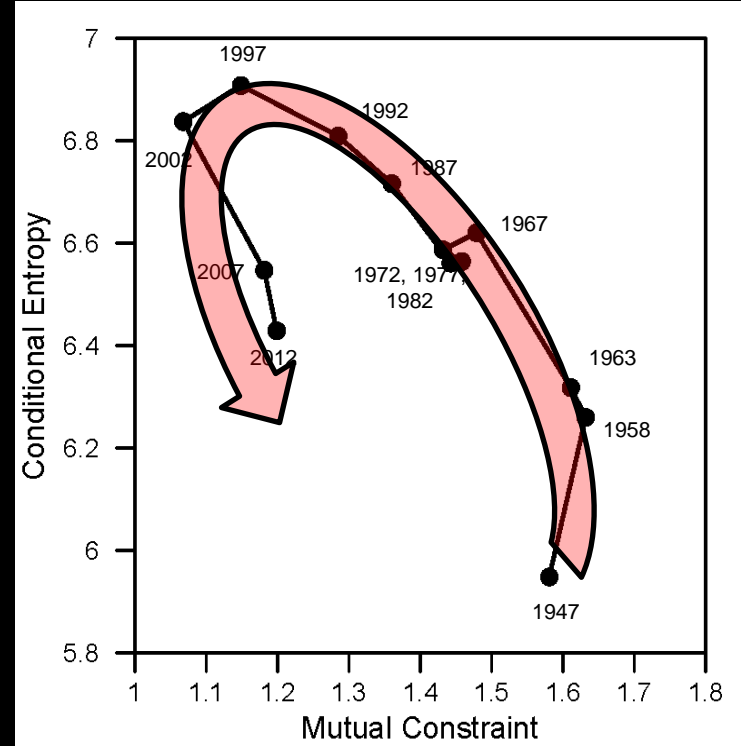
1/4	1/4
1/4	1/4



0	1
0	0

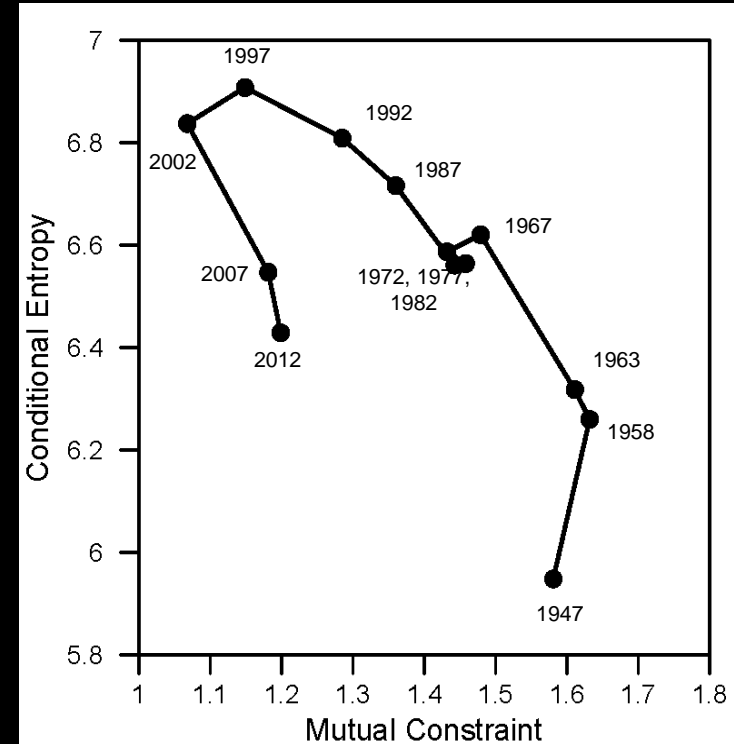
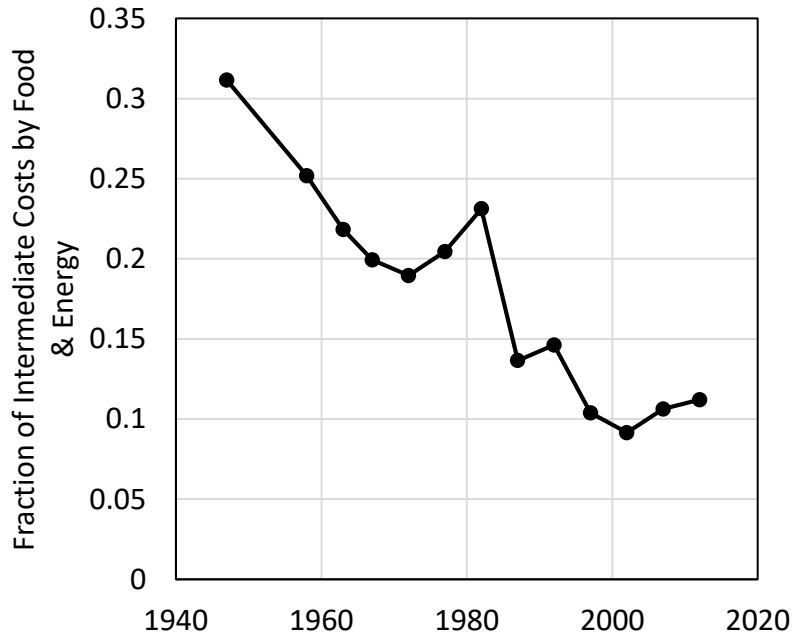
0	1/2
1/2	0

