

# 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  $t = 0, 1, 2, \dots$
- **Households:** continuum of identical households; consume output and supply labor
- **Firms:** continuum of monopolistically competitive firms, each belongs to one of  $N$  sectors, indexed  $i \in \{1, 2, \dots, N\}$ ; 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:

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

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:  $C_t = \iota^C \prod_{i=1}^N C_i^{\bar{\omega}_i^C}$ ,  $\sum_{i=1}^N \bar{\omega}_i^C = 1$ ,  $\bar{\omega}_i^C \geq 0, \forall i$

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

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

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

## Firms: production

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

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

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  $\bar{\alpha}_i + \sum_{k=1}^N \bar{\omega}_{ik} = 1$ ,  $\bar{\alpha}_i \geq 0, \bar{\omega}_{ik} \geq 0, \forall i, k$

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

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

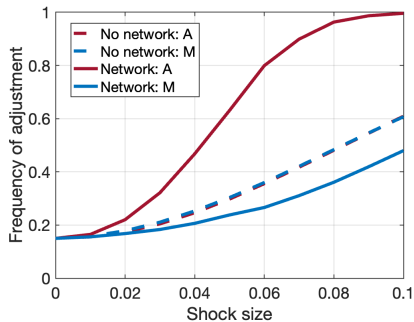
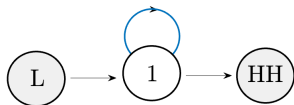
$$V_{i,t}(p) = \tilde{\mathcal{D}}_{i,t}(p) + \beta \mathbb{E}_t \left[ \left\{ 1 - \eta_{i,t+1}(p - \sigma_i \varepsilon_{i,t+1} - m_{t+1}) \right\} \times V_{i,t+1}(\overbrace{p - \sigma_i \varepsilon_{i,t+1} - m_{t+1}}^{\text{"Eroded" real price}}) \right] \\ + \beta \mathbb{E}_t \left[ \underbrace{\eta_{i,t+1}(p - \sigma_i \varepsilon_{i,t+1} - m_{t+1})}_{\text{Prob. of adjustment}} \times \left( \max_{p'} V_{i,t+1}(p') - \kappa_{i,t} \right) \right]$$

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

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

## Toy example 1: roundabout production

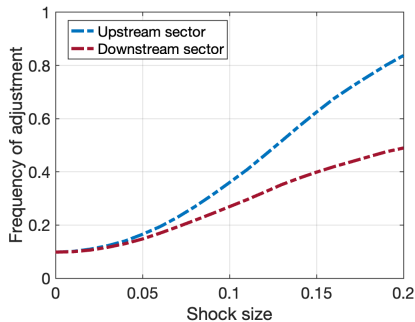
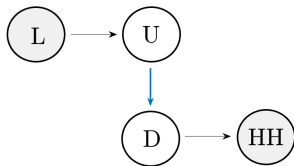
- Marginal cost:  $MC(j) = \zeta(j) \times \frac{1}{A} \times M^{\bar{\alpha}} p^{1-\bar{\alpha}} = \zeta(j) \times \frac{M}{A} \times \left(\frac{p}{M}\right)^{1-\bar{\alpha}}$





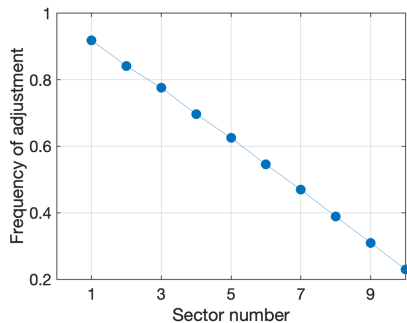
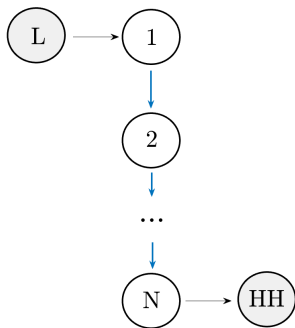
## Toy example 2: two-sector vertical chain

