Carbon Pricing and Monetary Policy in an Estimated Macro-Climate Model

Sofia Semik

Goethe University Frankfurt

Introduction

- EU aims for a **low-carbon economy** with **sustainable energy production**
  - Main instrument: Carbon price through EU Emission Trading System (ETS)

- Empirical evidence suggests carbon price increases **reduce emissions**, but lead to short-term **GDP losses** and **inflationary pressures**

→ **Can macro-climate models account for the emprical effects of carbon price shocks?**

→ **How should monetary policy respond to carbon price shocks?**

This paper

- Provide **empirical evidence** on macroeconomic implications of EU ETS carbon price changes using carbon price shock series from Känzig (2023)
- Estimate a macro-climate New Keynesian model to **match empirical impulse responses** to a carbon price shock
- Key macro-climate model features:
    - **Limited substitutability** between fossil and green energy
    - Frictions in **fossil energy adjustment**
    - **Heterogeneous** households
- Assess **optimal monetary policy** response to carbon price shocks

Related literature

- **Empirical evidence on macroeconomic effects of carbon price shocks:** Känzig (2023), Metcalf and Stock (2023), Konradt and Weder di Mauro (2023), Känzig and Konradt (2023)

- **Impact of carbon pricing on inflation and monetary policy:** Sahuc et al. (2025), Carli et al. (2025), Coenen et al. (2024), Olovsson and Vestin (2023), Nakov and Thomas (2023), Del Negro et al. (2023), Airaudo et al. (2023), Ferrari and Nispi Landi (2023), Diluiso et al. (2021)

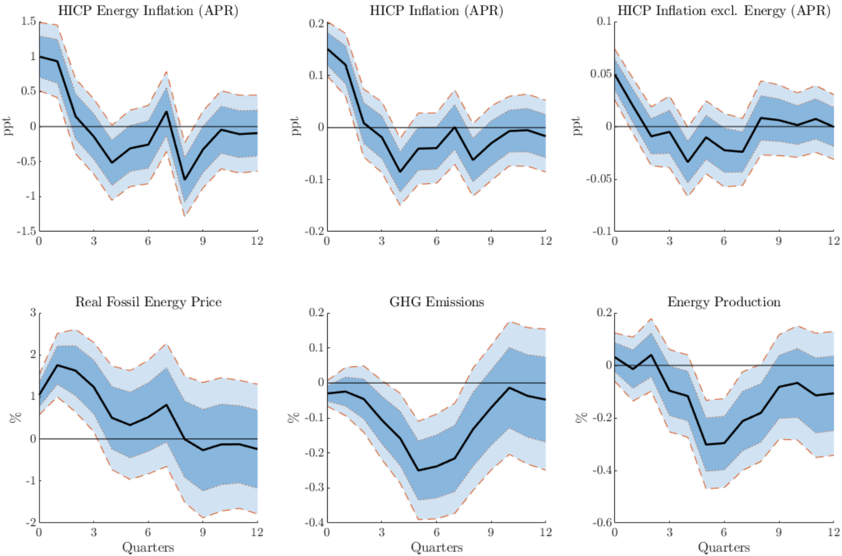
Empirical analysis

- Quarterly euro area data from 1999Q1 to 2019Q4
- Identify response of aggregate variables y_i using **local projections**:

$$y_{i,t+h} = \beta^i_{h,0} + \varphi^i_h CPShock_t + \beta^i_{h,1} y_{i,t-1} + ... + \beta^i_{h,p} y_{i,t-p} + \epsilon_{i,t,h}$$