U.S. Data



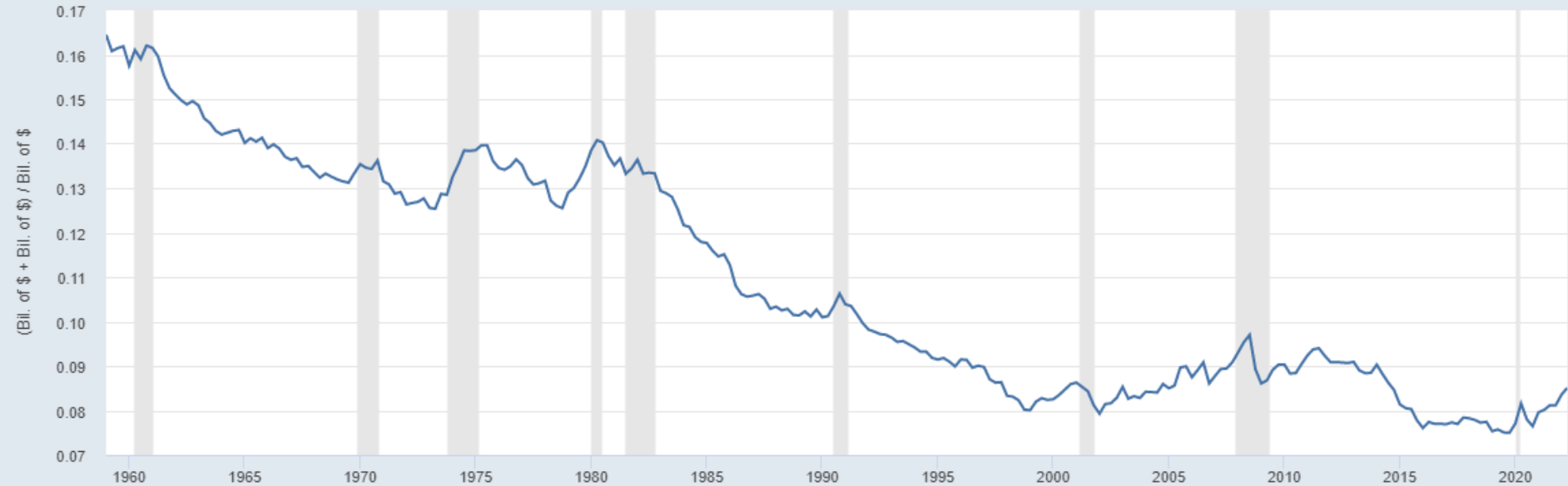
U.S. Food and Energy Costs have not declined since ~2000

U.S. Data



U.S. Food and Energy Costs have not

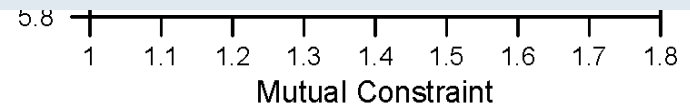
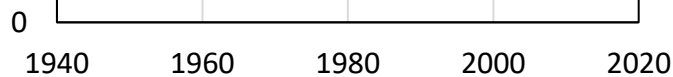
FRED — (Personal consumption expenditures: Energy goods and services + Personal consumption expenditures: Food) / Gross Domestic Product



Shaded areas indicate U.S. recessions.

