Energy shocks and aggregate fluctuations

WORK IN PROGRESS

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Econ Dynamics

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Motivation

- ▶ How important is energy for economic fluctuations ?
  - Energy – e.g. oil or electricity – is complementary in production
  - Contribute to output growth, industrial production, transportation . . .

- ▶ Large literature on Oil price shocks...
  - Controversies (J. Hamilton vs. L. Kilian) about the sources of shocks to explain oil prices
  - What is the most important propagation mechanism ?
  - Are the shocks on other energy sources similar ?
- ▶ Quantitative question :
  - What impact of such a sectoral shock ?
  - Are energy shocks important drivers of business cycles ?
  - What are the transmission channels ?

Introduction – Motivation

► Oil price shocks : large & persistent effects on industrial production
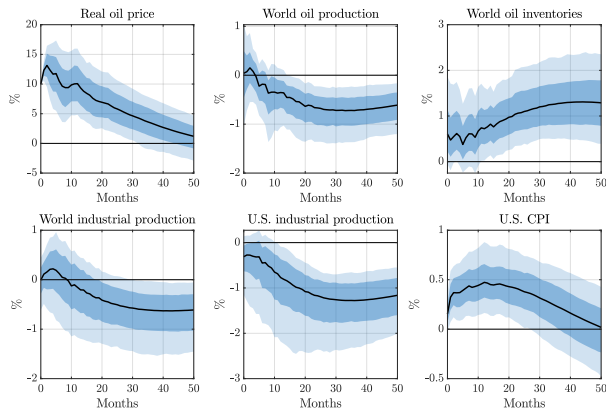
Kaenzig (2019)
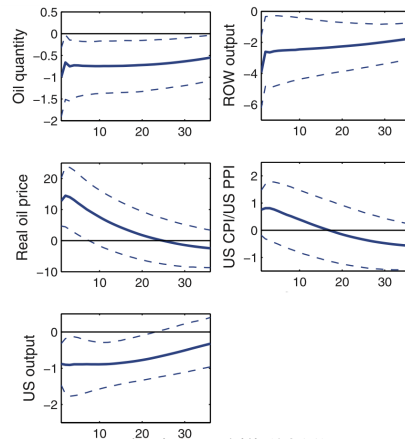
Lippi & Nobili (2011)

Introduction – This project

▶ Try to provide a quantitative answer on the importance of energy

▶ Theoretical contribution : simplest RBC framework
- Energy as a complementary factor and non-linearity in the production process
- Micro-founded "Hotelling-type" energy sector in the spirit of Bornstein, Krusell, and Rebelo (2021)
- DSGE model with multiple wedges in the spirit of Chari Kehoe McGrattan (2007-2016)

▶ Empirical contribution :
- Business cycle accounting and shock decompositions

Introduction – This project

- ▶ Business cycle accounting :
  - Introduce 4 "reduced form" shocks (efficiency wedge, labor wedge, investment wedge, market clearing wedge)
  - In addition, 4 structural shocks specific to the energy sector (demand vs. supply)
    - TFP and directed technical change (=energy augmenting demand shifter)
    - Supply and reserve extraction shocks (supply shifter)
    - Energy wedge-markup and demand shock (development of the RoW)
  - Filter the shocks and estimate the parameters
- ▶ Some counterfactual analysis
  - What are the effects of reducing energy use/carbon emissions by 35% by 2030 ?
  - Effects on reallocation, labor/capital, fossil/non-fossil

Model - RBC - Production

▶ Production process :

$$Y = \mathcal{F}(M, L) = Z_t \left[\alpha^{\frac{1}{\varepsilon_y}} M^{\frac{\varepsilon_y - 1}{\varepsilon_y}} + (1 - \alpha)^{\frac{1}{\varepsilon_y}} L^{\frac{\varepsilon_y - 1}{\varepsilon_y}} \right]^{\frac{\varepsilon_y}{\varepsilon_y - 1}}$$

$$M = \mathcal{M}(E, K) = \left[\eta^{\frac{1}{\varepsilon_e}} (Z_t^e E)^{\frac{\varepsilon_e - 1}{\varepsilon_e}} + (1 - \eta)^{\frac{1}{\varepsilon_e}} K^{\frac{\varepsilon_e - 1}{\varepsilon_e}} \right]^{\frac{\varepsilon_e}{\varepsilon_e - 1}}$$

- Special case : if $\varepsilon_e \to 0$, $\mathcal{M} \sim$ Leontieff,
  if $\varepsilon_e \to 1$, $\mathcal{M} \sim$ Cobb-Douglas
- Shocks : TFP Z_t and Energy augmenting technological shock Z_t^e

▶ Price of energy as the marginal product (demand curve) :

$$Q_t^E = \frac{\partial \mathcal{F}(M, L)}{\partial M} \frac{\partial \mathcal{M}(E, K)}{\partial E} = \alpha Y^{1/\varepsilon_y} M^{(1/\varepsilon_e) - (1/\varepsilon_y)} \eta (Z_t^{es})^{\frac{\varepsilon_e - 1}{\varepsilon_e}} E^{-1/\varepsilon_e}$$

