Energy shocks and aggregate fluctuations

WORK IN PROGRESS

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Econ Dynamics

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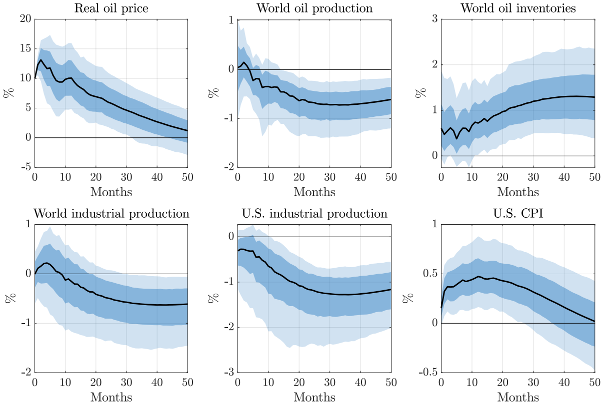
Motivation

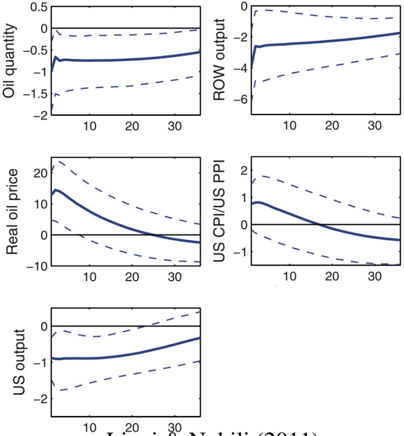
- How important is energy for economic fluctuations ?
  - Energy – e.g. oil or electricity – is complementary in production
  - Contribute to output growth, industrial production, transportation . . .
- Large literature on Oil price shocks...
  - Controversies (J. Hamilton vs. L. Kilian) about the sources of shocks to explain oil prices
    - Is it supply disruptions (e.g. instability in the Middle East)
    - ... or demand shocks (e.g. US business cycles/rise of China)
  - Are these insights a general feature of the energy sector or specific to oil ?
- Quantitative question :
  - What impact of such a sectoral shock ?
  - Are energy shocks important drivers of business cycles ?
  - What are the transmission channels and propagation mechanisms ?

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 – both with trend γ / γ^e
- Price of energy as the marginal product (demand curve) :

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

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 : *Energy demand shock*
- 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)*

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

s.t.

  - Evolution of "Exploration capital" K_t^E

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

  - 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 – *Energy supply shock*

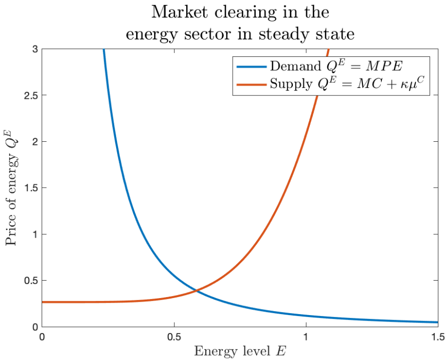
$$\log \xi_t^e = \rho^r \log \xi_t^e + \omega_t^e \qquad \log \xi_t^p = \rho^p \log \xi_t^p + \omega_t^p$$

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 $\mathcal{R}^E$

$$Q^f_{t+1}\xi^p_{t+1} = \nu\bar{C}(s^E_{t+1})^{\nu-1} + \mu^{\mathcal{R}}_{t+1}$$

$$\mu^{\mathcal{R}}_t = \mathbb{E}_t\left[\Lambda_{t+1}\left(Q^f_{t+1}\xi^p_{t+1}s^E_{t+1} + (1 - s^E_{t+1})\mu^{\mathcal{R}}_{t+1} - \bar{C}(s^E_{t+1})^{\nu}\right)\right]$$



Model – RBC

- Rest of model : standard RBC :
  - Representative HH, preferences a la *King Plosser Rebelo*

