A Heterogeneous Agents Model of Energy Consumption and Energy Conservation

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[1]Czech National Bank, The views expressed herein are those of the authors and do not necessarily reflect the view of the Czech National Bank

- In this paper we study *energy price shocks - monetary policy-energy conservation* nexus in a heterogeneous framework
- Both energy price shocks and monetary policy affect different groups of households differently
  - what are the main channels of distributional effects of monetary policy? Based on HFCS Slacalek et al. (2020): IES, somewhat smaller net interest rate exposure; large indirect effect through labour market
  - heterogeneity in energy consumption: share of raw energy expenditures in household consumption differs with the households' income Figure
- Investment into abatement capital can have stimulative effect on economic growth
- Abatement and distributional aspects amplify (change) propagation of monetary policy in response to energy price shocks

Incremental contribution

- We study how inflation targeting monetary policy influences households' energy conservation decisions
  - it builds resilience to energy price fluctuations
  - the qualitative conclusions can be extended to wide range of products, e.g. fuel consumption
- We further consider several types of monetary policy responses to energy price shocks
  - the persistence and the "shape" of energy price shocks are important
  - we study how each type of policy affects energy savings and each agent's consumption
  - there is a trade-off between stimulating investment and reducing inflation

Literature

- There is a growing literature on heterogeneous agents and distributional effects of monetary policy:
  - empirical work: e.g. Slacalek et al. (2020);
  - theoretical framework with endogenous labour market: Challe et al. (2017), Ravn and Sterk (2021);
- We relate to studies on monetary policy reaction to energy price shocks, Natal (2012), Kormilitsina (2011):
  - but we add abatement and distributional effects;
- We relate to the general equilibrium models of energy consumption and emissions:
  - Varga et al. (2022), Campiglio et al. (2022), Kiuila and Rutherford (2013)
  - they formulate abatement capital and costs in terms of reducing emissions
- and we somewhat relate to the literature on effects of transmission to renewable energy on economic growth
  - Pradhan and Ghosh (2022), Dogan et al. (2020), or Chica-Olmo et al. (2020)
  - there is no consensus so far

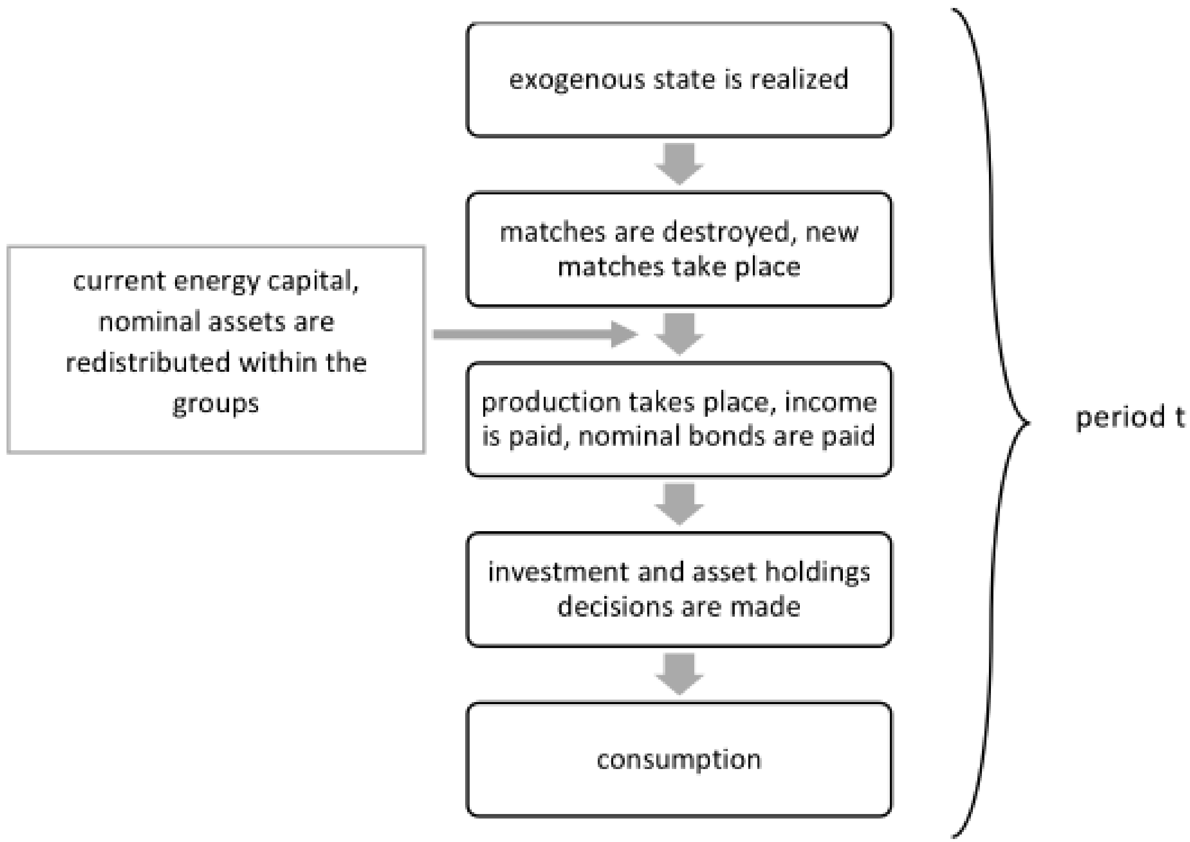
Model overview

- We incorporate search and matching frictions into the labour market, with endogenous labour market tightness
  - Nash bargaining, vacancy costs, exogenous separation rate
- Households: employed, unemployed, firm owners (out of the labour-force) Equations
  - consume non-energy and energy goods (CES aggregator)
  - supply labour (inelastically) or earn firms
  - invest into abatement capital, physical capital (firm owners), nominal assets
- Firms : Equations
  - use energy, labour and physical capital to produce non-energy goods
- Government: provides unemployment benefits and collect taxes
- Central bank: conducts monetary policy in response to the deviations of *policy* inflation (and/or output)