Model – Energy sector - 1

▶ Total energy use E_t is a combination of two sources :

$$E_t = \left(\omega^{\frac{1}{\varepsilon_f}} \left(E_t^f \right)^{\frac{\varepsilon_f - 1}{\varepsilon_f}} + (1 - \omega)^{\frac{1}{\varepsilon_f}} \left(E_t^{nf} \right)^{\frac{\varepsilon_f - 1}{\varepsilon_f}} \right)^{\frac{\varepsilon_f}{\varepsilon_f - 1}}$$

- Fossil fuel E_t^f – oil, gas or coal – produced by a foreign monopoly facing a finite resource problem á la Hotelling (next slide

  ▶ Face an exogenous demand from the rest of the world :

  $$E_t^{f,us} + E_t^{row} = E_t^w$$

  ▶ E_t^{row} is exogenous and follow an AR(1) process

- A cleaner energy E_t^{nf} – nuclear, hydroelectric, solar, wind – is produced by a competitive (static) supplier facing the convex cost function $\mathcal{C}(E_t^{nf})$

  $$Q_t^{nf} = \bar{C} \left(E_t^{nf} \right)^{\nu_{nf}}$$

Model – Energy sector - 2

▶ World fossil fuel production problem :

- Microfunded as in : *"A World Equilibrium Model of the Oil Market", Bornstein, Krusell and Rebelo (2021)*

$$V_0^E = \max_{\{I_t^E, E_t^w\}} \mathbb{E}_0 \sum_{t=0}^{\infty} \left[Q_t^f E_t^w - I_t^E - \bar{C} \Big(\frac{E_t^w}{\mathcal{R}_t^E} \Big)^\nu \mathcal{R}_t^E \right]$$

s.t.

- Evolution of "Exploration capital" K_t^E

$$K_{t+1}^E = (1 - \lambda) K_t^E + \xi_t^e \Theta \big(I_t^E \big)^\theta \big(L^E \big)^{1-\theta}$$

- Reserves of fossil fuels are discovered with a lag $\mathcal{R}_t^E$

$$\mathcal{R}_{t+1}^E = \mathcal{R}_t^E - E_t + \lambda K_t^E$$

- AR(1) shock on the cost of exploration :

$$\log \xi_t^e = \rho \log \xi_t^e + \omega_t^e$$
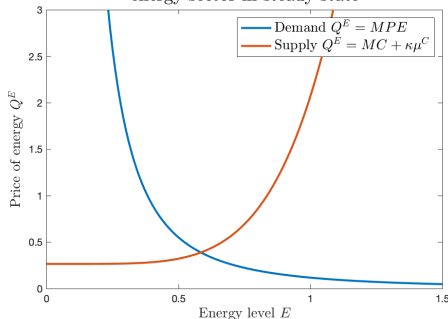
Model – Energy sector - 3

▶ This allows for lags λ in a model *a la Hotelling*
- FOCs : optimal decisions for $s_t^E = \frac{E_t^w}{\mathcal{R}_t^E}$ and $\mathcal{R}^E$

$$Q_{t+1}^f = \nu \bar{C}(s_{t+1}^E)^{\nu-1} + \mu_{t+1}^{\mathcal{R}}$$

$$\mu_t^{\mathcal{R}} = \mathbb{E}_t \left[\Lambda_{t+1} \left(Q_{t+1}^f s_{t+1}^E + (1 - s_{t+1}^E)\mu_{t+1}^{\mathcal{R}} - \bar{C}(s_{t+1}^E)^{\nu} \right) \right]$$

Market clearing in the
energy sector in steady state

Model – RBC

▶ Rest of model : standard RBC :

- Representative HH, preferences a la *King Plosser Rebelo*

$$U(C,L) = \tfrac{1}{1-\sigma}\left(C_t^{1-\sigma} v(L_t)^{\sigma} - 1\right)$$

$$\Rightarrow \quad 1 = \mathbb{E}_t[\Lambda_{t,t+1}(1 + r_{t+1}^k)\frac{1 + \tau_{t+1}^i}{1 + \tau_t^i}] \quad \& \quad MRS_{c/\ell} = (1 - \tau_t^{\ell})W_t$$

- LoM for capital and investment with adjustment cost
- Market clearing for output $C_t + I_t + \varphi(I_t) + G_t = Y_t$

▶ Business cycle accounting exercise with set of shocks :

- TFP shock Z_t and ω^z
- Labor wedge τ_t^{ℓ} and ω^{ℓ}
- Investment wedge τ_t^i and ω^i
- Government wedge G_t and ω^g

Shocks to the energy sectors

▶ The wedges in the RBC model are ad hoc/*reduced form* shocks
  • Assumption that these shocks are structural from the point of view of the energy sector.