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

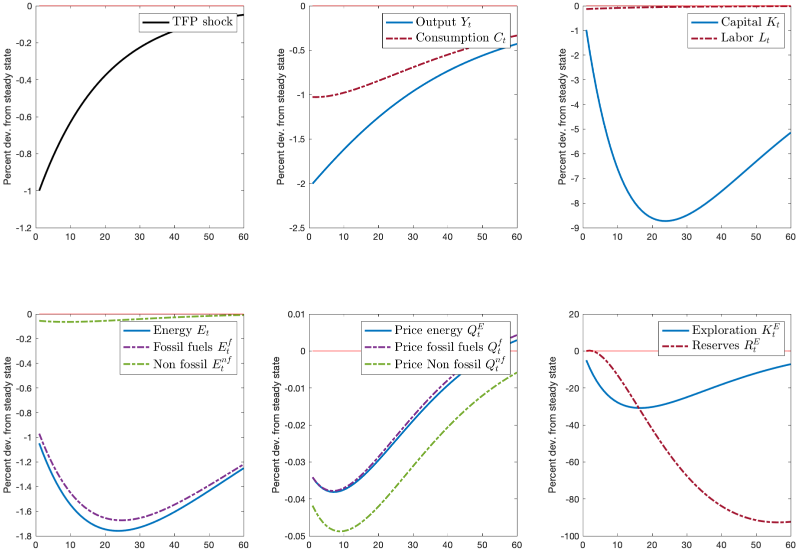
$$\Rightarrow \quad 1 = \mathbb{E}_t[\Lambda_{t,t+1}(1+r_{t+1}^k)\frac{1+\tau_{t+1}^i}{1+\tau_t^i}] \qquad \& \quad MRS_{c/\ell} = (1-\tau_t^\ell)W_t$$