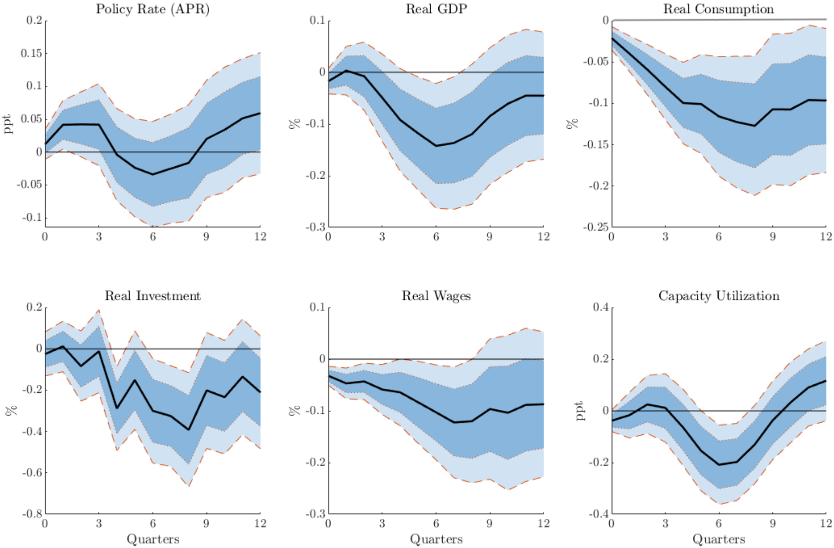
  - Use three lags of dependent variables as controls (p=3), horizon h=12
- $CPShock_t$: carbon price shock time series from Känzig (2023)
- 12 variables: Macro variables, energy prices and greenhouse-gas emissions

Impulse responses to a carbon price shock



Solid line: Point estimate. Dark and light shaded areas: 68 and 90% confidence bands.
Shock is normalized to increase annual energy inflation by 1 percentage point.

Impulse responses to a carbon price shock



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Model: Households

- **Two types of households**: Hand-to-mouth (H) and Ricardian (R) with standard preferences:

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left\{ \ln(c_{t,j} - b c_{t-1,j}) - \frac{h_{t,j}^{1+\phi}}{1+\phi} \right\}, \; j \in \{H, R\}$$

- Households consume a bundle of **energy** (C_t^E) and **non-energy goods** (C_t^X):

$$c_{t,j} = \left(\gamma_{c,j}^{\frac{1}{\varrho_c}} (c_{t,j}^E)^{\frac{\varrho_c - 1}{\varrho_c}} + (1-\gamma_{c,j})^{\frac{1}{\varrho_c}} (c_{t,j}^X)^{\frac{\varrho_c - 1}{\varrho_c}} \right)^{\frac{\varrho_c}{\varrho_c - 1}}, \; j \in \{H, R\}$$

- Calvo sticky wages

⏩ Budget Constraints

Model: Intermediate-good production

- Intermediate goods are a composite of **energy** (e_t^Y) and a capital-labor bundle following Hassler et al. (2021b):

$$y_t = \left((1-\gamma_Y)^{\frac{1}{\varrho_Y}} \left(A_t^Y (k_{t-1}^Y)^{\alpha} (h_t^Y)^{1-\alpha} \right)^{\frac{\varrho_y - 1}{\varrho_y}} + \gamma_Y^{\frac{1}{\varrho_y}} (e_t^Y)^{\frac{\varrho_y - 1}{\varrho_y}} \right)^{\frac{\varrho_Y}{\varrho_Y - 1}}$$

- Firms are monopolistic competitors and set price P_t^X subject to Calvo price setting frictions

- **Climate change** from fossil energy use negatively affects TFP ⏩ Details

Model: Energy sector firms

- **Energy bundling firms** combine fossil and green energy sources:

$$e_t = \left((1-\zeta)^{\frac{1}{\xi}} (e_t^G)^{\frac{\xi-1}{\xi}} + \zeta^{\frac{1}{\xi}} (e_t^F \, (1-\Gamma_t))^{\frac{\xi-1}{\xi}} \right)^{\frac{\xi}{\xi-1}}$$

- **Quadratic adjustment cost** on fossil energy use:

$$\Gamma_t = \frac{\kappa_E}{2} \left(\frac{e_t^F}{e_{t-1}^F} - 1 \right)^2$$

- Energy firms face **carbon tax** τ_t as surcharge on fossil energy price:

$$\Pi_t^E = p_t^E e_t - (1+\tau_t) p_t^F e_t^F - p_t^G e_t^G$$

- Fossil and green energy producing firms:

$$e_t^j = A_t^j (k_{t-1}^j)^{\alpha} (h_t^j)^{1-\alpha}, \quad j \in (F, G)$$

Model: Monetary and Fiscal Policy

- Climate policy: Fiscal authority levies **carbon tax** τ_t on energy firms and rebates revenues to households via lump-sum transfers:

$$\log(\tau_t) = (1-\rho_\tau)\log(\overline{\tau}) + \rho_\tau \log(\tau_{t-1}) + \epsilon_t^\tau, \quad \epsilon_t^\tau \sim \mathcal{N}(0, \sigma_\epsilon^2)$$

