JUNE 9, 2021

The University of Texas at Austin
Energy Institute

INVESTIGATING DECOUPLING AND STRUCTURAL DYNAMICS VIA THE "HARMONEY" BIOPHYSICAL GROWTH MODEL

IAEE International Conference, June 7-9, 2021

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Motivations of research

- Improved macroeconomic theoretical frameworks
  - Real dynamics
  - Physical and monetary (including debt) variables

- Explain “debt” versus “energy” debates
  - #1: it is debt that has become unsustainable, not energy
  - #2: it is energy that has become constrained, not debt
  - Can we tell the difference? How?
    - “Answer”: Make/Use models with both biophysical and debt feedbacks

Description of “HARMONEY” model

“Human And Resources with MONEY”

Results here are from a submitted manuscript using an updated v1.1 HARMONEY model

V1.1

King, Carey W., Interdependence of Growth, Structure, Size and Resource Consumption During an Economic Growth Cycle, arXiv pre-print: https://arxiv.org/abs/2106.02512.

v1.0 in *Ecological Economics*:

King, Carey W., An Integrated Biophysical and Economic Modeling Framework for Long-Term Sustainability Analysis: the HARMONEY Model, Ecological Economics, 169, March 2020, 106464. https://doi.org/10.1016/j.ecolecon.2019.106464

Biophysical Models

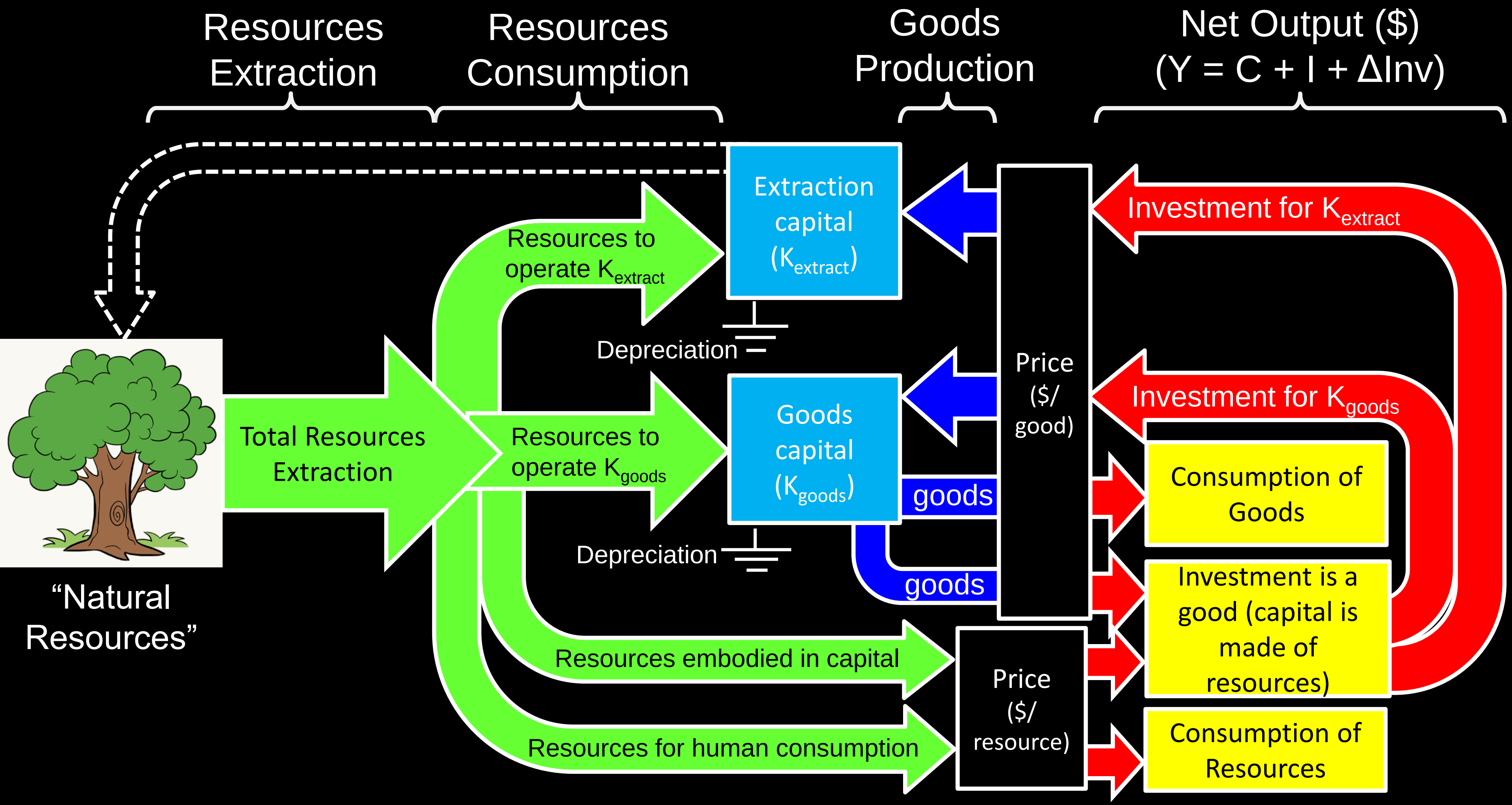
Population
Natural Resources
Capital (sometimes)

Economic Models

Population
Capital
Wages
Employment
Debt (sometimes)

Research Approach

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


Resources Extraction
Resources Consumption
Goods Production
Net Output ($) (Y = C + I + ΔInv)
Extraction capital ($K_{extract}$)
Resources to operate $K_{extract}$
Depreciation
Price ($/ good)
Investment for $K_{extract}$
Investment for K_{goods}
Total Resources Extraction
Resources to operate K_{goods}
Goods capital (K_{goods})
goods
goods
Depreciation
Consumption of Goods
Investment is a good (capital is made of resources)
"Natural Resources"
Resources embodied in capital
Resources for human consumption
Price ($/ resource)
Consumption of Resources

Important model feedbacks

- Death rates increase with low household resources consumption
- As resources are depleted, extraction capital requires more resource consumption to extract the marginal resource
- Capital (physical) investment requires physical resource consumption
  - Resources are embodied in capital

Economic (growth) model

Capital & Debt

- Each sector has its own physical capital (*K*), investment (*I*), and debt (*D*)
  - $\dot{K} = {}^{I}/_{P_g} - \delta K$ = gross physical investment – depreciation
  - $\dot{D} = (I - \delta P_g K) - \Pi$ = net investment – net profit

Gross Output

- Physical output (*X*) of each sector is a Leontief (limited by capital, K, or labor, L, or resource input as fuel):
  - Goods: $X = \frac{K_g CU_g}{v} = L_g \cdot a \quad \forall\, L_g = \frac{K_g CU_g}{a \cdot v}$
  - Extraction: $X = \delta_y y K_e CU_e = L_e \cdot a \quad \forall\, L_e = \frac{\delta_y y K_e CU_e}{a}$

CU = capacity utilization
a = labor productivity
v = capital:output ratio (or capital productivity)

Gross Investment

- Investment is a (linear) function of profit share, Π/Y (or profit rate, π_r)
  - Keen, S (1995) *J. of Post-Keynesian Economics*; Keen (2013) *J. of Econ. Behavior and Organization*
  - Bovari *et al.* (2018) *Ecological Economics*

- $I = \kappa_0(\text{depreciation}) + \kappa_1(\text{profit})$ (results use $\kappa_0=1$, $\kappa_1=1.5$)
  $= \kappa_0(P_g\delta K) + \kappa_1\Pi/Y$

where,

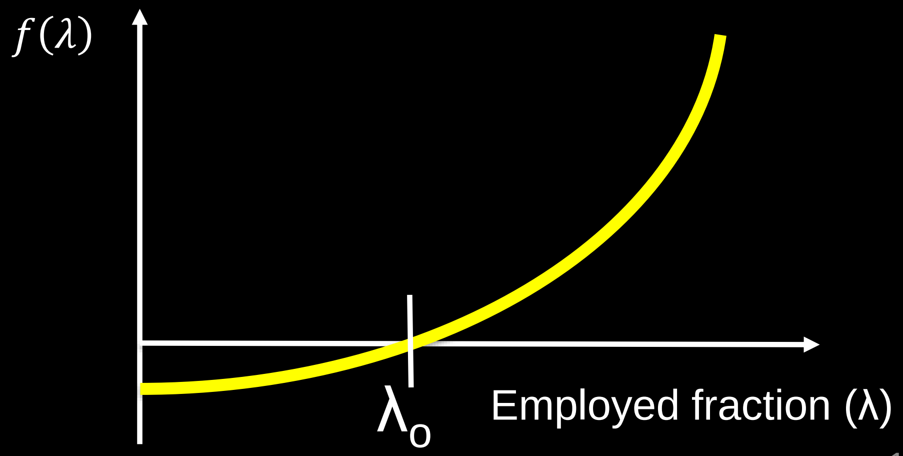
- Π = net profit = value added – wages – interest payments – depreciation
- $P_g\delta K$ = value of capital depreciation

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
- $w_1 = w_2 = 1$, full labor bargaining power



Input-Output representation of money flows

				Net Output			
		Goods	Extraction	Consumption	Investment	ΔInventory	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				
Value Added	Wages	wL_g	wL_e				
Value Added	Interest	rD_g	rD_e				
Value Added	Depreciation	$P_g \gamma K_g$	$P_g \gamma K_e$				
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$$a_{ee} = \frac{\text{resource to operate } K_e}{\text{total resource extraction}}$$

Input-Output representation of money flows

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Fuel to operate capital

$$a_{ee} = \frac{\eta_e K_e CU_e}{\delta y K_e CU_e} = \frac{\eta_e}{\delta y} = \frac{[\text{resource/time}]}{[\text{resource/time}]}$$

y = resources left in environment

This a_{ee} is depletion feedback from "net energy", or how much energy it takes to run the energy sector

	Goods	$P_g a_{gg} X_g$	$P_g a_{ge} X_e$	C_g	$I_e + I_g$	ΔInv_g	$P_g X_g$
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y = resources left in environment

Solving for prices

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

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

- Prices change with a time delay, τ:

$$\dot{P}_i = \frac{1}{\tau}\left((1 + \mu_i)c_i - P_i\right)$$

Solving for prices: “full cost”

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

$$c_g = \underbrace{P_g a_{gg} + P_e a_{eg}}_{\text{goods and resources}} + \left(wL_g + r_L D_g + \delta P_g K_g\right)/X_g$$

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

Solving for prices: “marginal cost”

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

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

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

Simulation results

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

Note the causal effects assumed in the model …

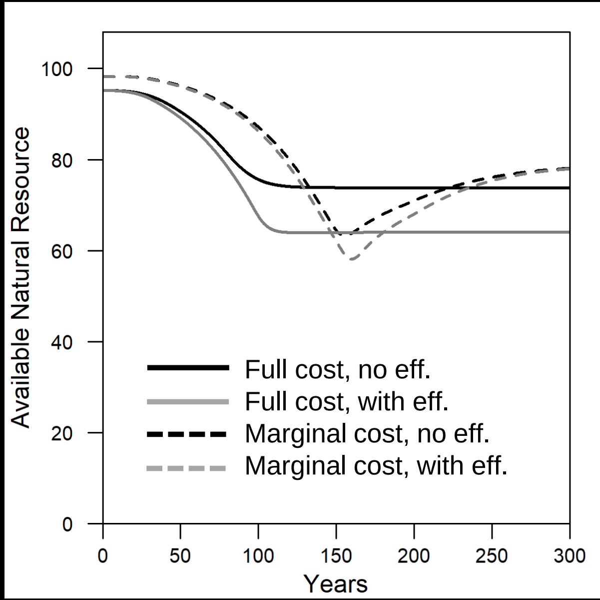
- 1st: sectors invest in new capital
- 2nd: calculate labor
- 3rd: determine if labor or capital is limiting output
  - Calculate sector output [gross (X) and net (Y)]
  - Calculate all other macroeconomic factors (wages, profit, etc.)
- 4th: household consumption (C) is "left over" output after investment ($C = Y – I – \Delta Inv$)
  - ΔInv: change in value of inventories