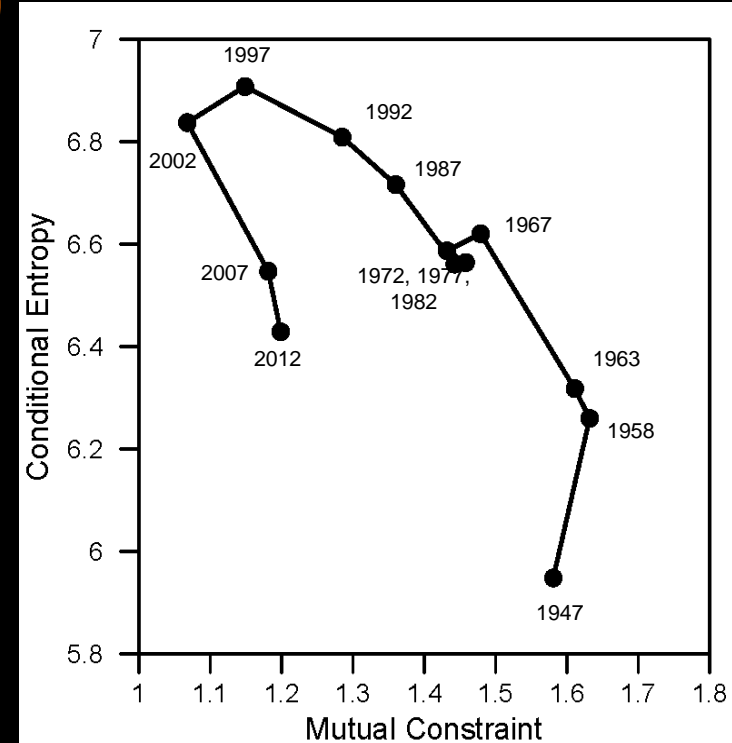
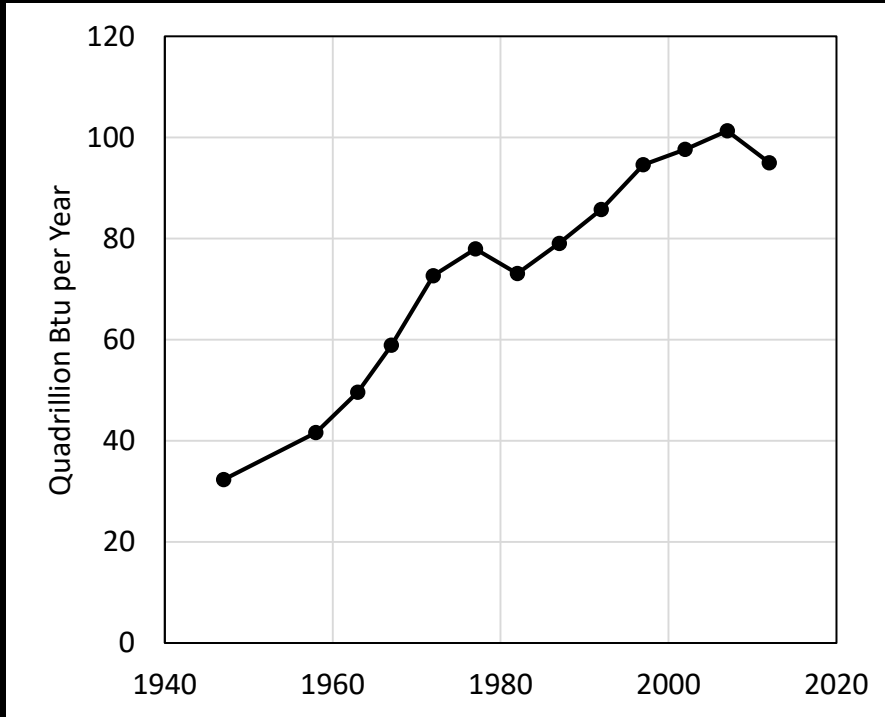
Source: U.S. Bureau of Economic Analysis