- Monetary Policy: Central bank follows standard Taylor rule stabilizing **headline inflation** and GDP gap

$$\frac{r_t}{r} = \left(\frac{r_{t-1}}{r}\right)^{\rho_r} \left(\left(\frac{\pi_t}{\pi}\right)^{\phi_\pi} \left(\frac{gdp_t}{\overline{gdp}}\right)^{\phi_y} \right)^{(1-\rho_r)}$$

⏩ Details

Parameters and Model Estimation

- Calibrate one set of parameters for the euro area and estimate the remaining parameters conditional on the calibrated parameters
- Estimate model using Bayesian **impulse response matching** developed in Christiano, Trabandt and Walentin (2011)
- Minimize distance between dynamic responses to **carbon price shock** ϵ_t^τ in model and analog impulse responses in the data
- 10 variables used for estimation: energy inflation, headline inflation, real fossil energy price, policy rate, emissions, real GDP, real consumption, real investment, real wages and capacity utilization

Calibrated Parameters

Parameter	Description	Value	Source
$(p^E c_{e,R})/(p_R c_R)$	Energy share in consumption R	0.07	Eurostat, HFCS (2015)
$(p^E c_{e,H})/(p_H c_H)$	Energy share in consumption H	0.16	Eurostat, HFCS (2015)
$(p^E e^Y)/(p^C y)$	Energy share in production	0.07	Coenen et al. (2024)
e^G/e	Green energy share	0.2	Eurostat
β	Discount factor	0.995	Annual real rate 2%
φ	Inverse Frisch elasticity	1	Standard value
α	Capital share in production	0.3	Standard value
δ	Depreciation rate	0.025	Standard value
μ_P	Gross st.-st. price mark-up	1.2	Standard value
μ_W	Gross st.-st. wage mark-up	1.2	Standard value
δ_S	Decay atmospheric carbon	0.9983	Hassler et al. (2020)
$100 \cdot \psi$	Damage coefficient	0.002698	Hassler et al. (2020)

Estimated Parameters

Parameter	Prior	Posterior	
	$\mathcal{D}$, Mode [5-95%]	Mode	[5-95%]
Energy complementarity firms, ϱ_y	$\mathcal{G}$, 0.32 [0.13 1.07]	**0.07**	[0.02 0.20]
Energy complementarity households, ϱ_c	$\mathcal{G}$, 0.32 [0.13 1.07]	**0.12**	[0.04 0.29]
Substitution green and fossil energy, ξ	$\mathcal{U}$, – [0.2 3.8]	**0.38**	[0.23 0.72]
Fossil energy adjustment cost, κ_E	$\mathcal{U}$, – [1.5 28.5]	**10.1**	[6.4 16.3]
Share of hand-to-mouth agents, λ	$\mathcal{B}$, 0.28 [0.15 0.48]	**0.25**	[0.16 0.39]
Habit persistence, b	$\mathcal{B}$, 0.63 [0.34 0.83]	**0.73**	[0.43 0.88]
Calvo wage stickiness, θ_w	$\mathcal{B}$, 0.76 [0.43 0.92]	**0.84**	[0.60 0.96]
Investment adjustment costs, κ_I	$\mathcal{G}$, 3.20 [1.27 10.73]	**3.65**	[0.28 8.50]
Capacity utilization adj. costs, κ_U	$\mathcal{G}$, 0.44 [0.15 2.46]	**0.22**	[0.03 1.02]
Calvo price stickiness, θ_p	$\mathcal{B}$, 0.76 [0.43 0.92]	**0.61**	[0.35 0.81]
Taylor rule inflation coeff., ϕ_π	$\mathcal{G}$, 1.58 [1.36 1.84]	**1.53**	[1.25 1.88]
Taylor rule output coeff., ϕ_y	$\mathcal{G}$, 0.04 [0.01 0.26]	**0.04**	[0.00 0.15]
Interest rate smoothing, ρ_r	$\mathcal{B}$, 0.85 [0.61 0.94]	**0.95**	[0.90 0.99]
Autocorr. carbon shock, ρ_τ	$\mathcal{B}$, 0.75 [0.44 0.95]	**0.90**	[0.85 0.95]
Std.Dev. carbon shock, σ_τ	$\mathcal{IG}$, 0.07 [0.04 0.56]	**0.26**	[0.21 0.35]