▶ For now :
  • Match log deviation from growth trend
  • Shocks : $\tau_t^i = \rho_i \tau_{t-1}^i + \sigma^i \omega_t^i, \forall i$, with $\omega_t^i \sim \mathcal{N}(0, 1)$
  • This assumption is used for out identification

▶ In practice :
  • Kalman filtering for processes of shocks
    ▶ 4 macro shocks, 4 energy shocks
    ▶ 3 macro times series, 3 energy time series
  • MCMC/Bayesian inference for parameters – variances of shocks and structural parameters
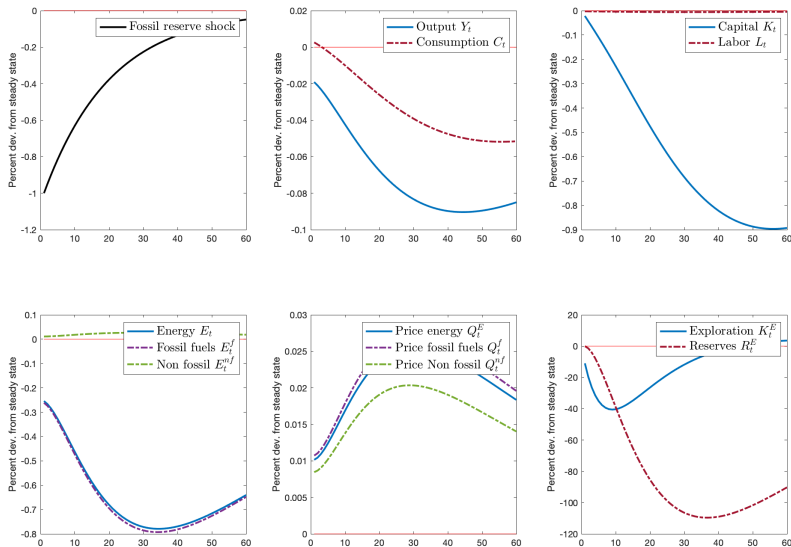
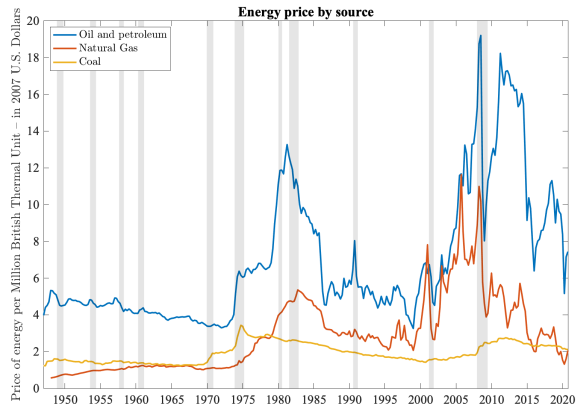# Result : Demand shocks – TFP