Key assumptions

- We employ assumption from Challe et al. (2017) of perfect risk-sharing among the *employed workers*.
  - households are grouped in identical families, a "planner" optimizes family wealth and redistributes (averages) nominal assets among the employed workers
  - Guess-and-verify first period unemployed do not "save their savings". The borrowing limits for unemployed workers is zero
- We adopt a similar assumption to holdings of abatement capital details
  - employed and unemployed workers live in separate "residencies" and move between the residencies when their employment status changes
  - workers can not take their abatement capital with them, which is taken by the state
  - new-movers to every residence receive from the state the average in this residence amount of abatement capital
- The abatement capital is produced domestically

Timeline


exogenous state is realized
matches are destroyed, new matches take place
current energy capital, nominal assets are redistributed within the groups
production takes place, income is paid, nominal bonds are paid
investment and asset holdings decisions are made
consumption
period t

- Parameters in policy rules are constant!

$$\frac{R_t}{\bar{R}} = \left(\frac{R_{t-1}}{\bar{R}}\right)^{\rho_r} \left[\left(\frac{E_t \Pi^p_{t+1}}{\bar{\Pi}}\right)^{\phi_\pi} \left(\frac{E_t y_{t+1}}{\bar{y}}\right)^{\phi_y} \right]^{1-\rho_r} \epsilon^r_t .$$

$$E_t \Pi^p_{t+1} = (E_t \Pi^c_{t+1})^{1-\phi_e} (E_t \Pi^e_{t+1})^{\phi_e} .$$

- Economy is initially in the steady state
- Model is linearised around the steady state
- Inflation expectations are perfectly anchored

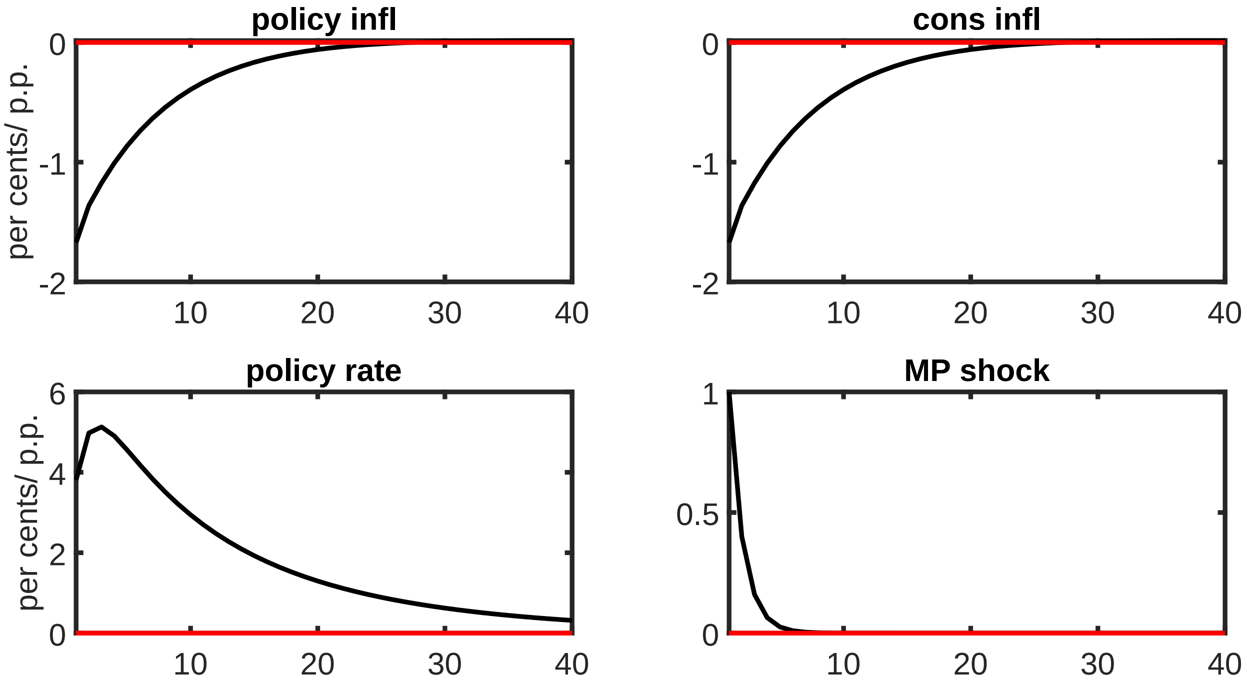
Baseline policy rule: $\phi_y = 0$, $\phi_\pi = 2$.

