The unequal economic consequences of carbon pricing

Konstanz Seminar on Monetary Theory and Monetary Policy

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The looming climate crisis

- Looming **climate crisis** put climate change at **top** of the **global policy agenda**
- **Carbon pricing** increasingly used as a tool to mitigate climate change **but:**
- **Little known** about effects on **emissions** and the **economy** in practice
    - Effectiveness?
    - Short-term economic costs?
    - Distributional consequences?

This paper

- New evidence from the European **Emissions Trading Scheme** (**ETS**), the **largest** carbon market in the world
- Exploit **institutional features** of the EU ETS and **high-frequency data** to estimate **aggregate** and **distributional** effects of **carbon pricing**
    - Cap-and-trade system: **Market price** for carbon, liquid **futures markets**
    - Regulations in the market **changed** considerably over time
    - Isolate **exogenous** variation by measuring carbon price change in **tight window** around **policy events**
    - Use as **instrument** to estimate dynamic causal effects of a **carbon policy shock**

Main results

- Carbon policy has **significant** effects on emissions and the economy
- A shock **tightening** the **carbon pricing regime** leads to
  - a significant **increase in energy prices**, persistent **fall in emissions** and uptick in green innovation
  - not without **cost**: **economic activity falls**, consumer prices increase
  - costs **not** borne **equally** across society: **poor** lower their consumption significantly, **rich** barely affected
- **Poor** not only more exposed because of **higher energy share**, also face a stronger **fall** in **income**

Main results

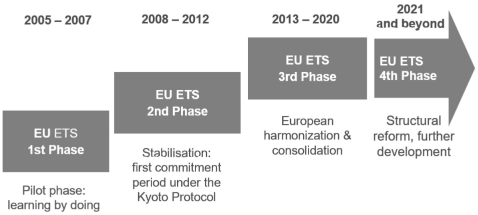
- **Indirect effects** via income and employment are **key** for the transmission
  - account for over **2/3** of the aggregate effect on consumption
- **Climate-economy model** with **heterogeneity** in energy shares, income incidence and MPCs can account for these facts
  - **targeted fiscal policy** can reduce **economic costs** of carbon pricing **without** compromising **emission reductions**

European carbon market

- Established in 2005, covers around **40%** of EU GHG emissions
- **Cap** on total emissions covered by the system, reduced each year
- **Emission allowances** (**EUA**) allocated within the cap
  - free allocation
  - auctions
  - international credits
- Companies must surrender **sufficient** EUAs to cover their yearly emissions
  - enforced with heavy fines
- Allowances are **traded** on secondary markets (spot and **futures** markets)

European carbon market

- Establishment of EU ETS followed **learning-by-doing** process
- Three main **phases**, **rules updated continuously**
  - address market issues
  - expand system
  - improve efficiency
- Lots of **regulatory events**



Carbon price

Figure 1: EUA price

Regulatory events

- Collected **comprehensive list** of **regulatory update** events
  - Decisions of European Commission
  - Votes of European Parliament
  - Judgments of European courts
- Of interest in this paper: regulatory news on the **supply of allowances**
  - National **allocation plans**
  - **Auctions**: timing and quantities
  - Use of international credits
- **Identified 126** relevant **events** from 2005-2018

Details

High-frequency identification

- **Idea**: Identify carbon policy surprises from changes in EUA futures price in tight window around regulatory event

$$CPSurprise_{t,d} = \frac{F_{t,d}^{carbon} - F_{t,d-1}^{carbon}}{P_{t,d-1}^{elec}},$$

where $F_{t,d}$ is settlement price of the EUA front contract on event day d in month t and $P_{t,d-1}^{elec}$ is the wholesale electricity price on the day before

Carbon policy surprises

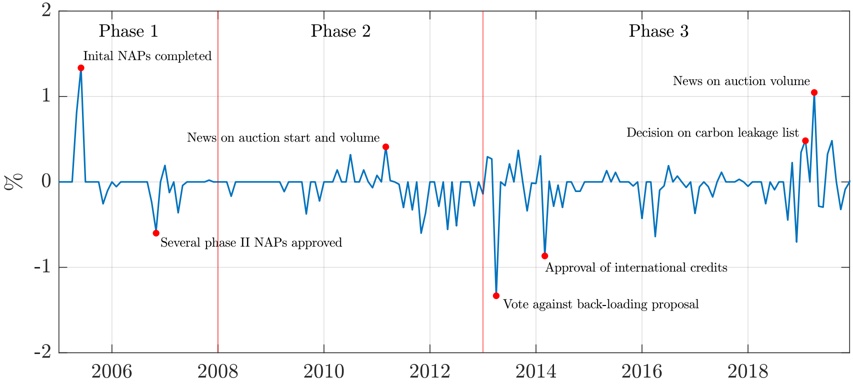


Figure 2: The carbon policy surprise series

Diagnostics Alternative

Econometric framework

- **Carbon policy surprise series** has good properties but still imperfect measure

  $\Rightarrow$ Use it as an external **instrument** to estimate dynamic causal effects on variables of interest (Stock and Watson, 2012; Mertens and Ravn, 2013) ▸ Details

- For estimation I rely on VAR techniques given the short sample ▸ More

The aggregate effects of carbon pricing

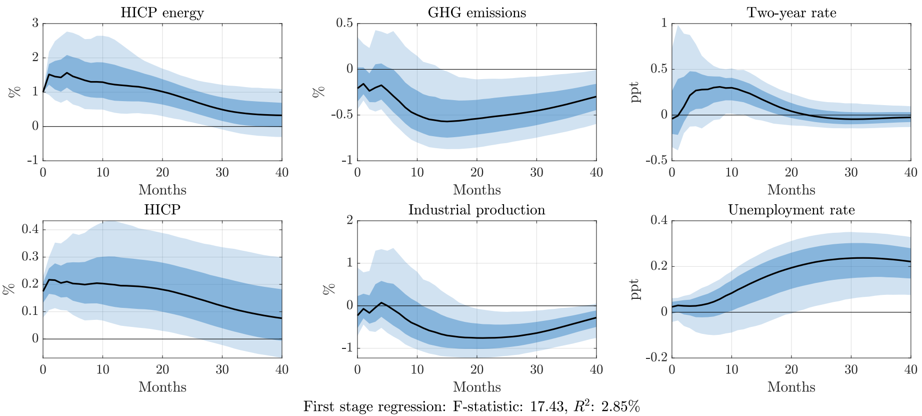


Figure 3: Responses to carbon policy shock, normalized to increase HICP energy by 1%

The solid line is the point estimate and the dark and light shaded areas are 68 and 90% confidence bands

More

Internal instrument results

Oil shock

Propagation channels

- **Energy prices** play an important role in the **transmission** of **carbon policy**
  - Suggests that **power sector** largely **passes through** emissions cost to energy prices, in line with previous evidence
- **Higher energy prices** can have significant effects on the economy via **direct** and **indirect** channels
- Better understand transmission by mapping out responses of wider range of macro and financial variables using local projections

$$y_{i,t+h} = \beta^i_{h,0} + \psi^i_h CPShock_t + \beta^i_{h,1} y_{i,t-1} + \ldots + \beta^i_{h,p} y_{i,t-p} + \xi_{i,t,h}$$

The transmission to the macroeconomy

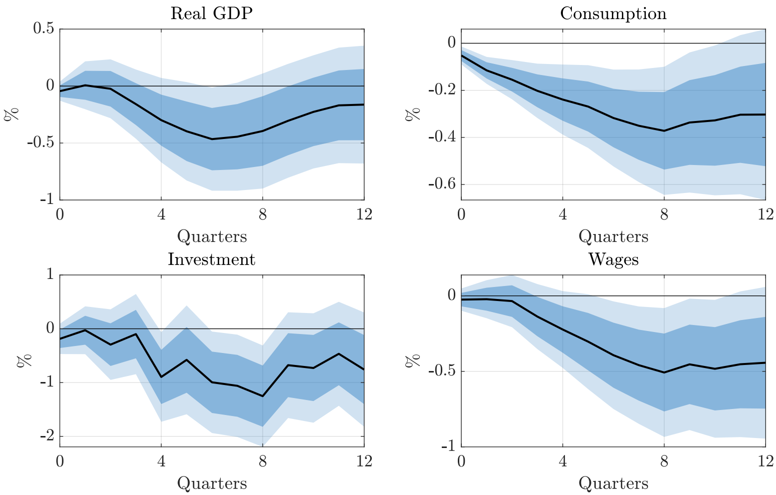


Figure 4: Effect on GDP and components

The transmission to the macroeconomy

- **Fall in GDP** similar to industrial production
- Looking at components, fall driven by **lower consumption and investment**
  - magnitudes much larger than can be accounted for by **direct effect** via energy prices
  - **indirect effects** via income seem to be important
- Little response of financial variables and uncertainty

The heterogeneous effects of carbon pricing

- Big debate on **energy poverty** amid Commission's 'Fit for 55' proposal
- Crucial to better understand the **distributional** effects crucial of **carbon pricing**
- Also helps to sharpen understanding of **transmission channels** at work

The heterogeneous effects of carbon pricing

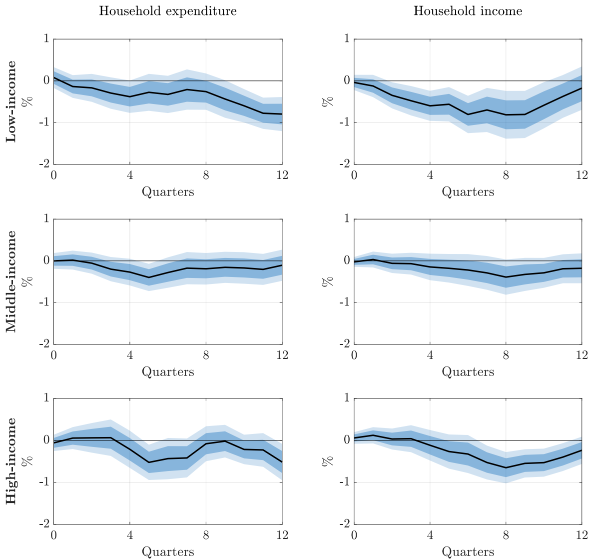
- Study **heterogeneous effects** of carbon pricing on **households**
- **Problem**: Household-level micro data not available at the EU level for long enough and regular sample
  - Focus on **UK** where high-quality micro data on **income** and **expenditure** is available
  - Check external validity using data for Denmark and Spain