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



### 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)

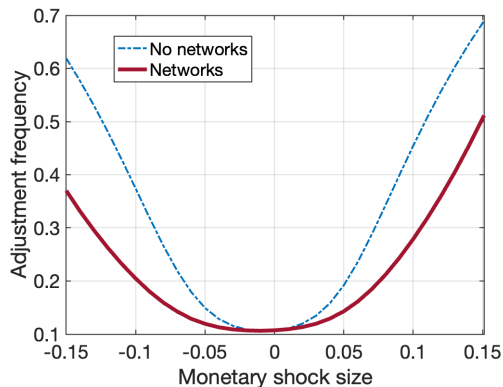
<i>Aggregate parameters</i>			
$\beta$	$0.96^{1/12}$	Discount factor (monthly)	Golosov and Lucas (2007)
$\epsilon$	3	Goods elasticity of substitution	Midrigan (2011)
$\bar{\pi}$	0.02/12	Trend inflation (monthly)	ECB target
$\rho$	0.90	Persistence of the TFP shock	Half-life of seven months
<i>Sectoral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

## *Monetary shocks*

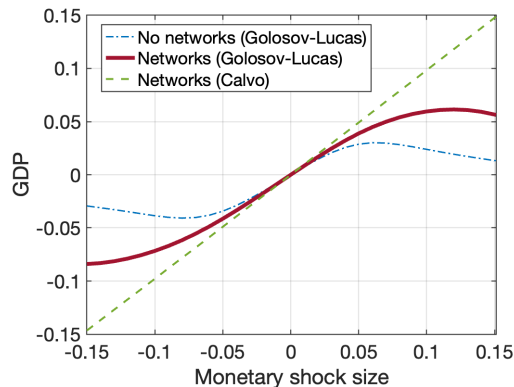
$$\log M_t = \bar{\pi} + \log M_{t-1} + \varepsilon_t^M$$

