Optimal Monetary Policy during a Cost-of-Living Crisis

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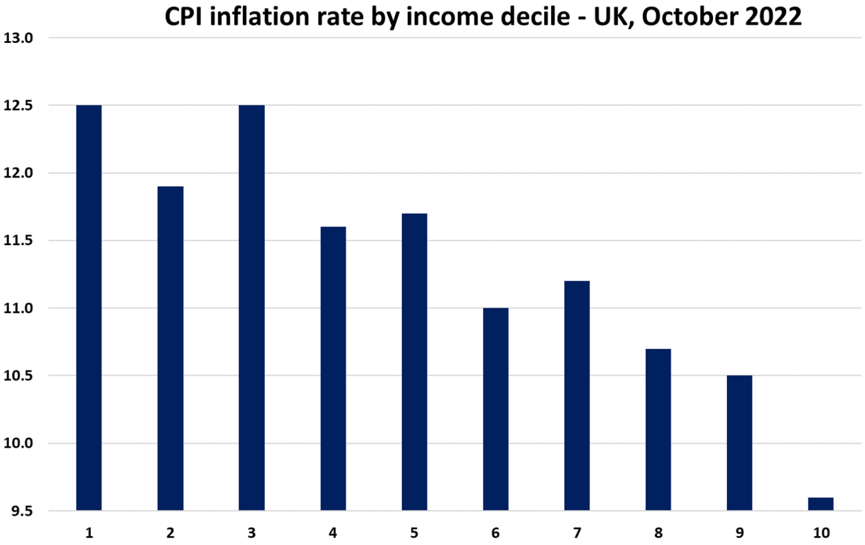
Cost-of-Living Crisis



Source: ONS.

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- Generalized, non-homothetic preferences
  - heterogeneous consumption baskets, inflation rates, real interest rates, real wages
  - heterogeneous demand elasticities

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2) Analytical characterisation (“sufficient statistics”)

- NKPC wedges
- additional price index: *Marginal* CPI
- transmission of sectoral shocks (necessity vs luxury)

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3) Optimal policy

Literature

Households

Unit mass of households, indexed by i. Die with probability δ. Idiosyncratic productivity level $\theta(i)$. Born with some initial level of wealth, $b(i)$.

K goods sectors, indexed by $k = 1, 2, ...$ Continuum of symmetric varieties within each sector, indexed by j.

Utility:

$$\mathbb{E}_t \sum_{s=0}^{\infty} (\beta(1-\delta))^{t+s} \left(U(\mathbf{c}_{t+s}(i)) - \chi(n_{t+s}(i)/\theta(i)) \right)$$

where

$$U(\mathbf{c}) = U(\mathcal{U}_1(\mathbf{c^1}), ..., \mathcal{U}_K(\mathbf{c^K}))$$

- *Outer* utility function U is weakly separable in products produced in different sectors, and twice differentiable.
- *Inner* utility function $\mathcal{U}_k$ is concave, symmetric and twice Fréchet differentiable.

Households

- Households decide on consumption, labour supply and bond holdings.
- Budget constraint household i:

$$e_t(i) + b_t(i) = R_{t-1} b_{t-1}(i) + n_t(i) W_t + \sum_k \varsigma(i) div_{k,t},$$

where $e_t(i) = \sum_k e_{k,t}(i) = \sum_k \int_0^1 p_{k,t}(j) c_{k,t}(i,j) di$.

Hand-to-Mouth households

- Within each household "type", a fraction of households lives hand-to-mouth, setting $b_t(i) = b_{t-1}(i)$.
- Presence of HtM households may vary across distribution, can be flexibly calibrated.

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Cross-price elasticity:	$\rho_{k,l}(i) = \frac{\partial c_k(i)}{\partial P_l} \frac{P_l}{c_k(i)}$	$\bar{\rho}_{k,l} = \frac{\partial C_k}{\partial P_l} \frac{P_l}{C_k}$

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Demand elasticity:	$\epsilon_k(i) = -\frac{\partial c_k(i,j)}{\partial p_k(j)} \frac{p_k(j)}{c_k(i,j)}$	$\bar{\epsilon}_k = \int \frac{e_k(i)}{E_k} \epsilon_k(i) di$

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Super-elasticity:	$\epsilon_k^s(i) = \frac{\partial \epsilon_k(i)}{\partial p_k(j)} \frac{p_k(j)}{\epsilon_k(i)}$	$\bar{\epsilon}_k^s = \frac{\partial \bar{\epsilon}_k}{\partial p_k(j)} \frac{p_k(j)}{\bar{\epsilon}_k}$

Firms

- Monopolistically competitive. Maximize expected PV of profits.
- Can adjust their price only with probability $1 - \theta_k$.
- Production function, allowing for I-O linkages:

$$y_{k,t}(j) = A_{k,t} F_k(n_{k,t}(j), \tilde{Y}_{1,k,t}(j), .., \tilde{Y}_{K,k,t}(j))$$