  - 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

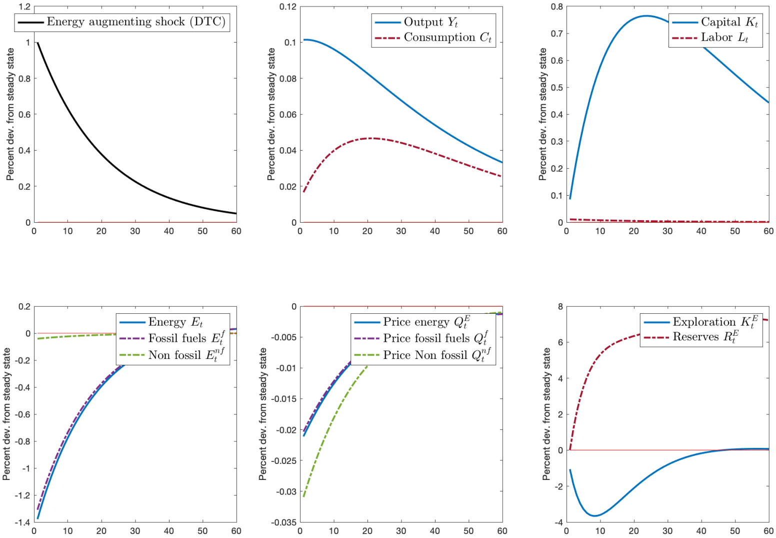
Shocks to the energy sectors

- 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

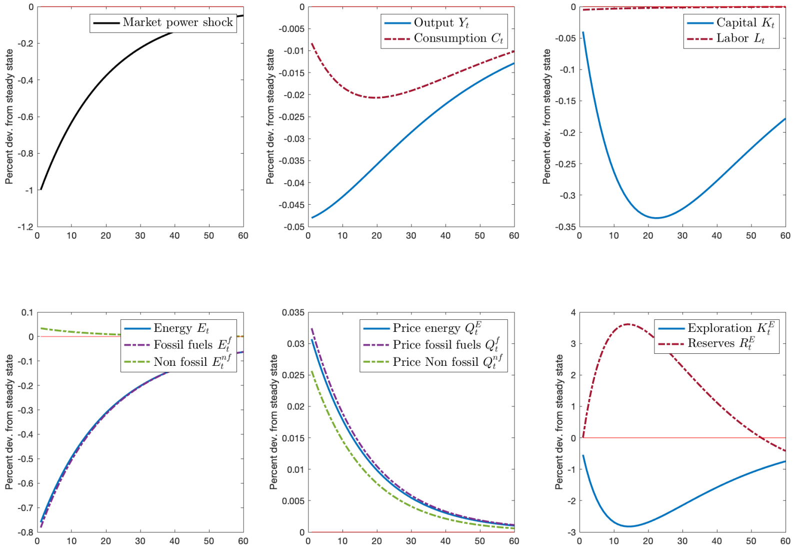
Result : Demand shocks – TFP



Result : Demand shocks - DTC

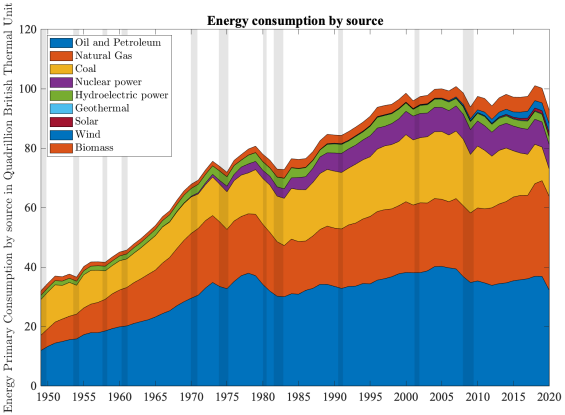


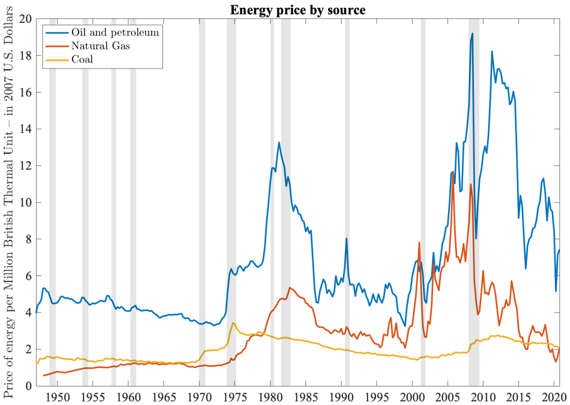
Result : Energy wedge – Market power

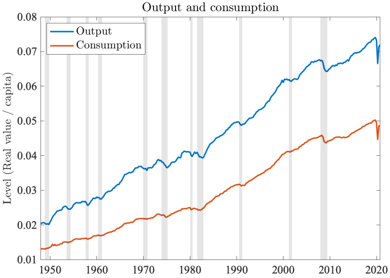


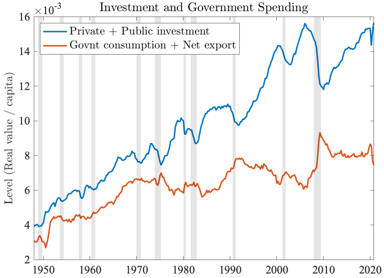
Data - Sample : U.S. data 1949-2020

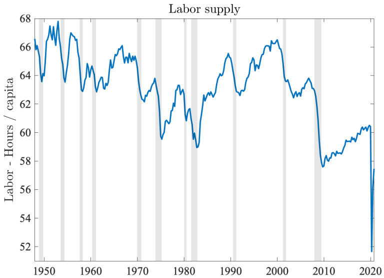
- Energy consumed vs. Prices

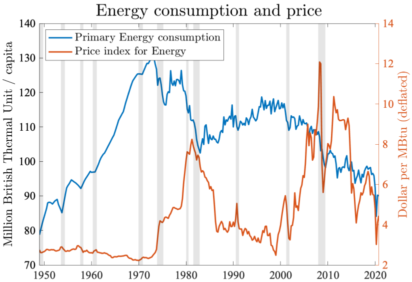




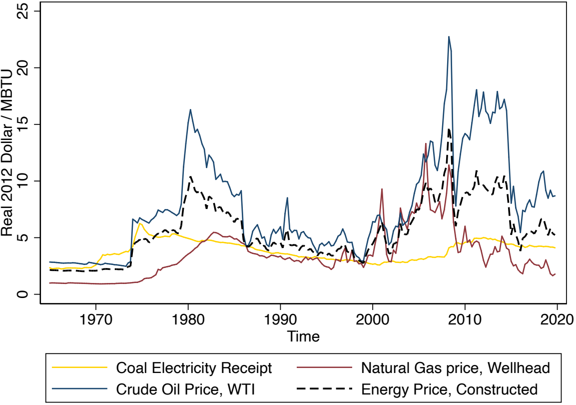

Output and consumption
Output
Consumption
Level (Real value / capita)
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
1950
1960
1970
1980
1990
2000
2010
2020