# Cascades dampening following monetary shocks

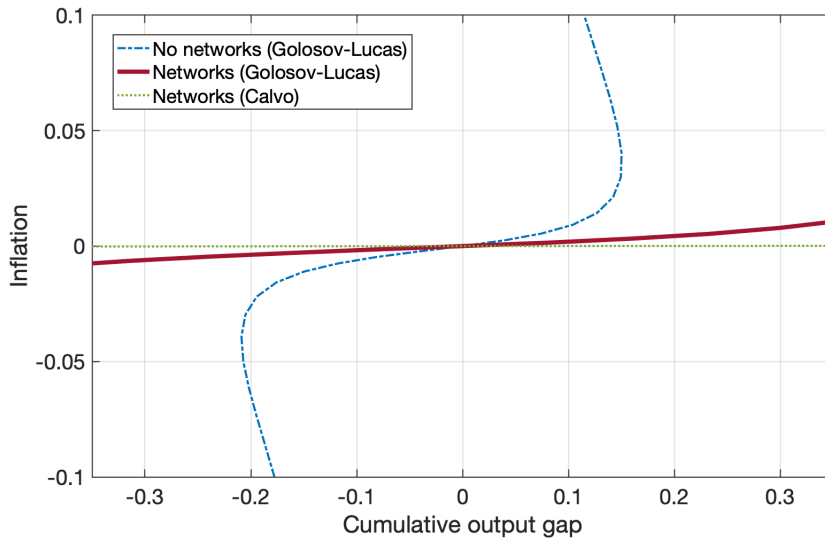
(a) Aggregate adjustment frequency



(b) GDP



## Non-linear Phillips Curves



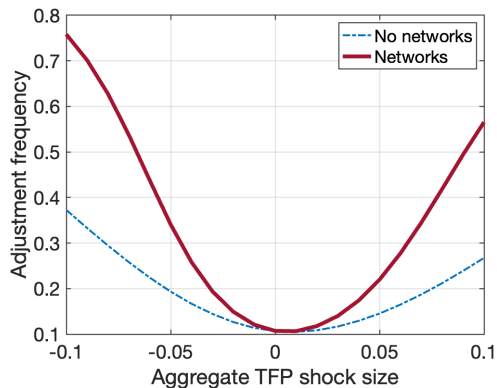


### *Aggregate TFP shocks*

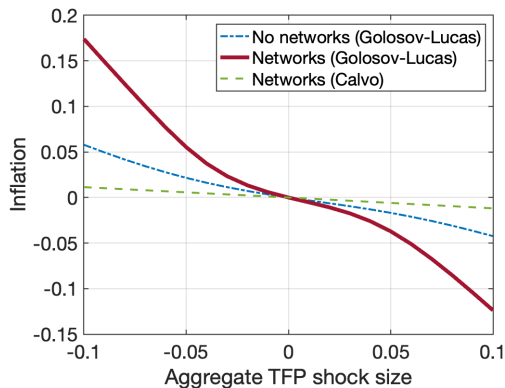
$$\log A_t = \rho \log A_{t-1} + \varepsilon_t^A$$