Living costs and food survey

- **LCFS** is the major UK survey on household spending
  - provides detailed information on **expenditure, income**, and household **characteristics**
  - fielded every year but interview date allows to construct **quarterly** measures
- I compile a **repeated cross-section** spanning the period 1999 to 2018
- To estimate effects, I use a **grouping estimator** using **normal disposable income** as the grouping variable:
  - **Low-income**: Bottom 25%
  - **Middle-income**: Middle 50%
  - **High-income**: Top 25%

Descriptive statistics

Heterogeneity by income group



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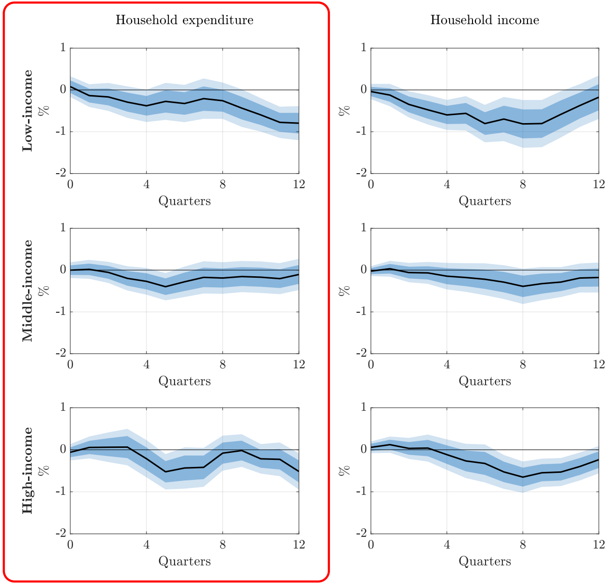

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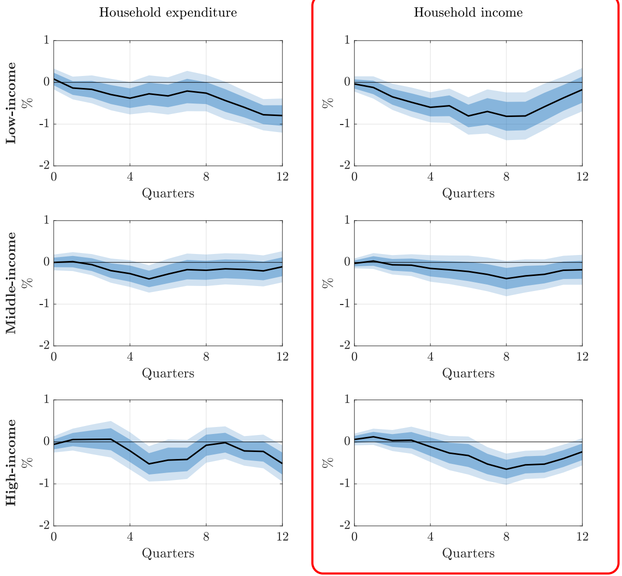

Direct versus indirect effects

Table 1: Cumulative changes over impulse horizon in pounds

	Overall	By income group		
		Low-income	Middle-income	High-income
Expenditure				
Energy	23.88	28.36	22.53	22.11
	[-16.93, 64.69]	[8.21, 48.51]	[-18.02, 63.07]	[-0.96, 45.17]
Non-durables	-103.75	-134.76	-92.33	-95.60
excl. energy	[-212.38, 4.87]	[-241.21, -28.32]	[-192.67, 8.02]	[-279.87, 88.67]
Durables	-6.95	-2.92	-0.44	-23.99
	[-56.09, 42.20]	[-20.75, 14.92]	[-10.37, 9.50]	[-71.44, 23.45]
Income				
	-203.70	-214.90	-138.65	-322.60
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Direct versus indirect effects

- Energy bill increases but **cannot** account for fall in expenditure, **indirect effects** via income seem important
  - account for **over 2/3** of the aggregate consumption response
- **Low-income** households face larger increase in energy bill and stronger fall in income, have to adjust their expenditure more
  - Policy heavily **regressive** after accounting for indirect effects
  - **Low-income** households account for $\sim$**30%** of the aggregate effect on consumption though they account for much smaller consumption share in normal times ($\sim$15%)

Heterogeneity in income responses

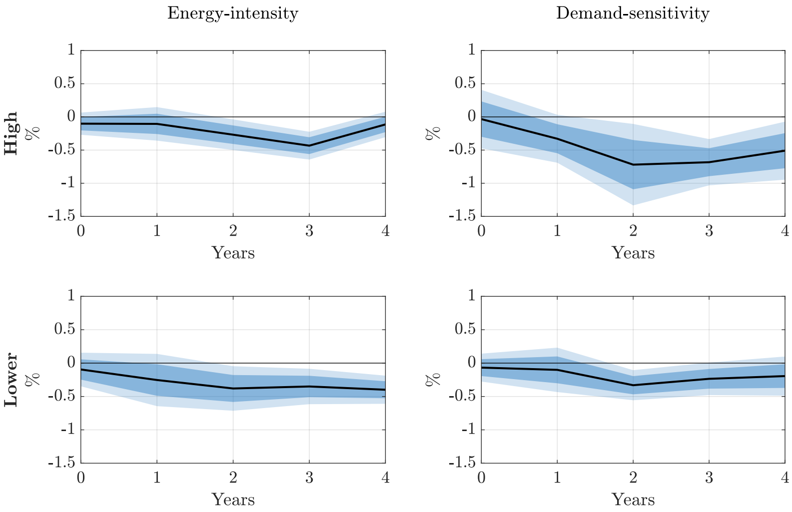

Figure 5: Income response by sector of employment

Heterogeneity in income responses

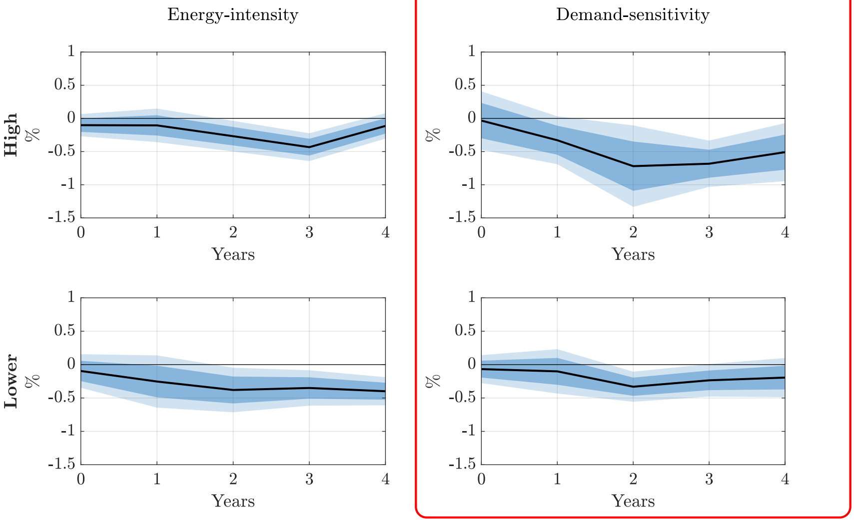

Figure 5: Income response by sector of employment

Heterogeneity in income responses

Table 2: Sectoral distribution of employment

Sectors	Overall	By income group		
		Low-income	Middle-income	High-income
Energy-intensity				
High	21.6	9.8	25.6	25.8
Lower	78.4	90.2	74.4	74.2
Demand-sensitivity				
High	30.5	49.0	27.2	18.1
Lower	69.5	51.0	72.8	81.9

Policy implications

- Fiscal policies **targeted** to the **most affected** households can **reduce** the economic **costs** of climate change mitigation policy
    - To the extent that energy demand is **inelastic**, this should **not compromise** emission reductions
    - Intuition confirmed in heterogeneous agent climate-economy model ▸ More
- Especially relevant given recent surge in European carbon prices
    - Distributional effects could threaten **public support** of the policy ▸ Suggestive evidence

Beyond the short term

- An often used argument for carbon prices is that it fosters **directed technological change**

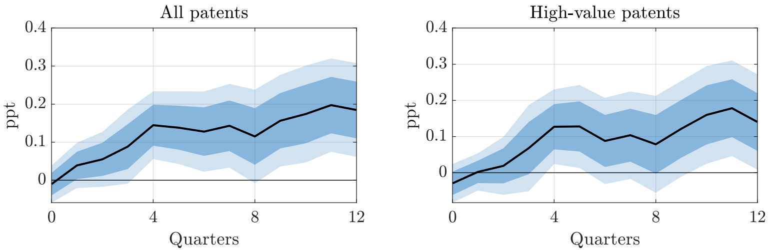

Figure 6: Share of low-carbon patents

- Use **patent data** from the EPO, document significant increase in climate change mitigation patenting
- Key for longer-term **transition** to **low-carbon economy**

Conclusion

- New evidence on the **economic effects** of **carbon pricing** from the European carbon market
- Policy successful in **reducing emissions**, but comes at an **economic cost**
- These costs are **not borne equally** across society, policy is heavily **regressive** after accounting for **indirect** effects
- Targeted fiscal policy can reduce these costs without compromising emission reductions

Thank you!