  - aggregate + sectoral productivity shocks
- Demand constraint:

$$y_{k,t}(j) = \int_0^1 d_k \left(p_{k,t}(j), \mathbf{p}_{k,t}, e_{k,t}(i)\right) di + \tilde{d}_k \left(p_{k,t}(j), \mathbf{p}_{k,t}, \right) \tilde{Y}_{k,t}.$$

Government & Market clearing

- Fiscal policy eliminates steady-state markups.
- Monetary policy rule:

$$\hat{R}_t = \phi \pi_{cpi,t} + u_t^R.$$

  alternatively: optimal policy

- Markets for goods, bonds and labor clear.
- Deceased households are replaced by their steady-state versions

Output gap

Case without HtM

Output gap:

$$\tilde{\mathcal{Y}}_t = \mathbb{E}_t \tilde{\mathcal{Y}}_{t+1} - \sigma \mathbb{E}_t \left(\hat{R}_t - \pi_{mcpi,t+1} - \hat{r}_t^* \right)$$

where $\pi_{mpci,t} \equiv \sum_k \overline{\partial_e e_k} \pi_{k,t}$ is the *Marginal* CPI index.

New Keynesian Phillips Curve

sector k, no I-O linkages

$$\pi_{k,t} = \kappa_k \tilde{\mathcal{Y}}_t + \lambda_k \left(\mathcal{NH}_t + \mathcal{M}_{k,t} - \mathcal{P}_{k,t} \right) + \beta \mathbb{E}_t \pi_{k,t+1},$$

$$\tilde{\mathcal{Y}}_t = \hat{\mathcal{Y}}_t - \hat{\mathcal{Y}}_t^*, \qquad \text{(Output gap)}$$

$$\mathcal{NH}_t = \sum_l (\overline{\partial_e e_l} - \bar{s}_l)(\hat{P}_{l,t} - \hat{P}_{l,t}^*), \qquad \text{(Non-homotheticity wedge)}$$

$$\mathcal{M}_{k,t} = \int \gamma_{e,k}(i) \frac{c_k(i)}{C_k} \hat{c}_{k,t}(i) di - \Gamma_k \tilde{\mathcal{Y}}_t, \qquad \text{(Endogenous markup wedge)}$$

$$\mathcal{P}_{k,t} = (\hat{P}_{k,t} - \hat{P}_{cpi,t}) - (\hat{P}_{k,t}^* - \hat{P}_{cpi,t}^*), \qquad \text{(Relative price wedge)}$$

Homotheticity: $\overline{\partial_e e_l} - \bar{s}_l = \mathcal{NH}_t = 0$

CES: $\gamma_{e,k}(j) = \Gamma_k = \mathcal{M}_{k,t} = 0$

Non-Homotheticity wedge

Intuition

- Workers consider on which goods they spend *at the margin*.

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- Labor supply optimally increases following an increase in the *relative* price of necessities:

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- Following a negative shock to necessities, price stickiness dampens relative increase in necessity prices.
  - negative output gap.

Endogenous markup wedge

Case without HtM

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$$\mathcal{M}_{k,t}^P = \sum_l \mathcal{S}_{k,l} \left(\hat{P}_{l,t} - \hat{P}_{k,t} \right)$$

$$\mathcal{M}_{k,t}^D = \mathbb{E}_t \mathcal{M}_{k,t+1}^D - \sum_l \sigma_{k,l}^{\mathcal{M}} (\hat{R}_t - \mathbb{E}_t \pi_{l,t+1}) - \frac{\delta}{1-\delta} \mathbb{E}_t \mathcal{M}_{k,t+1}^0$$

$$\mathcal{M}_{k,t-1}^0 = \frac{1}{(1-\delta)R} \mathbb{E}_t \mathcal{M}_{k,t}^0 + \int \gamma_{b,k}(i) \frac{b(i)}{RE} di \left(\hat{R}_{t-1} - \pi_{cpi,t} \right)$$
$$- \sum_l \int \gamma_{b,k}(i) \left(\frac{e(i)}{E} (s_l(i) - \bar{s}_l) + \frac{\psi W n(i)}{WN} (\partial_e e_l(i) - \overline{\partial_e e_l}) \right) di \hat{P}_{l,t-1}$$
$$- \frac{R-1}{R} \mathcal{M}_{k,t-1}^D$$

Policy insights: analytical results

Two simplifying assumptions:

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$\mathcal{NH}_t$, $\mathcal{M}_{k,t}$ *and* $\mathcal{P}_{k,t}$ *evolve independently of monetary policy.*

Result 2 (divine coincidence under CES preferences)
When $\mathcal{M}_{k,t} = 0$, *fluctuations in the output gap can be eliminated by stabilising the Marginal CPI index* $\pi_{mpci,t} \equiv \sum_k \overline{\partial_e e_k} \pi_{k,t}$.

$$\pi_{mcpi,t} = \kappa \tilde{\mathcal{Y}}_t + \beta \mathbb{E}_t \pi_{mcpi,t+1}.$$

