Business Cycles with Pricing Cascades

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Motivation

- Recent events have brought new evidence regarding the drivers and dynamics of inflation:

  i Possibility of **large inflationary swings** in advanced economies ▸ Show

  Challenge: *NKPC with a realistic slope requires implausibly large shocks* (L'Huillier and Phelan, 2024)

  ii Fluctuations in the **frequency of price adjustment** (Montag and Villar, 2023; Cavallo et al., 2024) ▸ Show

  Challenge: *a fixed menu cost model matches the frequency at the cost of an implausibly steep NKPC* (Blanco et al., 2024)

  iii Importance of **sector-specific** drivers of inflation (Schneider, 2023; Rubbo, 2024) ▸ Show

  Challenge: *need to allow for large sector-specific shocks in a setting with menu costs*

- Develop a **dynamic quantitative** general equilibrium model that features: a number of **sectors interconnected by networks** with **state-dependent pricing** that is solved **fully non-linearly**

New cyclical mechanism: interaction of **networks** and pricing **cascades**

- **Interaction** of our model ingredients creates pricing **cascades**: large movements in aggregates trigger additional price adjustment decisions at the extensive margin

- **Demand shocks** **Networks slow down** adjustment along the extensive margin: **cascades dampening**
  - i Networks slow down the desired price changes, and firms are less willing to pay the cost of adjustment
  - ii Quantitatively, delivers a "global flattening" of the Phillips Curve, implying strong monetary non-neutrality even following very large shocks

- **Supply shocks** (Agg./sectoral) **Networks speed up** price adjustment: **cascades amplification**
  - i Networks amplify the desired price changes, and firms are more willing to pay the adjustment cost
  - ii Quantitatively, creates frequency increases and inflationary spirals following aggregate TFP/markup shocks, or TFP/markup shocks to sectors that are major suppliers to the rest of the economy

Model overview

- **Timing**: infinite-horizon setting in discrete time, indexed by $t = 0, 1, 2, \ldots$
- **Households**: continuum of identical households; consume output and supply labor
- **Firms**: continuum of monopolistically competitive firms, each belongs to one of N sectors, indexed $i \in \{1, 2, \ldots, N\}$; there is a measure one of firms in each sector
- **Factors**: firms use labor and intermediate inputs purchased from other firms
- **Government Policy**: central bank sets the level of money supply M_t

Households

- The representative household maximizes expected lifetime utility:

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left[\log C_t - L_t\right]$$

  subject to a standard budget constraint

- Households are also subject to a **cash-in-advance** constraint: $P_t^C C_t \leq M_t$

- Aggregate consumption: $C_t = \iota^C \prod_{i=1}^N C_i^{\overline{\omega}_i^C}, \quad \sum_{i=1}^N \overline{\omega}_i^C = 1, \quad \overline{\omega}_i^C \geq 0, \forall i$

- Sectoral consumption: $C_{i,t} = \left\{ \int_0^1 \left[\zeta_{i,t}(j) C_{i,t}(j)\right]^{\frac{\epsilon-1}{\epsilon}} dj \right\}^{\frac{\epsilon}{\epsilon-1}}, \quad \epsilon > 1$

  where $\zeta_{i,t}(j)$ is a **firm-level quality** process:

$$\log \zeta_{i,t}\left(j\right) = \log \zeta_{i,t-1}\left(j\right) + \sigma_i \varepsilon_{i,t}\left(j\right)$$

Firms: production

- Any firm j in sector i has access to the following production technology:

$$Y_{i,t}(j) = \iota_i \frac{1}{\zeta_{i,t}(j)} \times A_{i,t} \times L_{i,t}(j)^{\overline{\alpha}_i} \prod_{k=1}^{N} X_{i,k,t}(j)^{\overline{\omega}_{ik}},$$

where $A_{i,t}$ is a **sectoral productivity** process, $L_{i,t}(j)$ is firm-level labor input, $X_{i,k,t}(j)$ is firm-level intermediate input demand for sector k's goods and $\overline{\alpha}_i + \sum_{k=1}^{N} \overline{\omega}_{ik} = 1, \quad \overline{\alpha}_i \geq 0, \overline{\omega}_{ik} \geq 0, \; \forall i, k$

- Cost-minimization delivers the following real marginal cost:

$$MC_{i,t}(j) = \zeta_{i,t}(j) \times \frac{M_t}{A_{i,t}} \times \prod_{k=1}^{N} \frac{P_{k,t}^{\omega_{ik}}}{M_t}$$

Firms: pricing

- Price resetting involves paying a sector-specific **menu cost** $\kappa_{i,t}$ measured in labor hours

- Let $p_{i,t}(j) \equiv \log \tilde{P}_{i,t}(j) = \log \frac{P_{i,t}(j)}{\zeta_{i,t}(j) M_t}$ be the quality-adjusted *log* real price