- MP shock

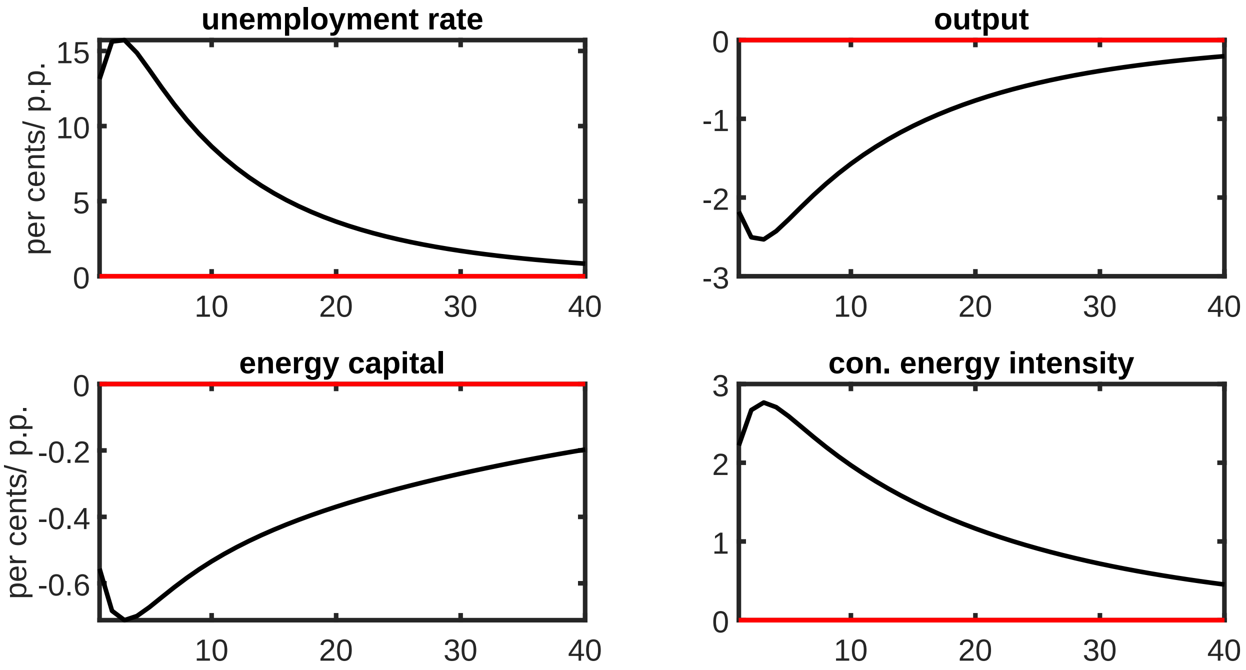
- expected energy price shock

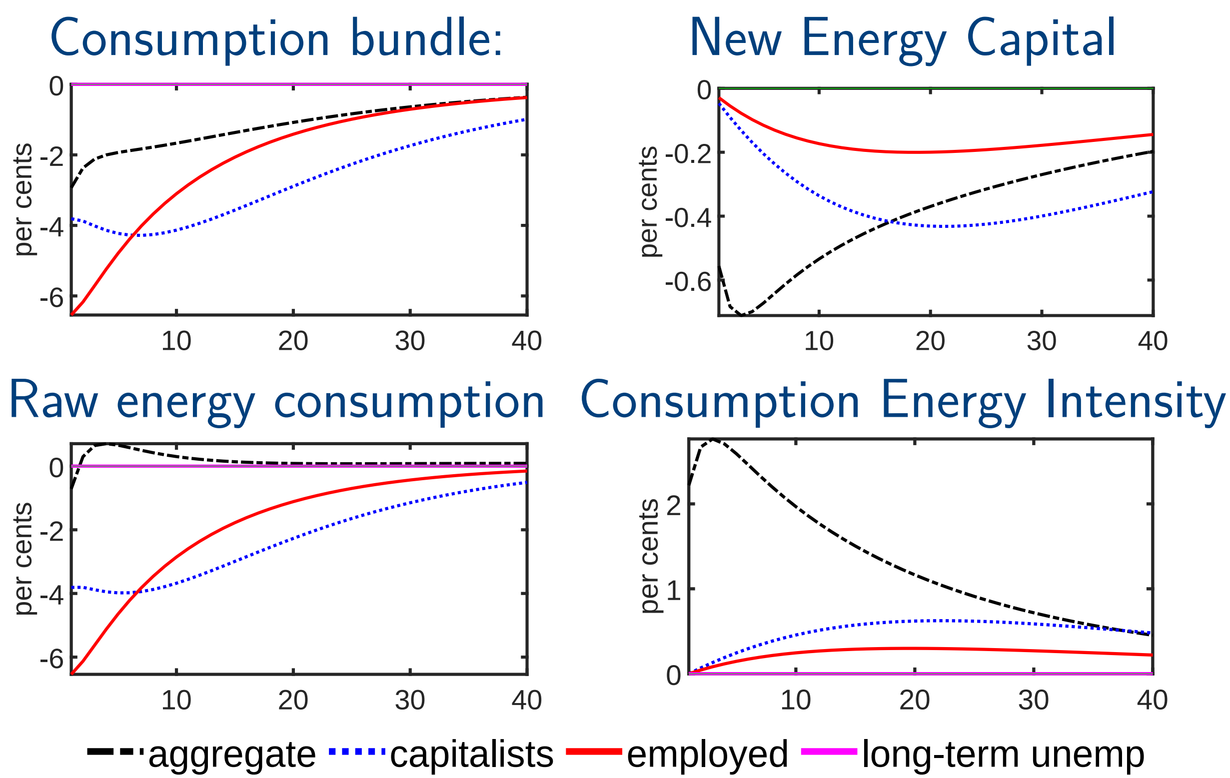
Policy simulations Simulations Simulations2

Monetary policy shock: baseline policy rule



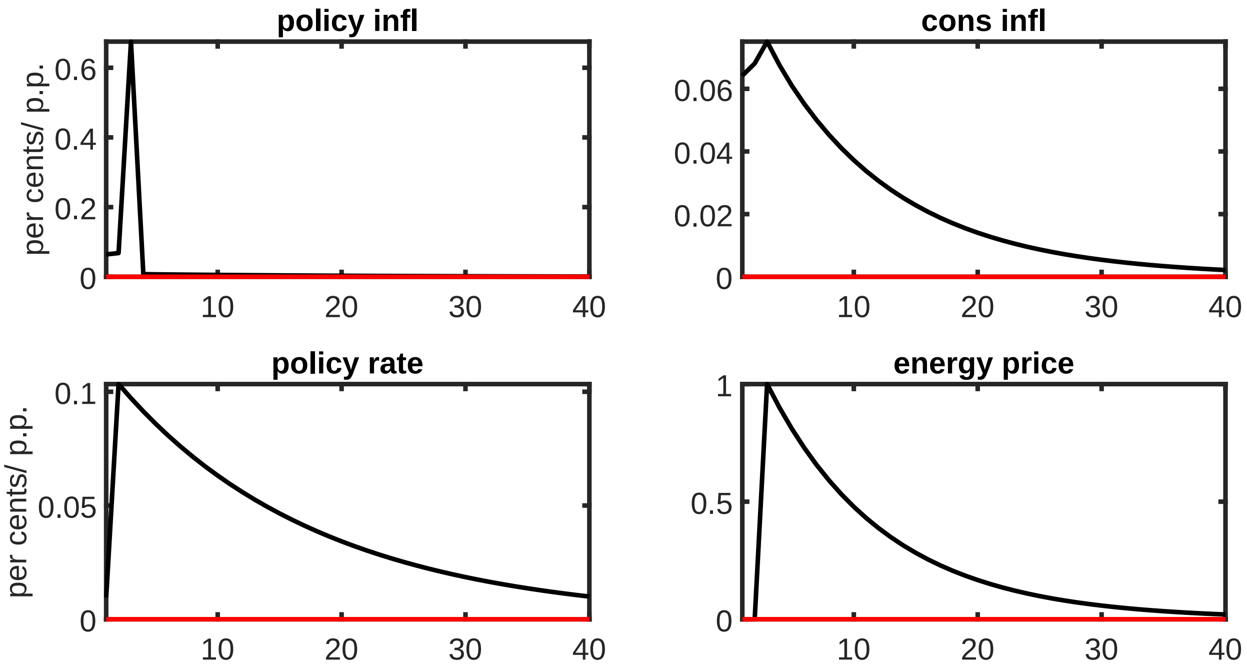
Monetary policy shock: baseline policy rule II