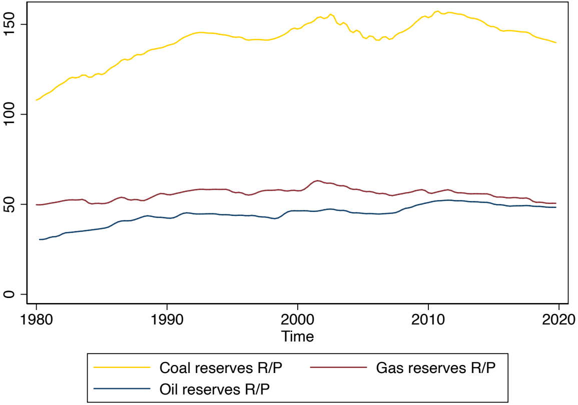

Investment and Government Spending
×10^-3
Private + Public investment
Govnt consumption + Net export
Level (Real value / capita)
16
14
12
10
8
6
4
2
1950
1960
1970
1980
1990
2000
2010
2020


Labor supply
Labor - Hours / capita
68
66
64
62
60
58
56
54
52
1950
1960
1970
1980
1990
2000
2010
2020

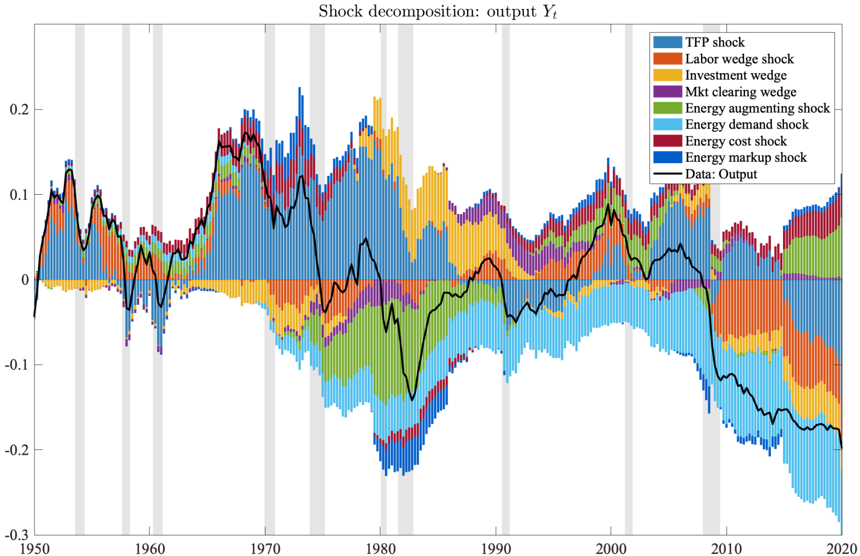

Energy consumption and price
Primary Energy consumption
Price index for Energy
Million British Thermal Unit / capita
Dollar per MBtu (deflated)
140
130
120
110
100
90
80
70
14
12
10
8
6
4
2
1950
1960
1970
1980
1990
2000
2010
2020