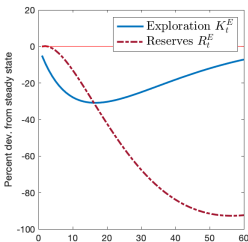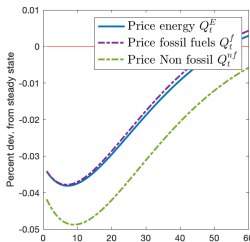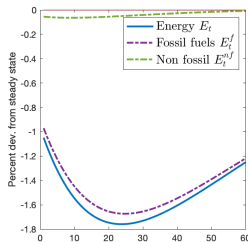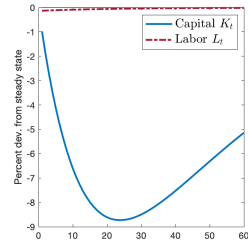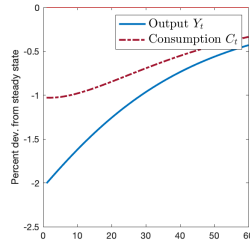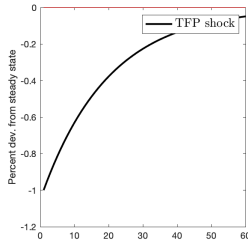
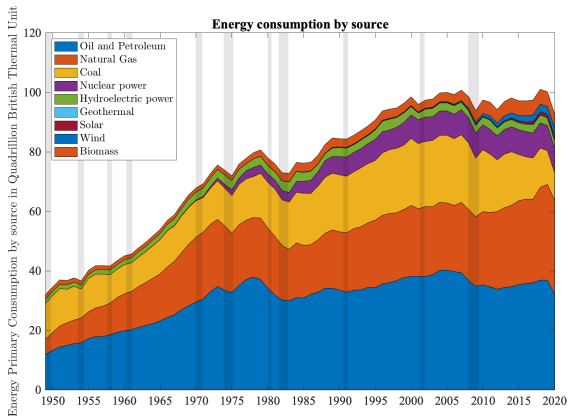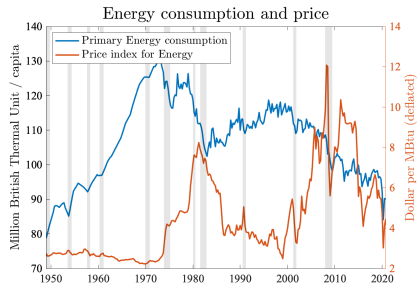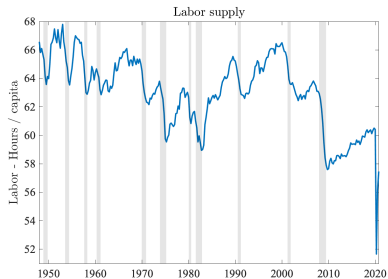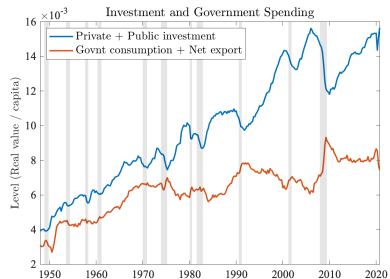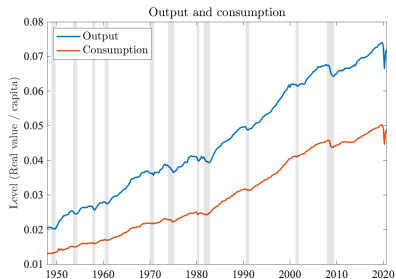# Result : Demand shocks - DTC
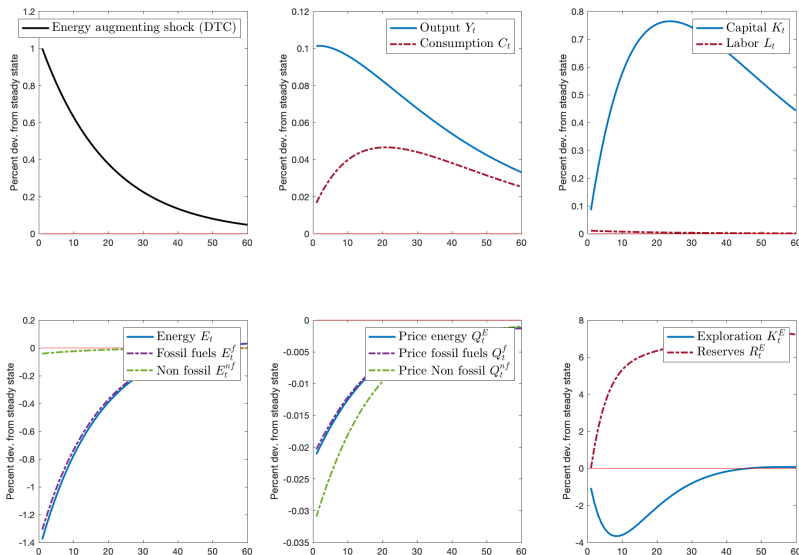
Result : Energy wedge – Market power