fred.stlouisfed.org



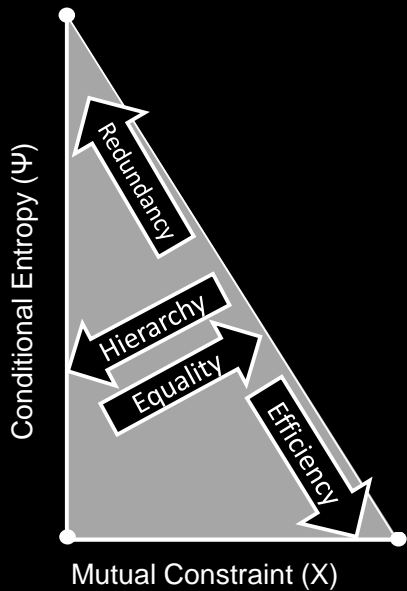
U.S. Energy Consumption has been ~constant since about 2000

U.S. Data



The model also mimics an interesting “structural” trend of the U.S. (marginal cost results) (tracking money flows in input-output tables)

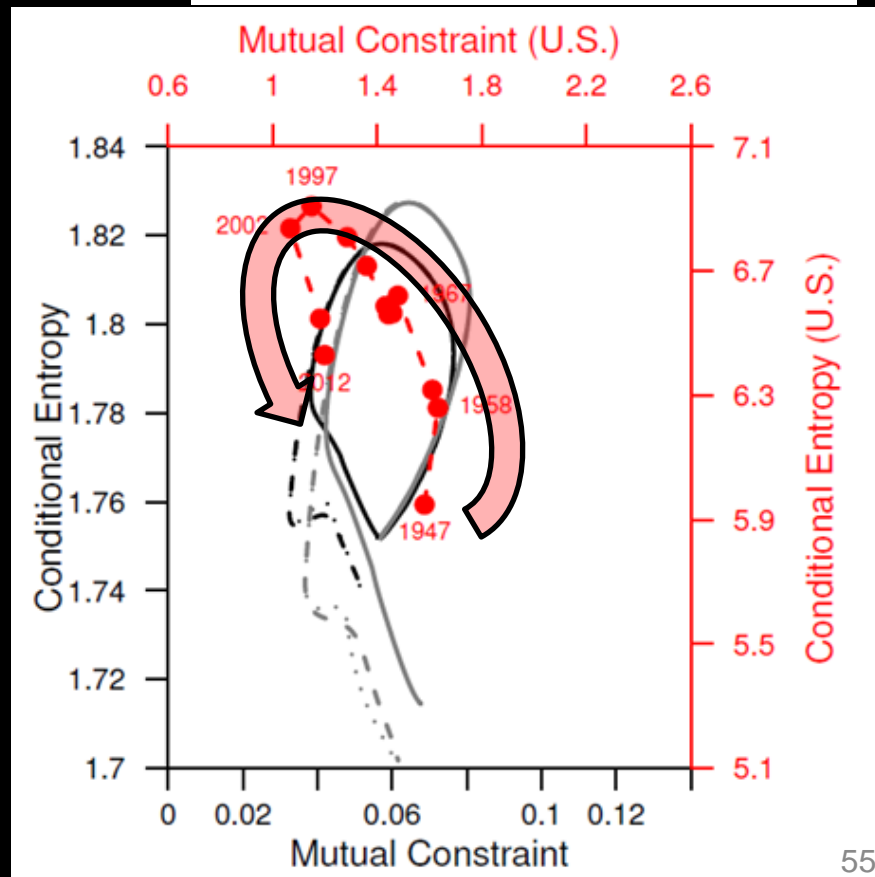
1/4	1/4
1/4	1/4



0	1
0	0

0	1/2
1/2	0

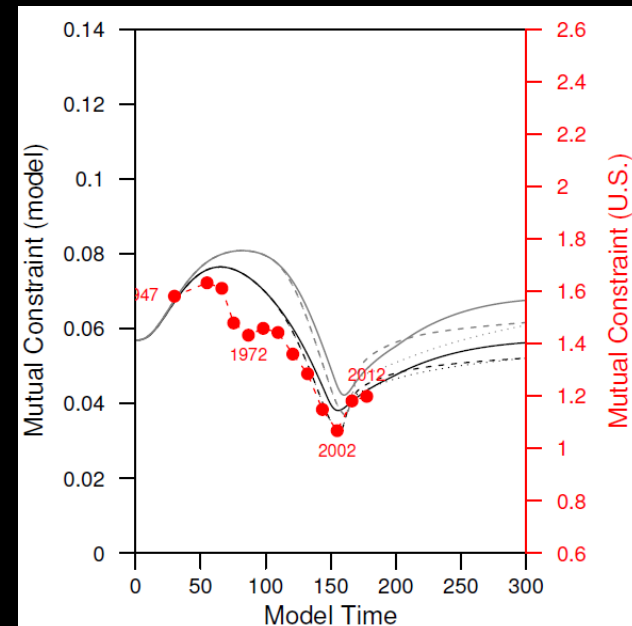
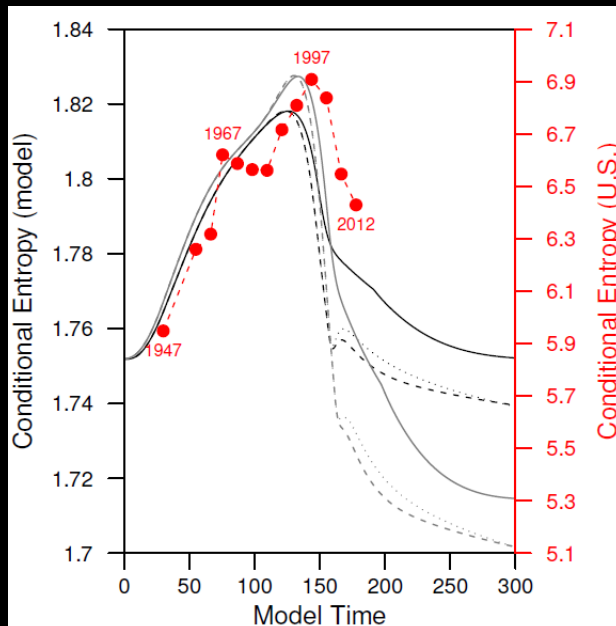