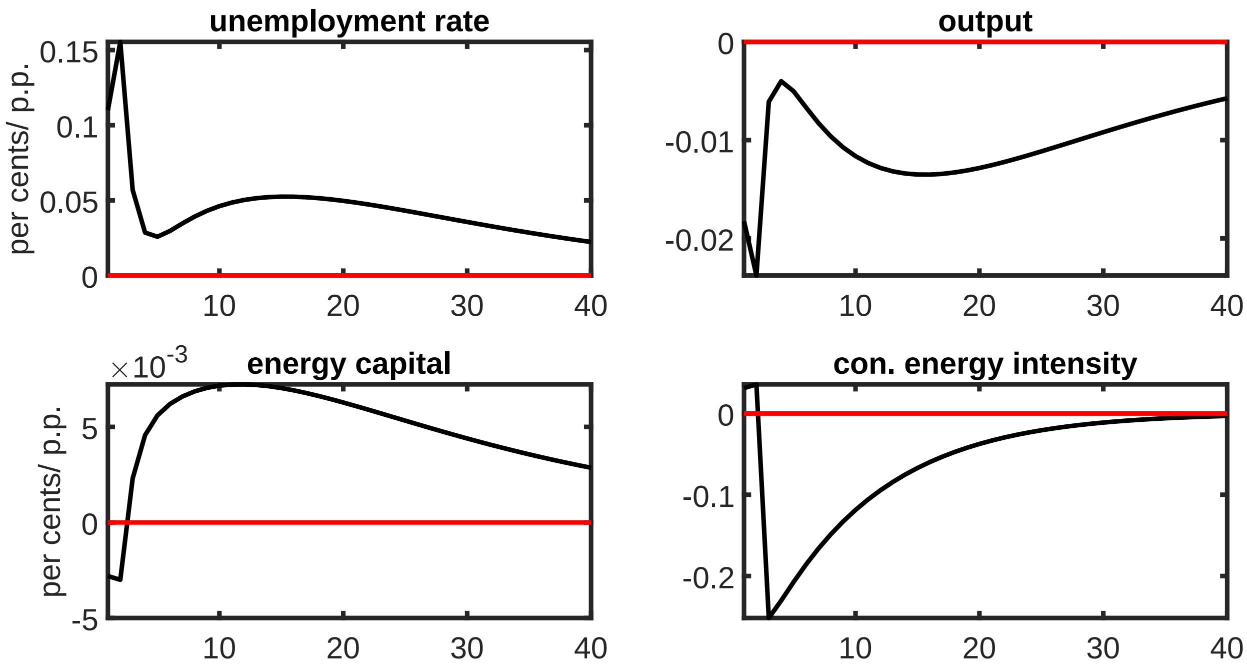
Consumption bundle:
New Energy Capital
Raw energy consumption
Consumption Energy Intensity
per cents
0
-2
-4
-6
10
20
30
40
0
-0.2
-0.4
-0.6
0
-2
-4
-6
2
1
0
aggregate
capitalists
employed
long-term unemp

Plan


policy infl
per cents/ p.p.
0.6
0.4
0.2
0
10
20
30
40
cons infl
0.06
0.04
0.02
0
10
20
30
40
policy rate
per cents/ p.p.
0.1
0.05
0
10
20
30
40
energy price
1
0.5
0
10
20
30
40