Example events

Table 3: Regulatory update events (extract)

	Date	Event description	Type
54	30/11/2012	Commission rules on temporary free allowances for power plants in Hungary	Free alloc.
55	25/01/2013	Update on free allocation of allowances in 2013	Free alloc.
56	28/02/2013	Free allocation of 2013 aviation allowances postponed	Free alloc.
57	25/03/2013	Auctions of aviation allowances not to resume before June	Auction
58	16/04/2013	The European Parliament voted against the Commission's back-loading proposal	Auction
59	05/06/2013	Commission submits proposal for international credit entitlements for 2013 to 2020	Intl. credits
60	03/07/2013	The European Parliament voted for the carbon market back-loading proposal	Auction
61	10/07/2013	Member states approve addition of sectors to the carbon leakage list for 2014	Free alloc.
62	30/07/2013	Update on industrial free allocation for phase III	Free alloc.
63	05/09/2013	Commission finalized decision on industrial free allocation for phase three	Free alloc.
64	26/09/2013	Update on number of aviation allowances to be auctioned in 2012	Auction

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Diagnostics

- **Narrative account**:
- **Autocorrelation**:
- **Forecastability**:
- **Orthogonality**:
- **Background noise**:

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- **Background noise**: ✓ Variance on event days over 6 times larger than on control days

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Autocorrelation

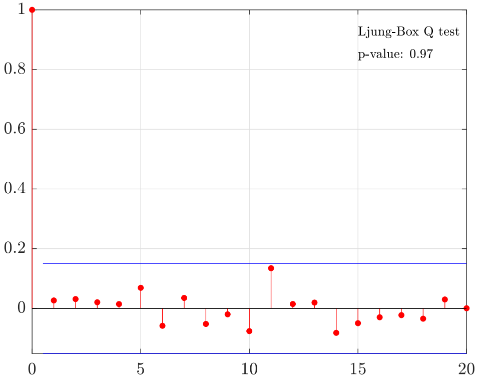

Figure 7: The autocorrelation function of the carbon policy surprise series

Forecastability

Table 4: Granger causality tests

Variable	p-value
Instrument	0.3279
EUA price	0.7060
HICP energy	0.7961
GHG emissions	0.6615
HICP	0.9949
Industrial production	0.7633
Two-year rate	0.5066
Unemployment rate	0.2473
Stock prices	0.7887
REER	0.1595
Oil price	0.3280
Joint	0.9339

Orthogonality

Shock	Source	ρ	p-value	n	Sample
Monthly measures					
Global oil market					
Oil supply	Kilian (2008) (extended)	-0.16	0.10	104	2005M05-2013M12
	Kilian (2009) (updated)	-0.00	0.97	164	2005M05-2018M12
	Caldara, Cavallo, and Iacoviello (2019)	-0.11	0.24	128	2005M05-2015M12
	Baumeister and Hamilton (2019)	-0.15	0.04	176	2005M05-2019M12
	Känzig (2021) (updated)	0.12	0.11	176	2005M05-2019M12
Global demand	Kilian (2009) (updated)	-0.09	0.27	164	2005M05-2018M12
	Baumeister and Hamilton (2019)	-0.07	0.35	176	2005M05-2019M12
Oil-specific demand	Kilian (2009) (updated)	0.10	0.21	164	2005M05-2018M12
Consumption demand	Baumeister and Hamilton (2019)	0.13	0.10	176	2005M05-2019M12
Inventory demand	Baumeister and Hamilton (2019)	0.02	0.78	176	2005M05-2019M12
Monetary policy					
Monetary policy shock	Jarociński and Karadi (2020)	0.08	0.32	140	2005M05-2016M12
Central bank info	Jarociński and Karadi (2020)	0.07	0.40	140	2005M05-2016M12
Financial & uncertainty					
Financial conditions	BBB spread residual	-0.04	0.61	176	2005M05-2019M12
Financial uncertainty	VIX residual (Bloom, 2009)	-0.05	0.48	176	2005M05-2019M12
	VSTOXX residual	-0.06	0.43	176	2005M05-2019M12
Policy uncertainty	Global EPU (Baker, Bloom, and Davis, 2016)	-0.07	0.37	176	2005M05-2019M12
Quarterly measures					
Fiscal policy	Euro area (Alloza, Burriel, and Pérez, 2019)	0.08	0.60	43	2005Q2-2015Q4
	Germany	0.24	0.12	43	2005Q2-2015Q4
	France	-0.03	0.85	43	2005Q2-2015Q4
	Italy	0.05	0.74	43	2005Q2-2015Q4
	Spain	0.14	0.36	43	2005Q2-2015Q4

Notes: The table shows the correlation of the carbon policy surprise series with a wide range of different shock measures from the literature, including global oil market shocks, monetary policy, financial and uncertainty shocks. ρ is the Pearson correlation coefficient, the p-value corresponds to the test whether the correlation is different from zero and n is the sample size.

Background noise

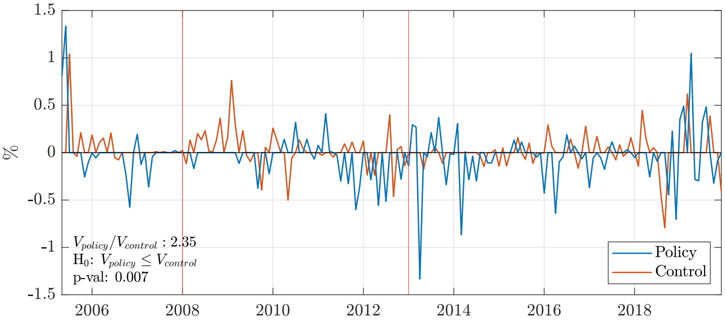

Figure 8: The carbon policy and the control series

Notes: This figure shows the carbon policy surprise series together with the surprise series constructed on a selection of control days that do not contain a regulatory announcement but are otherwise similar.

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Change in carbon price relative to electricity prices

$$CPSurprise_{t,d} = F_{t,d} - F_{t,d-1}$$

Figure 9: The carbon policy surprise series

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External instrument approach

- Structural VAR

$$\mathrm{y}_t = \mathrm{b} + \mathrm{B}_1 \mathrm{y}_{t-1} + \cdots + \mathrm{B}_p \mathrm{y}_{t-p} + \mathrm{S}\boldsymbol{\varepsilon}_t, \qquad \boldsymbol{\varepsilon}_t \sim N(0, \boldsymbol{\Omega})$$

- **External instrument:** variable z_t *correlated* with the **shock of interest** but *not* with the **other shocks**
- **Identifying assumptions**:

$$\mathbb{E}[z_t \varepsilon_{1,t}] = \alpha \neq 0 \qquad \text{(Relevance)}$$

$$\mathbb{E}[z_t \boldsymbol{\varepsilon}_{2:n,t}] = 0, \qquad \text{(Exogeneity)}$$

$$\mathrm{u}_t = \mathrm{S}\boldsymbol{\varepsilon}_t \qquad \text{(Invertibility)}$$

- Use **carbon policy surprise series** as *external instrument* for **energy price**

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Internal instrument approach

- Augment VAR by external instrument: $\bar{y}_t = (z_t,\ y_t')'$

$$\bar{y}_t = b + B_1 \bar{y}_{t-1} + \cdots + B_p \bar{y}_{t-p} + S\varepsilon_t, \qquad \varepsilon_t \sim N(0, \Omega)$$

- **Identifying assumptions**:

$$\mathbb{E}[z_t \varepsilon_{1,t}] = \alpha \neq 0 \qquad \text{(Relevance)}$$

$$\mathbb{E}[z_t \varepsilon_{2:n,t}] = 0, \qquad \text{(Contemporaneous exogeneity)}$$

$$\mathbb{E}[z_t \varepsilon_{t+j}] = 0, \quad \text{for } j \neq 0 \qquad \text{(Lead-lag exogeneity)}$$

- Robust to **non-invertibility** but instrument has to be orthogonal to leads and lags of structural shocks

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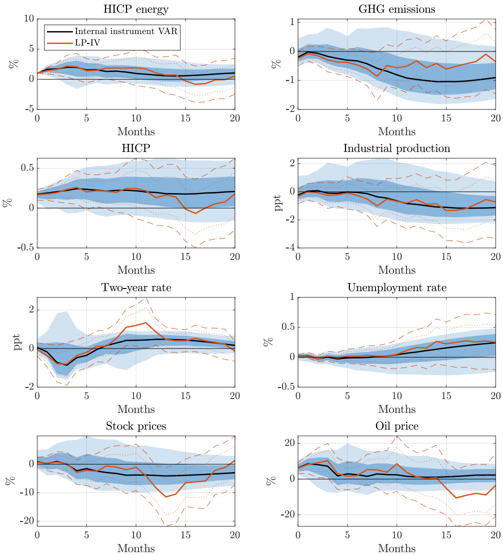
Local projections versus internal instrument approach



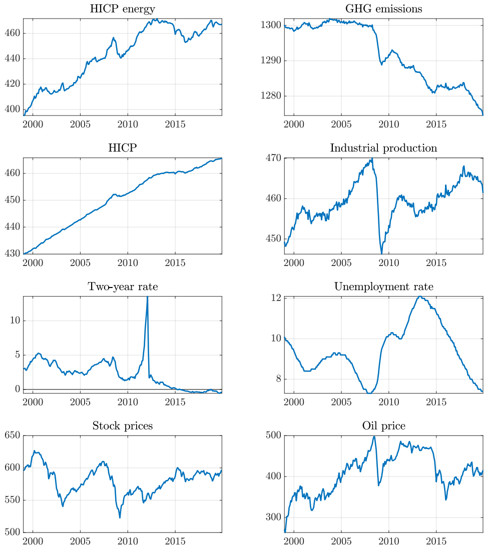
Empirical specification

- 8 variable system, **euro area** data:
  - **Carbon block**: HICP[1] energy, total GHG emissions
  - **Macro block**: headline HICP, industrial production, unemployment rate, policy rate, stock market index, REER
- 6 lags as controls
- Estimation sample: 1999M1-2018M12

▸ Data

[1] HICP: Harmonized index of consumer prices

Data


HICP energy
GHG emissions
HICP
Industrial production
Two-year rate
Unemployment rate
Stock prices
Oil price
2000
2005
2010
2015