- The value of a firm in sector i that has set a quality-adjusted real price p:

$$V_{i,t}(p) = \tilde{\mathcal{D}}_{i,t}(p) + \beta \mathbb{E}_t \left[\left\{ 1 - \eta_{i,t+1} \left(p - \sigma_i \varepsilon_{i,t+1} - m_{t+1} \right) \right\} \times V_{i,t+1} \left(\overbrace{p - \sigma_i \varepsilon_{i,t+1} - m_{t+1}}^{\text{"Eroded" real price}} \right) \right]$$

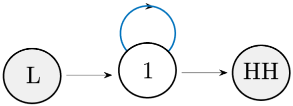
$$+ \beta \mathbb{E}_t \left[\underbrace{\eta_{i,t+1} \left(p - \sigma_i \varepsilon_{i,t+1} - m_{t+1} \right)}_{\text{Prob. of adjustment}} \times \left(\max_{p'} V_{i,t+1} \left(p' \right) - \kappa_{i,t} \right) \right]$$

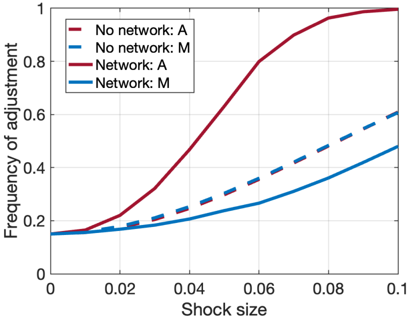
- Following Golosov and Lucas (2007), we assume the following **adjustment hazard** $\eta_{i,t}(.)$:

$$\eta_{i,t}(p) = \mathbf{1}(L_{i,t}(p) > 0) = \mathbf{1} \left(\max_{p'} V_{i,t} \left(p' \right) - V_{i,t}(p) > \overline{\kappa}_i \right)$$

Toy example 1: roundabout production

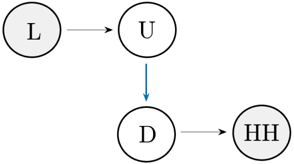
- Marginal cost: $MC(j) = \zeta(j) \times \frac{1}{A} \times M^{\overline{\alpha}} P^{1-\overline{\alpha}} = \zeta(j) \times \frac{M}{A} \times \left(\frac{P}{M}\right)^{1-\overline{\alpha}}$

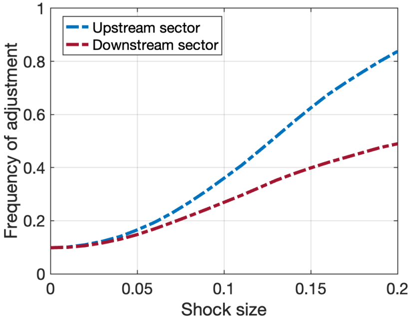




Toy example 2: two-sector vertical chain

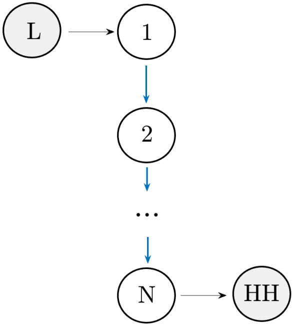
- Marginal costs: $MC_U(j) = \zeta_U(j) \times \frac{1}{A_U} \times M, \quad MC_D(j) = \zeta_D(j) \times \frac{1}{A_D} \times P_U$

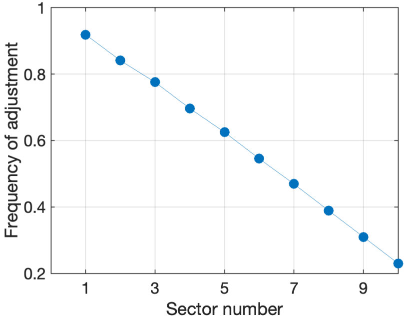




Toy example 3: *N*-sector vertical chain

- Marginal costs: $MC_i(j) = \zeta_i(j) \times \frac{1}{A_i} \times P_{i-1}$





QUANTITATIVE RESULTS

Computation

- **Steady state**: solve the stationary Bellman equations and firms' price distribution on a grid of log quality-adjusted real prices for every sector
- Consider a **known** sequence of money supply $\{\Delta \log M_t\}_{t=0}^{\infty}$ and productivity $\{\log A_{k,t}\}_{t=0}^{\infty}$
- Assume that after a finite time period T the economy converges back to the stationary distribution
- From a guess for the sequences of aggregate and sectoral variables, follow **backward-forward iteration** until convergence:
  1. Starting from $t = T$, iterate **backwards** to $t = 0$ to solve for the micro value functions
  2. Starting from $t = 0$, iterate **forwards** to $t = T$ to solve for price distributions and aggregate numerically

Calibration (Euro Area, monthly frequency)