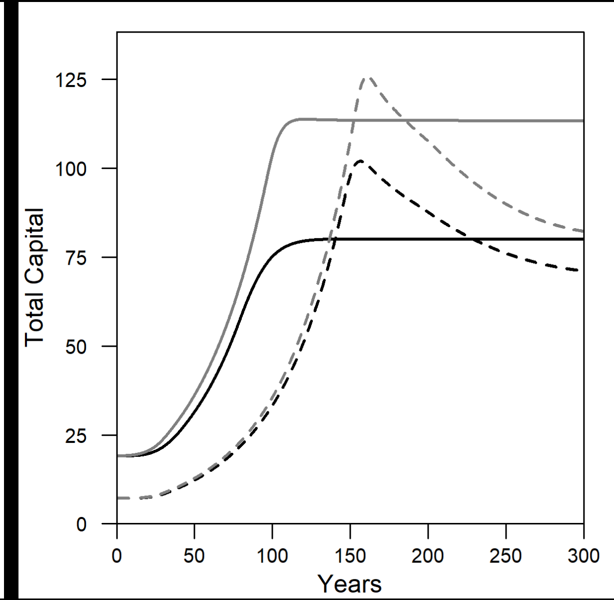
Points to keep in mind

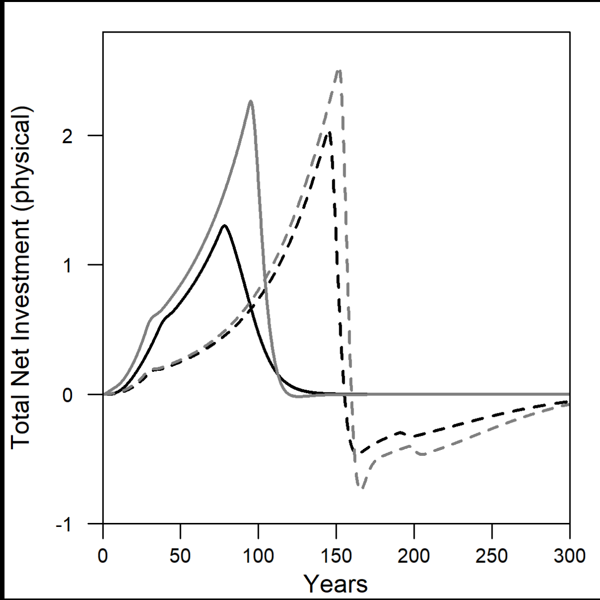
- I vary two things to compare results
  - 1) The definition of cost in solving prices (full vs. marginal)
  - 2) If there is an (exogenous) increase in efficiency of capital operation (fuel input)

- The model grows from an equilibrium of a "small economy"
  - Resource extraction = δ_y y K_e CU_e
  - Small economy: extraction parameter, δ_y, is set low
  - Growing economy: extraction parameter, δ_y, is increased (using 3rd order time delay)
    - Makes it possible to extract more resources with existing capital, which enables profits for net investment and growth

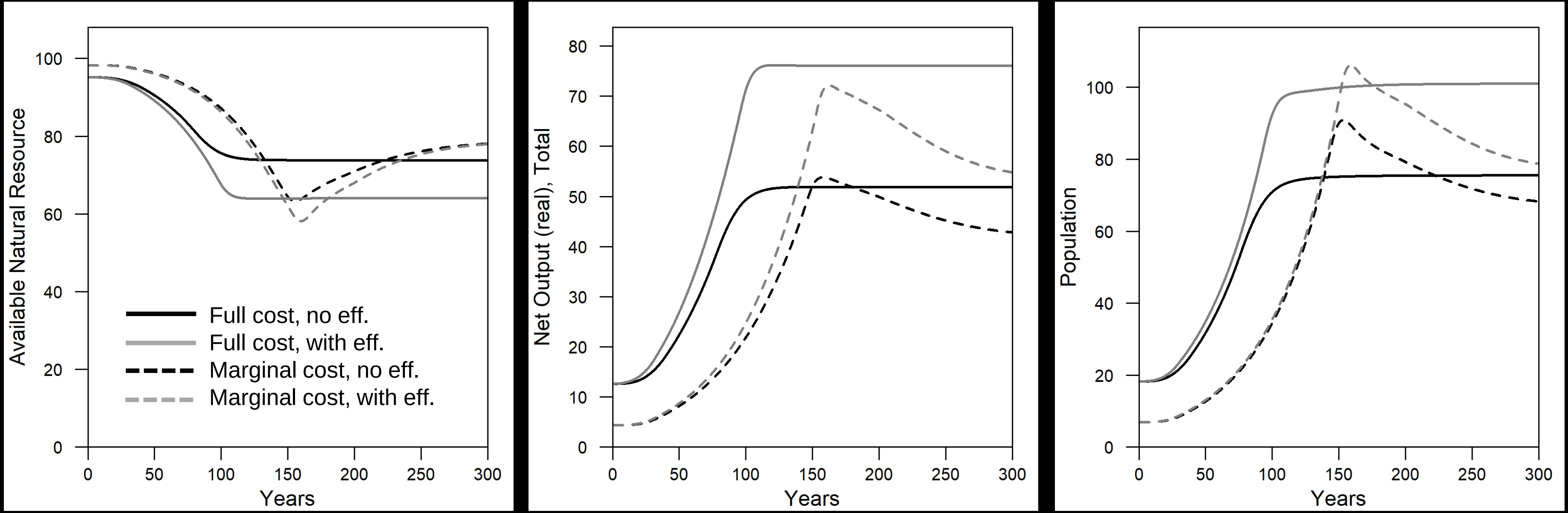
Highlights of simulation of model: Resources, capital, and investment





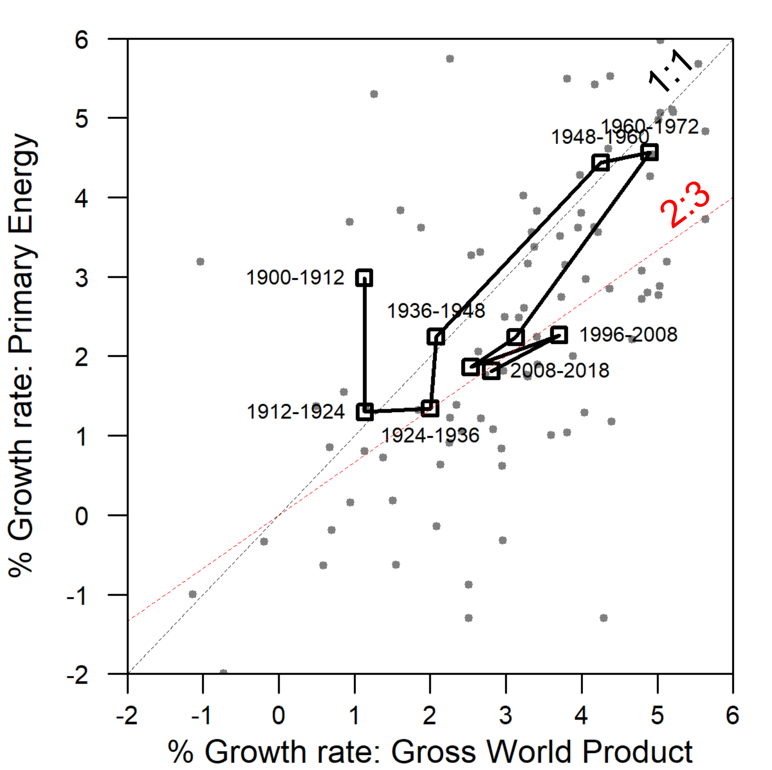


Highlights of simulation of model: Resources, net output, and population



Metabolic View of the Economy

Checking the “metabolic growth” of the economy



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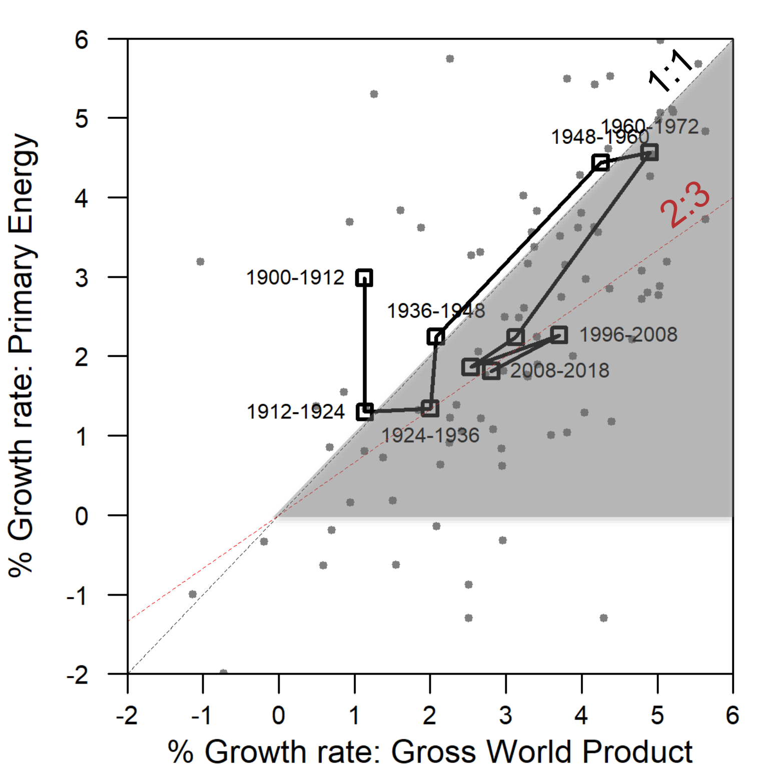
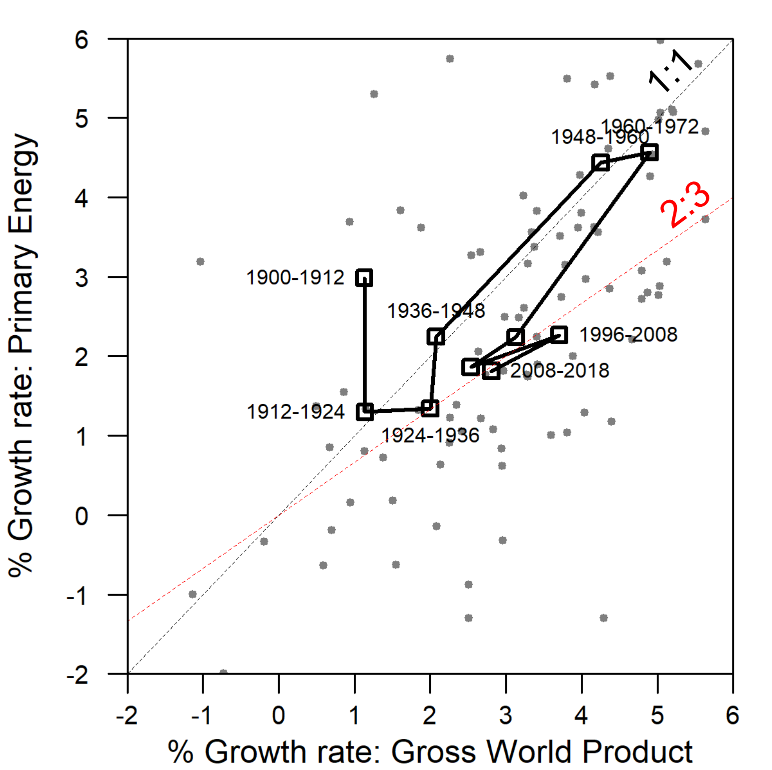
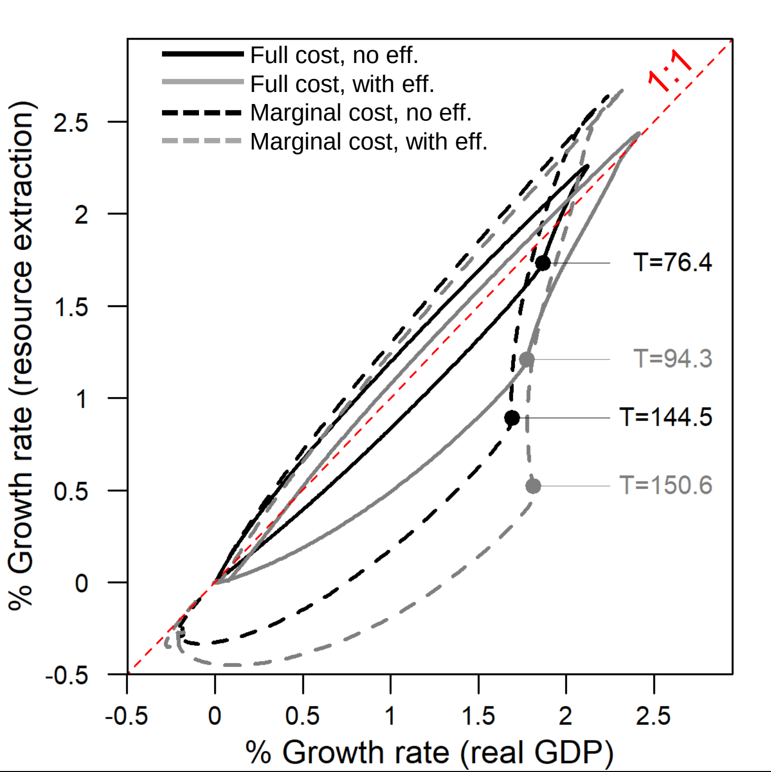