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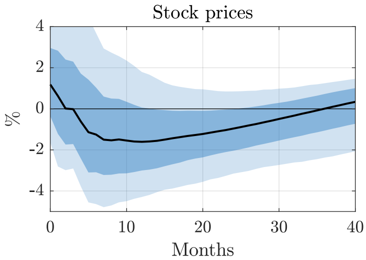
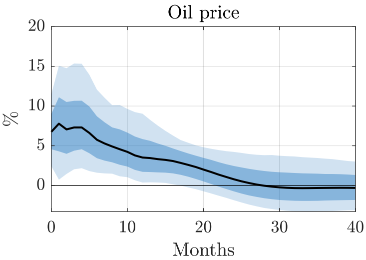
Financial variables





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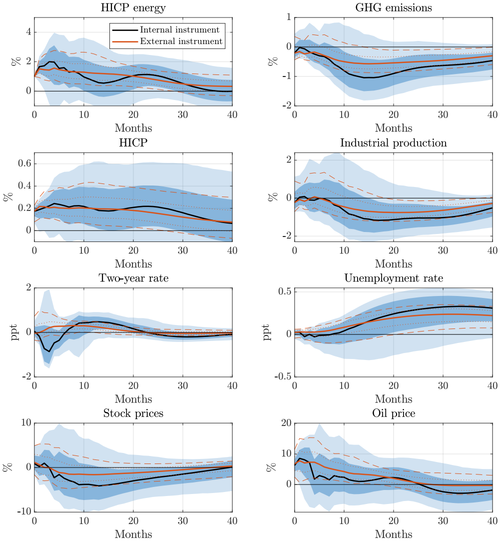
Internal versus external instrument approach



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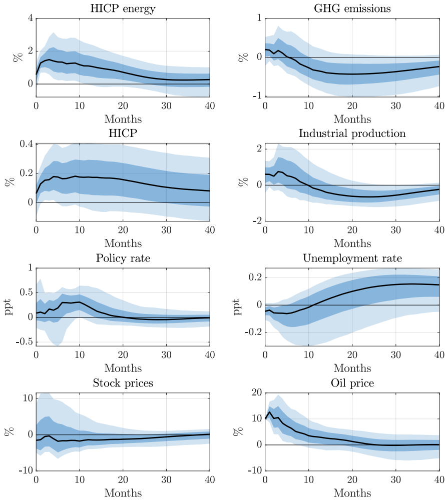
Responses to oil supply news shock



First stage regression: F-statistic: 5.74, R^2: 2.85%

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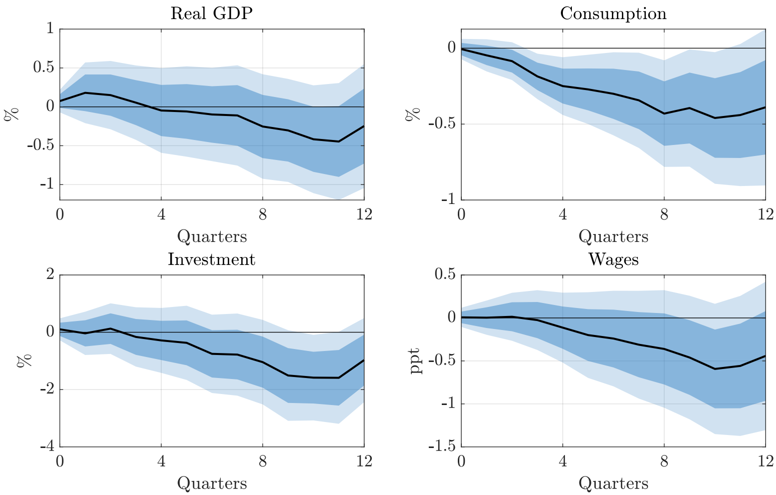
Responses to oil supply news shock



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Model with carbon price

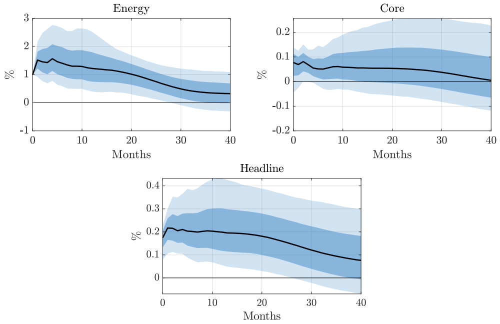

Figure 11: Model including carbon spot price

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Historical importance

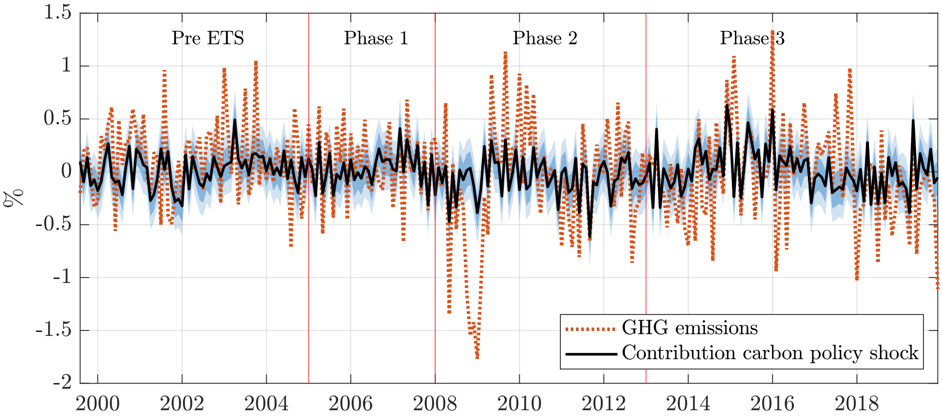

Figure 12: Historical decomposition of emissions growth

Historical importance

- **Carbon policy shocks** have **contributed meaningfully** to historical variations in energy prices, emissions and macro variables
- **But**: Did **not** account for the fall in emissions following the global financial crisis
  - supports the **validity** of the identified shock

▸ More ◂ Back

Historical importance

Table 5: Variance decomposition

h	HICP energy	Emissions	HICP	IP	Two-year rate	Unemp. rate	Stock prices	Oil price
Panel A: Forecast variance decomposition (SVAR-IV)								
6	0.38	0.12	0.46	0.02	0.04	0.05	0.02	0.22
	[0.03, 0.49]	[0.02, 0.42]	[0.04, 0.57]	[0.01, 0.30]	[0.01, 0.24]	[0.00, 0.33]	[0.01, 0.31]	[0.01, 0.33]
12	0.31	0.18	0.32	0.05	0.08	0.08	0.03	0.20
	[0.03, 0.41]	[0.02, 0.43]	[0.03, 0.46]	[0.02, 0.33]	[0.01, 0.22]	[0.01, 0.37]	[0.01, 0.33]	[0.02, 0.31]
24	0.30	0.22	0.23	0.13	0.08	0.18	0.04	0.20
	[0.03, 0.38]	[0.02, 0.39]	[0.02, 0.39]	[0.02, 0.34]	[0.02, 0.21]	[0.01, 0.43]	[0.01, 0.31]	[0.02, 0.27]
36	0.28	0.20	0.18	0.16	0.08	0.23	0.04	0.16
	[0.03, 0.35]	[0.02, 0.36]	[0.02, 0.35]	[0.02, 0.33]	[0.02, 0.21]	[0.01, 0.44]	[0.02, 0.31]	[0.02, 0.24]
Forecast variance ratio (SVMA-IV)								
6	0.04, 0.21	0.01, 0.06	0.04, 0.21	0.00, 0.01	0.03, 0.14	0.00, 0.01	0.00, 0.02	0.01, 0.08
	[0.01, 0.39]	[0.00, 0.25]	[0.01, 0.40]	[0.00, 0.17]	[0.01, 0.37]	[0.00, 0.15]	[0.00, 0.19]	[0.01, 0.24]
12	0.03, 0.15	0.03, 0.15	0.03, 0.15	0.01, 0.03	0.03, 0.18	0.00, 0.01	0.01, 0.04	0.01, 0.06
	[0.01, 0.36]	[0.00, 0.45]	[0.01, 0.39]	[0.00, 0.27]	[0.01, 0.41]	[0.00, 0.21]	[0.00, 0.27]	[0.01, 0.26]
24	0.02, 0.13	0.04, 0.23	0.02, 0.11	0.02, 0.10	0.03, 0.19	0.02, 0.09	0.01, 0.06	0.01, 0.06
	[0.01, 0.36]	[0.00, 0.50]	[0.00, 0.39]	[0.00, 0.32]	[0.02, 0.38]	[0.00, 0.33]	[0.00, 0.31]	[0.01, 0.26]
36	0.02, 0.12	0.04, 0.21	0.02, 0.09	0.02, 0.13	0.04, 0.20	0.03, 0.14	0.01, 0.06	0.01, 0.06
	[0.01, 0.33]	[0.00, 0.46]	[0.00, 0.36]	[0.00, 0.32]	[0.02, 0.38]	[0.00, 0.38]	[0.01, 0.31]	[0.01, 0.26]

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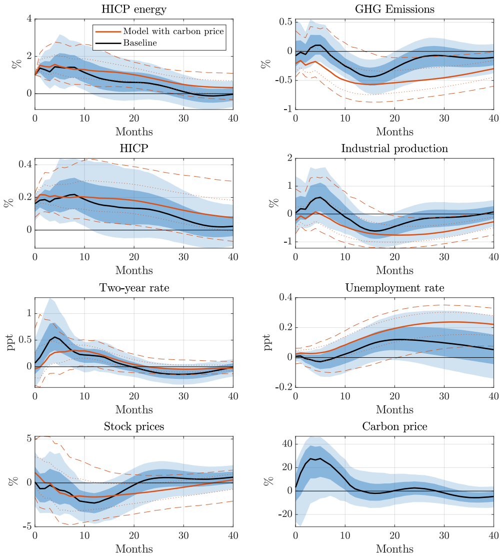
Model with carbon price