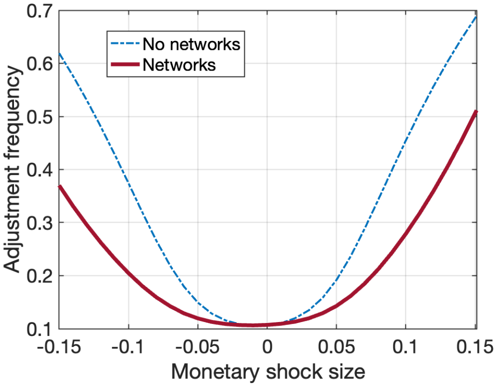
Aggregate parameters			
β	$0.96^{1/12}$	Discount factor (monthly)	Golosov and Lucas (2007)
ϵ	3	Goods elasticity of substitution	Midrigan (2011)
$\overline{\pi}$	0.02/12	Trend inflation (monthly)	ECB target
ρ	0.90	Persistence of the TFP shock	Half-life of seven months
Sectoral parameters			
N	39	Number of sectors	Data from Gautier et al. (2024)
$\{\overline{\omega}_i^C\}_{i=1}^N$		Sector consumption weights	World IO Tables
$\{\overline{\omega}_{ik}\}_{i,k=1}^N$		Sector input-output matrix	World IO Tables
$\{\overline{\alpha}_i\}_{i=1}^N$		Sector labor weights	World IO Tables
Firm-level pricing parameters			
$\{\overline{\kappa}_i\}_{i=1}^N$		Menu costs	Estimated to fit frequency, std dev.
$\{\sigma_i\}_{i=1}^N$		Std. dev. of firm-level shocks	of Δp from Gautier et al. (2024)

Monetary shocks

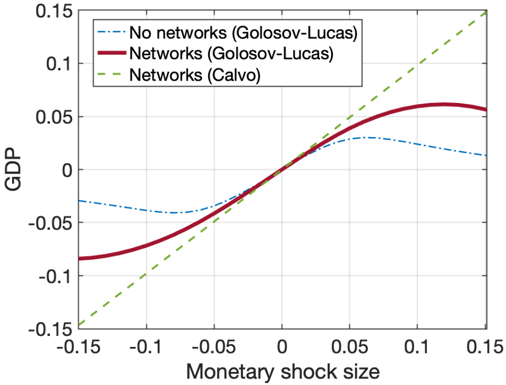
$$\log M_t = \overline{\pi} + \log M_{t-1} + \varepsilon_t^M$$

Cascades dampening following monetary shocks

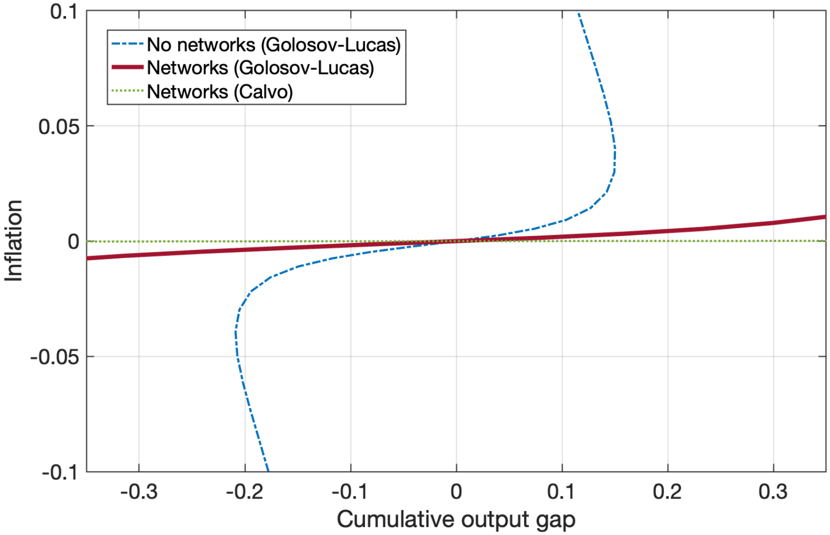
(a) Aggregate adjustment frequency



(b) GDP



Non-linear **Phillips Curves**

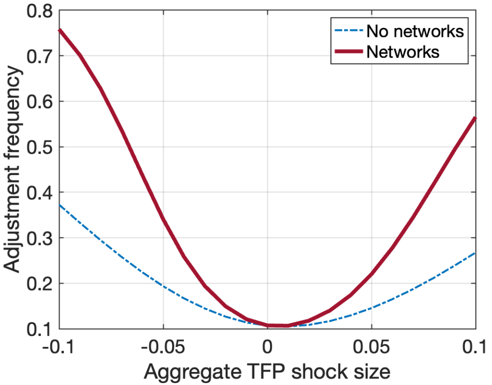


Aggregate TFP shocks

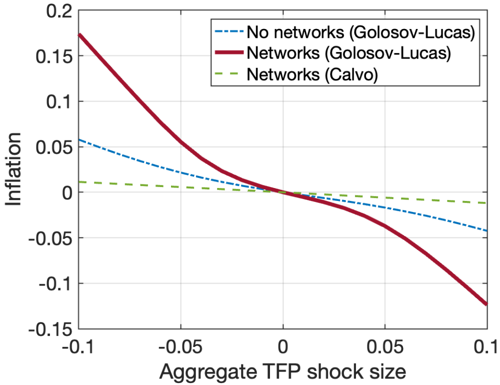
$$\log A_t = \rho \log A_{t-1} + \varepsilon_t^A$$