Data - Sample : U.S. data 1949-2020

► Energy consumed vs. Prices

Price and Reserves

Shocks decomposition - energy shocks and output
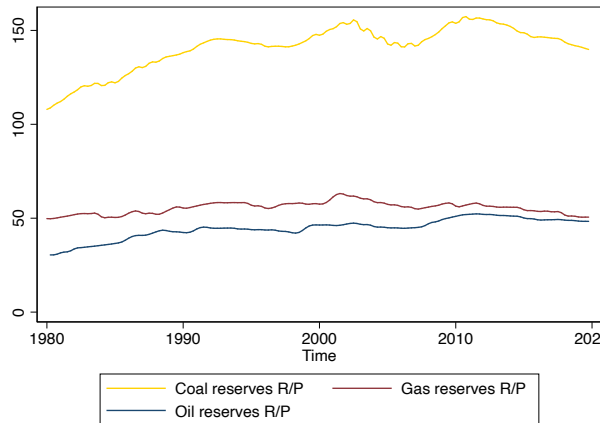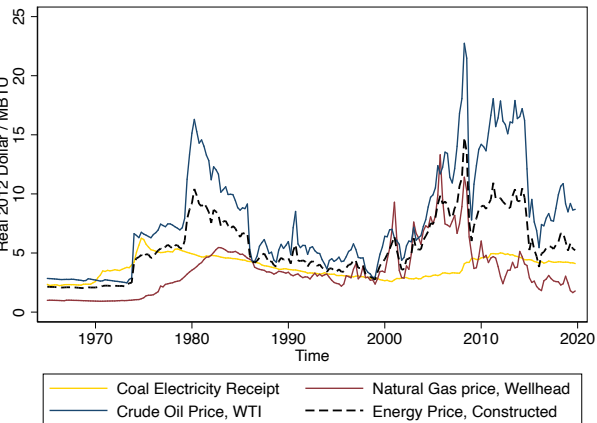
Shock decomposition: output Y_t
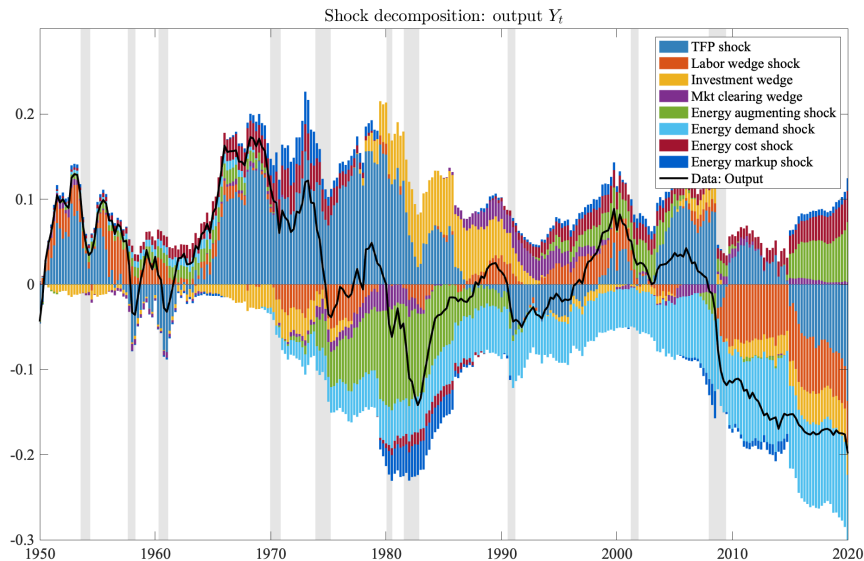
Case study – Second Oil price shock of 1979-1980
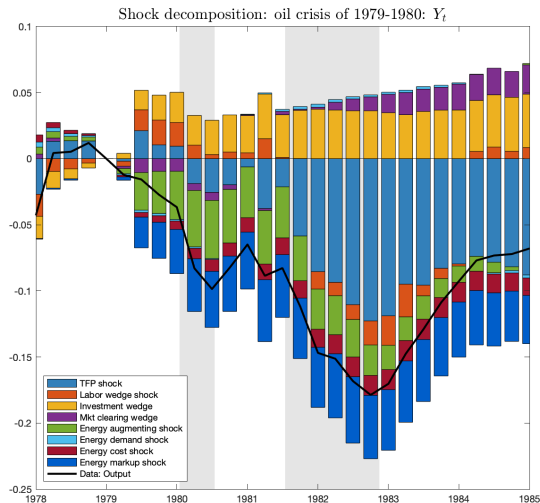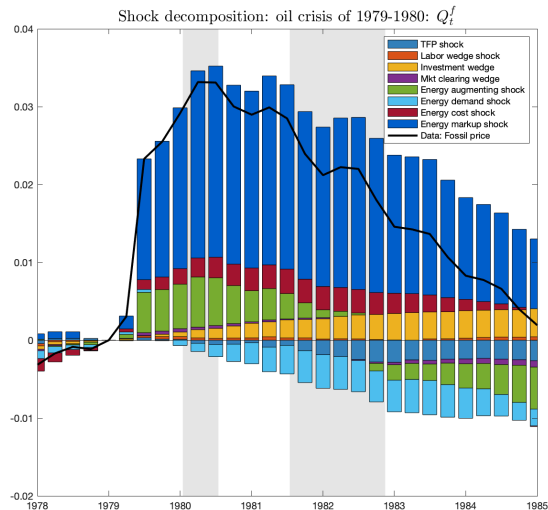
Shock decomposition: oil crisis of 1979-1980: Q_t^f

Shock decomposition: oil crisis of 1979-1980: Y_t

Comments and lessons

▶ Representative firm/ household may not yield empirically relevant predictions :
  - Explain qualitative implications of energy shocks, but not the right magnitude price/quantity !
    – IRF : shocks lead to large reactions of quantities (but not prices)
    – Taken to the data : shocks are a large contributor to business cycles.
▶ Question : which feature of the model represents the most relevant transmission mechanisms ?
  - Nominal rigidities and aggregate demand channel
  – Energy shocks distort prices