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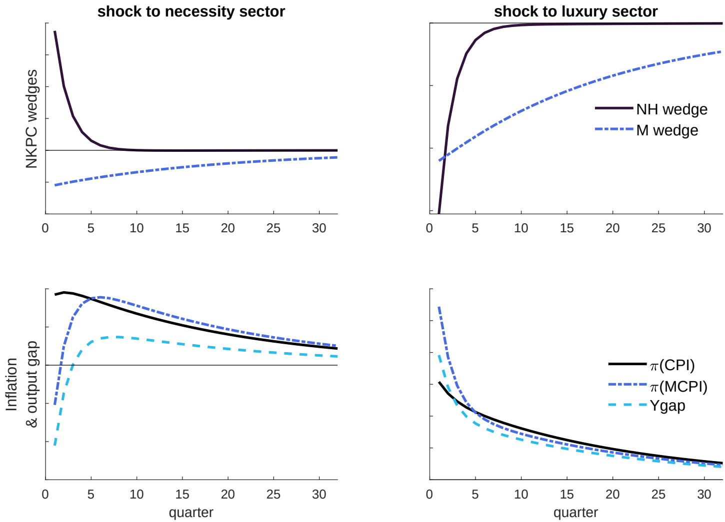
Result 3 (breakdown coincidence under non-CES preferences)
When $\mathcal{M}_{k,t} \neq 0$ there does not exist any inflation index which can be fully stabilised together with the output gap.

Illustration



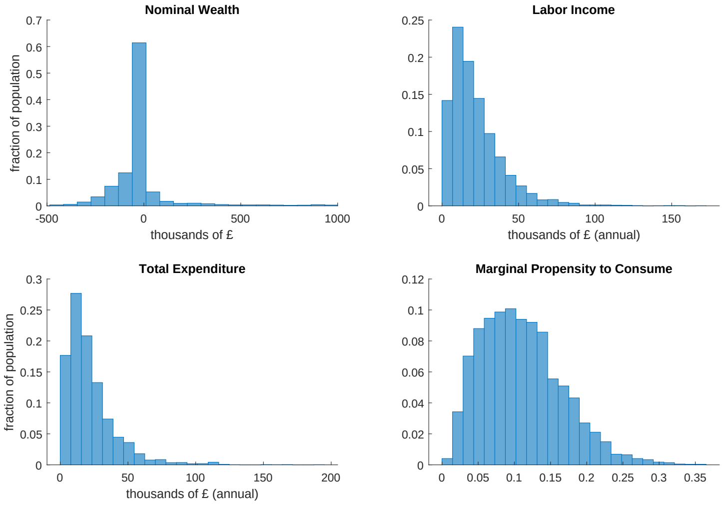
Model solution

The full model has a block-recursive structure:

- Can write as block of $5K+3$ core equations
  - keeps track of relevant distributional objects.
- Straightforward to solve for dynamics distributions and aggregates.
- Quantitative implementation: discipline with data from the Living Costs and Food (LCF) survey.

Full model (incl. I-O linkages and HtM households)

Steady-state distributions



Source: LCF. MPC's calibration based on UK evidence from Albuquerque and Green (2022).

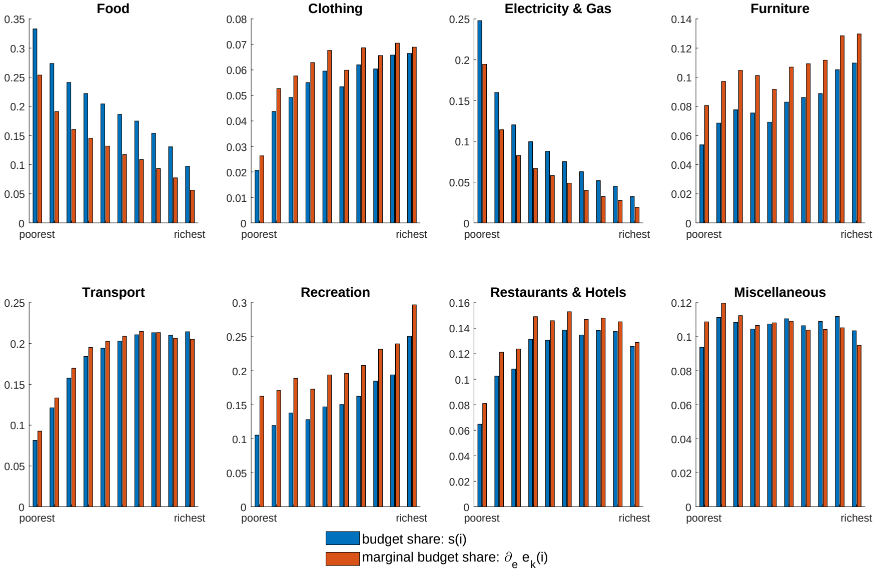
Outer utility

Following Comin et al. (2021), we assume a *non-homothetic CES* form:

$$\sum_{k=1}^{K} \mathcal{V}_k(i) \left(\frac{c_k(i)}{g(U(i))^{\zeta_k}} \right)^{\frac{\eta-1}{\eta}} = 1.$$

- Preference shifter: $\ln \mathcal{V}_k(i) = \beta_k x(i) + v_k(i)$,
- We set $\eta = 0.1$ and estimate ζ_k following Comin et al. (2021), but with data on household-level expenditures from the LCF for the years 2001-2019.
- We then compute distribution of marginal budget shares, $\partial_{ek}(i)$.