A. Jarvis and C. W. King (in review)

- The gray area represents an economy in a state of “relative decoupling”
  - Both energy consumption and GDP are increasing
  - GDP is increasing faster than energy consumption

Checking the “metabolic growth” of the economy





Times are ~ peak profit shares

A. Jarvis and C. W. King (in review)

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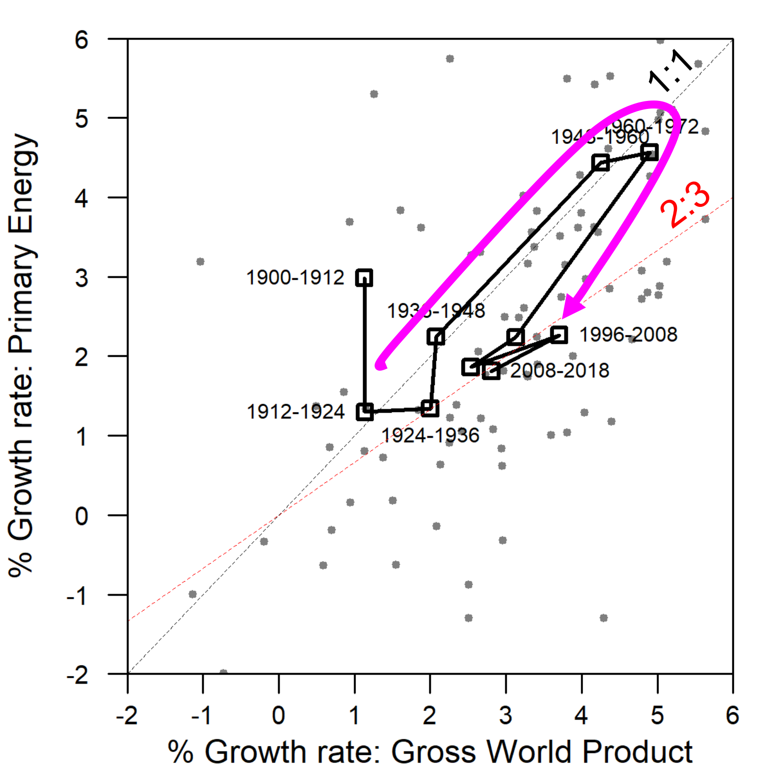

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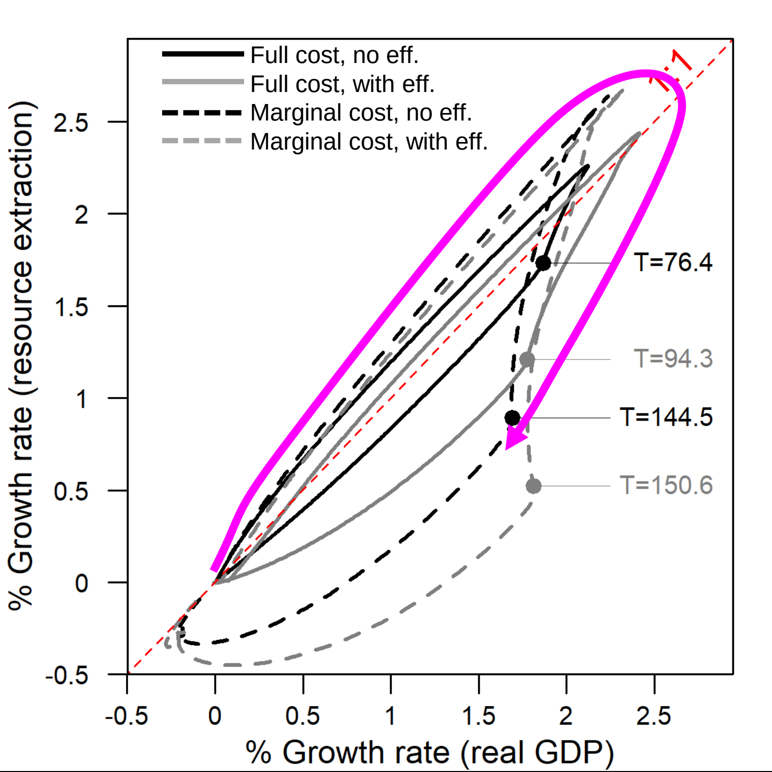

Times are ~ peak profit shares

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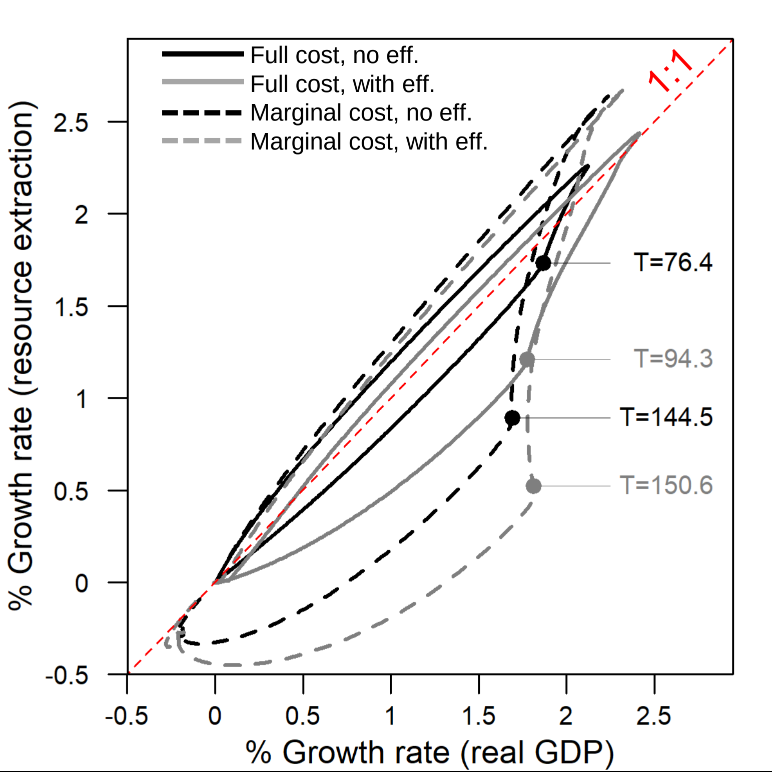
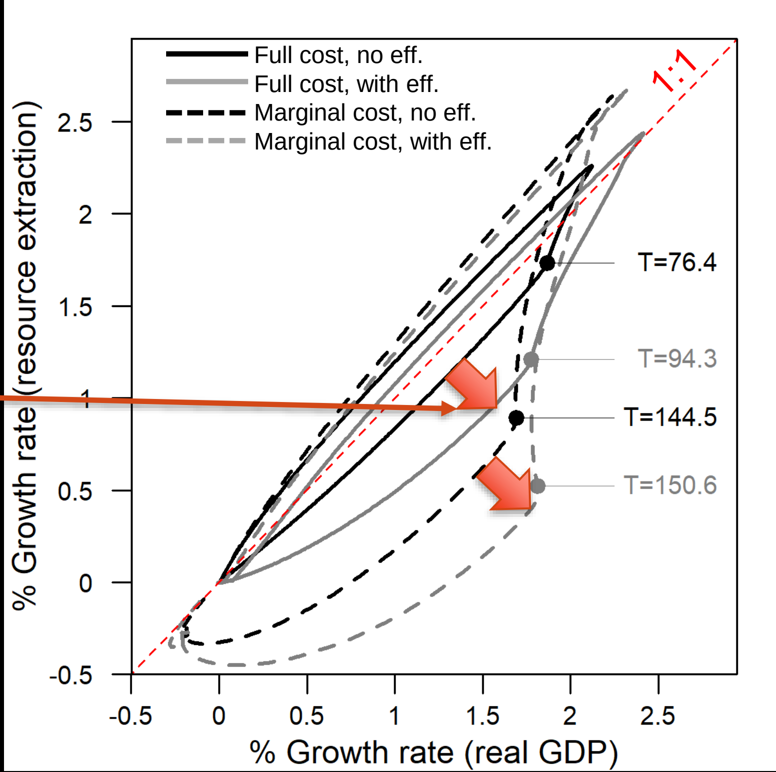