First stage regression: F-statistic: 9.54, R^2: 4.06%

The role of energy prices

To better understand **role** of **power sector** perform event study using daily futures and stock prices

$$q_{i,d+h} - q_{i,d-1} = \beta^i_{h,0} + \psi^i_h CPSurprise_d + \beta^i_{h,1}\Delta q_{i,d-1} + \ldots + \beta^i_{h,p}\Delta q_{i,d-p} + \xi_{i,d,h}$$

- $q_{i,d+h}$: (log) price of asset i, h days after event d
- $CPSurprise_d$: carbon policy surprise on event day
- ψ^i_h: effect on asset price i at horizon h

The role of energy prices

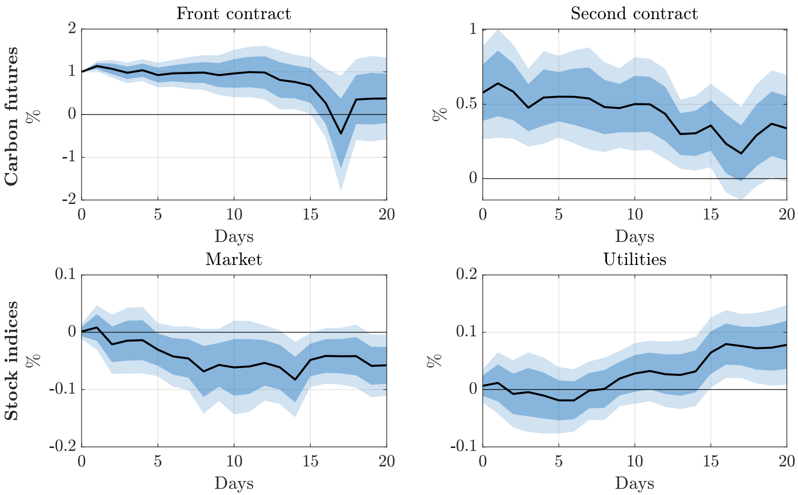


Figure 14: Carbon price and stock market indices

The role of energy prices

- **Carbon futures** prices **increase** significantly after carbon policy surprise
- **Stock market** does not respond on impact but only **falls** with a lag
- **Utilities sector** is the **only** sector displaying a **positive** response
  - Supports interpretation that utilities sector **passes through** emissions cost to their customers

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Foreign exchange and trade

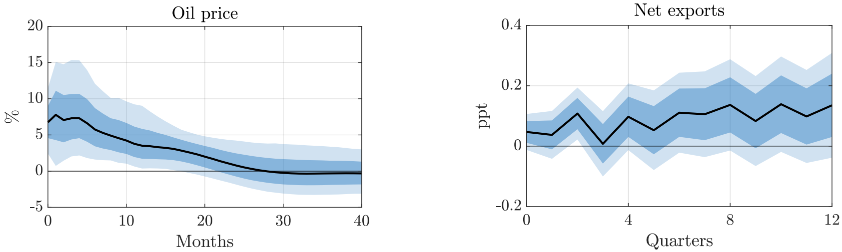

Figure 15: Effect on foreign exchange and trade

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Descriptive statistics

Table 6: Descriptive statistics on households in the LCFS

	Overall	By income group		
		Low-income	Middle-income	High-income
Income and expenditure				
Normal disposable income	6,748	3,740	6,807	10,866
Total expenditure	4,458	3,025	4,444	6,238
Energy share	7.2	9.5	7.2	5.2
Non-durables (excl. energy) share	81.5	81.6	81.6	81.3
Durables share	11.2	8.9	11.2	13.5
Household characteristics				
Age	51	47	54	49
Education (share with post-comp.)	34.0	25.7	29.7	51.2
Housing tenure				
Social renters	20.8	46.9	17.4	3.7
Mortgagors	42.3	25.5	41.3	60.0
Outright owners	36.9	27.7	41.3	36.4

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Descriptive statistics

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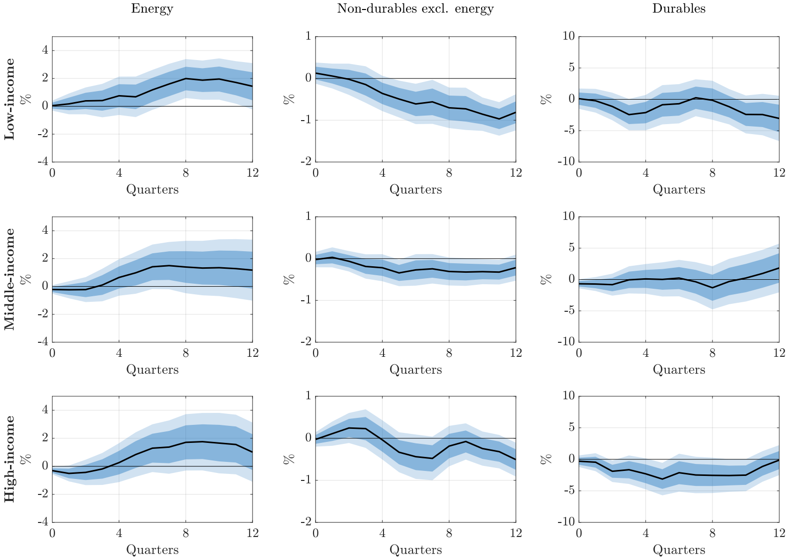
Energy versus non-energy expenditure



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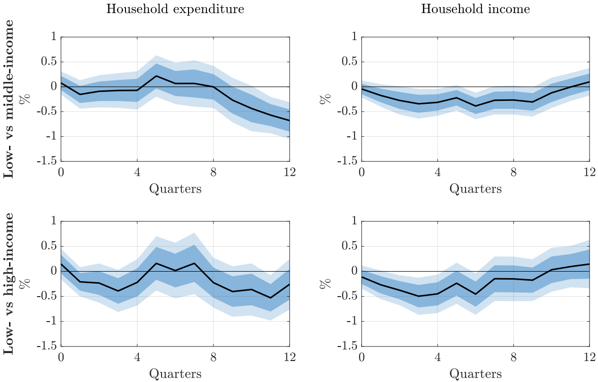
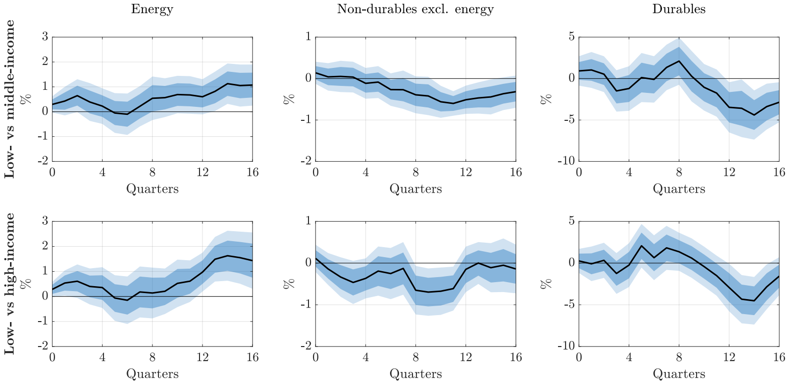
Group differences



Group differences



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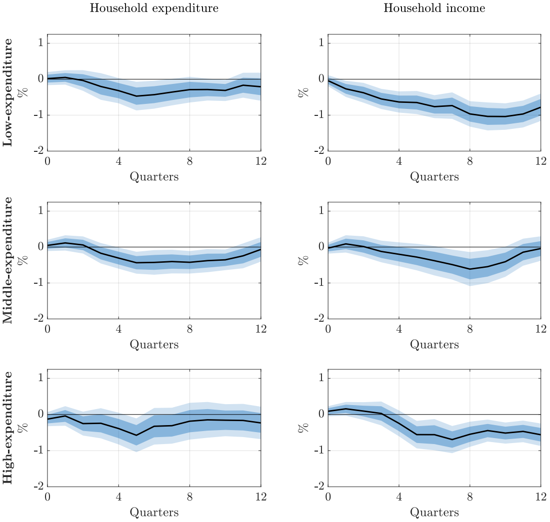
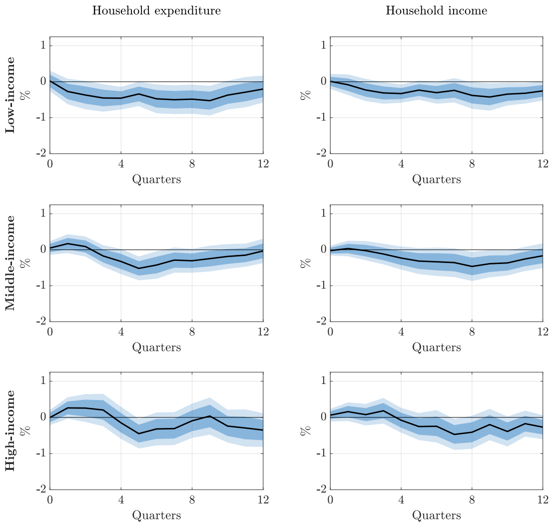
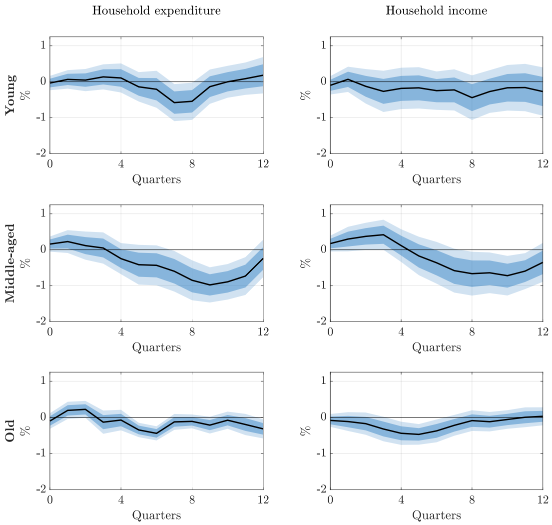
Group by expenditure