Budget shares



Inner utility

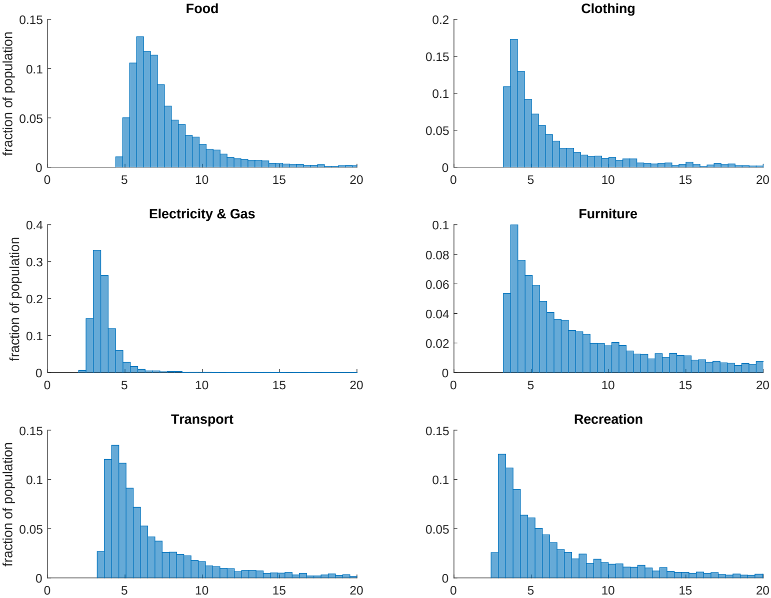
- Assume HARA form:

$$\epsilon_k(i) = a_k + \frac{b_k}{e_k(i)}.$$

- Calibrate $\{a_k, b_k\}_{k=1}^{K}$ to target (given the distribution of expenditures):
  - ONS estimates for markups by sector.
  - Average pass-through of 60 percent (Amiti et al., 2019).

Distribution of demand elasticities

histograms



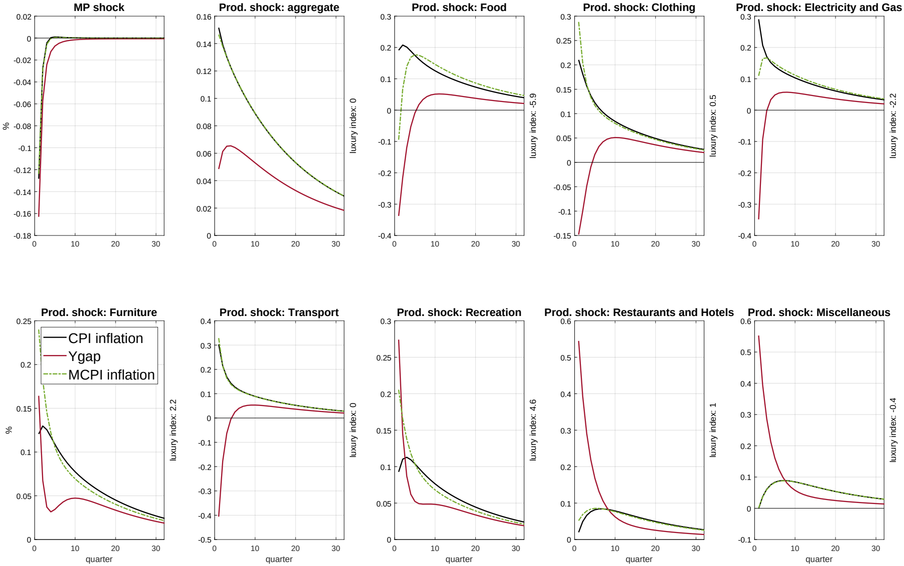
Parameter values

Parameter	description	value
β	subjective discount factor	0.99
ψ	Frisch elasticity	1
σ	elasticity of intertemporal substitution	1
δ	death probability	0.0083
ϕ	Taylor rule coefficient	1.5
η	cross-sector elasticity of substitution	0.1
ρ_R	persistence monetary policy shock	0.25
ρ_A	persistence productivity shocks	0.95

Notes: Model period: 1 quarter. Model calibrated to Input-Output matrix reported by the ONS. Calvo parameters target price durations reported by. Dixon and Tian (2017).