Price and Reserves

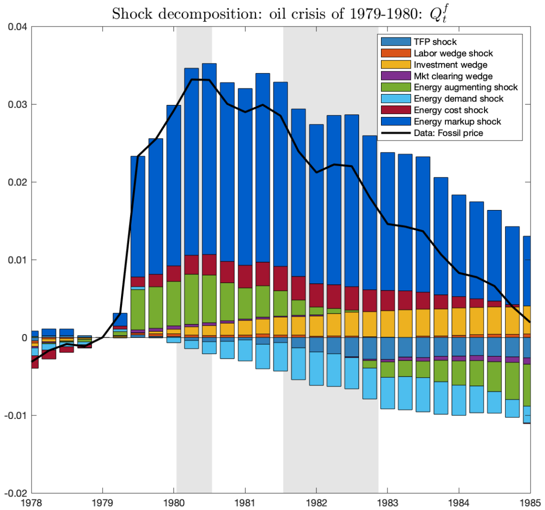


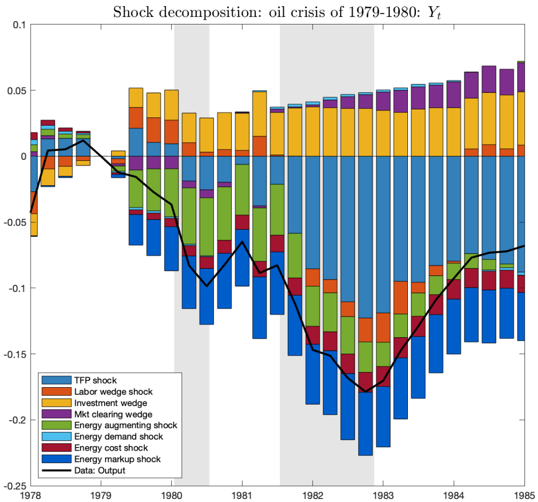


Shocks decomposition - energy shocks and output



Case study – Second Oil price shock of 1979-1980

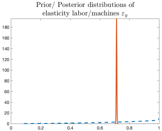


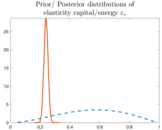


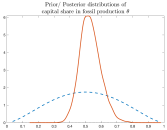
Shock decomposition and estimation

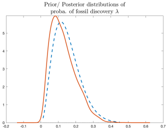
	Parameters	Post. mean
ε_y	Elasticity Machine/Labor	0.701
ε_e	Elasticity Energy/Capital	0.235
ε_f	Elasticity Fossil/Renewable	1.59
φ	Inverse Frisch elasticity	1.73
ν	Cost elasticity of fossil production	5.45
ν^f	Cost elasticity of renewable production	6.50
θ	Capital intensity of energy	0.55
λ	Lags in energy production	0.12

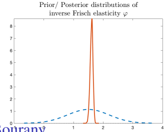
Shocks		Contrib. to $\mathbb{V}\mathrm{ar}(Y_t)$
Z_t	TFP/ Efficiency wedge	64.1%
$\tau_t^\ell, \tau_t^i, \tau_t^g$	Labor/invest/mkt wedges	27.1%
$Z_t^e, E_t^{row}, \xi_t^e, \xi_t^p$	Energy shocks	37%

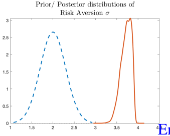


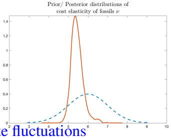


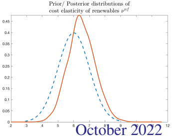












Comments and lessons

- Energy shocks as important drivers of business cycles fluctuations :
  - Contribute to $> 30\%$ of variance of aggregate production
  - Elasticity of energy < 0.2 : Production function is close to Leontieff.
  - Mostly through firm energy and investment decisions

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- 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 too large contributor to business cycles.
- Question : which feature of the model represents the most relevant transmission mechanisms ?
  - Nominal rigidities and aggregate demand channel
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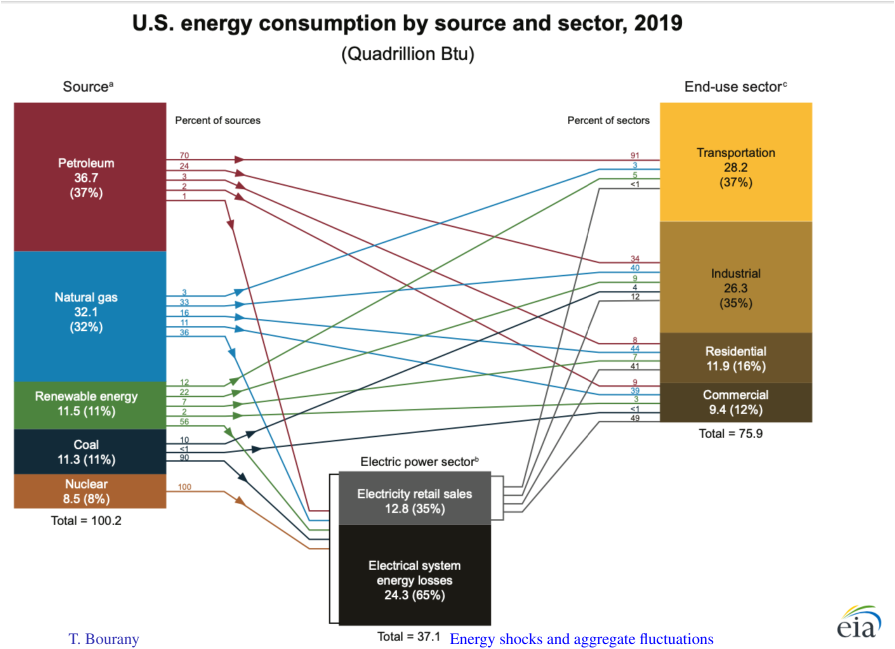
  - Large share of TFP/efficiency wedge : may imply that sectoral allocation matters
  - Chari Kehoe McGrattan (2007) : generate efficiency wedge from input/output frictions
  - Direct effect on consumption
  - Heterogeneous effects on Households (spender/saver model)