## Cascades amplification following TFP shocks

(a) Aggregate adjustment frequency

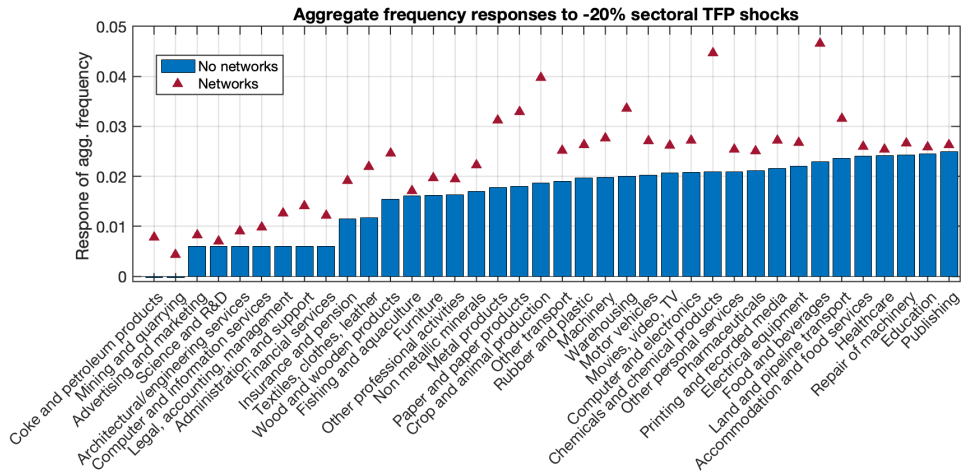


(b) CPI inflation



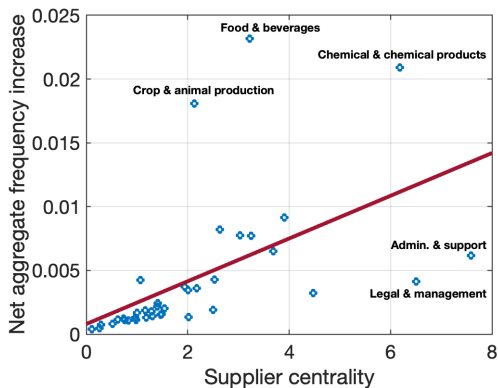
## ***Sectoral TFP shocks***

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

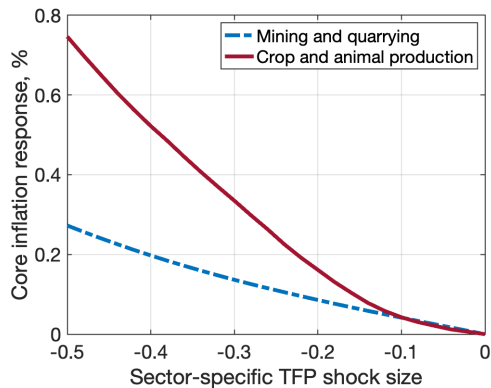


# Aggregate frequency responses vs. sectoral Supplier Centrality

(a) (Net) aggregate adjustment frequency



(b) Core inflation response

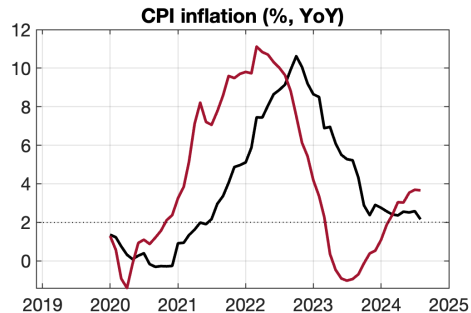
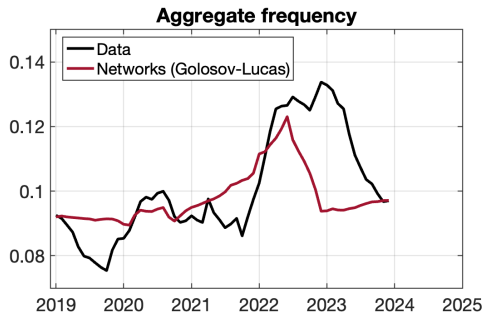


## **APPLICATION: (POST-) COVID EURO AREA INFLATION**

## Model vs. Data

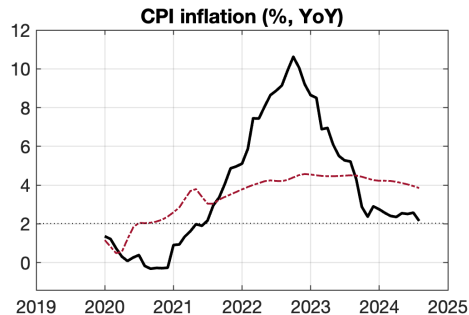
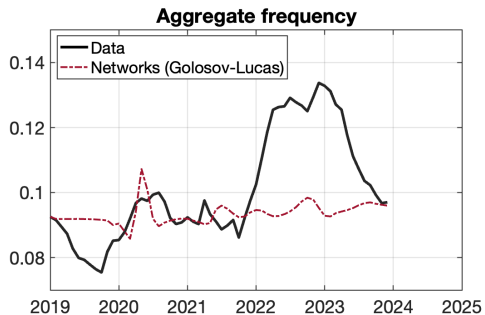
- To assess the model quantitatively, we feed in observed demand and supply processes as exogenous shocks
- **Aggregate demand shock:** Euro Area nominal GDP as a proxy for the  $\{M_t\}_{t \geq 0}$  process
- **Energy price shock:** calibrate the productivity process of the “Mining and Quarrying” sector 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

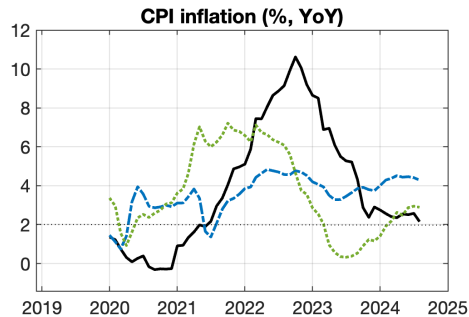
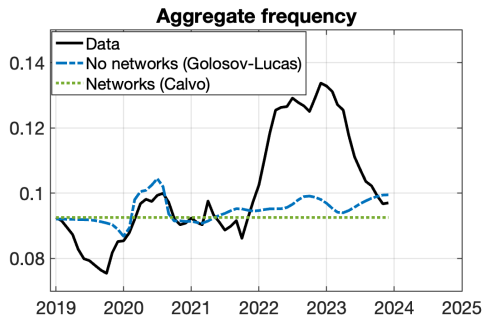




## Model vs. Data: baseline setup, no commodity shocks



## Model vs. Data: alternative setups, all shocks



## Conclusions

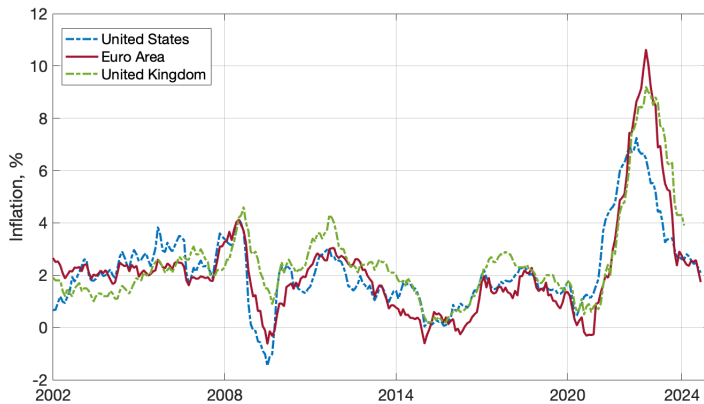
- Present a **dynamic quantitative** general equilibrium model that features: a number of **sectors interconnected by networks** with **state-dependent pricing** that is solved **fully non-linearly**
- Networks **slow down** the extensive margin pricing response to **demand shocks**: **cascades dampening**
- 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.