Notes: Posterior mode and intervals are based on a standard MCMC algorithm with 500,000 draws (5 chains, 50% burn-in, acceptance rate about 27%). $\mathcal{B}, \mathcal{G}, \mathcal{U}, \mathcal{IG}$ denote beta, gamma, uniform and inverse-gamma distributions, respectively.

Posterior Mode of Key Parameters

- **Substitution elasticity** between green and fossil energy $\xi = 0.38$ below unity
    - Green and fossil energy are **complements** rather than substitutes

- Fossil energy adjustment cost is significantly positive: $\kappa_E \approx 10$
    - **Slow adjustment of fossil energy use** in energy production

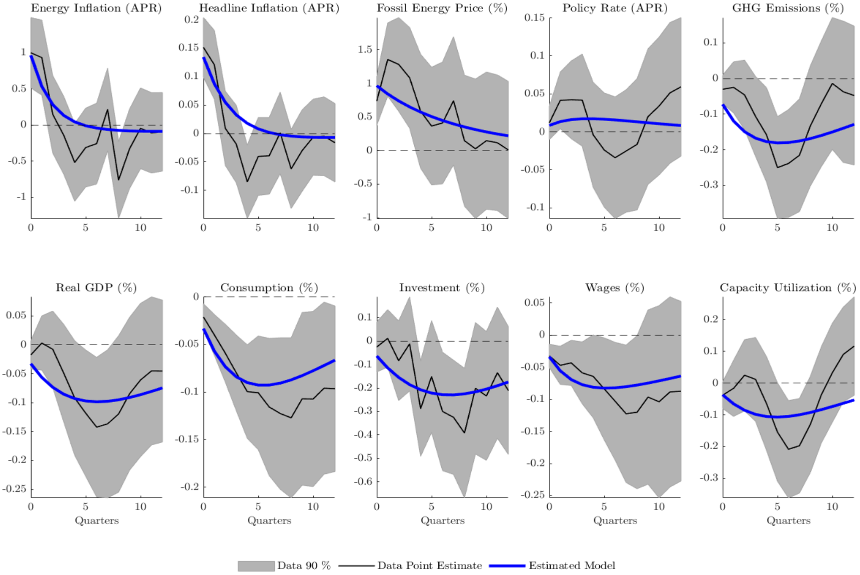
- Share of hand-to-mouth households: $\lambda = 0.25$
    - **Household heterogeneity** shapes the economy's response

- **Strong complementarity** between energy and non-energy goods
    - in consumption: $\varrho_c = 0.12$
    - in production: $\varrho_y = 0.07$