U.S. energy consumption by source and sector, 2019
(Quadrillion Btu)
Source[a]
Percent of sources
Petroleum 36.7 (37%)
Natural gas 32.1 (32%)
Renewable energy 11.5 (11%)
Coal 11.3 (11%)
Nuclear 8.5 (8%)
Total = 100.2
End-use sector[c]
Percent of sectors
Transportation 28.2 (37%)
Industrial 26.3 (35%)
Residential 11.9 (16%)
Commercial 9.4 (12%)
Total = 75.9
Electric power sector[b]
Electricity retail sales 12.8 (35%)
Electrical system energy losses 24.3 (65%)
Total = 37.1
eia

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

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

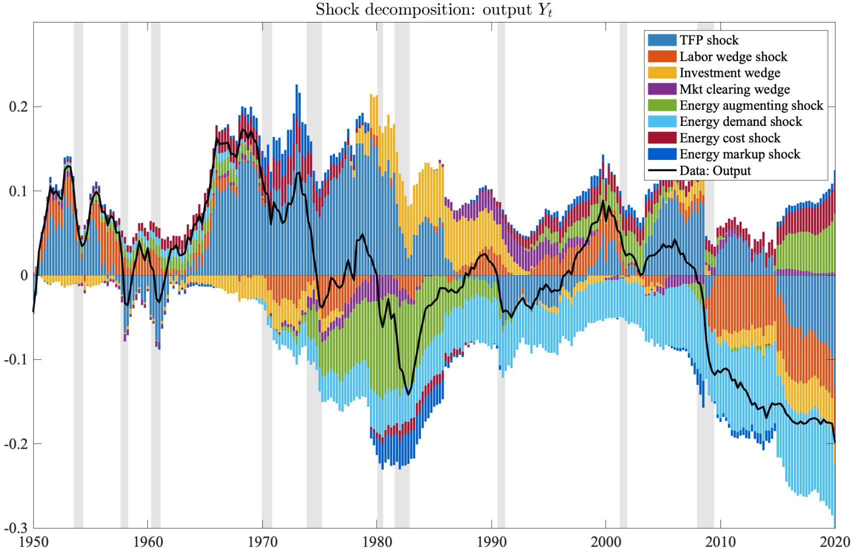
$$\max_{\{C_j, L_j, E_r, E_d\}_j} \mathbb{E}_{t_0} \sum_t \beta^t \left(\log(C) + V(R, E_r) + V(D, E_d) - \psi \left(\sum_j L_j\right)^{\frac{\varphi}{\varphi+1}}\right)$$