Plan

Expected energy price shock: baseline policy rule



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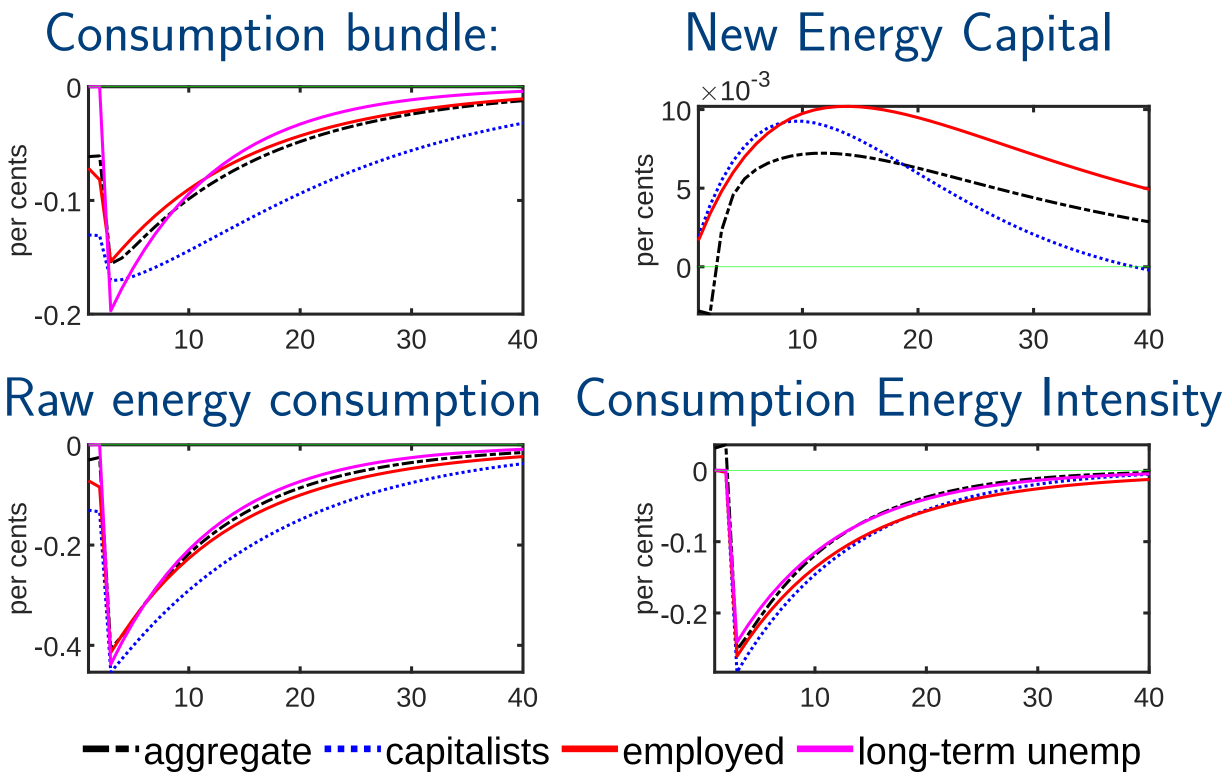
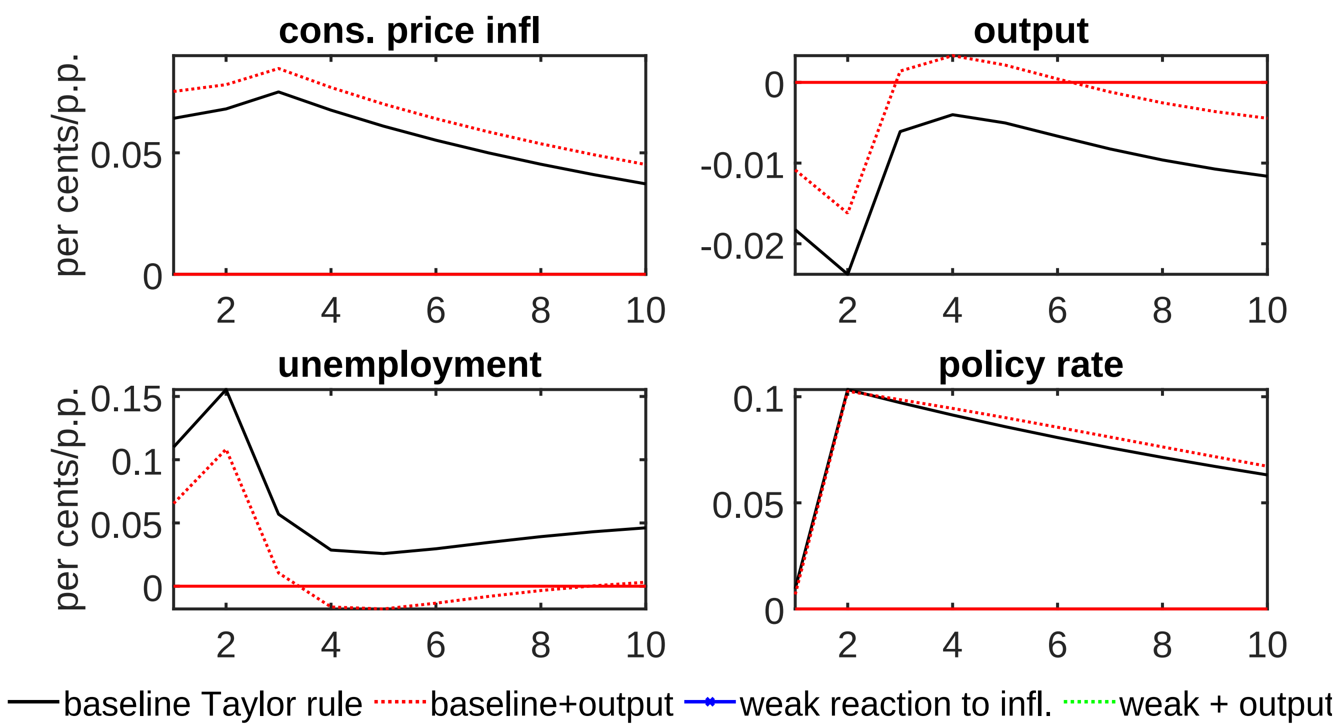
Energy price shock: distributional effects