Group by permanent income

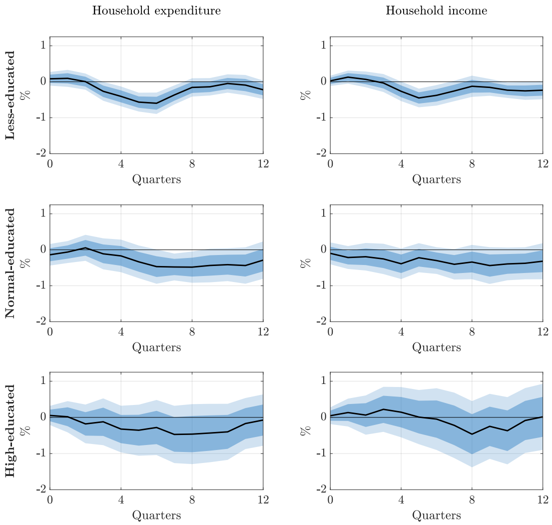


Group by age

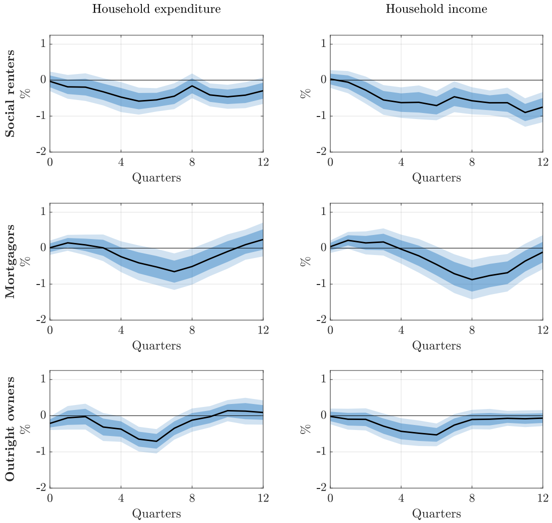


Household expenditure
Household income
Young
Middle-aged
Old
%
Quarters
1
0
-1
-2
0
4
8
12

Group by education



Group by housing tenure



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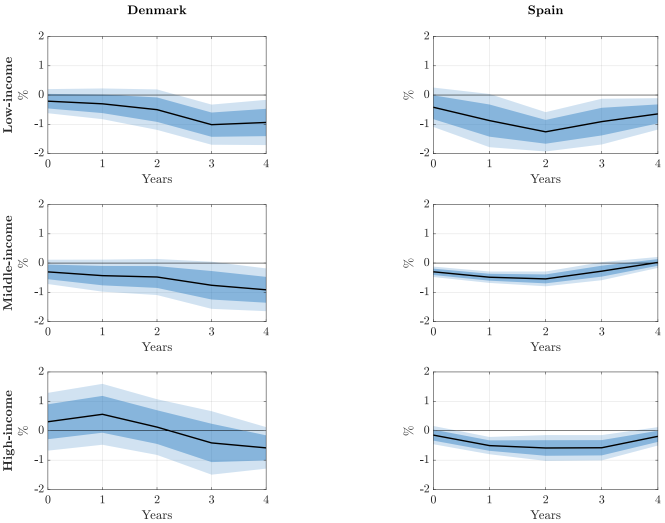
External validity



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What drives the income response?

- Significant **heterogeneity** in income responses
- **Potential explanations**:
  - Heterogeneity in **labor income** because of differences in **employment sector** ▸ More
  - Differences in **income composition**: labor versus. **financial income** ▸ More

Heterogeneity by sector of employment

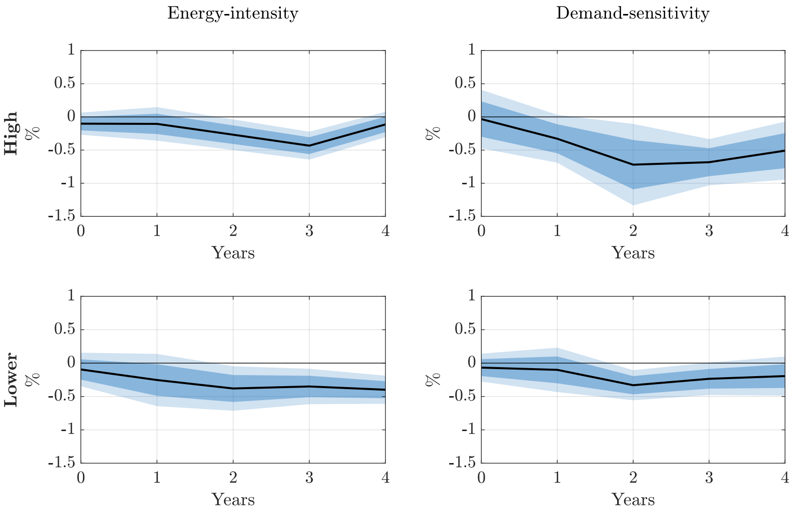

Figure 16: Income response by sector of employment

Heterogeneity by sector of employment

Table 7: Sectoral distribution of employment

Sectors	Overall	By income group		
		Low-income	Middle-income	High-income
Energy-intensity				
High	21.6	9.8	25.6	25.8
Lower	78.4	90.2	74.4	74.2
Demand-sensitivity				
High	30.5	49.0	27.2	18.1
Lower	69.5	51.0	72.8	81.9

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Definition of sector groups

Table 8: Sectors by energy intensity and demand sensitivity

Group	Sectors	SIC sections
High energy intensity	Agriculture, forestry, and fishing; mining and quarrying; manufacturing; electricity, gas and water supply (utilities); transport, storage and communications	A-E, I
Lower energy intensity	Construction; Wholesale and retail trade; Hotels and restaurants; Financial intermediation; Real estate, renting and business; Public administration and defense; Education; Health and social work; Other community, social and personal services	F-H, J-Q
High demand sensitivity	Construction; Wholesale and retail trade; Hotels and restaurants; Other community, social and personal services	F-H, O-Q
Lower demand sensitivity	Agriculture, forestry, and fishing; mining and quarrying; manufacturing; electricity, gas and water supply (utilities); transport, storage and communications; Financial intermediation; Real estate, renting and business; Public administration and defense; Education; Health and social work	A-E, J-N

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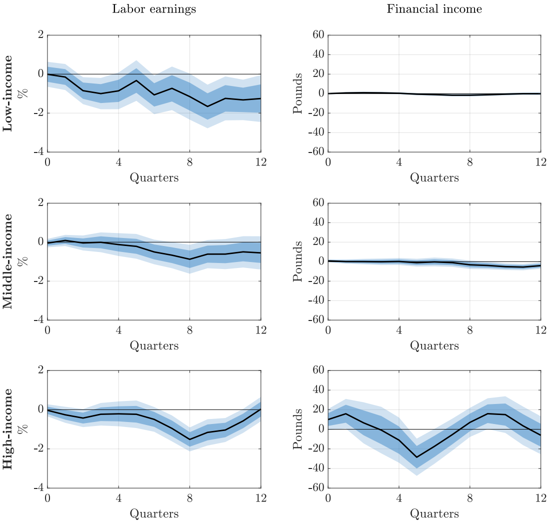
Earnings and financial income



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Energy expenditure

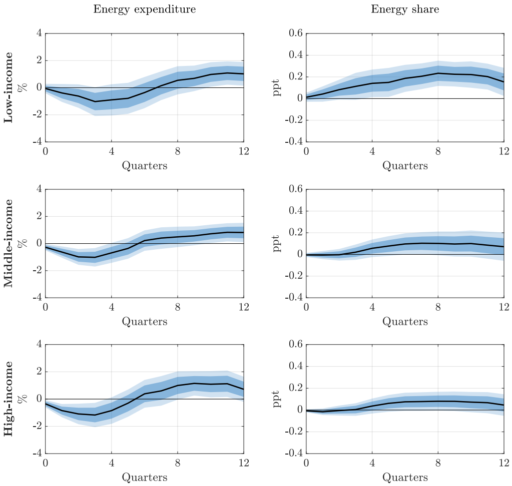

Figure 17: Energy expenditure and energy share by income group

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Model

- To study role of **redistributing** auction revenues, build a **climate-economy model** to use as a laboratory
- Climate-economy model with nominal rigidities and **household heterogeneity**
  - **Energy sector** producing energy/emissions using labor
  - **Non-energy NK sector** producing consumption good using energy, labor and capital
  - **Two households**: hand-to-mouth and savers differing in **energy expenditure shares**, **income incidence** and **MPCs**. Idiosyncratic risk as households switch between types
- Calibrated to match key micro and macro moments

▸ Model details

Redistributing carbon revenues

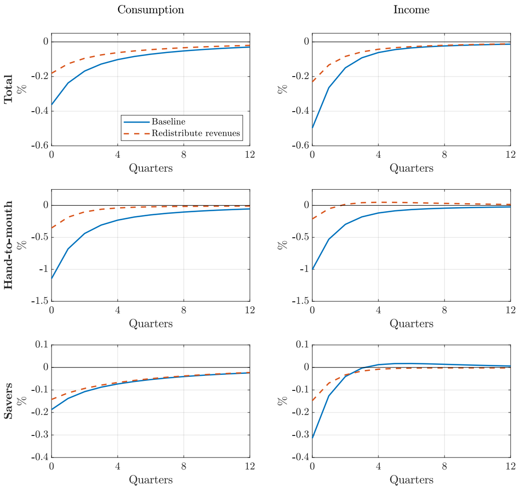

Figure 18: Responses to carbon tax shock

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Redistributing carbon revenues

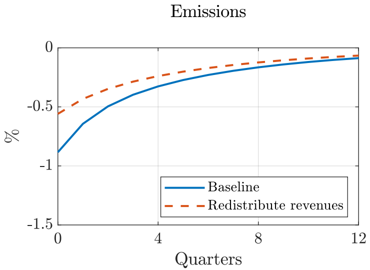

Figure 19: Responses to carbon tax shock

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Redistributing carbon revenues