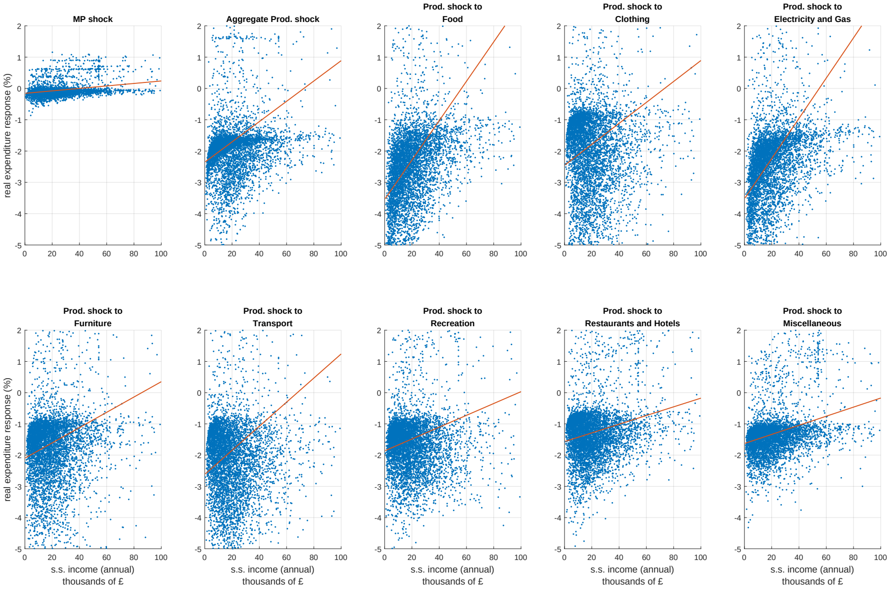
Responses to aggregate and sectoral shocks

Full model with IO linkages and HtM households



Effects across the distribution

Response of consumption in first year following the shock



Optimal monetary policy

Replace the rule for R_t by an optimizing CB who maximizes:

$$\mathcal{W} = \mathbb{E}\left(1-\delta\right)\int G(V^0(i), i)di + \delta \sum_{t_0=0}^{\infty} \beta^{t_0} \int G(V^{t_0}(i), i)di,$$

subject to all remaining model equations, where

$$V^{t_0}(i) = \sum_{s=0}^{\infty} \left(\left(1-\delta\right)\beta\right)^s \left(v\left(e_{t_0+s}^{t_0}(j), P_{1,t_0+s}, ..., P_{K,t_0+s}\right) - \chi\left(\frac{n_{t_0+s}^{t_0}(i)}{\theta(i)}\right)\right)$$

Social welfare function

Two assumptions:

i) CB treats steady-state inequality as efficient:

$$G'\left(V^{t_0}(i), i\right)\partial_e v\left(e(i), \hat{P}_1, ..., \hat{P}_K\right) = 1.$$

ii) CB weighs households' utility fluctuations equally:

$$G''\left(V_{ss}^{t_0}(i), i\right) = 0.$$

$\Rightarrow$ Dynamic welfare weight: $g(i) = \frac{E}{\psi\theta(j)Wn(i)+\sigma e(i)}$

Optimal policy: analytical results

under assumptions A.1-A.2

Result 7 (comparison to basic NK model):
If θ_k , $\bar{\epsilon}_k$ and $\bar{\epsilon}^s_k$ are equal across sectors, then the optimal policy problem can be expressed as:

$$\min_{\{\tilde{\mathcal{Y}}_t,\pi_{cpi,t}\}_{t=0}^{\infty}} \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left(\frac{\sigma+\psi}{\sigma\psi}\tilde{\mathcal{Y}}_t^2 + \tilde{\vartheta}\pi_{cpi,t}^2\right)$$

$$s.t.\ \pi_{cpi,t} = \kappa\tilde{\mathcal{Y}}_t + \beta(1-\delta)\mathbb{E}_t\pi_{cpi,t+1} + \lambda(\mathcal{M}_t + \mathcal{NH}_t),$$

where $\tilde{\vartheta} = \frac{\bar{\epsilon}\theta}{(1-\theta)(1-\beta\theta)}$, and where the wedges $\mathcal{M}_t \equiv \sum_{k=1}^{K} \bar{s}_k \mathcal{M}_{k,t}$ and $\mathcal{NH}_t$ evolve independently of monetary policy (Result 1).

→ heterogeneity matters for optimal policy!

Optimal policy

under assumptions A.1-A.2

Result 8 (dynamics under optimal policy)
The responses of the output gap and inflation to necessity and luxury shocks have the opposite sign under optimal policy, both in the short and in the medium run. The signs of the responses are summarised in the following table:

	Y gap	CPI	MCPI	NH wedge
Necessity shock (short run)	-	+	-	+
Necessity shock (medium run)	+	-	+	-
Luxury shock (short run)	+	-	+	-
Luxury shock (medium run)	-	+	-	+

Optimal policy

under assumptions A.1-A.2

Result 9 (comparison to strict CPI targeting)
Compared to a strict CPI targeting policy, the optimal policy is initially relatively loose (tight) following a negative necessity (luxury) shock, and relatively tight (loose) later on.