▸▸ Counterfactuals

Impulse Responses to a carbon price shock

Estimated Model vs. Data



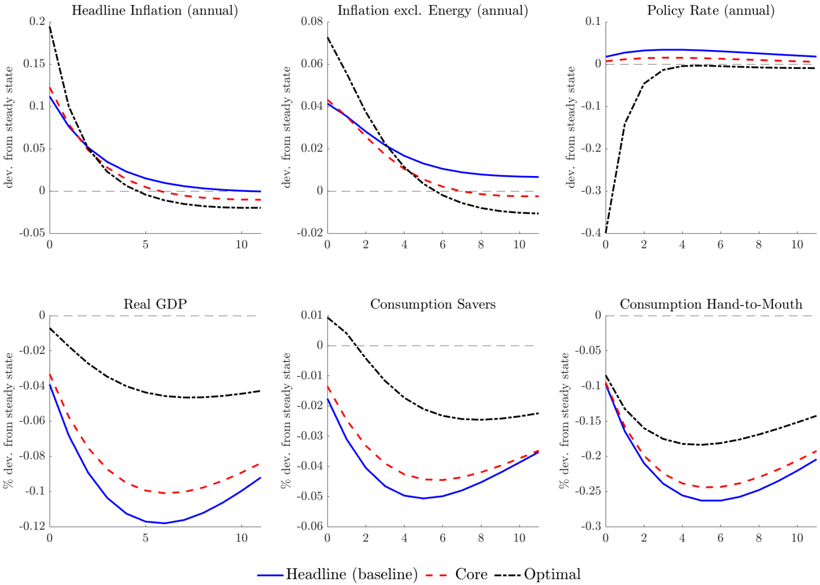
Monetary Policy

- Carbon price shock creates a **monetary policy trade-off**:
    - Inflation rises while output falls

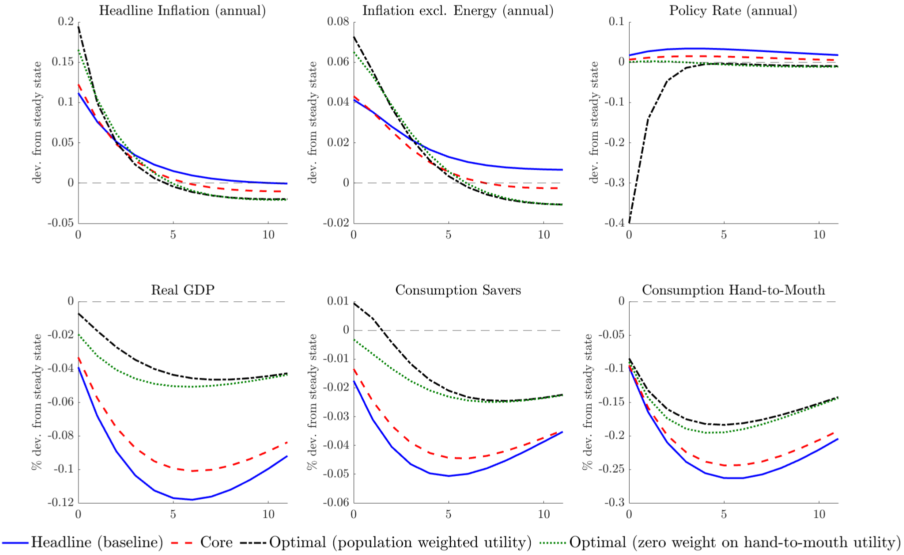
- Compare alternative monetary policy scenarios to **baseline Taylor rule**:
    1. Taylor rule with **core** instead of headline inflation
    2. **Ramsey planner** maximizing social welfare

$$\mathcal{W}_t = \lambda \mathcal{U}_{t,H} + (1-\lambda)\mathcal{U}_{t,R} + \beta \mathbb{E}_t \mathcal{W}_{t+1}$$

Monetary Policy



Monetary Policy



Conclusion

- **Empirical analysis**: Increase in EU-ETS carbon price leads to inflationary pressures, a drop in economic activity and gradual emission reduction
- **Model Estimation**: Estimated model is able to capture key macroeconomic dynamics following carbon price shock in the data well
- **Monetary Policy**: Optimal monetary policy mitigates GDP loss at the cost of temporarily higher inflation

Thank you for your attention!

Model: Households

- Budget constraint R agents:

$$P_t^E c_{t,R}^E + P_t^X c_{t,R}^X + P_t^I \sum_j i_t^j + B_t =$$

$$W_t h_{t,R} + \sum_j (R_t^k u_t^{k,j} - a(u_t^{k,j}) P_t^I) k_{t-1}^j + r_{t-1} B_{t-1} + T_{t,R} + \Pi_t$$

- Capital evolves according to:

$$k_t^j = (1-\delta) k_{t-1}^j + i_t^j \left(1 - S(i_t^j / i_{t-1}^j)\right), \; j \in \{Y, F, G\}$$