- Model can **match** the estimated (peak) magnitudes in the data
  - **Heterogeneity** plays a crucial role,
  - In RA model implausibly high energy share needed to match magnitudes
- **Redistributing tax revenues** to hand-to-mouth can
  - **reduce inequality** and **attenuate** aggregate effect on **consumption**
  - while emissions only change little

▸ More

Model details

Households

- Two types of households: λ hand-to-mouth H and $1-\lambda$ savers S
- Hand-to-mouth live paycheck to paycheck, consume all their income
- Savers choose consumption intertemporally, save/invest in capital and bonds
- Households subject to idiosyncratic risk: switch between types
    - probability to stay saver s, probability to stay hand-to-mouth h
- Only risk-free bonds are liquid and can be used to self-insure
- Centralized labor market structure: union sets wages

$$w_t = \varphi h_t^{\theta} \left(\lambda \frac{1}{p_{H,t}} U_x(x_{H,t}, h_t) + (1-\lambda) \frac{1}{p_{S,t}} U_x(x_{S,t}, h_t) \right)^{-1}$$

Model details

- Savers maximize lifetime utility $\mathbb{E}_0\left[\sum_{t=0}^{\infty}\beta^t U(x_{S,t},h_t)\right]$ subject to budget constraint and capital accumulation
- Consumption good is composite of energy and non-energy good

  $x_{S,t} = \left(a_{S,c}^{\frac{1}{\epsilon_X}} c_{S,t}^{\frac{\epsilon_X-1}{\epsilon_X}} + a_{S,e}^{\frac{1}{\epsilon_X}} e_{S,t}^{\frac{\epsilon_X-1}{\epsilon_X}}\right)^{\frac{\epsilon_X}{\epsilon_X-1}}$
- Optimizing behavior

$$
\begin{aligned}
c_{S,t} &= a_{S,c}\left(\frac{1}{p_{S,t}}\right)^{-\epsilon_X} x_{S,t} \\
e_{S,t} &= a_{S,e}\left(\frac{p_{e,t}}{p_{S,t}}\right)^{-\epsilon_X} x_{S,t} \\
\lambda_{S,t} &= \beta\,\mathbb{E}_t\left[(1+(1-\tau^k)r_{t+1}-\delta)\lambda_{S,t+1}\right] \\
\lambda_{S,t} &= \beta\,\mathbb{E}_t\left[\frac{R_t^b}{\Pi_{t+1}}\left(s\lambda_{S,t+1}+(1-s)\lambda_{H,t+1}\right)\right]
\end{aligned}
$$

Model details

- Hand-to-mouth are constrained, just exhaust their budget in every period

$$c_{H,t} = a_{H,c}\left(\frac{1}{p_{S,t}}\right)^{-\epsilon_x} x_{H,t}$$

$$e_{H,t} = a_{H,e}\left(\frac{p_{e,t}}{p_{S,t}}\right)^{-\epsilon_x} x_{H,t}$$

$$p_{H,t}x_{H,t} = y_{H,t}$$

Model details

Firms

- Energy producers, subject to carbon tax τ_t

$$e_t = a_{e,t} h_{e,t}$$
$$w_t = (1 - \tau_t) p_{e,t} \frac{e_t}{h_{e,t}}$$

- Consumption good producers

$$y_t = e^{-\gamma s_t} \left[(1-\nu)^{\frac{1}{\epsilon_y}} \left(a_t k_t^{\alpha} h_{y,t}^{1-\alpha} \right)^{\frac{\epsilon_y - 1}{\epsilon_y}} + \nu^{\frac{1}{\epsilon_y}} \left(e_{y,t} \right)^{\frac{\epsilon_y - 1}{\epsilon_y}} \right]^{\frac{\epsilon_y}{\epsilon_y - 1}}$$
$$r_t = \alpha v_{1,t} mc_t \frac{y_t}{k_t}$$
$$w_t = (1-\alpha) v_{1,t} mc_t \frac{y_t}{h_{y,t}}$$
$$p_{e,t} = v_{2,t} mc_t \frac{y_t}{e_{y,t}}$$
$$\hat{\pi}_t = \kappa \hat{mc}_t + \beta E_t \hat{\pi}_{t+1}$$

Model details

Climate block

$$s_t = (1-\varphi)s_{t-1} + \varphi_0 e_t$$

Fiscal and monetary policy

$$\lambda\omega_{H,t} = \tau^d d_t + \tau^k r_t^K k_t + \mu\tau_t p_{e,t} e_t$$

$$(1-\lambda)\omega_{S,t} = (1-\mu)\tau_t p_{e,t} e_t$$

$$\tau_t = (1-\rho_\tau)\tau + \rho_\tau \tau_{t-1} + \epsilon_{\tau,t}$$

$$\hat{r}_t^b = \rho_r \hat{r}_{t-1}^b + (1-\rho_r)(\phi_\pi \hat{\pi}_{T,t} + \phi_y \hat{y}_t) + \epsilon_{mp,t}$$

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Calibration

Parameter	Description	Value	Target/Source
β	Discount factor	0.99	Standard value
$1/\sigma$	Intertemporal elasticity of substitution	1	Standard value
$1/\theta$	Labor supply elasticity	1	Standard value
λ	Share of hand-to-mouth	0.25	Share of low-income households, LCFS
$1-s$	Probability of becoming H	0.04	Bilbiie (2020)
$a_{H,e}$	Distribution parameter H	0.078	Energy share of 9.5%, LCFS
$a_{S,e}$	Distribution parameter S	0.056	Energy share of 6.5%, LCFS
ϵ_{xH}	Elasticity of substitution energy/non-energy H	0.05	LCFS, Labandeira, Labeaga, and López-Otero (2017)
ϵ_{xS}	Elasticity of substitution energy/non-energy S	0.275	LCFS, Labandeira, Labeaga, and López-Otero (2017)
ϵ_{y}	Elasticity of substitution energy/non-energy firms	0.21	Labandeira, Labeaga, and López-Otero (2017)
δ	Depreciation rate	0.025	Smets and Wouters (2003)
α	Capital returns-to-scale	0.3	Standard value
ν	Energy returns-to-scale	0.07	Steady-state energy share of $\approx$ 7%; Eurostat
ϵ_p	Price elasticity	6	Steady-state markup of 20%; Christopoulou and Vermeulen (2012)
θ_p	Calvo parameter	0.825	Average price duration of 5-6 quarters; Alvarez et al. (2006)
γ	Climate damage parameter	$5.3 * 10^{-5}$	Golosov et al. (2014)
φ_0	Emissions staying in atmosphere	0.5359	Golosov et al. (2014)
$1-\varphi$	Emissions decay parameter	0.9994	Golosov et al. (2014)
ϕ_π	Taylor rule coefficient inflation	1.5	Smets and Wouters (2003)
ρ_r	Interest smoothing	0.8	Smets and Wouters (2003)
τ	Steady-state carbon tax	0.039	Implied tax rate from average EUA price
ρ_τ	Persistence carbon tax shock	0.85	Mean-reversion of approx. 20 quarters

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Role of heterogeneity

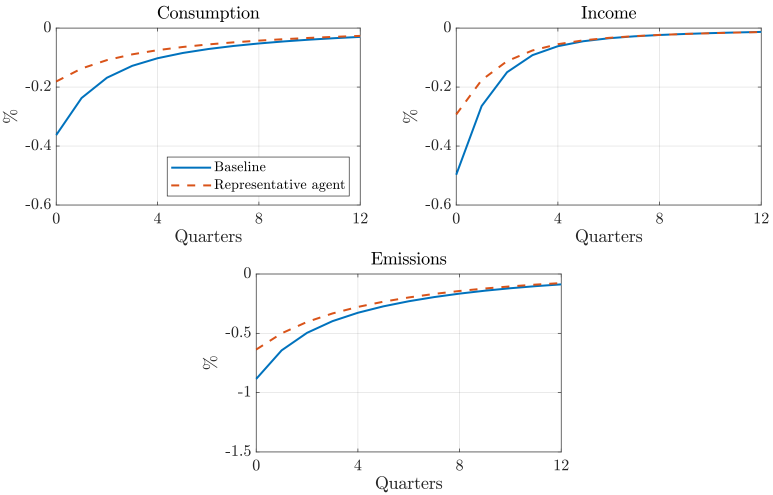

Figure 20: Responses to carbon tax shock

Role of monetary policy

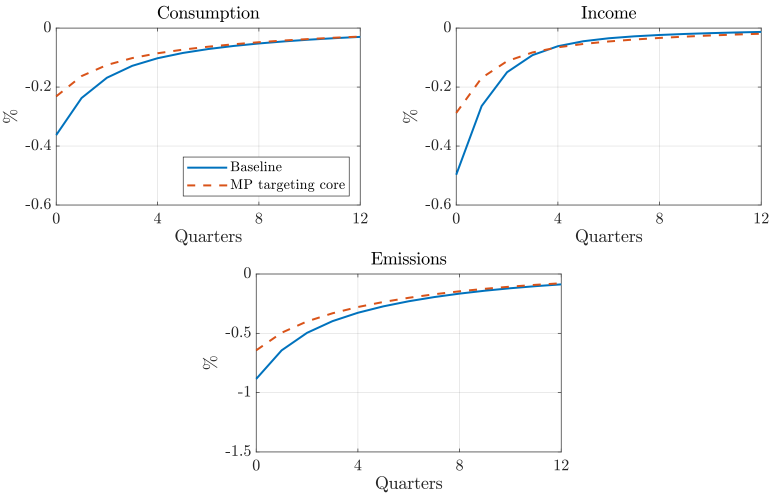

Figure 21: Responses to carbon tax shock

Attitudes towards climate policy

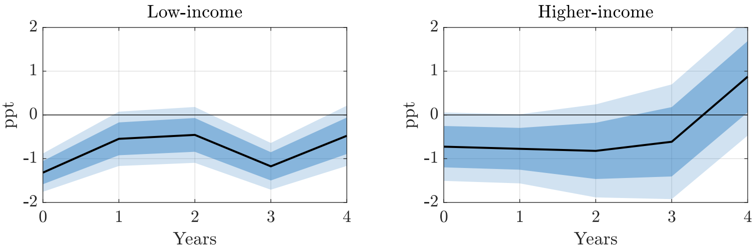

Figure 22: Effect on attitude towards climate policy by income group

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No effect on innovation for oil shocks