Cascades amplification following TFP shocks

(a) Aggregate adjustment frequency

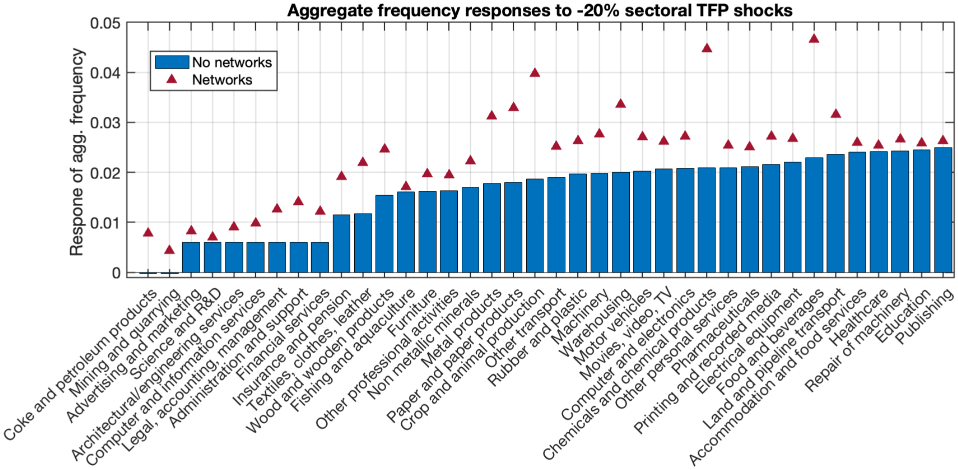


(b) CPI inflation



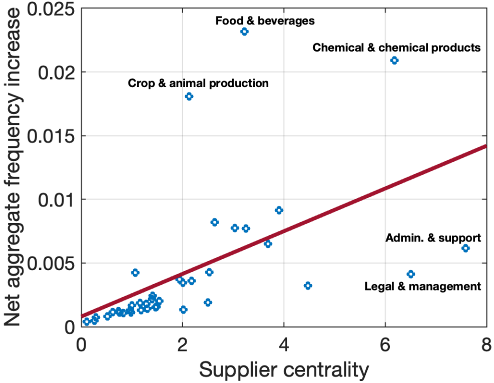
Sectoral TFP shocks

Aggregate frequency responses to sectoral TFP shocks (-20%)

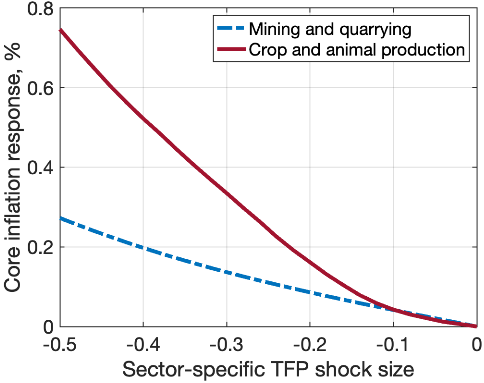


Aggregate frequency responses vs. sectoral **Supplier Centrality**

(a) (Net) aggregate adjustment frequency



(b) Core inflation response



APPLICATION: (POST-) COVID EURO AREA INFLATION

Model vs. Data

- To assess the model quantitatively, we feed in observed demand and supply processes as exogenous shocks

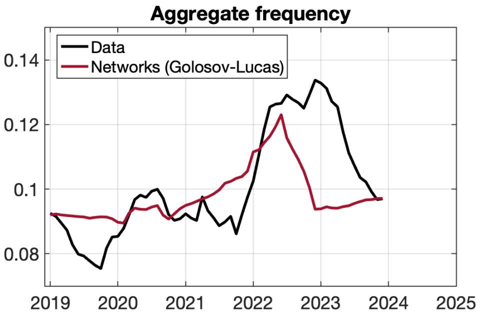
- **Aggregate demand shock**: Euro Area nominal GDP as a proxy for the $\{M_t\}_{t\geq 0}$ process

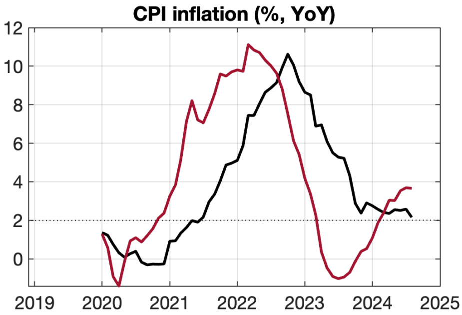
- **Energy price shock**: calibrate the productivity process of the "Mining and Quarrying" sector to match the IMF Global Price of Energy Index movements