Times are ~ peak profit shares

Checking the "metabolic growth" of the economy

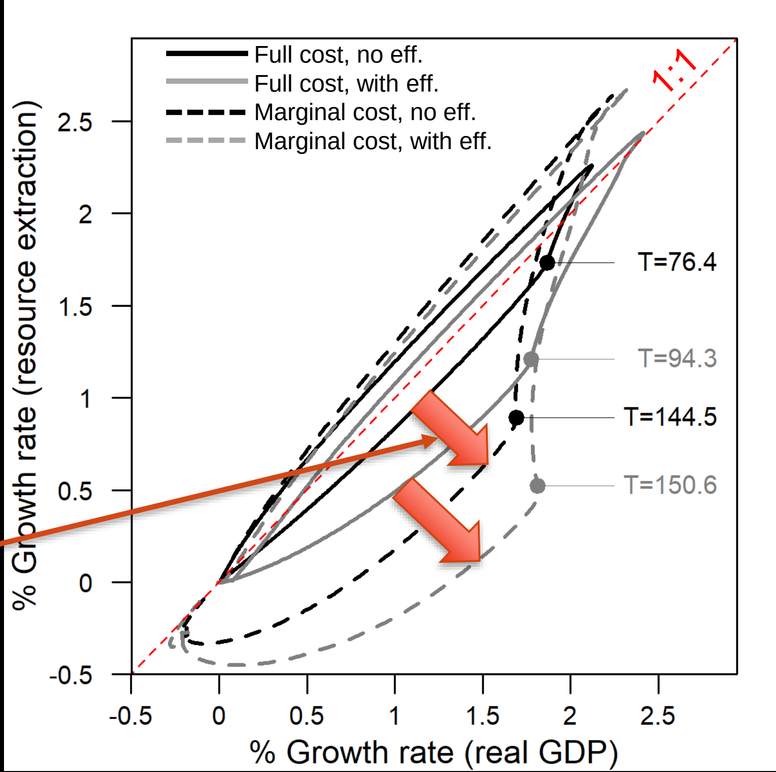
- More "decoupling" occurs due to
  - Increasing resource consumption efficiency of capital (e.g., fuel efficiency)



Times are ~ peak profit shares

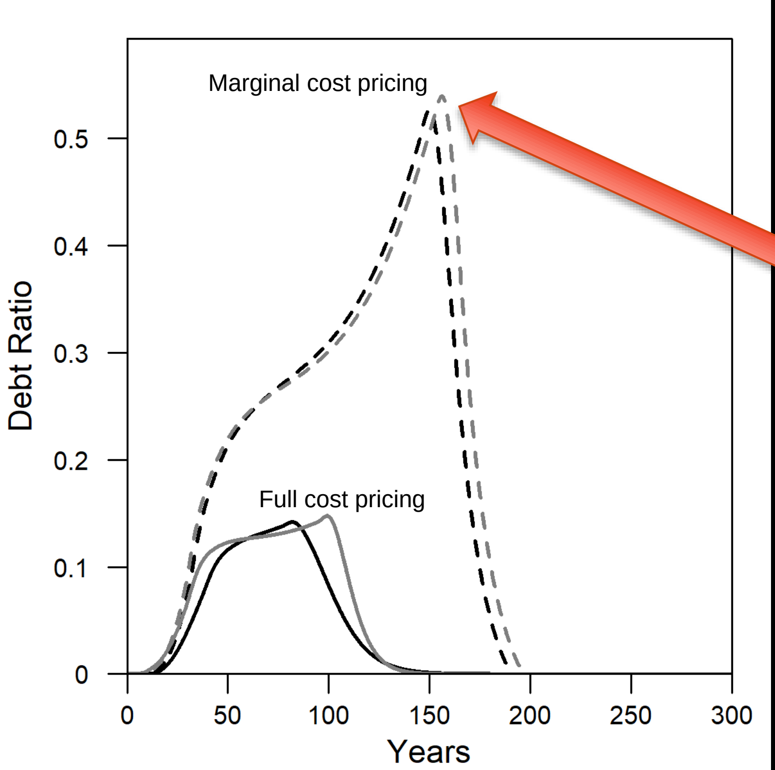
Checking the "metabolic growth" of the economy

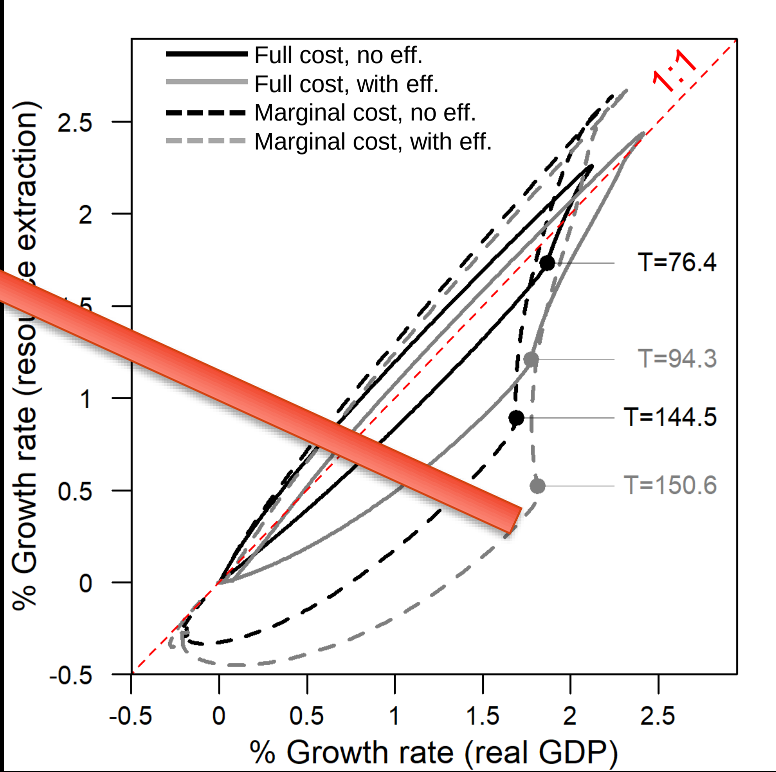
- More "decoupling" occurs due to
  - Increasing resource consumption efficiency of capital (e.g., fuel efficiency)
  - Using marginal rather than full costs



Times are ~ peak profit shares

Marginal costs pricing → higher debt ratios → more "decoupling"





Times are ~ peak profit shares

The model also mimics an interesting "structural" trend of the U.S.

Input-Output representation of money flows

				Net Output			
		Goods	Extraction	Consumption	Investment	ΔInventory	Total output
	Goods	$P_g a_{gg} X_g$	$P_g a_{ge} X_e$	C_g	$I_e + I_g$	ΔInv_g	$P_g X_g$
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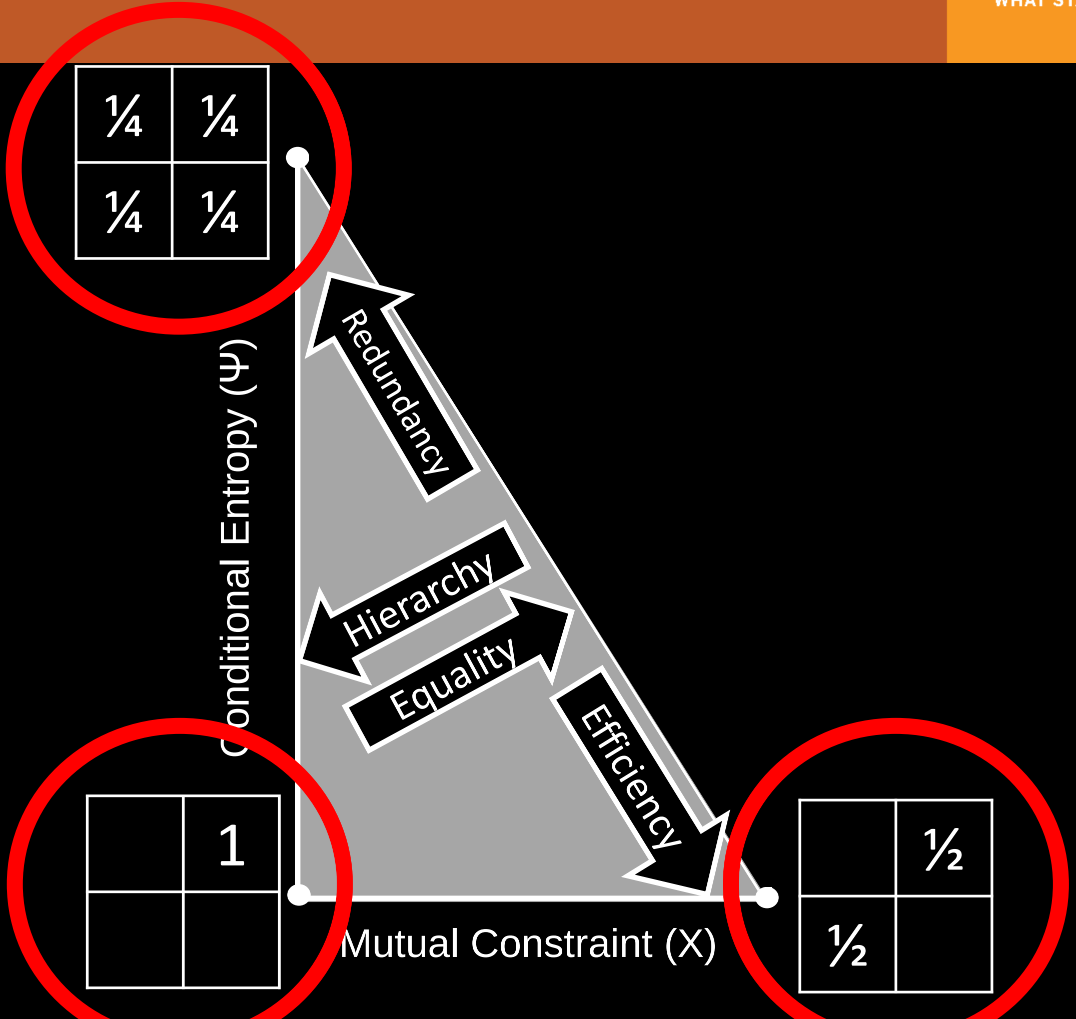
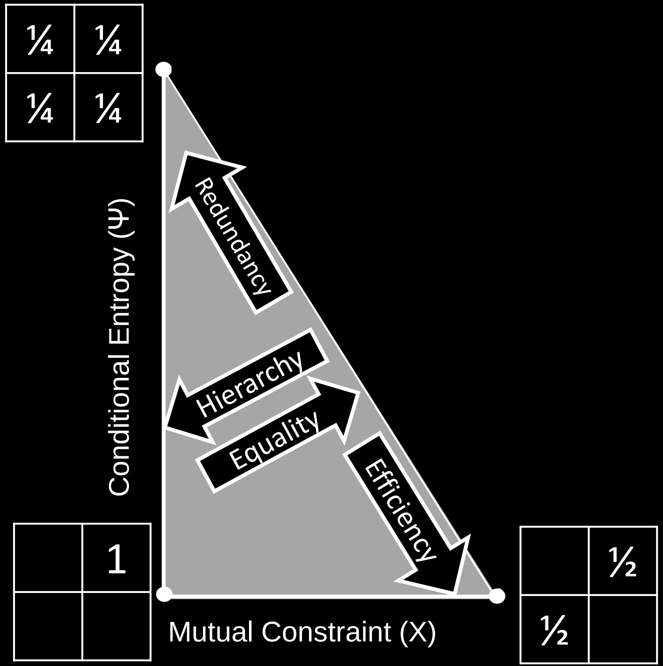

¼
¼
¼
¼
Redundancy
Conditional Entropy (Ψ)
Hierarchy
Equality
Efficiency
1
½
½
Mutual Constraint (X)

The model also mimics an interesting "structural" trend of the U.S.