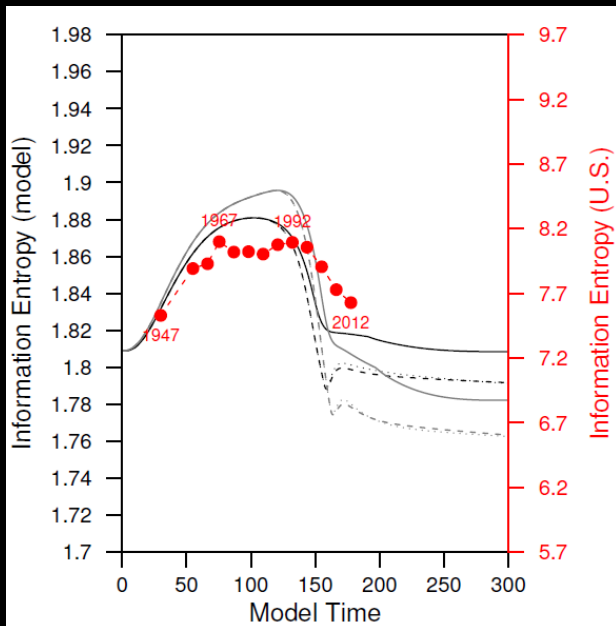
- MC-000 Marginal cost, full barg., no eff.
- - - MC-010 Marginal cost, no barg., no eff.
- ⋯ MC-011 Marginal cost, full barg., no eff., w/ Ponzi
- MC-100 Marginal cost, full barg., with eff.
- - - MC-110 Marginal cost, no barg., with eff.
- ⋯ MC-111 Marginal cost, full barg., no eff., w/ Ponzi



The model also mimics an interesting “structural” trend of the U.S. (marginal cost results)