- **Food price shock**: calibrate the productivity process of the "Crop and Animal Production" sector to match the IMF Global Price of Food Index movements

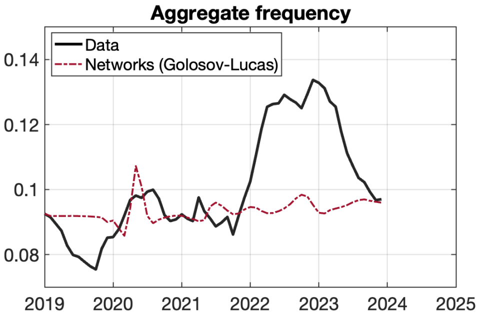
- **Labor market shock**: calibrate the productivity process of the labor union sector to match the hourly earnings dynamics in the Euro Area

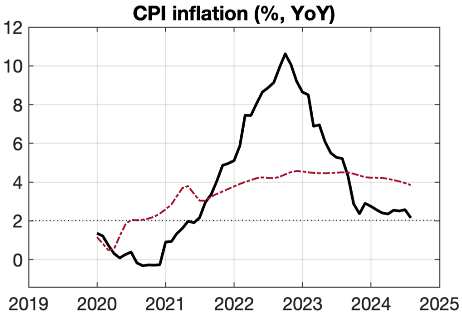
Model vs. Data: baseline setup, all shocks



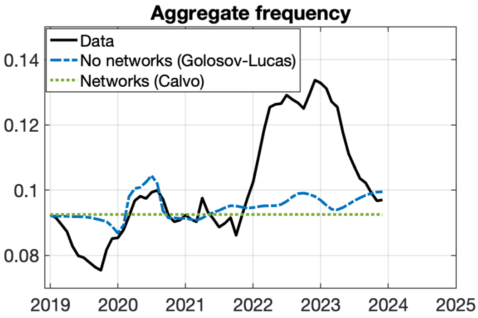


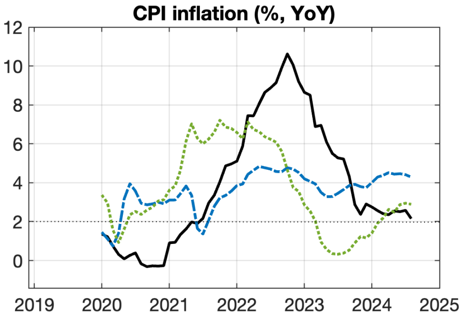
Model vs. Data: baseline setup, no commodity shocks





Model vs. Data: alternative setups, all shocks





Conclusions

- Present a **dynamic quantitative** general equilibrium model that features: a number of **sectors interconnected by networks** with **state-dependent pricing** that is solved **fully non-linearly**
- Networks **slow down** the extensive margin pricing response to **demand shocks**: **cascades dampening**
- Networks **speed up** the extensive margin response to **supply shocks**: **cascades amplification**
- **Interaction** of networks and pricing cascades crucial for **quantitatively** matching the observed surges in inflation and repricing frequency in the Euro Area

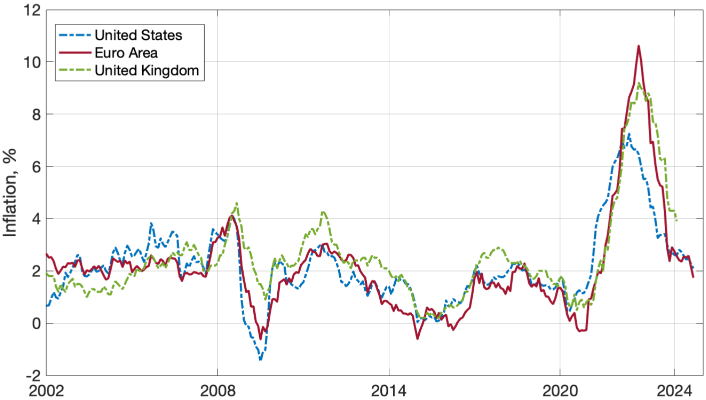
References

Gautier, Erwan, Cristina Conflitti, Riemer P. Faber, Brian Fabo, Ludmila Fadejeva, Valentin Jouvanceau, Jan-Oliver Menz, Teresa Messner, Pavlos Petroulas, Pau Roldan-Blanco, Fabio Rumler, Sergio Santoro, Elisabeth Wieland, and Hélène Zimmer (2024) "New Facts on Consumer Price Rigidity in the Euro Area," *American Economic Journal: Macroeconomics*, Vol. 16, p. 386–431.

Golosov, Mikhail and Robert E. Lucas (2007) "Menu Costs and Phillips Curves," *Journal of Political Economy*, Vol. 115, pp. 171–199.

APPENDIX

Evidence I: inflation spikes in advanced economies (headline)



Source: FRED.