(tracking money flows in input-output tables)



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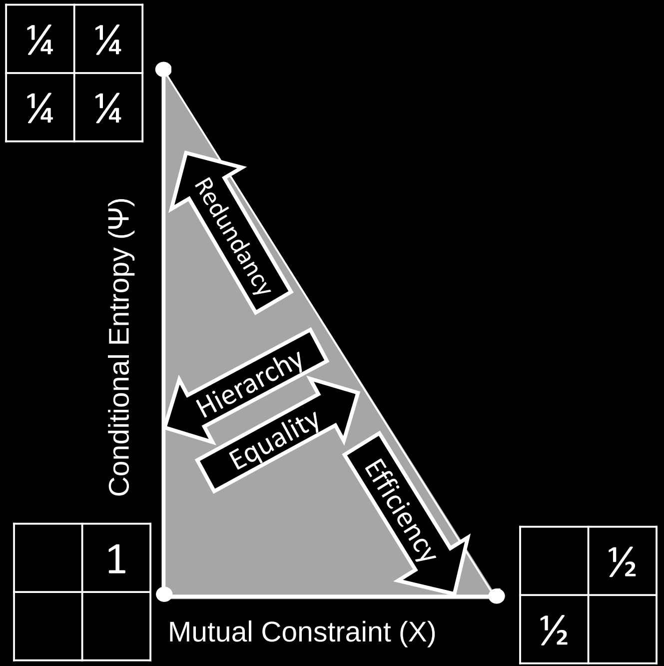
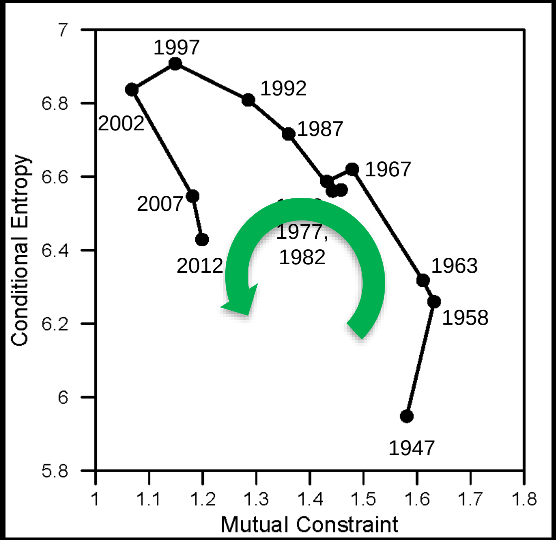
(tracking money flows in input-output tables)



U.S. Data



King (2016) *Biophy. Econ. & Res. Quality*

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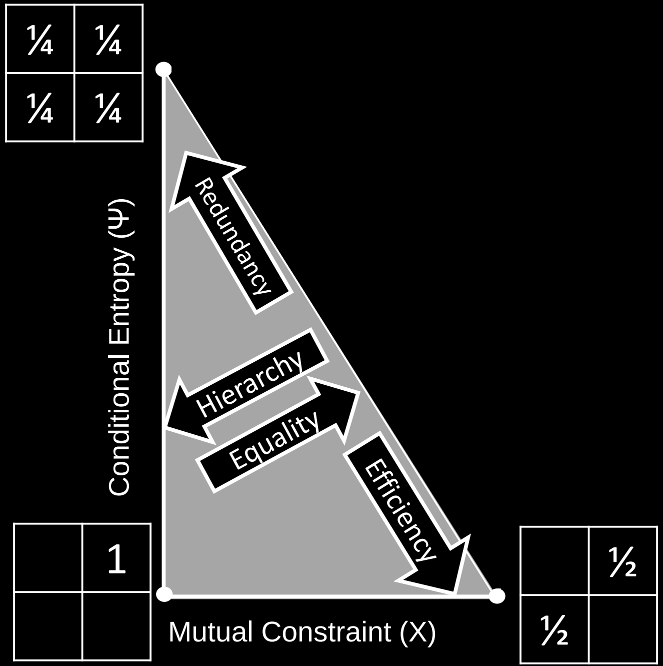
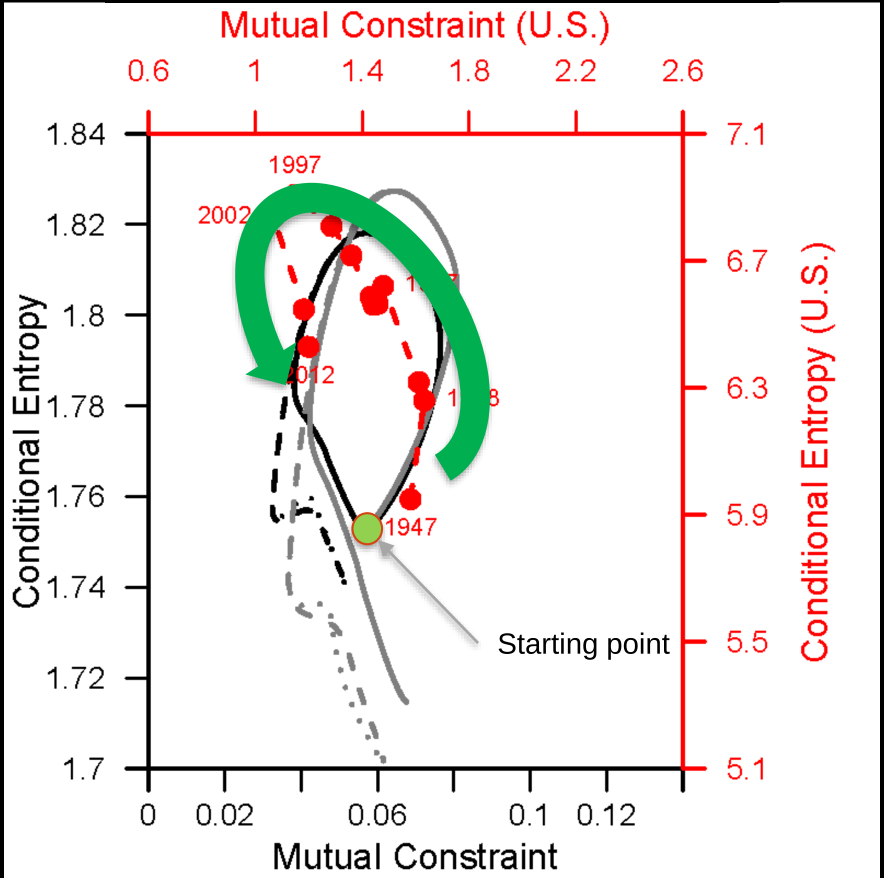


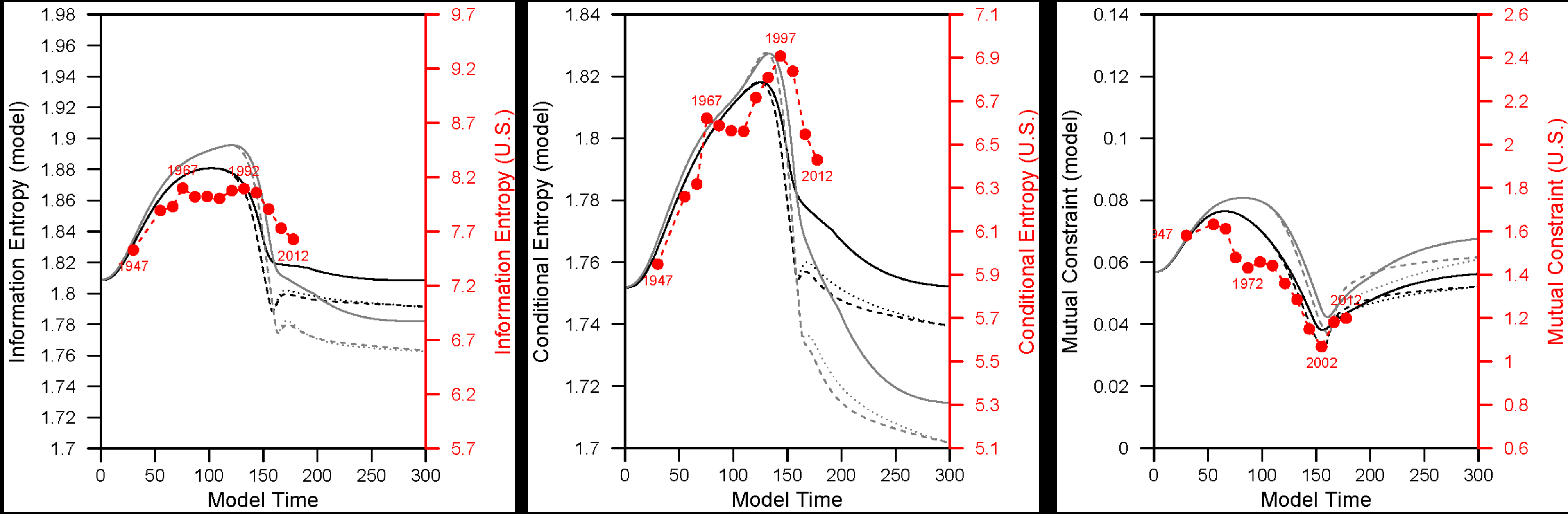
Marginal Cost Pricing Results



King (2016) *Biophy. Econ. & Res. Quality*

Low point in Mutual Constraint and peak in Conditional Entropy occur for similar resource-consumption reasons

Marginal Cost Pricing Results



Information Entropy = Conditional Entropy + Mutual Constraint

U.S. data: King (2016) *Biophy. Econ. & Res. Quality*

TEXAS
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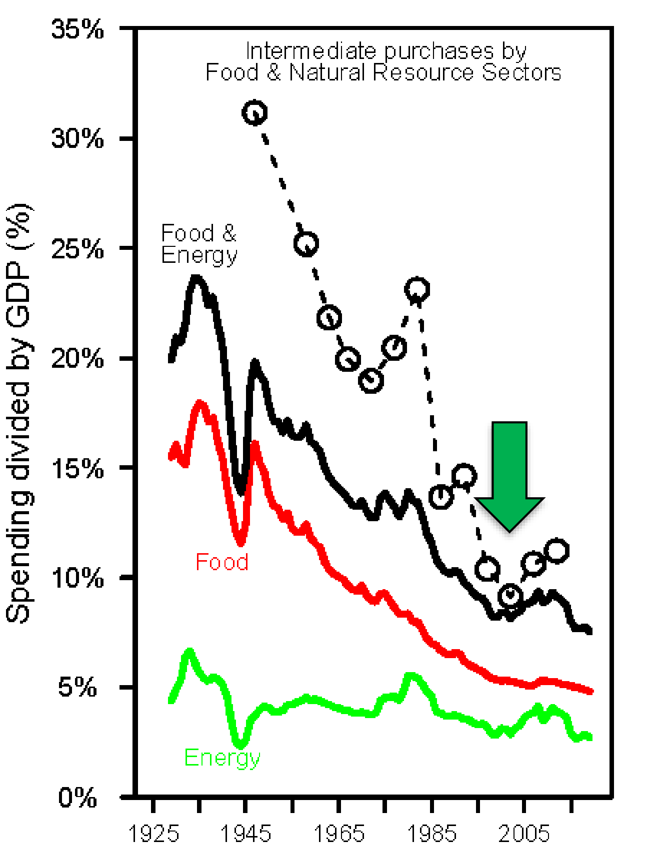
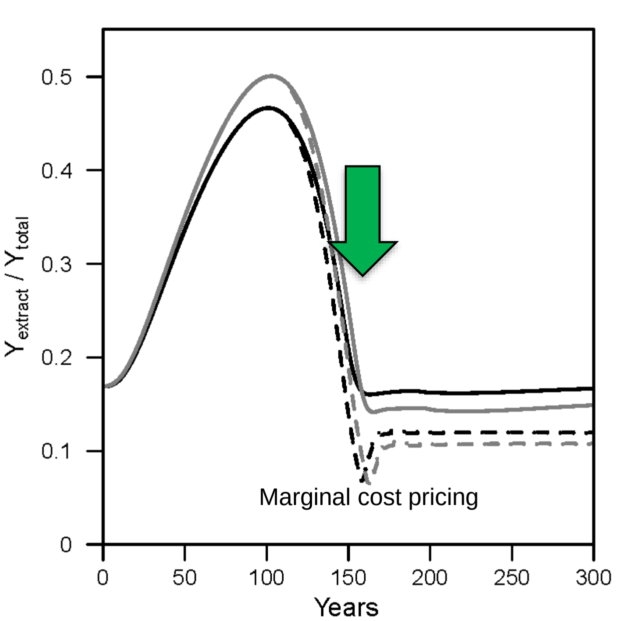
U.S. 2002:

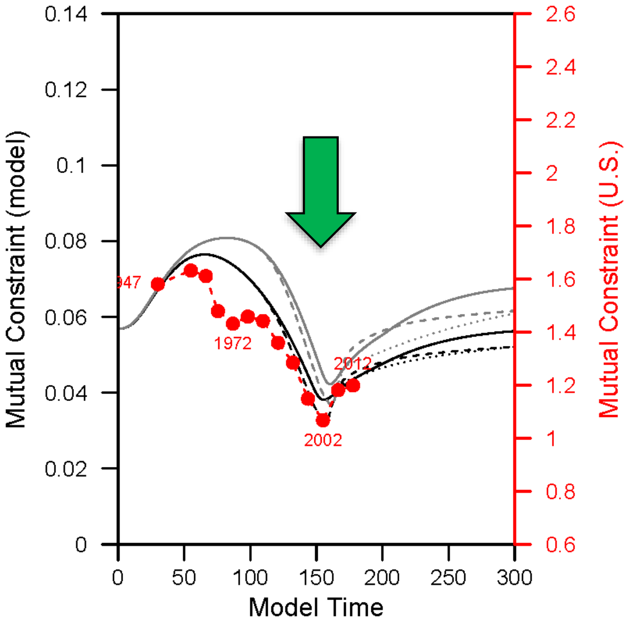
Cheapest (energy + food costs)/GDP

Marginal cost model, T=160:

lowest $Y_{extract}/Y_{total}$







King *The Economic Superorganism*, Chapter 2.

Takeaways: The HARMONEY model …

- … consistently tracks physical and economic flows
- … serves as a base model to add components (e.g., government, renewable energy sector, climate/atmosphere)
- … explains some (important) coincident trends in energy and money distribution (e.g., metabolic view of economy, I-O structure, wage share, debt)
- … shows how economic decisions (e.g., rate of investment) relate to physical resources and population

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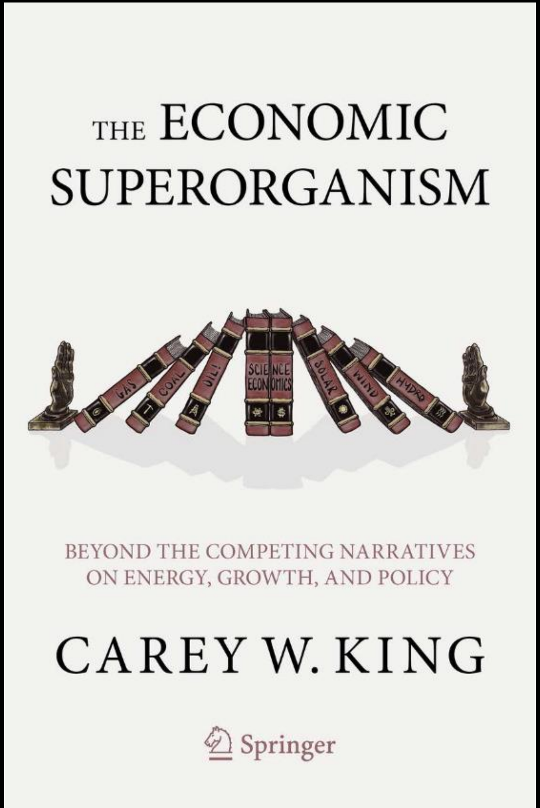
King, Carey W., Interdependence of Growth, Structure, Size and Resource Consumption During an Economic Growth Cycle, arXiv pre-print: https://arxiv.org/abs/2106.02512



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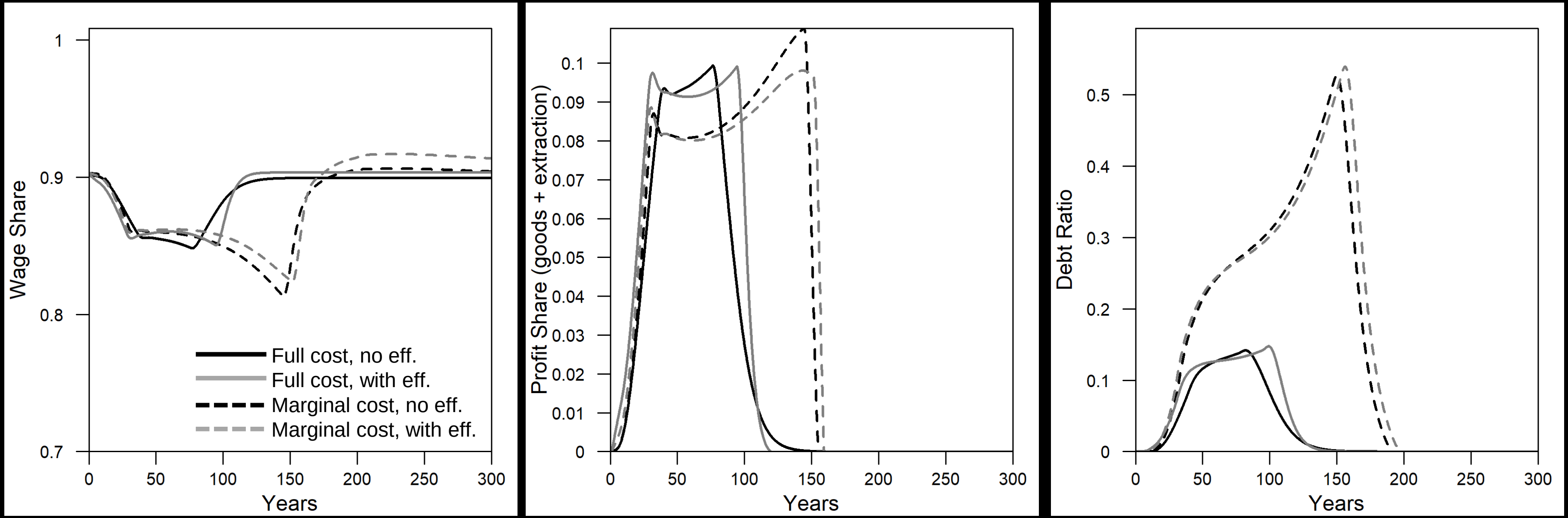
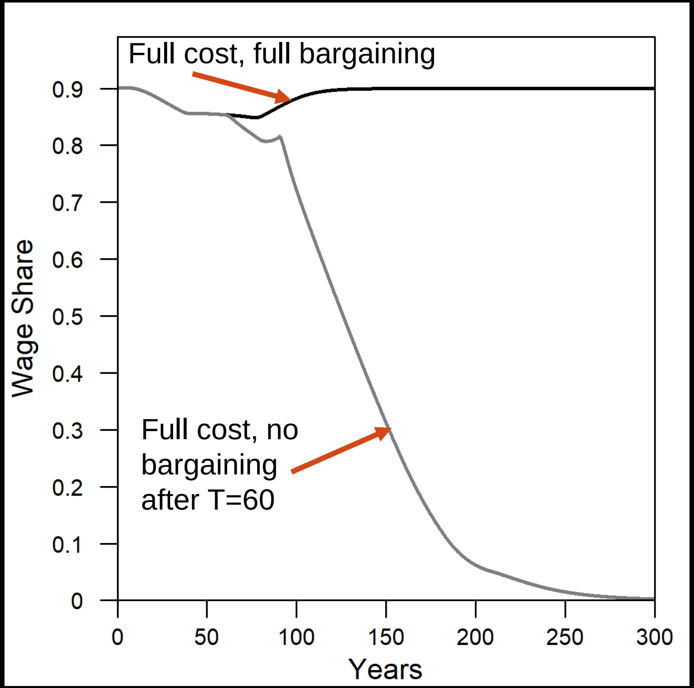
Tension between Wages and Profits at constant resources extraction

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



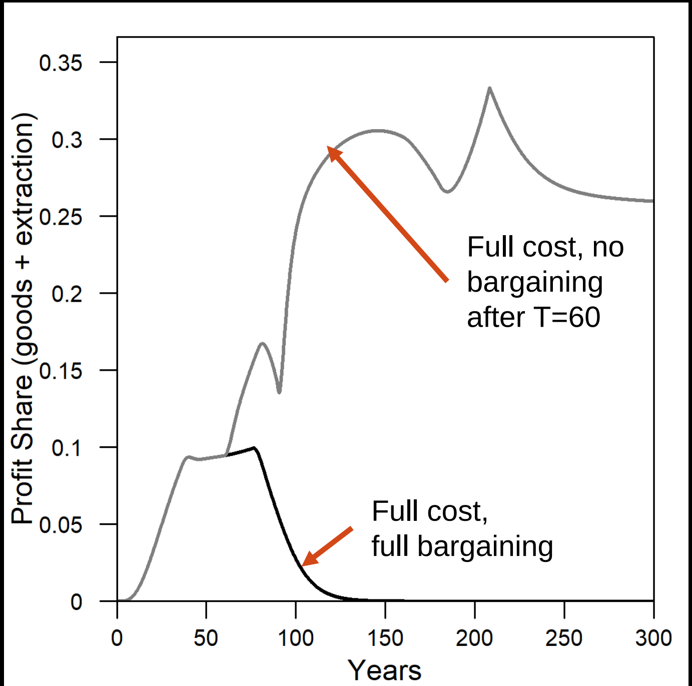
When economy stops growing, wage vs. profit tradeoff becomes more tenuous

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

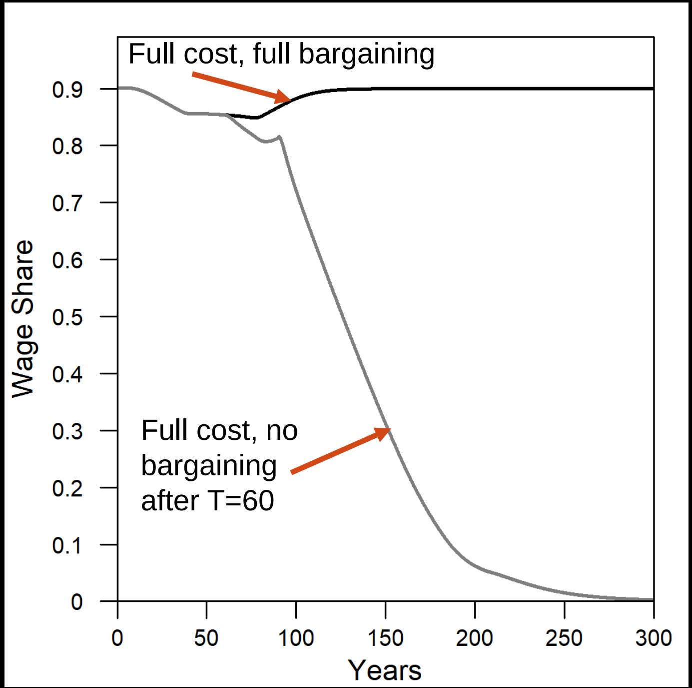


$$\frac{\dot{w}}{w} = f(\lambda) + \overset{0}{w_1}\frac{1}{\lambda}\frac{d\lambda}{dt} + \overset{0}{w_2}\,i$$

@ constant GDP and resources consumption: Full bargaining: wage share ↑ max., profit share ↓ 0 No bargaining: wage share ↓ 0, profit share ↑ max.