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

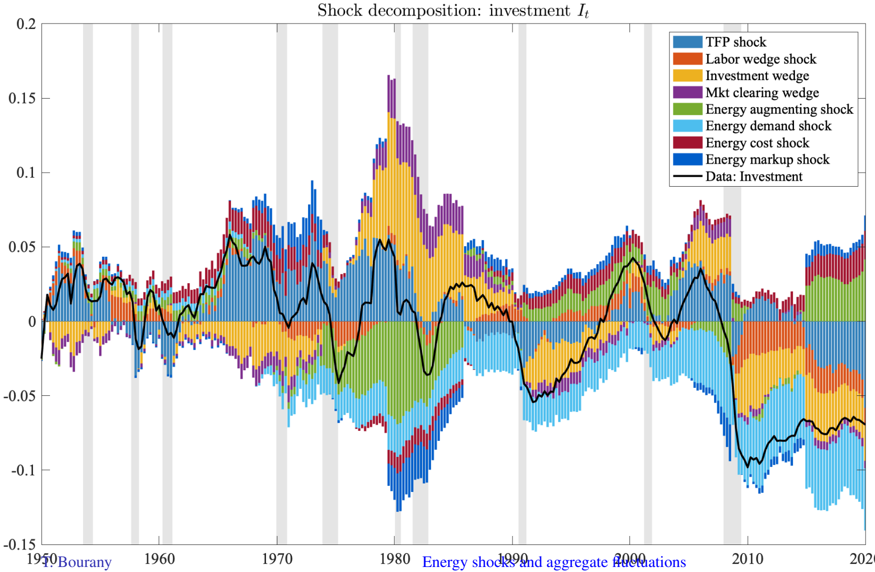
Conclusion and future paths

- 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)

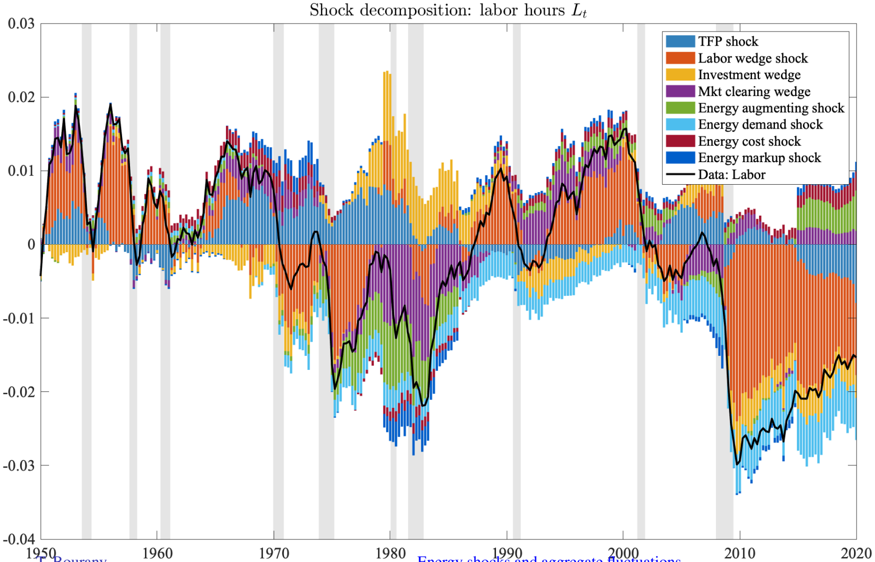
Shocks decomposition - energy shocks and output



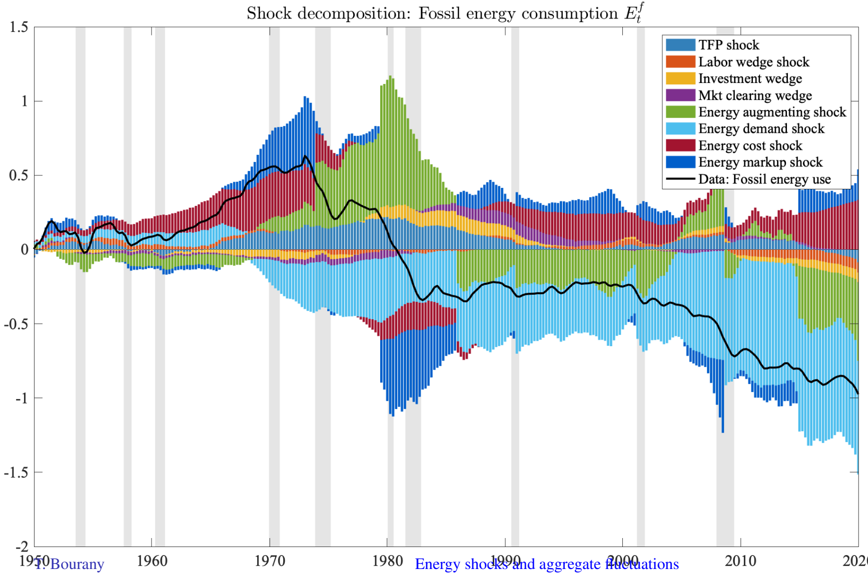
Shocks decomposition - energy shocks and investment



Shocks decomposition - energy shocks and labor



Shocks decomposition - energy shocks and energy use of fossils



Shocks decomposition - energy shocks and fossil price