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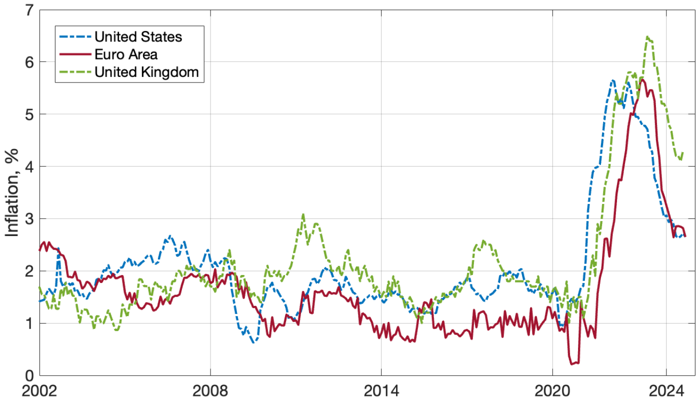
Evidence I: inflation spikes in advanced economies (core)



Source: FRED.

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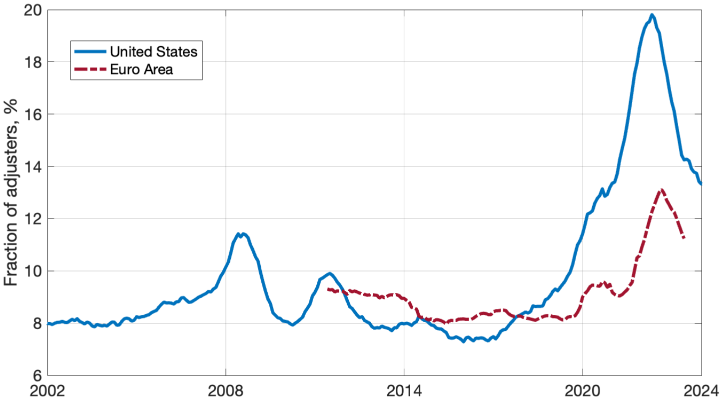
Evidence II: changes in frequency of price adjustment



Source: Montag and Villar (2024), Dedola et al. (2024).

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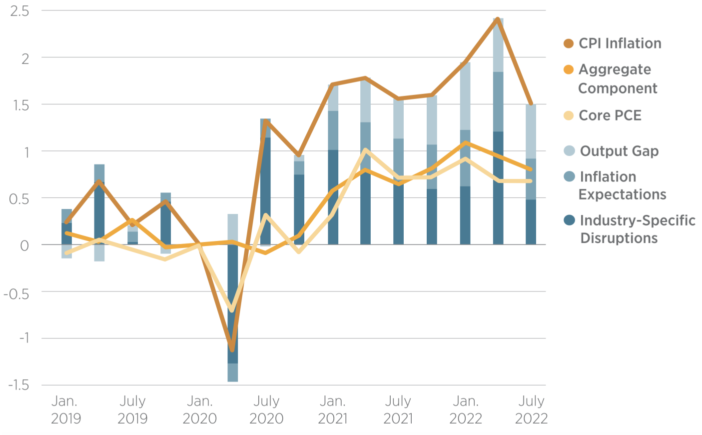
Evidence III: sectoral origins of inflation



Source: Rubbo (2024).

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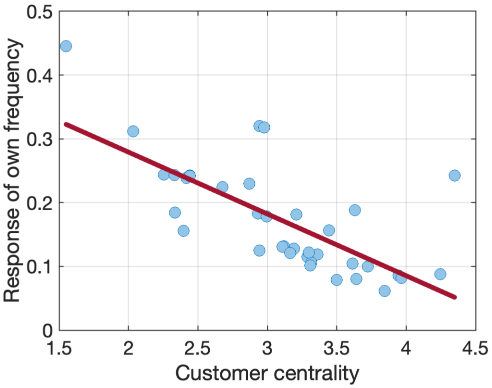
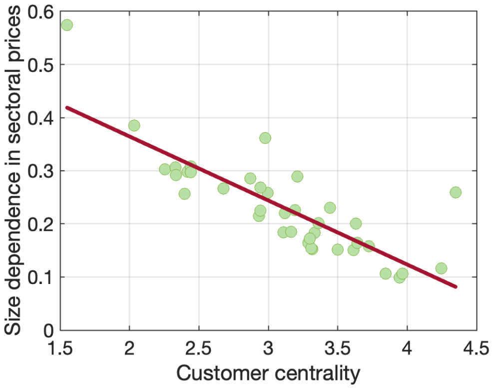
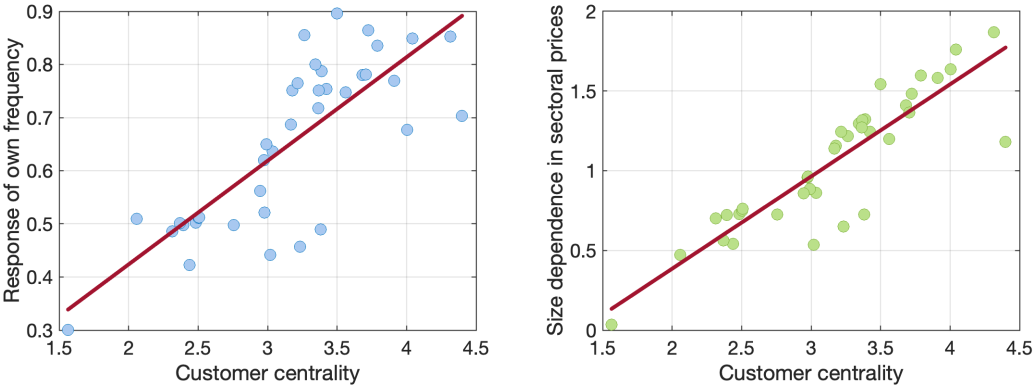
Sectoral frequencies and prices following monetary shocks