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  - Nominal rigidities and aggregate demand channel
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  - Large share of TFP/efficiency wedge : may imply that sectoral allocation matters
  – Chari Kehoe McGrattan (2007) : generate efficiency wedge from input/output frictions
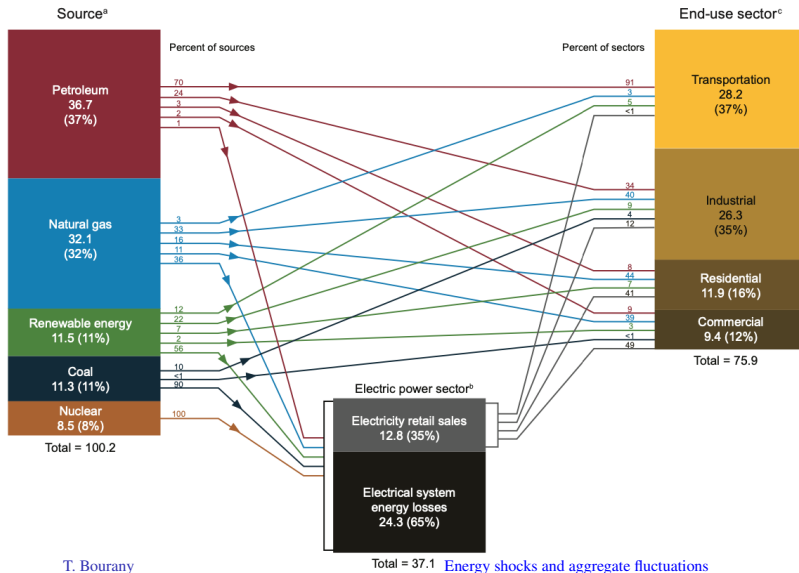
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  • Large share of TFP/efficiency wedge : may imply that sectoral allocation matters
  – Chari Kehoe McGrattan (2007) : generate efficiency wedge from input/output frictions
  • Direct effect on consumption
  – Heterogeneous effects on Households (spender/saver model)

U.S. energy consumption by source and sector, 2019

(Quadrillion Btu)

Source[a]		End-use sector[c]

Percent of sources

Percent of sectors

Petroleum
36.7
(37%)

70
24
3
2
1

Natural gas
32.1
(32%)

3
33
16
11
36

Renewable energy
11.5 (11%)

12
22
7
2
56

Coal
11.3 (11%)

10
<1
90

Nuclear
8.5 (8%)

100

Total = 100.2

Transportation
28.2
(37%)

91
3
5
<1

Industrial
26.3
(35%)

34
40
9
12

Residential
11.9 (16%)

8
44
7
41

Commercial
9.4 (12%)

9
39
3
49

Total = 75.9

Electric power sector[b]

Electricity retail sales
12.8 (35%)

**Electrical system
energy losses**
24.3 (65%)

Total = 37.1

Sectoral data

► Data from EIA :
  - Input volumes (quantity ! !) for 5 larges sectors :
  - Transportation, Industry, Residential, Commercial, Electricity sector
  - Sources and prices (!) for energy input : petroleum products, natural gas, coal, etc.
  - Yearly 1949-1973, Monthly 1973-2021.
► More granular surveys :
  - Survey for manufacturing (3 digits NAICS data), every 3-4 years, 1991,94,98,2002,06,10,14,18
  - Other surveys for residentials/commercial sector
  - All that need extensive cleaning :'(

Sectoral data

► Several facts :
- Energy inputs are inelastic in sectoral production
  - Oil/gas matter mostly for transportation (95%)
  - In industrial processes, little reallocation across sources
- Electrification
  - Slow + create a large gap between total energy and primary energy
  - Possibility of reallocation (from coal to gas)

Network model

▶ The economy is composed of $I + I^E$ sectors :

- I economic sectors – typically production sectors taken from the BEA – 2 digits NAICS
- I^E (wholesale) energy sectors – Oil, Natural gas, Nuclear, Coal, Renewables and Electricity.

$$Y_i = A_i \left[(1 - \theta_i)^{\frac{1}{\varepsilon_y}} \left(K_i^\alpha L_i^{(1-\alpha)} \right)^{\frac{\varepsilon_y - 1}{\varepsilon_y}} + \theta_i^{\frac{1}{\varepsilon_y}} M_i^{\frac{\varepsilon_y - 1}{\varepsilon_y}} \right]^{\frac{\varepsilon_y}{\varepsilon_y - 1}}$$

$$M_i = \left(\sum_{j=1}^{I+1} (\omega_{ij}^m)^{\frac{1}{\varepsilon_m}} M_{ij}^{\frac{\varepsilon_m - 1}{\varepsilon_m}} + \eta_i^{\frac{1}{\varepsilon_m}} E_i^{\frac{\varepsilon_m - 1}{\varepsilon_m}} \right)^{\frac{\varepsilon_m}{\varepsilon_m - 1}} \qquad \sum_{j=1}^{I} \omega_{ij} = 1 - \eta_i$$

$$E_i = \left(\sum_{k=1}^{I^E} (\omega_{ik}^e)^{\frac{1}{\varepsilon_e}} E_{ik}^{\frac{\varepsilon_e - 1}{\varepsilon_e}} \right)^{\frac{\varepsilon_e}{\varepsilon_e - 1}}$$

Network model

▶ Final demand from Household

$$C = \Big(\sum_{j=1}^{N} \xi_j^{\frac{1}{\varepsilon_c}} C_j^{\frac{\varepsilon_c-1}{\varepsilon_c}}\Big)^{\frac{\varepsilon_c}{\varepsilon_c-1}}$$

$$\max_{\{C_j, L_j, E_r, E_d\}_j} \mathbb{E}_{t_0} \sum_t \beta^t \Big(\log(C) + V(R, E_r) + V(D, E_d) - \psi\big(\sum_j L_j\big)^{\frac{\varphi}{\varphi+1}}\Big)$$

▶ Investment sector as in the old literature on multisectors RBC.