- Budget constraint H agents:

$$P_t^E c_{t,H}^E + P_t^X c_{t,H}^X = W_t h_{t,H} + T_{t,H}$$

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Model: Climate change

- Carbon emissions from the euro area and the rest of the world fuel the stock of atmospheric carbon S_t:

$$S_t = (1 - \delta_S) S_{t-1} + \psi_0 \left(e_t^F + e^{F\,row} \right)$$

  - ψ: carbon decay rate, ψ_0: share of emissions remaining in the atmosphere

- Environmental damage from atmospheric carbon reduces TFP:

$$A_t^i = a_t^i e^{-\psi S_t}, \qquad i \in \{Y, F, G\}$$

- Especially relevant for large shocks and longer time horizons

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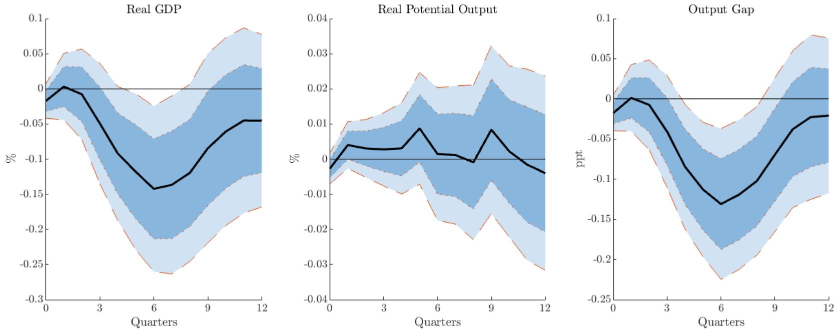
Impulse responses to a carbon price shock



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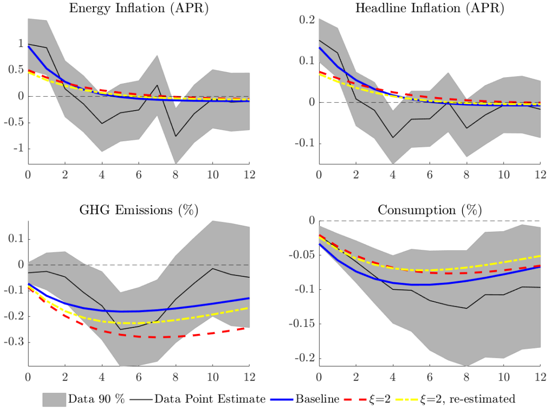
Impulse Responses: Baseline vs. $\xi = 2$



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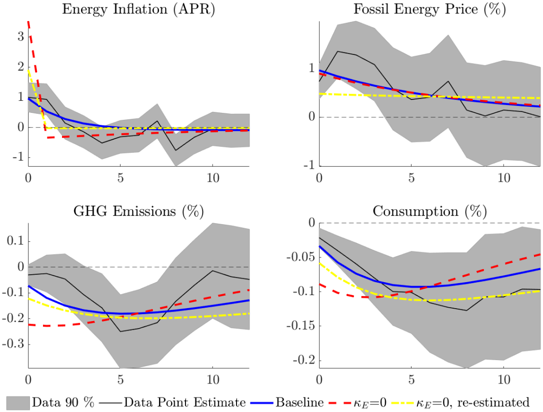
Impulse Responses: Baseline vs. $\kappa_E = 0$



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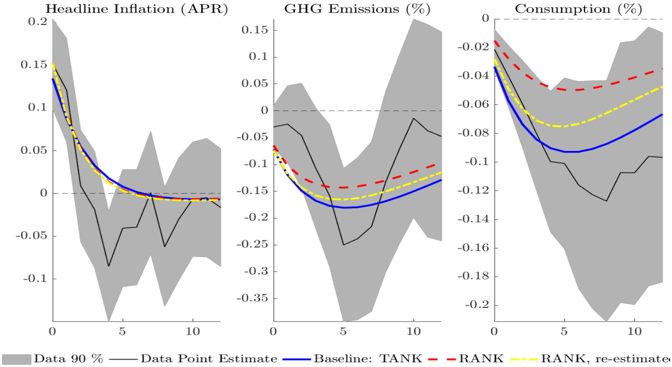
Impulse Responses: Baseline vs. RANK



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