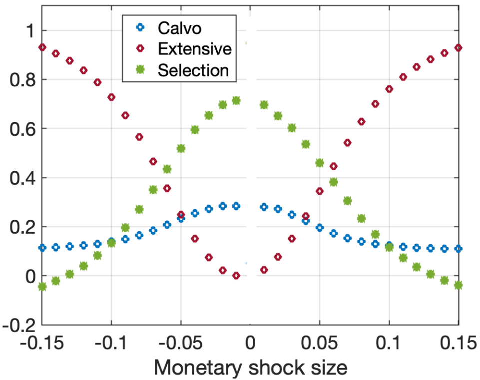
Sectoral frequencies and prices following TFP shocks

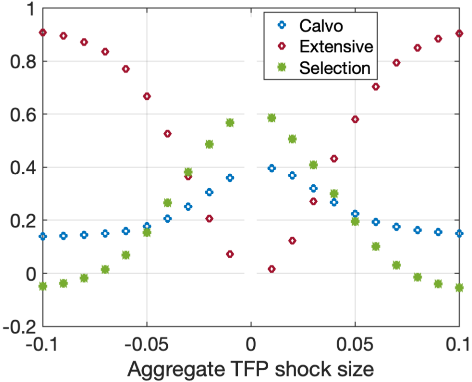


Inflation decomposition and network effects

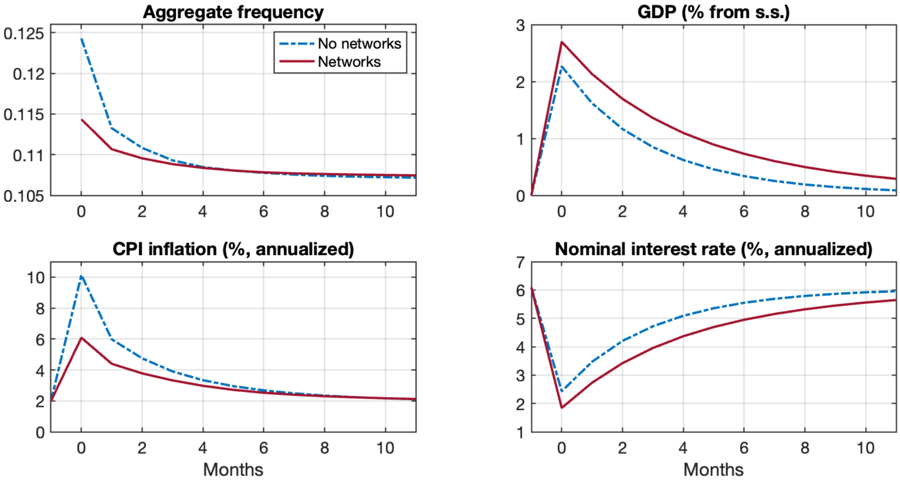
- Make use of the following inflation decomposition:

$$\Delta\pi \quad = \quad \Delta\pi^{\text{Calvo}} \quad + \quad \Delta\pi^{\text{Extensive}} \quad + \quad \Delta\pi^{\text{Selection}}$$