Conclusion and future paths

- ▶ How important is energy for economic fluctuations ?
  - With complementarity in production the energy shocks can be amplified
  - ... However, with reallocation toward the energy sector : the effects are smoothed dramatically
- ▶ In our quantitative exercise :
  - energy shocks increasing prices but not quantity can be important
  - Small effects of carbon taxes on reduction in energy use and emissions
- ▶ Future plans :
  - Multisector model and energy network with nested-CES
  - Investigate reallocation channels and policy counterfactual at the sector/source level (carbon tax/oil shock)
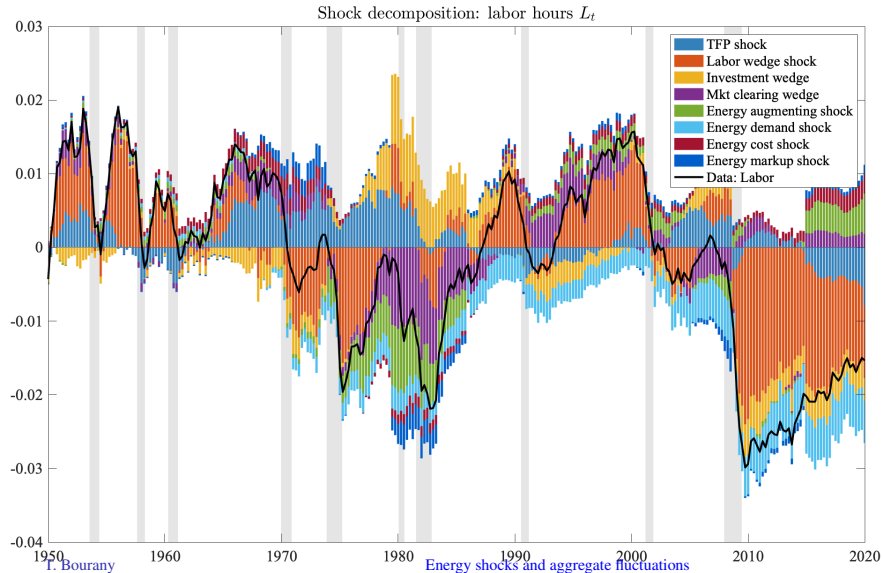
Shocks decomposition - energy shocks and output
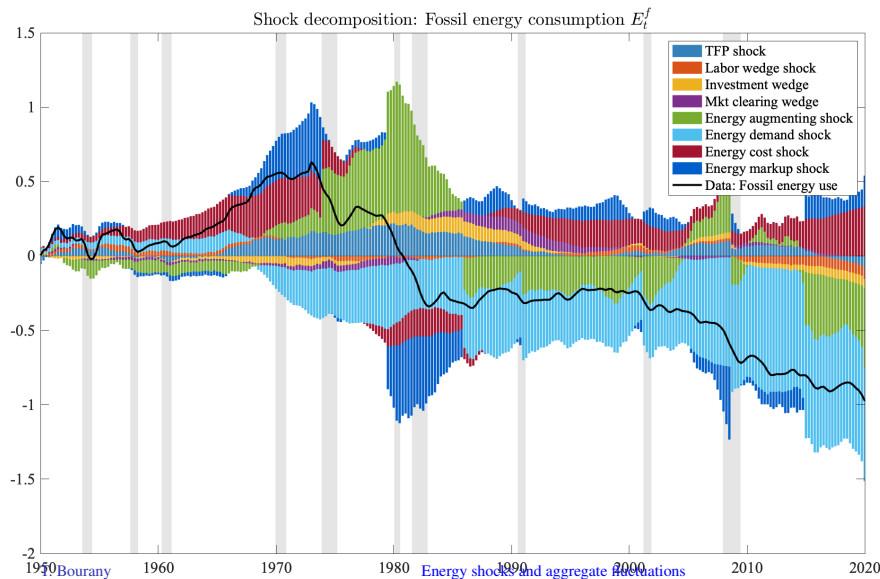

Shock decomposition: output Y_t
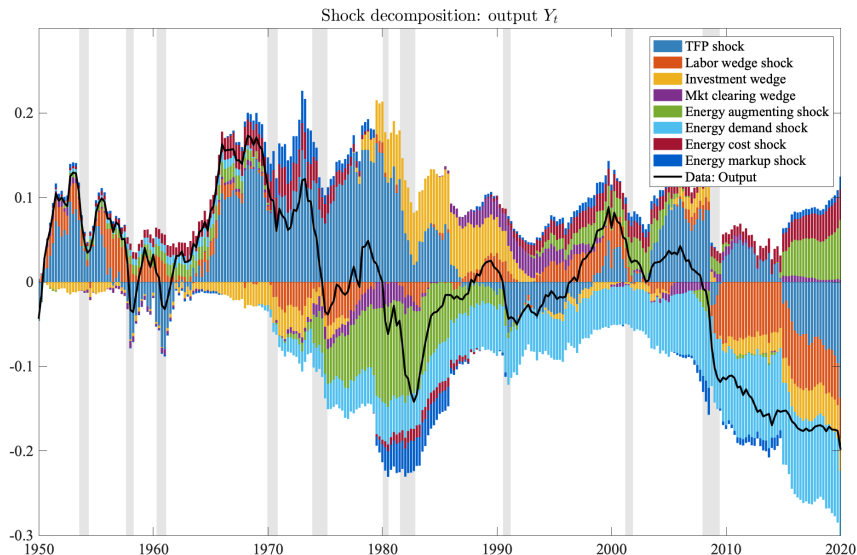
Shocks decomposition - energy shocks and investment