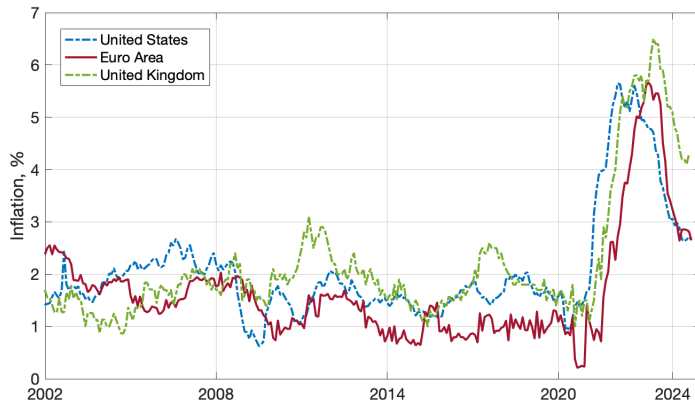
## APPENDIX

## Evidence I: inflation spikes in advanced economies (headline)



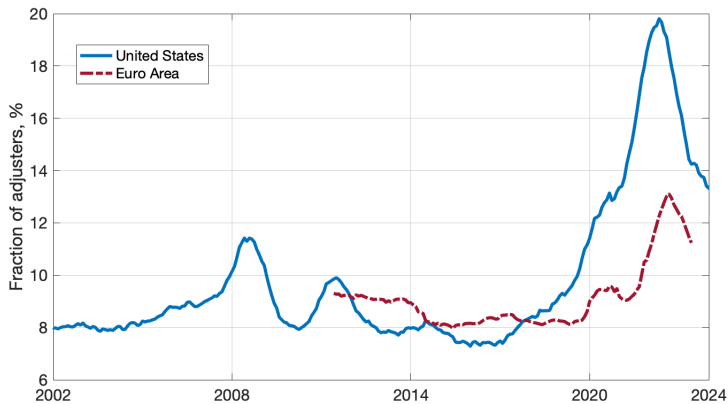
Source: FRED.

## Evidence I: inflation spikes in advanced economies (core)



Source: FRED.

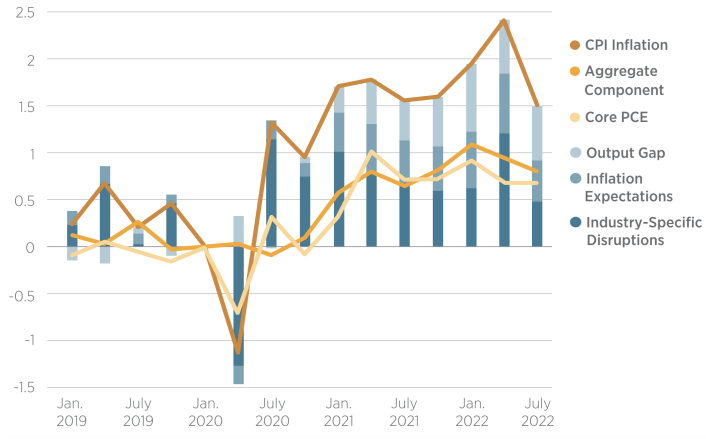
## Evidence II: changes in frequency of price adjustment