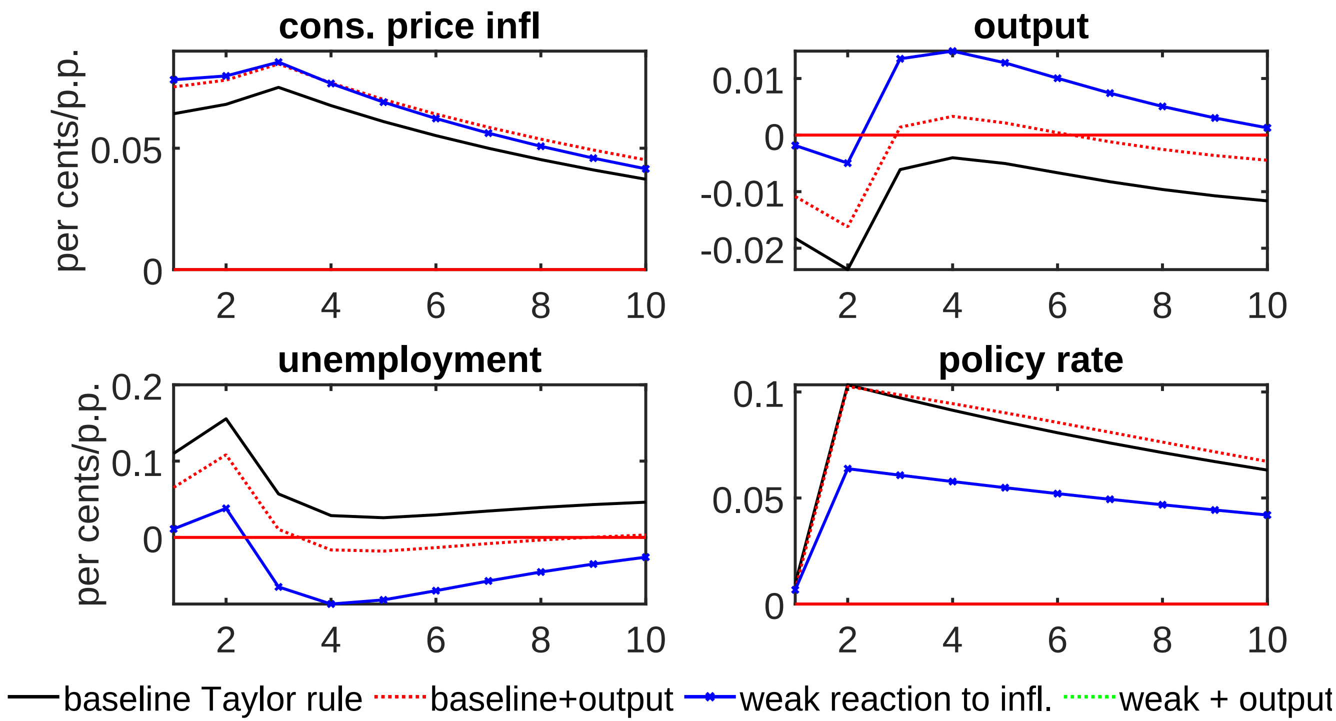
Plan

Policy Simulations



Plan

Policy Simulations



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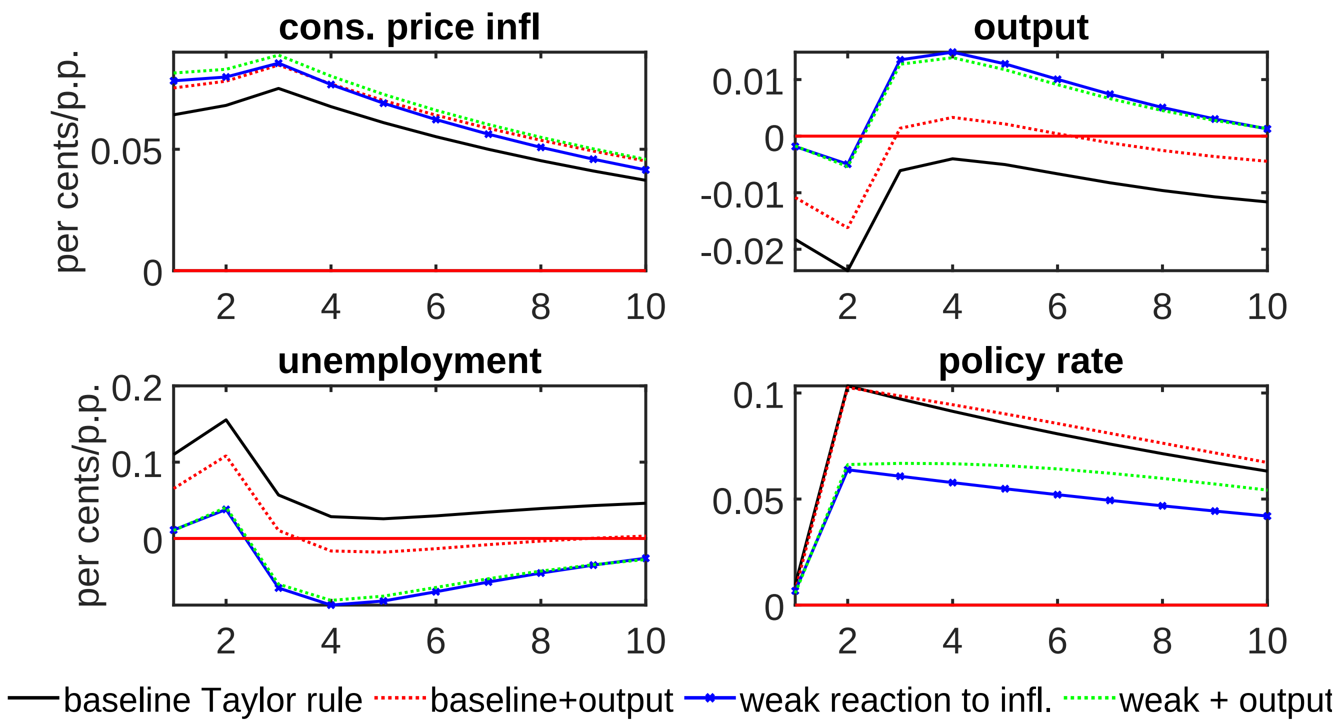

cons. price infl
output
unemployment
policy rate
per cents/p.p.
per cents/p.p.
0.05
0
0.01
0
-0.01
-0.02
0.2
0.1
0
0.1
0.05
0
2
4
6
8
10
baseline Taylor rule
baseline+output
weak reaction to infl.
weak + output