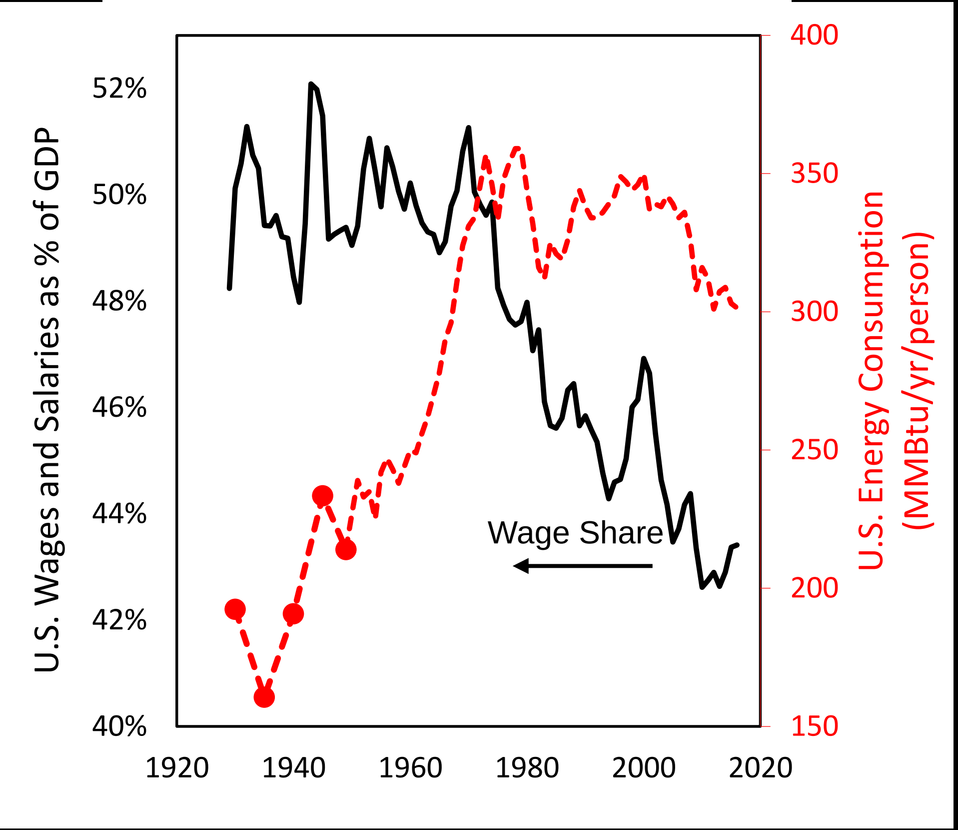


vs.

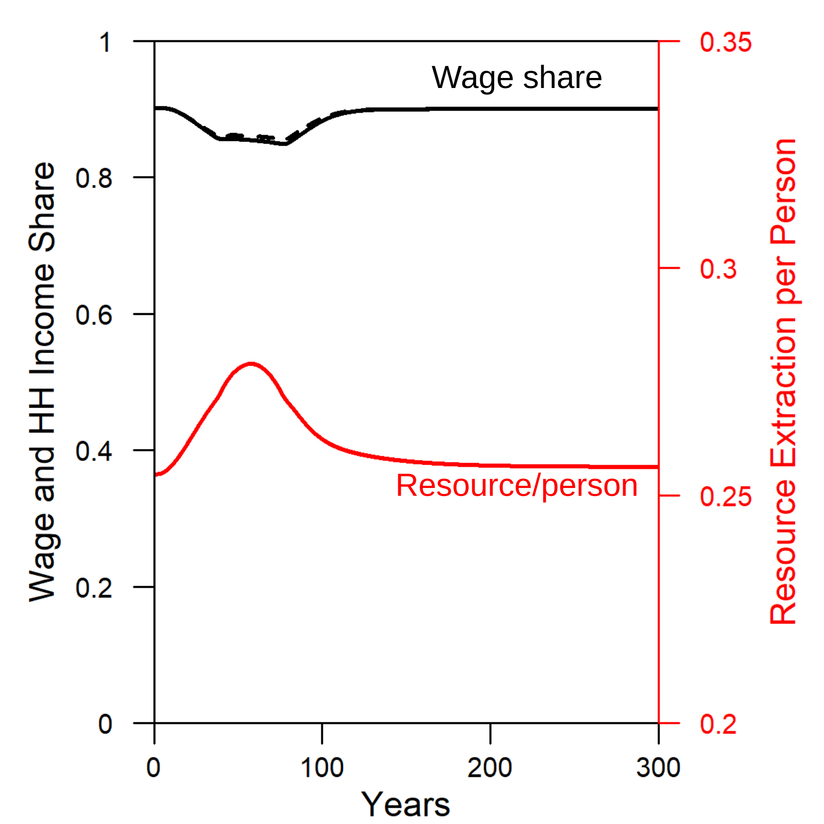


Does the theoretical model match anything interesting in the energy & economic data?

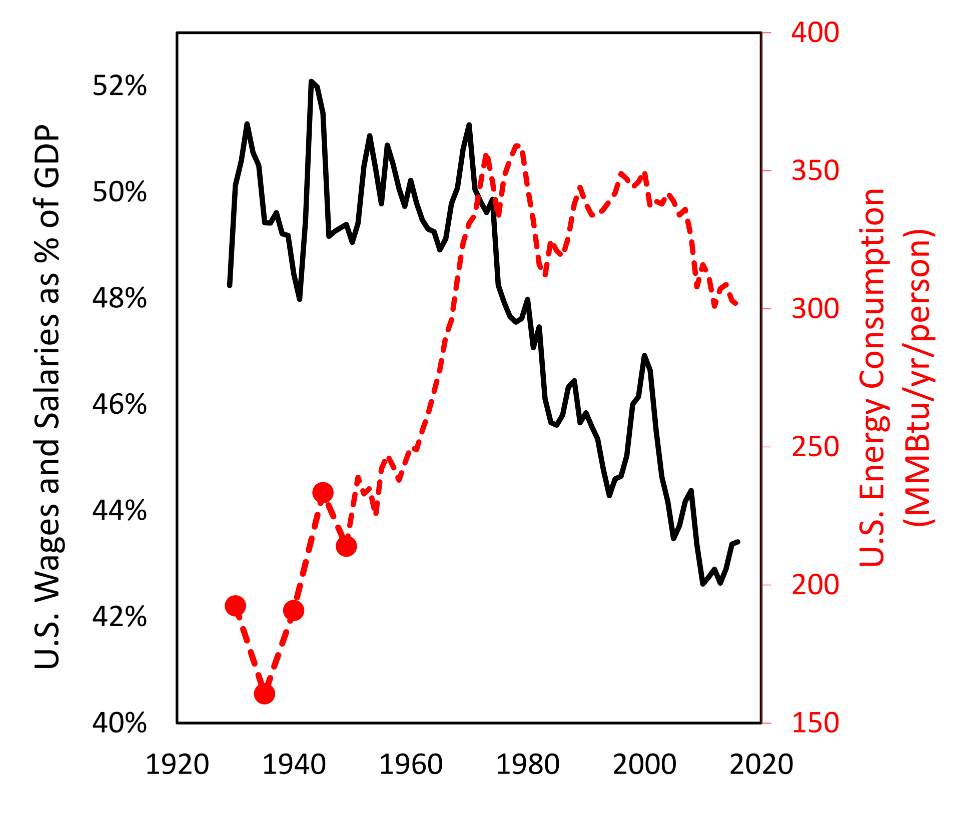
U.S. Data (1929-2016)



Model
(full cost, full wage bargaining power)

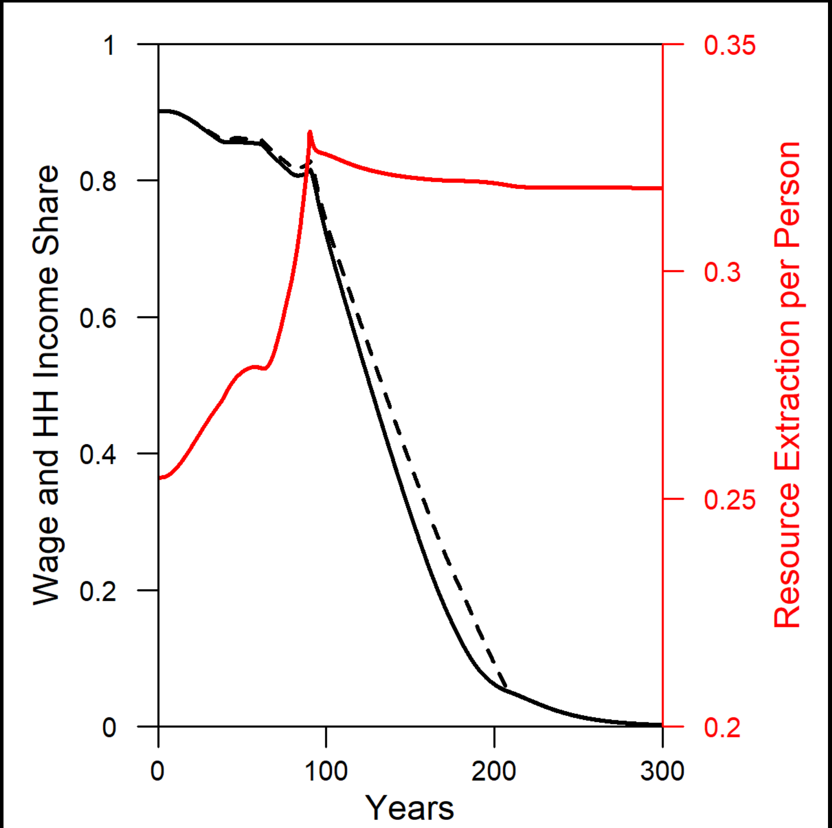


U.S. Data (1929-2016)