WHAT STARTS HERE CHANGES THE WORLD

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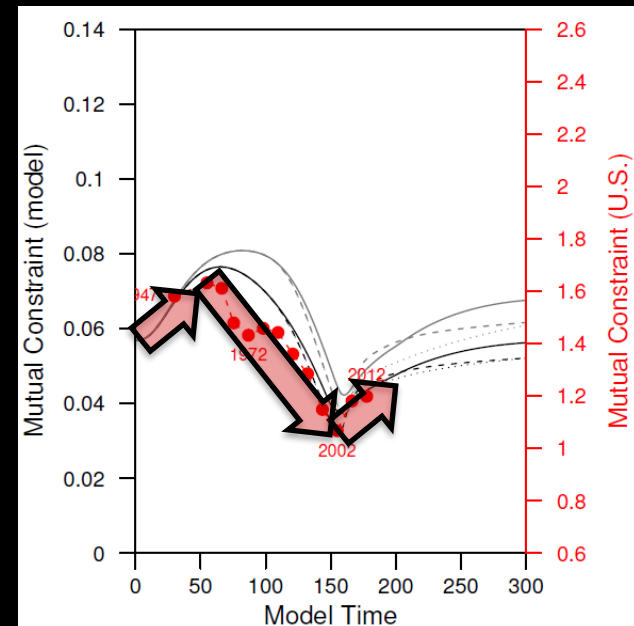
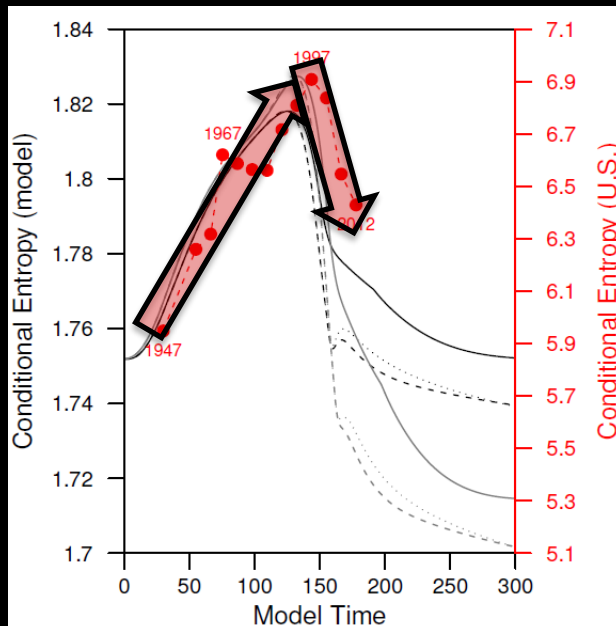
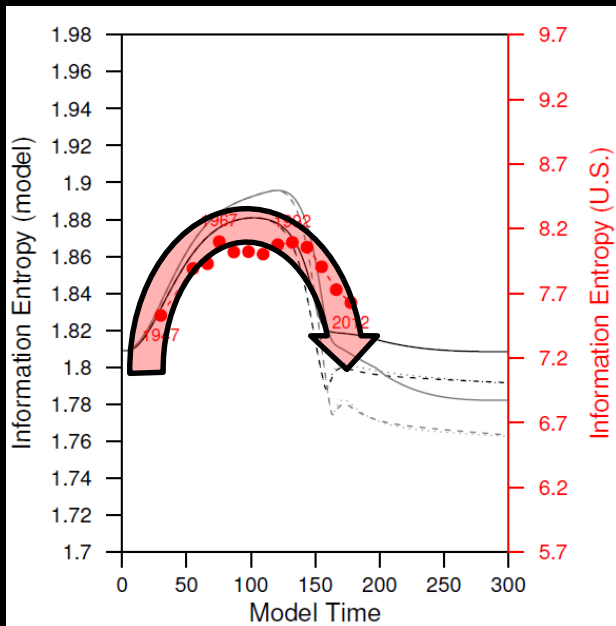


$$\text{Information Entropy} = \text{Conditional Entropy} + \text{Mutual Constraint}$$

The model also mimics an interesting “structural” trend of the U.S. (marginal cost results)