Policy Simulations

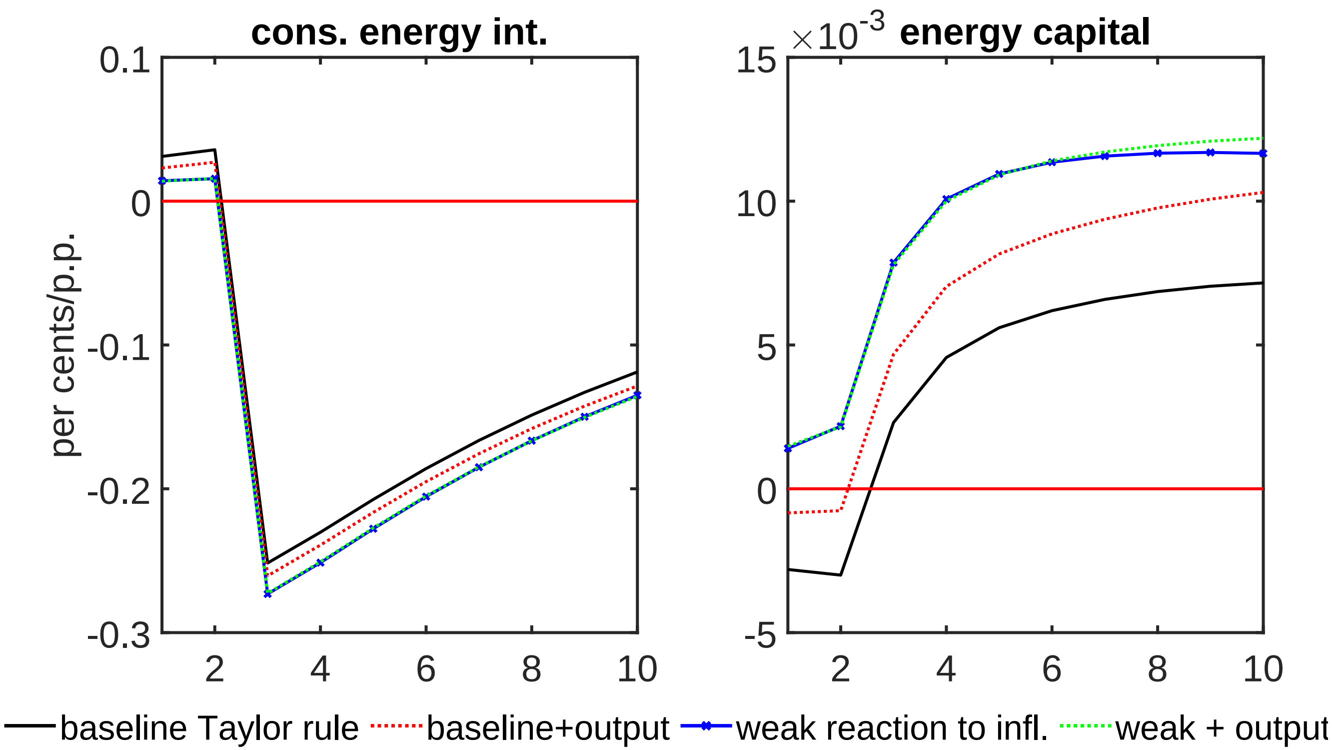
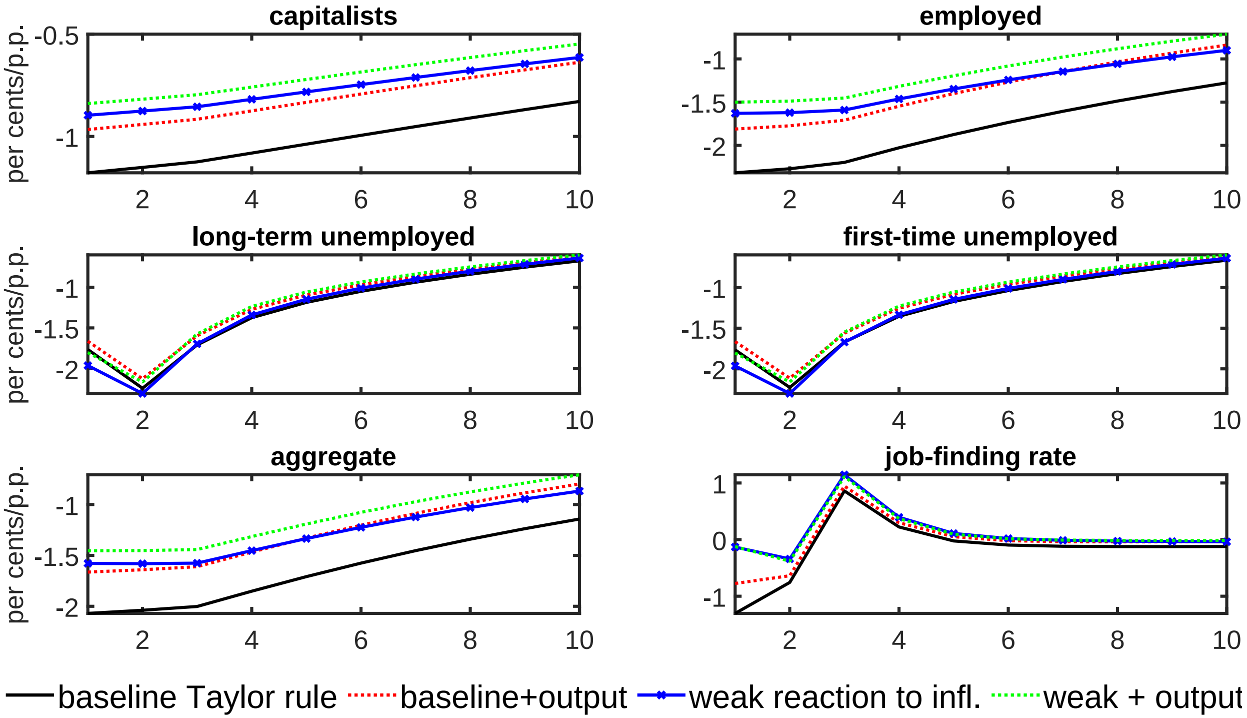


Figure: Policy Responses: Welfare, 1% Expected Energy Price Shock



Conclusions

- Monetary policy has an effect on investment in energy price resilience capital through:
  - direct effect by influencing returns on other assets
  - indirect, labour market, effect by changing the number of HtM
- An expected energy price shock increases investment into energy saving capital, which
  - can stimulate domestic production
  - insulate the economy against the energy prices fluctuations
- Too restrictive monetary policy in response to the energy price shock dampens investment into abatement capital
- It is up to fiscal authority to stimulate energy conservation