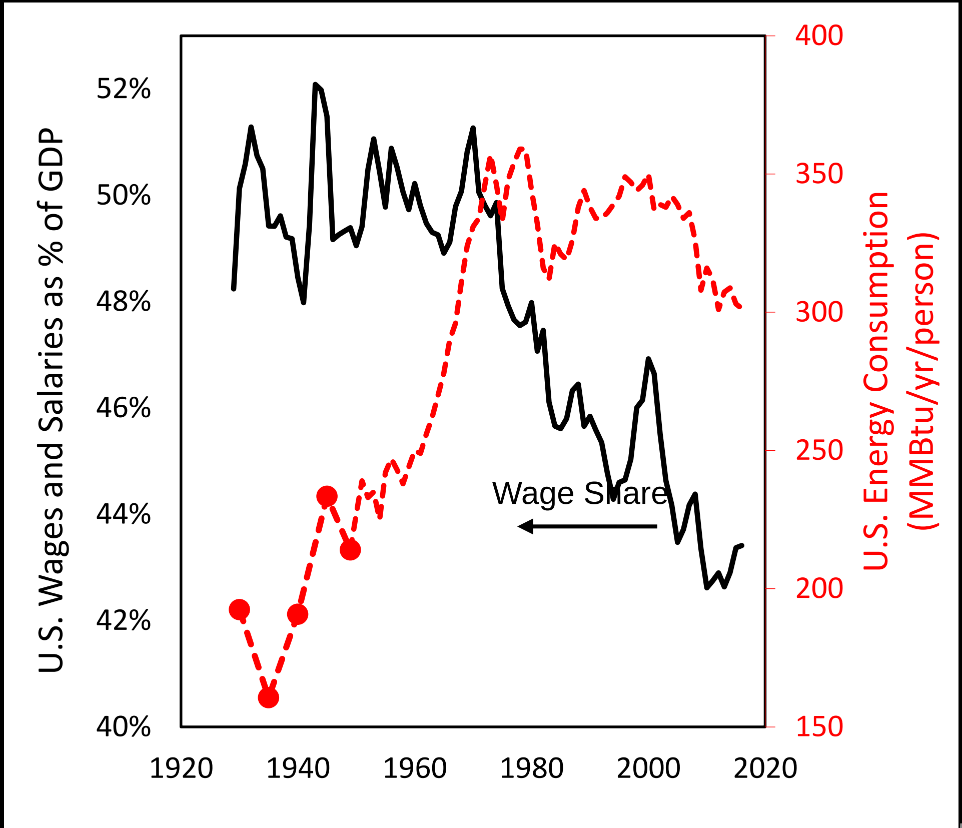


Model

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

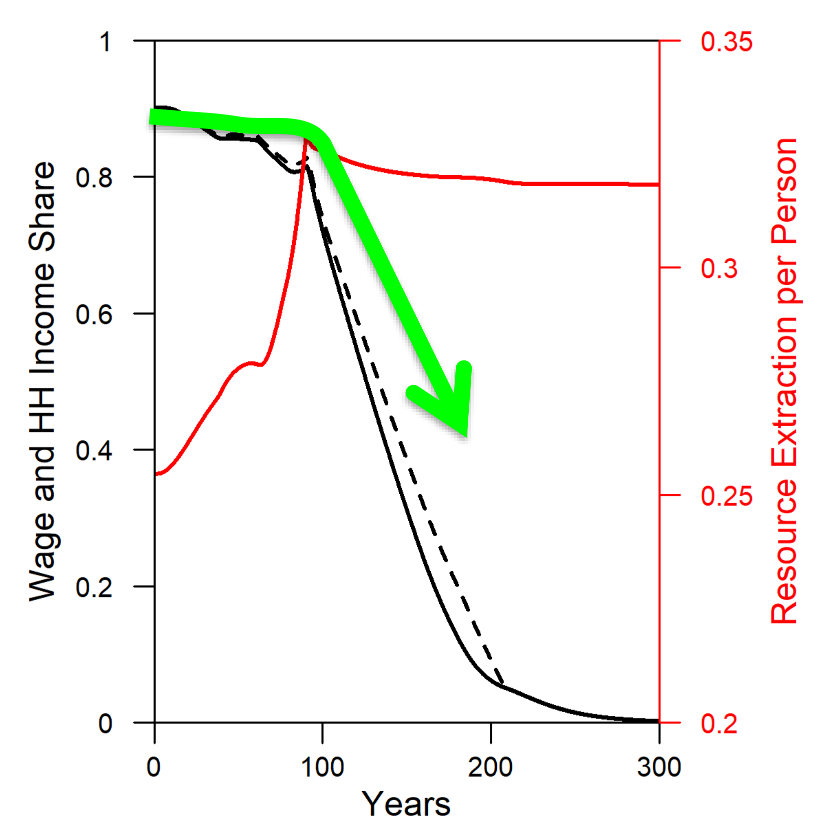


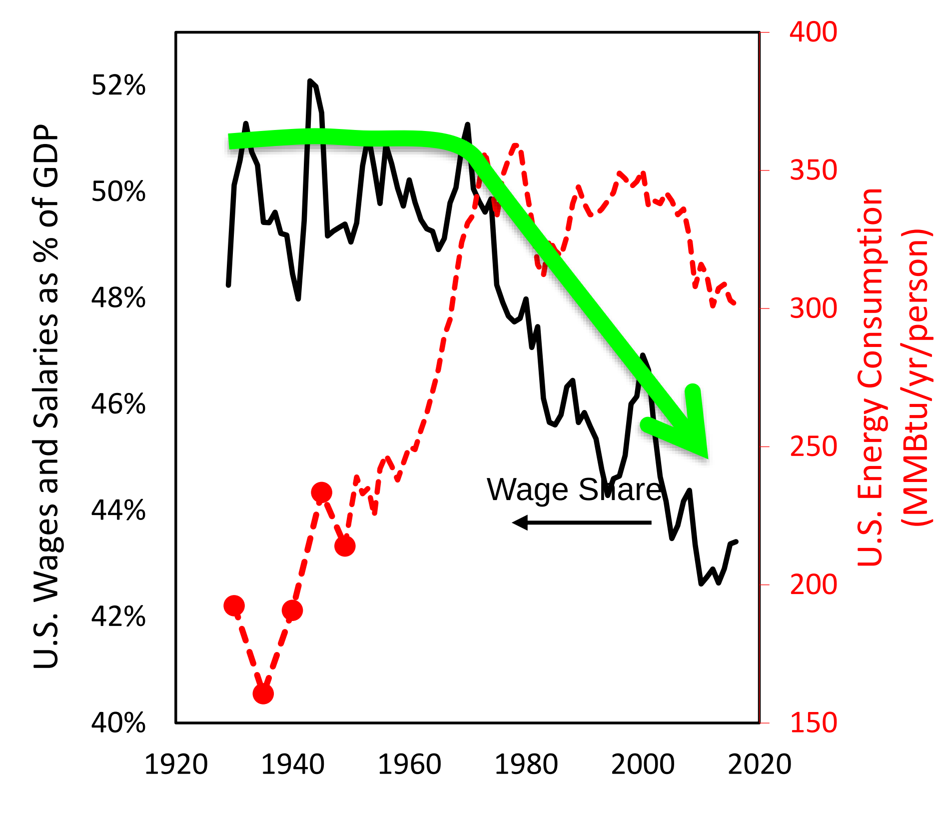
U.S. Data (1929-2016)



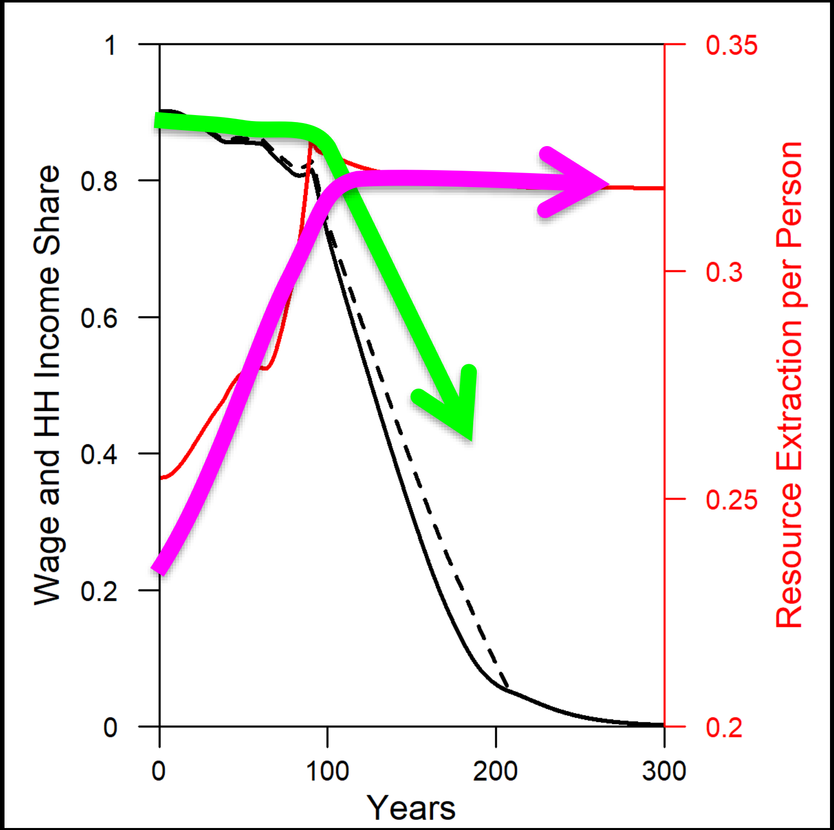
Model
(full cost, loss of wage bargaining Power from T=60 to T=160)

U.S. Data (1929-2016)

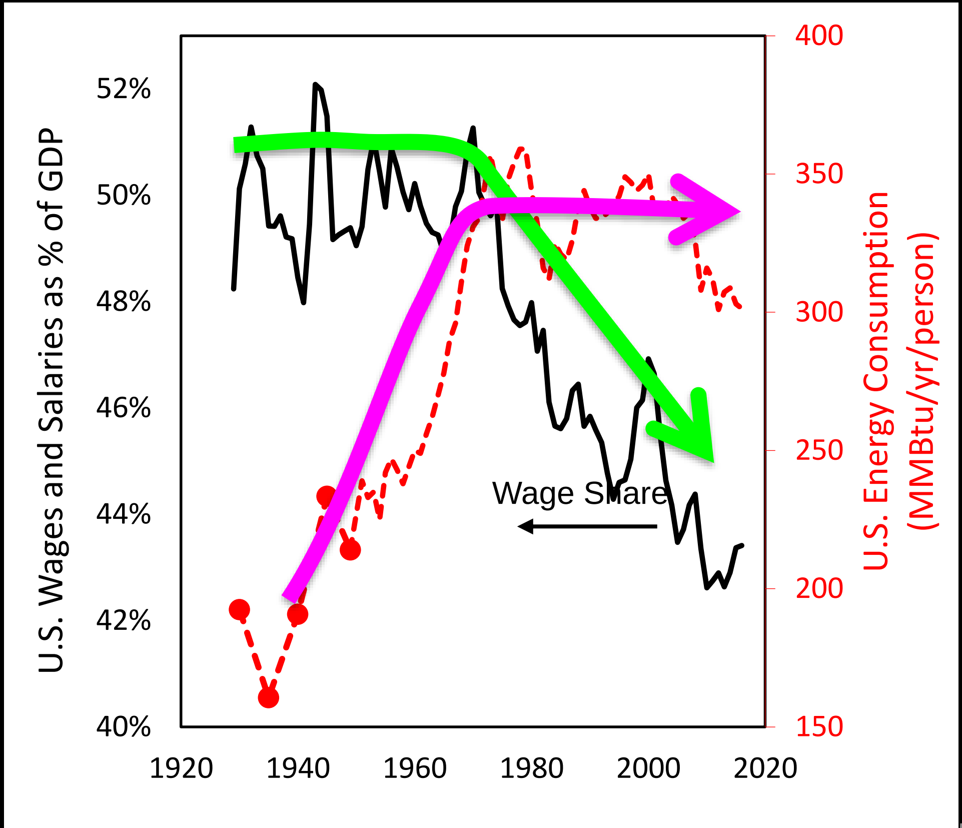




Model
(full cost, loss of wage bargaining Power from T=60 to T=160)



U.S. Data (1929-2016)



When resources consumption peaks (total, or per capita) …

… is there a *forced "choice"* or tradeoff between non-zero profits and full wage bargaining power?