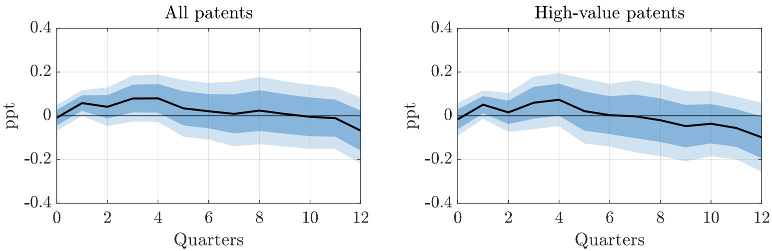

Figure 23: Share of low-carbon patents

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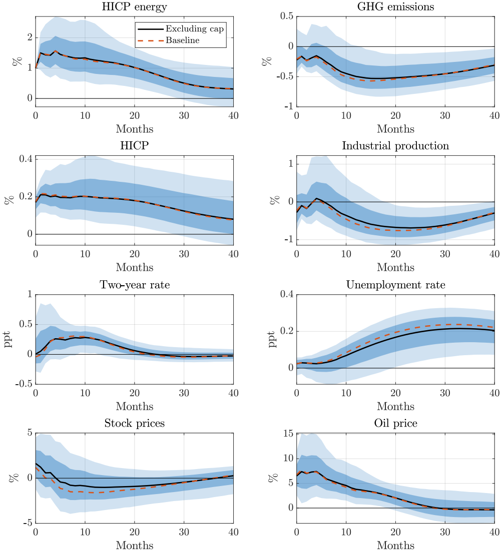
Robustness

Check **robustness** with respect to

- **Selection of events**: robust to just using NAP/auction events, robust to dropping largest events
- **Background noise**: robust to controlling for confounding news using a heteroskedasticity-based approach
- **Sample and specification choices**: robust to estimating on shorter sample, to lag order, and to using a smaller system to estimate effects

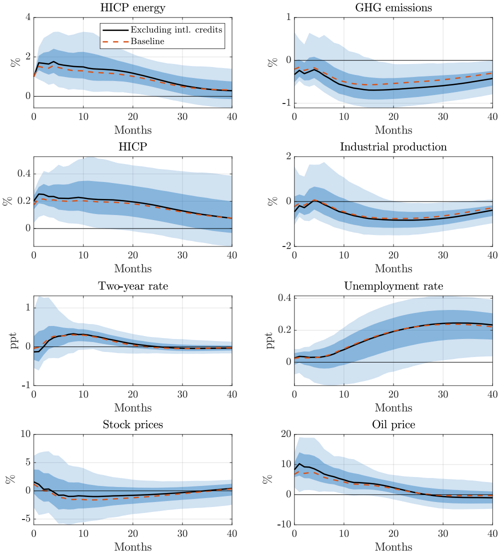
▸ Details

Excluding events regarding cap



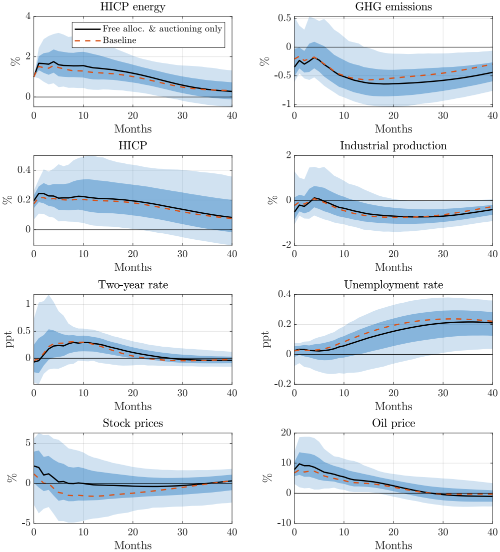
First stage regression: F-statistic: 18.97, R^2: 3.09%

Excluding events regarding international credits



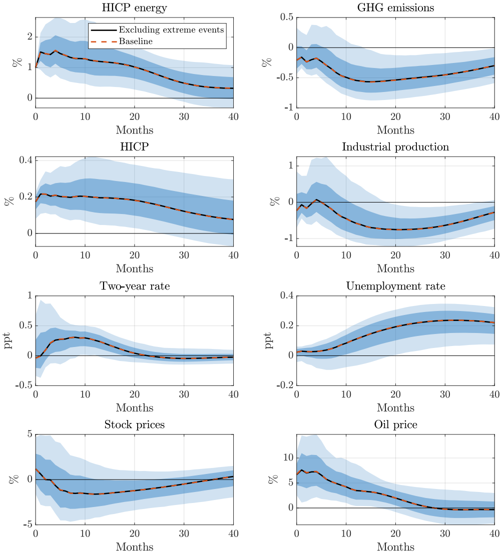
First stage regression: F-statistic: 11.99, R^2: 1.79%

Only using events regarding NAPs



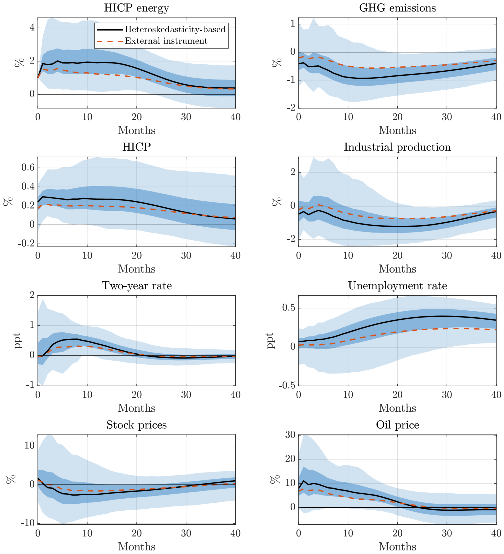
First stage regression: F-statistic: 13.46, R^2: 1.97%

Excluding extreme events

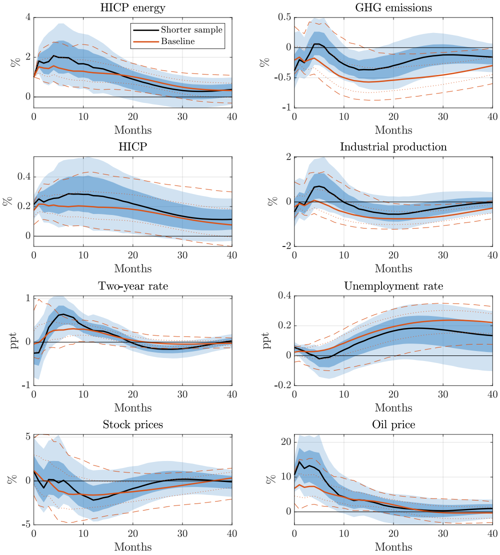


First stage regression: F-statistic: 17.43, R^2: 2.85%

Heteroskedasticity-based identification

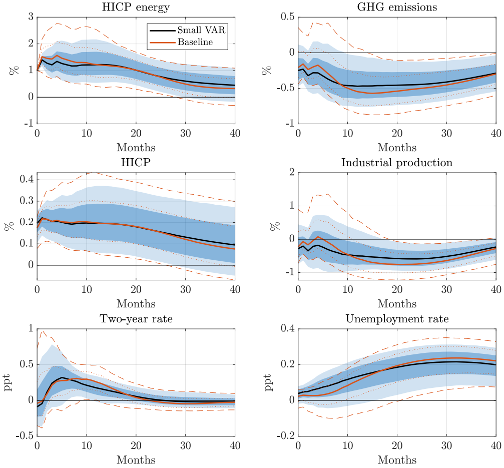


2005-2018 sample



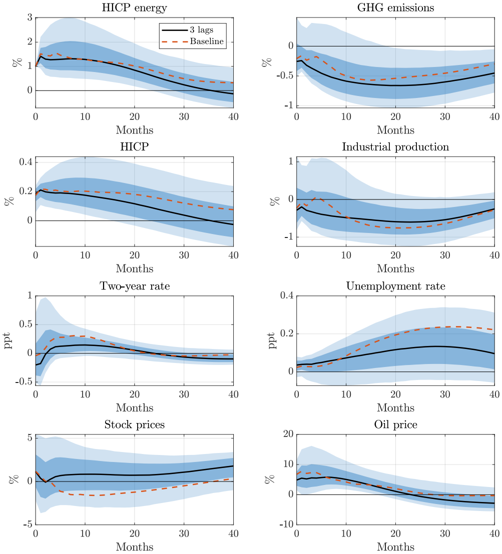
First stage regression: F-statistic: 6.44, R^2: 2.49%

Responses from smaller VAR



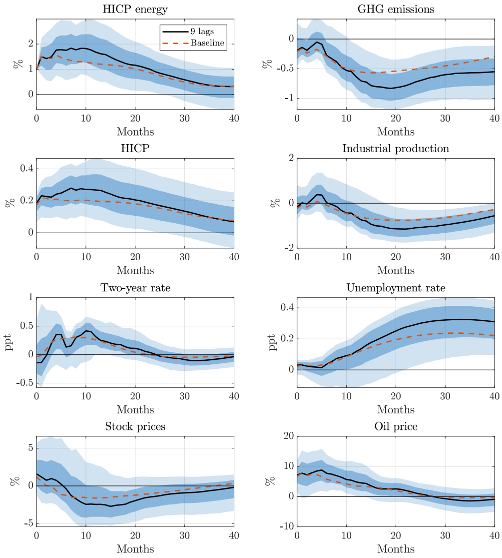
First stage regression: F-statistic: 6.72, R^2: 1.82%

VAR with 3 lags



First stage regression: F-statistic: 7.72, R^2: 1.79%

VAR with 9 lags



First stage regression: F-statistic: 17.51, R^2: 2.75%