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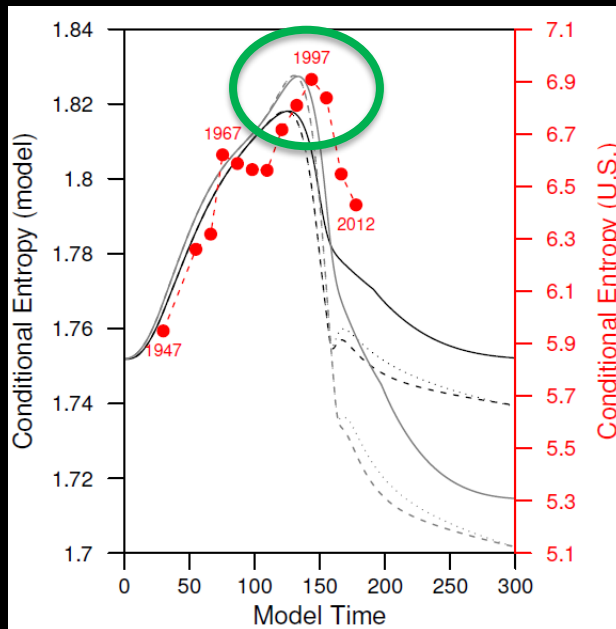
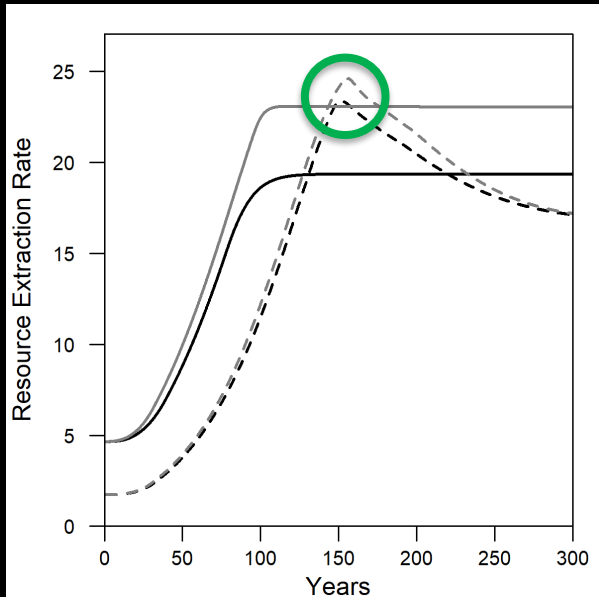
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The model also mimics an interesting “structural” trend of the U.S. (marginal cost results)

WHAT STARTS HERE CHANGES THE WORLD

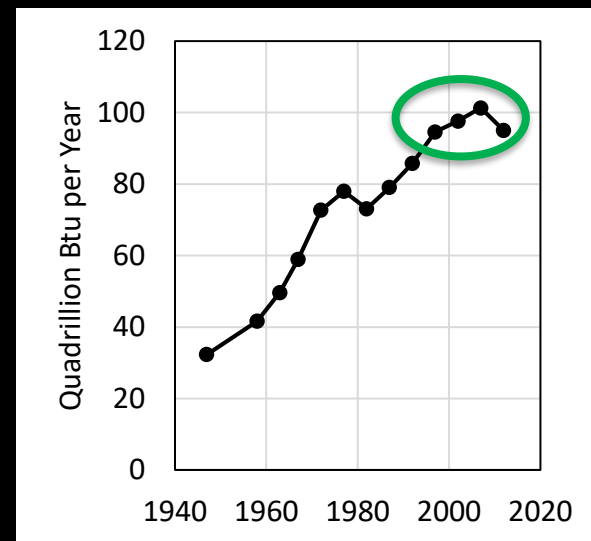
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- ⋯⋯⋯ MC-111 Marginal cost, full barg., no eff., w/ Ponzi

Model Data



Conditional Entropy

U.S. Data



Takeaways

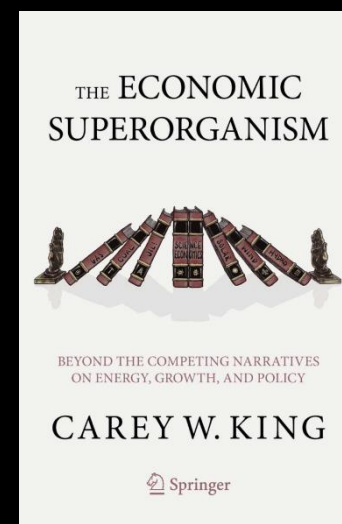
- consistently tracks physical and economic flows
- explains some (important) coincident trends in
 - energy (shift to relative decoupling) and
 - money distribution (e.g., wage share, debt, I-O structure)
- shows how economic decisions (e.g., investment and wage rules) relate to physical resources and population, and
- serves as a base model to add components (e.g., government, econ. sectors, different energy sources, climate/atmosphere).

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Lecturer, McCombs School of Business

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<https://link.springer.com/article/10.1007%2Fs41247-021-00093-8>



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