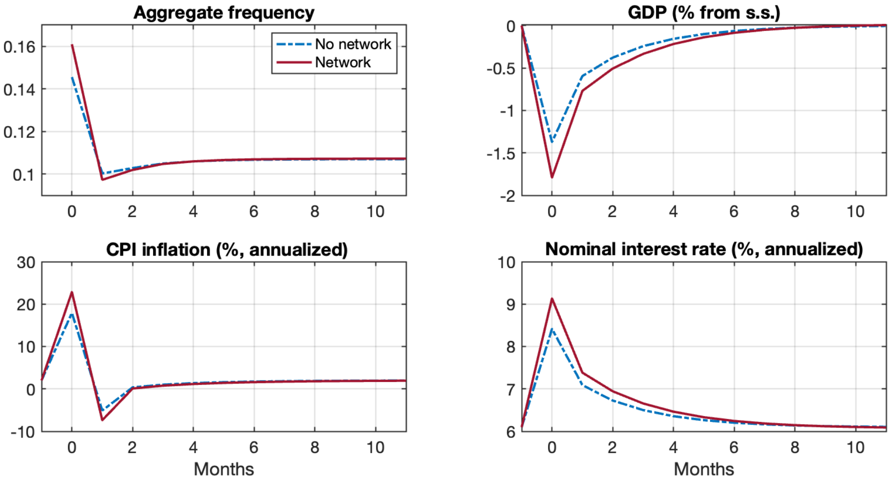




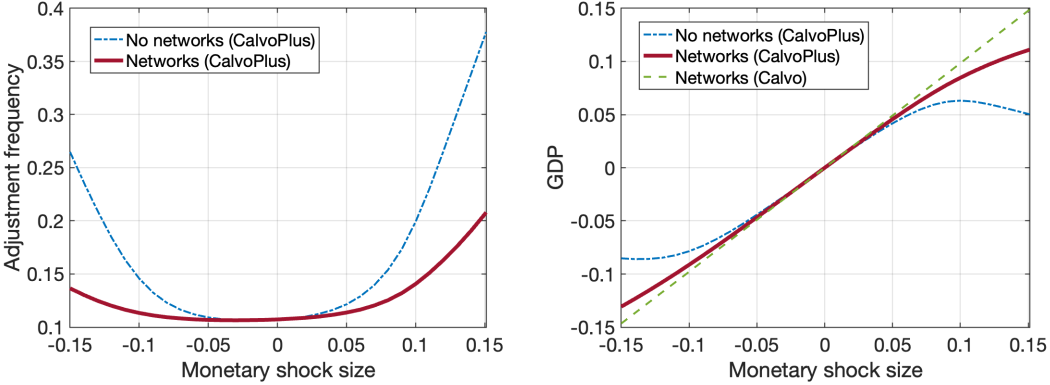
Cascades dampening following monetary shocks: Taylor rule



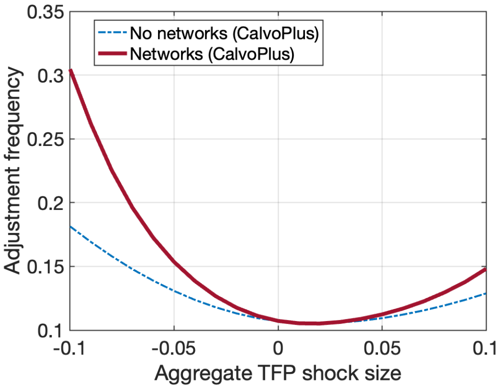
Cascades amplification following TFP shocks: Taylor rule

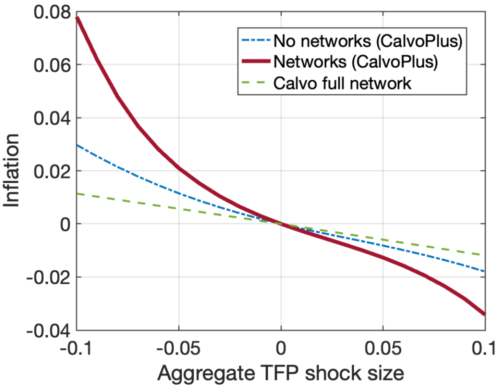


Cascades dampening following monetary shocks: CalvoPlus

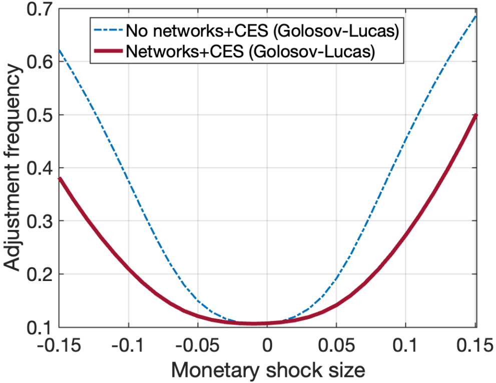


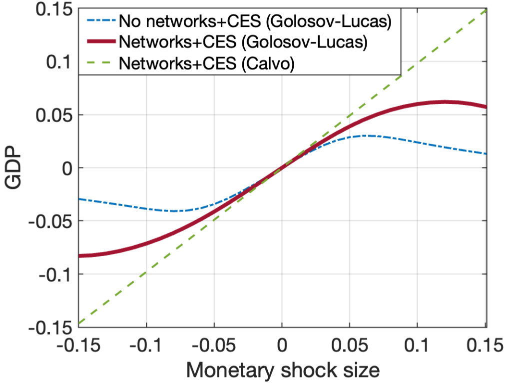
Cascades amplification following TFP shocks: CalvoPlus





Cascades dampening following monetary shocks: CES aggregation





Cascades amplification following TFP shocks: CES aggregation