$\rightarrow$ Delayed tightening during a cost-of-living crisis

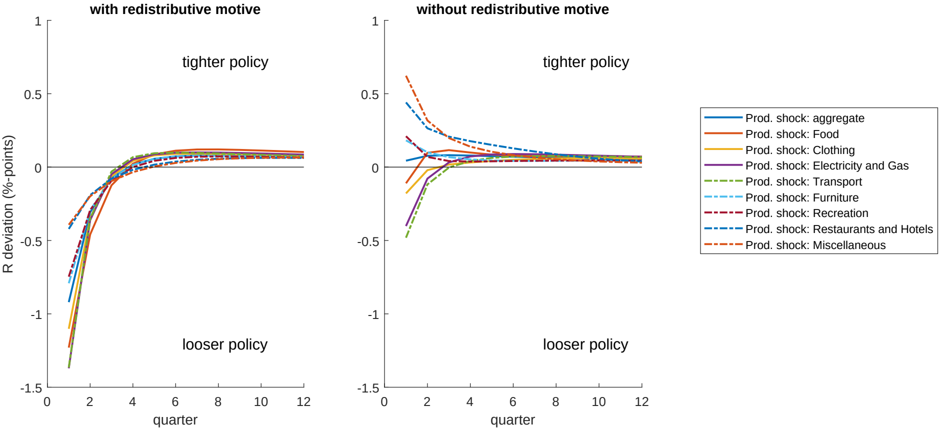
Optimal policy - full model

Including I-O linkages and HtM households

- Q. Is Optimal Policy looser or tighter than a rule $\hat{R}_t = \phi \pi_{cpi,t}$, in particular following necessity shocks?
- Idea: can implement optimal policy as an interest rule + "guidance" (=announced deviations from rule).
- Solve numerically for "guidance".

Optimal policy - full model

Including I-O linkages and HtM households



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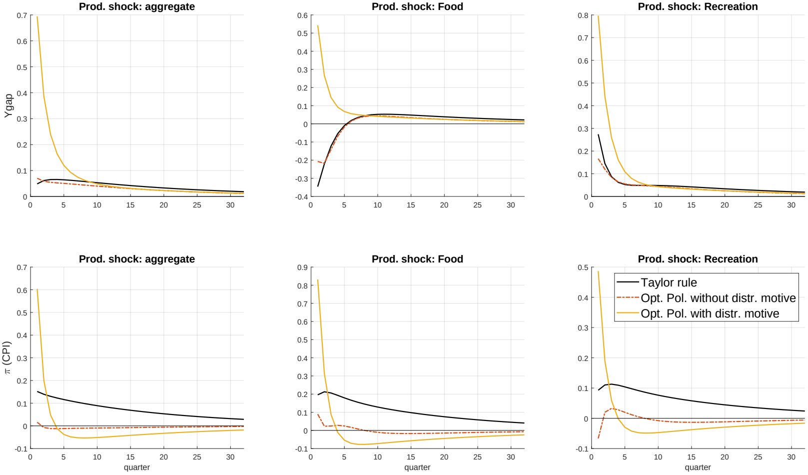

Conclusion

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- Productivity shocks turn into markup shocks
  - *but with rich dynamics governed by inequality*
  - *transmission highly dependent on sectoral source of the shock (necessity vs luxury)*

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  - *realistic heterogeneity in income, wealth and expenditures*
- Productivity shocks turn into markup shocks
  - *but with rich dynamics governed by inequality*
  - *transmission highly dependent on sectoral source of the shock (necessity vs luxury)*
- Emergence of *marginal* CPI as complementary metric for policy
- Optimal policy is relatively accommodative during cost-of-living crisis

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- **Multiple Sectors:** Pasten, R. and Weber (2020); Rubbo (2023); LaO and Tahbaz-Salehi (2019); Baqaee, Farhi and Sangani (2021); Guerrieri, Lorenzoni, Straub and Werning (2022), etc.
- **Heterogeneous households:** McKay, Nakamura and Steinsson (2016); Gornemann, Kuester and Nakajima (2016); Challe and Ragot (2016); Auclert (2019); Werning (2015); Kaplan, Moll and Violante (2017); Debortoli and Galí (2017); Bayer, Luetticke, Pham-Dao and Tjaden (2019), etc.
- **Non-homothetic preferences:** Portillo, Zanna, O'Connel and Peck (2016); Melcangi and Sterk (2019); Blanco and Diz (2021), etc.

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Literature

- **Non-homothetic preferences +**
  - **Growth:** Herrendorf, Rogerson and Valentinyi (2014); Boppart (2014); Comin, Laskhari and Mestieri (2021), etc.
  - **Inequality:** Engel (1857); Houthakker (1957); Hamilton (2001); Almås (2012); Argente and Lee (2021), etc.
  - **Taxation:** Jaravel and Olivi (2021); Xhani (2021), etc.
- **Optimal Policy in HANK**: Challe (2020); Bhandari, Evans, Golosov and Sargent (2021); Le Grand, Martin-Baillon and Ragot (2021); Nuno and Thomas (2022); Dávilla and Schaab (2022); Acharya, Challe and Dogra (2023); McKay and Wolf (2023).