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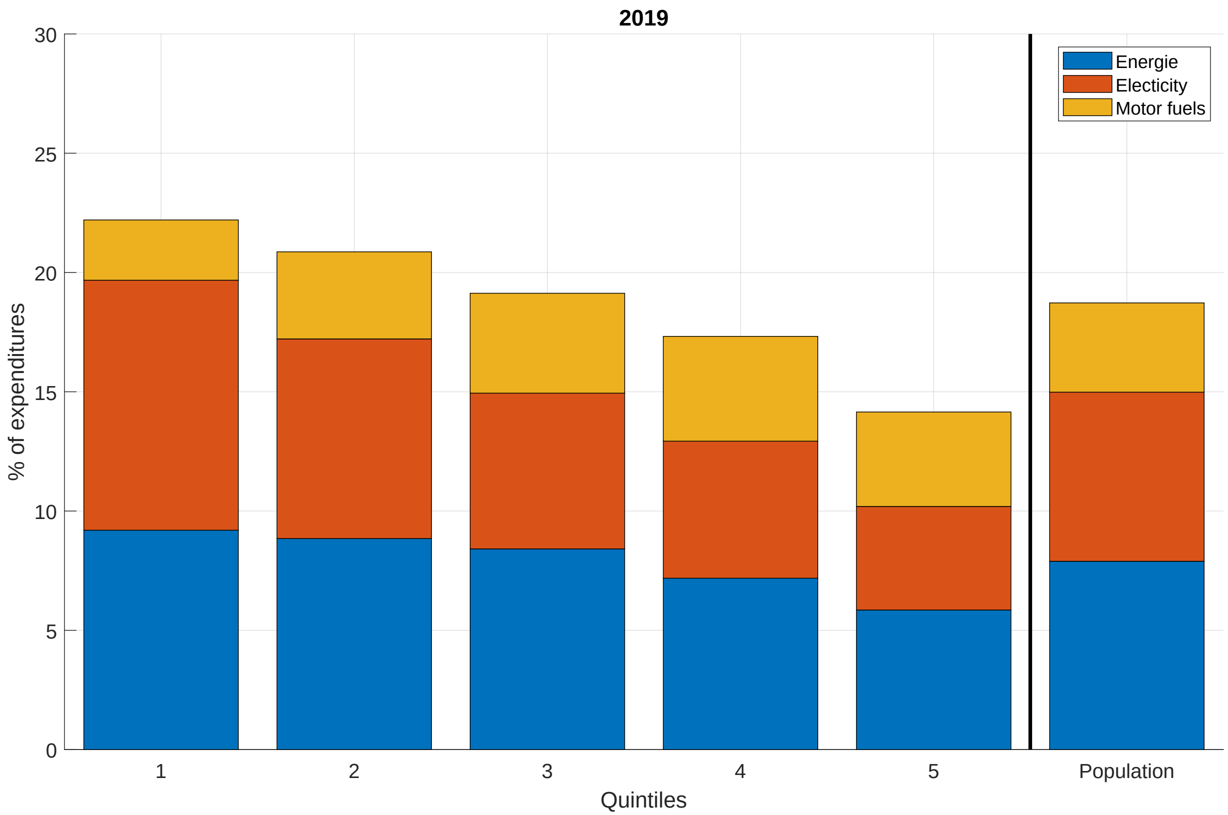
Share of energy in HH expenditures



Motivation

Each household maximizes the following utility subject to their expected employment status.

$$U_t(h) \equiv E_t \sum_{j=0}^{\infty} \beta^j \frac{\mathbb{C}_{t+j}(h)^{1-\mu}}{1-\mu}, \quad (1)$$

μ - relative risk aversion; $\mathbb{C}$ - composite consumption good; E^s - energy services; C - non-energy consumption good. The composite consumption good is:

$$\mathbb{C}_t(h) = \left[(1-\phi_e)^{\frac{1}{\lambda_e}} C_t(h)^{\frac{\lambda_e - 1}{\lambda_e}} + \phi_e^{\frac{1}{\lambda_e}} E_t^s(h)^{\frac{\lambda_e - 1}{\lambda_e}}\right]^{\frac{\lambda_e}{\lambda_e - 1}}, \quad (2)$$

$$E_t^s(h) = f(K_{h,t-1}^e) E^r(h)_t = \frac{\psi}{2}(K_{h,t-1}^e)^2 E^r(h)_t, \quad (3)$$

Model

Households: employed, unemployed, firm owners (out of the labour-fource)

Budget constraint:

- revenue side: for employed household nominal wage $(1-\tau)W_t$, for unemployed nominal benefits $P_t W_{\mu,t}$, for a firm owner - dividends and return on capital $(1-\tau)Rev$; return on bonds B_{t-1};
- expenditure side: consumption of goods and raw energy, C_t and E_t^r; nominal bond holdings B_t, investment into capital I_t and into abatement capital I_t^e, adjustment costs, $P_t^I = P_t$ is price of a domestically produced good.

Denoting after tax household income $\tilde{W}$:

$$P_t C_t + P_t^e E_t^r + B_t + P_t^I I_t (1 + S[I_t, I_{t-1}]) + P_t^I I_t^e (1 + S[I_t^e, I_{t-1}^e]) \leq \tilde{W}_t + R_t B_{t-1} \quad (4)$$

Model

Monopolistic competition, Rotemberg pricing tradition, production function:

$$Y_t = min\left[\frac{1}{1-\rho_o}A_t N_t^{1-\gamma_k} K_{t-1}^{\gamma_k}, \frac{1}{\rho_o}E_t^{rp}\right] \tag{5}$$

Competitive final good producer, first-order conditions:

$$Y_t(i) = \left(\frac{P_t(i)}{P_t}\right)^{-\gamma} Y_t, \tag{6}$$

Model

Nominal assets are average among employed workers:

$$\tilde{b}_{e,t} = \frac{1}{e_t} \left[(1 - \omega (1 - \eta_t))\, e_{t-1} b_{e,t-1} + \eta_t u_{t-1} \cdot 0 \right]. \tag{7}$$

The abatement capital is the same within the workers' employment status :

$$\tilde{k}^e_{u,t} = \bar{k}^e_u, \tag{8}$$

$$\tilde{k}^e_{e,t} = k^e_{e,t-1}. \tag{9}$$

Back

- employed workers:

$$P_tC_t + B_t + P_t^eE_t^r + P_t^II_t^e \leq (1-\tau)W_t + R_tB_{t-1}, \tag{10}$$
$$I_t^e = k_{e,t}^e - (1-\delta_e)\tilde{k}_{e,t}^e; \tag{11}$$

- poor HtM: first period unemployed

$$P_tC_t + P_t^eE_t^r + P_t^II_t^e \leq P_tW_{\mu,t} + R_tB_{t-1}, \tag{12}$$
$$I_t^e = \delta_e\tilde{k}_{u,t}^e; \tag{13}$$

unemployed for longer than 1 period

$$P_tC_t + P_t^eE_t^r + P_t^II_t^e \leq P_tW_{\mu,t}, \tag{14}$$
$$I_t^e = \delta_e\tilde{k}_{u,t}^e; \tag{15}$$

- rich HtM: firm owners

$$P_tC_t + B_t^c + P_t^eE_t^r + P_t^II_t^e + P_t^II_t \leq (1-\tau)Rev_t + R_tB_{t-1}^c, \tag{16}$$
$$I_t^e = k_{c,t}^e - (1-\delta_e)k_{c,t-1}^e, \tag{17}$$
$$I_t = k_t - (1-\delta_e)k_{t-1}, \tag{18}$$
$$B_t^c = \bar{b} < 0. \tag{19}$$