Shock decomposition: investment I_t
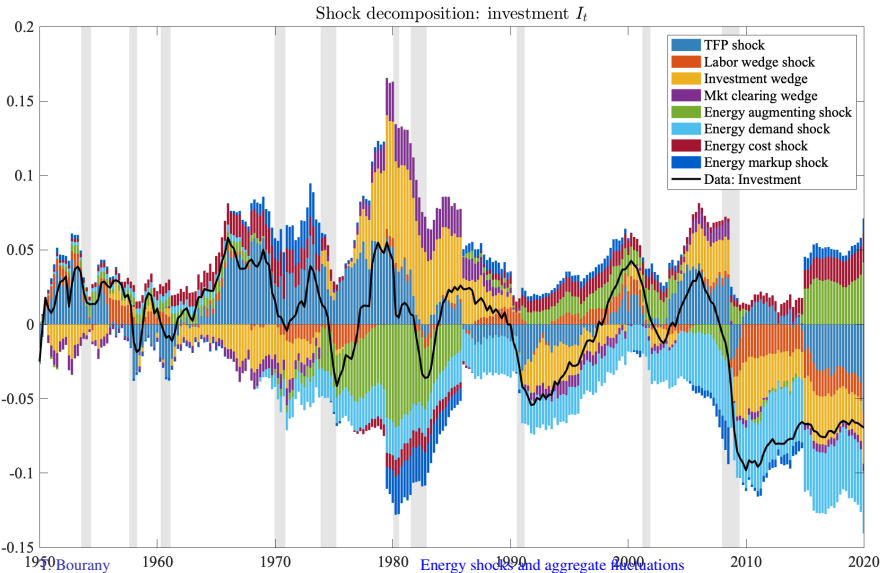
Shocks decomposition - energy shocks and labor

Shock decomposition: labor hours L_t

Shocks decomposition - energy shocks and energy use of fossils

Shock decomposition: Fossil energy consumption E_t^f

Legend:
- TFP shock
- Labor wedge shock
- Investment wedge
- Mkt clearing wedge
- Energy augmenting shock
- Energy demand shock
- Energy cost shock
- Energy markup shock
- Data: Fossil energy use

Shocks decomposition - energy shocks and fossil price

Shock decomposition: Fossil Energy Price Q_t^E
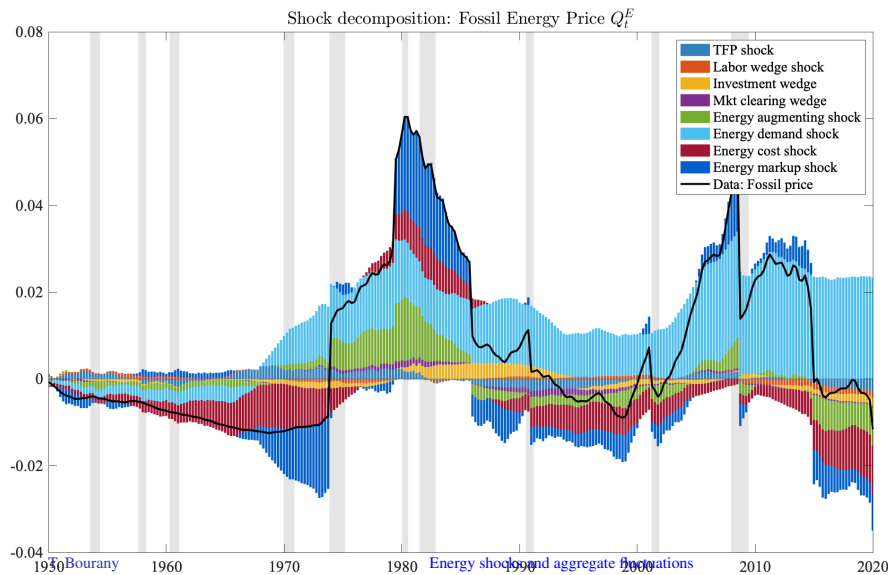
Parameters – Estimation

Parameters		Post. mean
ε_y	Elasticity Machine/Labor	0.65
ε_e	Elasticity Energy/Capital	0.20
φ	Inverse Frisch elasticity	1.1
ν	Cost elasticity of energy production	8.4
θ	Capital intensity of energy	0.43
λ	Lags in energy production	0.05