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Definitions

$$\lambda_k = \frac{(1-\theta_k)(1-\beta\theta_k)}{\theta_k}\frac{\bar{\epsilon}_k-1}{\bar{\epsilon}_k-1+\bar{\eta}_k}$$

$$\gamma_{e,k}(j) = \left(1 - \frac{\epsilon_k(j)}{\bar{\epsilon}_k}\left(1+\epsilon_k^s(j)\right)\right)\frac{1}{\bar{\epsilon}_k-1}$$

$$\bar{\epsilon}_k = \int \frac{e_k(j)}{E_k}\epsilon_k(j)dj$$

$$\bar{\eta}_k = \left(-\int\left(\epsilon_k(j)-\bar{\epsilon}_k\right)^2\frac{e_k(j)}{E_k}dj + \int\frac{\epsilon_k^s(j)}{\epsilon_k(j)}\frac{e_k(j)}{E_k}dj\right)/\bar{\epsilon}_k$$

$$\bar{s}_k = E_k/E$$

$$\bar{\xi}_k = \int_j \frac{\vartheta(j)Wn(j)}{\int_j \vartheta(j)Wn(j)}\xi_k(j)dj$$

$$\Gamma = \sum_k \bar{s}_k \int \gamma_{e,k}(j)\xi_k(j)\frac{e(j)}{E_k}dj$$

$$\mathcal{M}_t^D = \bar{s}_k \sum_k \mathcal{M}_{k,t}^D$$

$$\mathcal{M}_t^P = \sum_k \bar{s}_k \sum_l \int_j \frac{e_k(j)}{E_k}\gamma_{e,k}(j)\rho_{k,l}(j)dj \cdot \left(\hat{P}_{l,t} - \hat{P}_{k,t}\right)$$

Back

Endogenous markup wedge

Tractable distributional dynamics

$$\mathcal{M}_{k,t} = \mathcal{M}^P_{k,t} + \mathcal{M}^E_{k,t}$$
$$\mathcal{M}^E_{k,t} = \Gamma\hat{\mathcal{Y}}_t + \mathcal{M}^D_{k,t}$$
$$\mathcal{M}^P_{k,t} = \sum_l \mathcal{S}_{k,l}\left(\hat{P}_{l,t} - \hat{P}_{k,t}\right)$$
$$\mathcal{M}^E_{k,t} = \mathbb{E}_t\mathcal{M}^E_{k,t+1} - \bar{\gamma}_{e,k}\bar{\sigma}^{\mathcal{M}}_k\hat{R}_t + \sum_l \bar{\gamma}_{e,k}\bar{\sigma}^{\mathcal{M}}_{k,l}\mathbb{E}_t\pi_{l,t+1} - \frac{\delta}{1-\delta}\mathbb{E}_t\mathcal{M}^0_{k,t}$$

Endogenous markup wedge

Tractable distributional dynamics

$$
\begin{aligned}
\mathcal{M}_{k,t} &= \mathcal{M}^P_{k,t} + \mathcal{M}^E_{k,t} \\
\mathcal{M}^E_{k,t} &= \Gamma \hat{\mathcal{Y}}_t + \mathcal{M}^D_{k,t} \\
\mathcal{M}^P_{k,t} &= \sum_l \mathcal{S}_{k,l} \left(\hat{P}_{l,t} - \hat{P}_{k,t} \right) \\
\mathcal{M}^E_{k,t} &= \mathbb{E}_t \mathcal{M}^E_{k,t+1} - \bar{\gamma}_{e,k} \bar{\sigma}^{\mathcal{M}}_k \hat{R}_t + \sum_l \bar{\gamma}_{e,k} \bar{\sigma}^{\mathcal{M}}_{k,l} \mathbb{E}_t \pi_{l,t+1} - \frac{\delta}{1-\delta} \mathbb{E}_t \mathcal{M}^0_{k,t}
\end{aligned}
$$

$$
\begin{aligned}
\frac{1}{(1-\delta)\,R} \hat{\mathcal{M}}^0_{k,t} = {} & \hat{\mathcal{M}}^0_{k,t-1} - \int \gamma_{b,k}(j) \frac{b(j)}{RE} dj \left(\hat{R}_t - \sum_l \bar{s}_l \pi_{l,t+1} \right) \\
& - \left(1 + \frac{\bar{\psi}}{\bar{\sigma}} \right) \int \gamma_{b,k}(j) \frac{wn(j)}{WL} dj \hat{\mathcal{Y}}_t + \frac{R-1}{R} \hat{\mathcal{M}}^E_{k,t} \\
& - \sum_l \int \gamma_{b,k}(j) \left(\frac{e(j)}{E} \left(\bar{s}_l - s_l(j) \right) + \frac{wn(j)}{WL} \left(\bar{\psi}_l - \psi_l(j) \right) \right) dj \hat{P}_{l,t}
\end{aligned}
$$

Back

Output gap

Output gap:

$$\tilde{\mathcal{Y}}_t = (\frac{1}{\bar{\sigma}} + \frac{1}{\psi})(\hat{\mathcal{Y}}_t - \hat{\mathcal{Y}}_t^*)$$

Aggregate demand index:

$$\hat{\mathcal{Y}}_t = \mathbb{E}_t \hat{\mathcal{Y}}_{t+1} - \bar{\sigma}\left(\hat{R}_t - \mathbb{E}_t \pi_{cpi,t+1} - \mathbb{E}_t \tilde{\pi}_{\mathcal{NH},t+1}\right),$$

where

$$\tilde{\pi}_{\mathcal{NH},t} = \sum_{k=1}^{K} \left(\frac{\bar{\sigma}_k + \psi \bar{\bar{\xi}}_k}{\bar{\sigma} + \psi} - \bar{s}_k \right) \pi_{k,t}$$

Flex-price agg. demand index:

$$\hat{\mathcal{Y}}_t^* = \sum_k \frac{\psi \bar{\bar{\xi}}_k + \bar{s}_k}{1 + \bar{\sigma}} \hat{A}_{k,t}$$

Back

Welfare loss

Assumptions A1-A2 and $\mathcal{M} = 0$

$$\mathcal{L}_s^{\tilde{\mathcal{Y}}} = \frac{\bar{\psi}}{1 + \frac{\bar{\psi}}{\bar{\sigma}}} \left\{ \tilde{\mathcal{Y}}_s^2 - \mathcal{C}_s^{\tilde{\mathcal{Y}}} \right\}$$

$$\mathcal{L}_s^{\pi} = \sum_k \vartheta \bar{s}_k \cdot \pi_{k,s}^2$$

$$\mathcal{L}_s^{d} = \mathbb{E}_\delta \int g\left(j\right) \left(\tau_{t_0}(j) + \sum_k \sum_{s \geq t_0} \frac{R-1}{R^{s+1-t_0}} \frac{e(j)}{E} s_k(j) A_{k,s} \right)^2 dj$$

$$- 2\mathbb{E}_\delta \int \frac{\xi(j)}{1 + \frac{\theta(j) W n(j) \psi}{e(j) \sigma}} \tau_{t_0}(j) \sum_k \sum_{s \geq t_0} \frac{R-1}{R^{s+1-t_0}} A_{k,s} dj)$$

Welfare loss

Assumptions A1-A2 and $\mathcal{M} = 0$

$$\mathcal{L}_s^{\tilde{\mathcal{Y}}} = \frac{\bar{\psi}}{1+\frac{\bar{\psi}}{\bar{\sigma}}} \left\{ \tilde{\mathcal{Y}}_s^2 - \mathcal{C}_s^{\tilde{\mathcal{Y}}} \right\}$$

$$\mathcal{L}_s^{\pi} = \sum_k \vartheta \bar{s}_k \cdot \pi_{k,s}^2$$

$$\mathcal{L}_s^{d} = \mathbb{E}_\delta \int g(j) \left(\tau_{t_0}(j) + \sum_k \sum_{s \geq t_0} \frac{R-1}{R^{s+1-t_0}} \frac{e(j)}{E} s_k(j) A_{k,s} \right)^2 dj$$
$$- 2\mathbb{E}_\delta \int \frac{\xi(j)}{1+\frac{\theta(j) Wn(j)\psi}{e(j)\sigma}} \tau_{t_0}(j) \sum_k \sum_{s \geq t_0} \frac{R-1}{R^{s+1-t_0}} A_{k,s} dj)$$

where

$$\tau_{t_0}(j) = \left(1 - \frac{1}{R}\right) \sum_{s \geq t_0} \frac{1}{R^{s-t_0}} \left(\frac{b(j)}{RE} \left(R_s - \pi_{cpi,s+1}\right) - \sum_k \frac{e(j)}{E} \left(s_k(j) - \bar{s}_k\right) \right)$$

$$\mathcal{C}_s^{\tilde{\mathcal{Y}}} = \mathbb{E}_\delta \int \frac{\left(1-\frac{1}{R}\right)\frac{b(j)}{E}}{1+\frac{\theta(j) Wn(j)\psi}{e(j)\sigma}} \left(\sum_{s \geq t_0} \frac{R-1}{R^{s+1-t_0}} \left(\tilde{\mathcal{Y}}_s - \sum_k \left(\xi(j) - \bar{\xi}\right) \left(P_{k,s} - {P^*}_{k,s}\right) \right) \right)^2 dj$$

Welfare loss

general

$$\mathcal{L}_s^{\tilde{\mathcal{Y}}} = \frac{\bar{\psi}}{1+\frac{\bar{\psi}}{\bar{\sigma}}} \int \frac{e(j)}{E} \left(\hat{W}_s - \sum_k \xi_k(j) \left(\hat{P}_{k,s} + \hat{A}_{k,s} \right) \right)^2 dj + \mathcal{C}_s^{\tilde{\mathcal{Y}}}$$

$$\mathcal{L}_s^{\pi} = \sum_k \bar{s}_k \vartheta_k \pi_{k,s}^2$$

$$\mathcal{L}_s^{s} = -\sum_k \bar{s}_k \sum_l \mathcal{S}_{k,l} \left(\hat{P}_{l,s} + \hat{A}_{l,s} \right) \left(\hat{P}_{k,s} + \hat{A}_{k,s} \right)$$

$$\mathcal{L}_s^{r} = \frac{\bar{\sigma}}{1+\frac{\bar{\psi}}{\bar{\sigma}}} \sum_{k,l} \mathcal{E}_{k,l} \left\{ \left(\hat{P}_{k,s} + \hat{A}_{k,s} \right) \left(\hat{P}_{l,s} + \hat{A}_{l,s} \right) - \mathcal{C}_{k,l}^{r} \right\}$$

$$\mathcal{L}^{d} = \mathbb{E}_{\delta} \int g(j)\, \hat{\tau}_{t_0}(j)^2 dj + \mathcal{C}^{d}$$

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