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

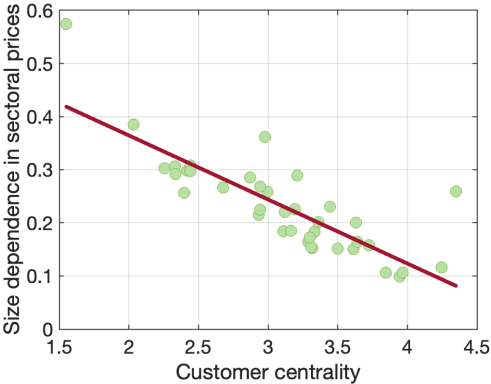
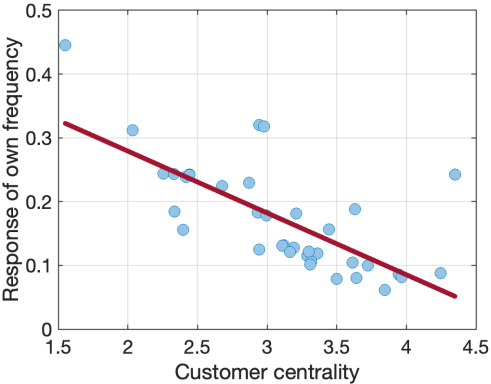


### Evidence III:    sectoral origins of inflation

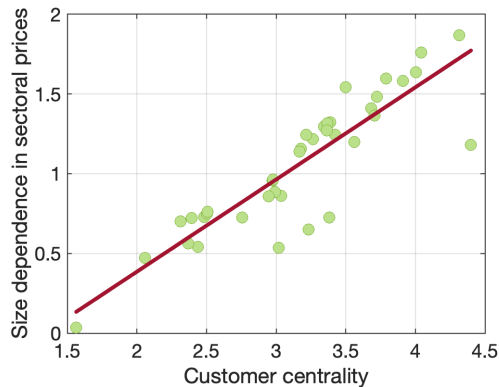
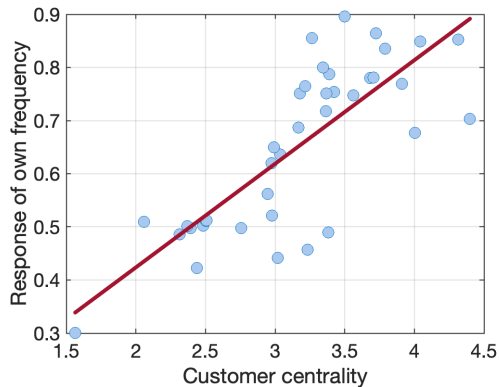


Source: Rubbo (2024).

# Sectoral frequencies and prices following monetary shocks



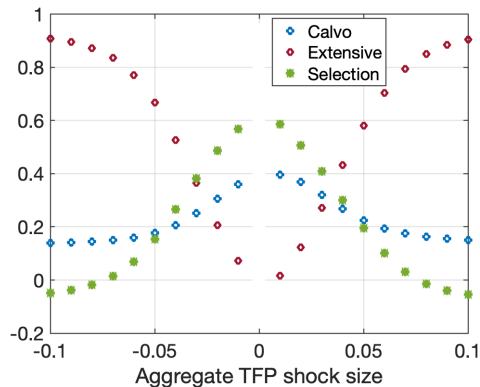
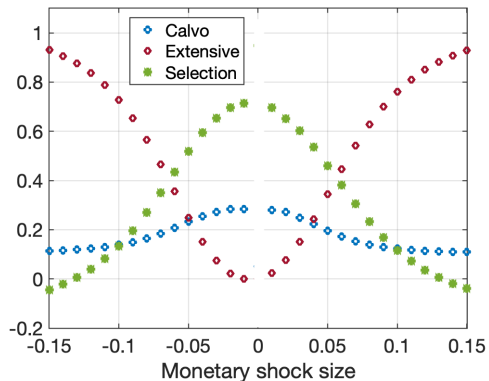
## Sectoral frequencies and prices following TFP shocks



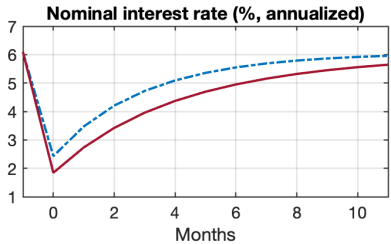
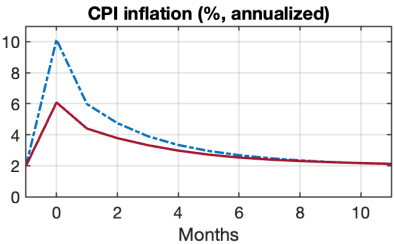
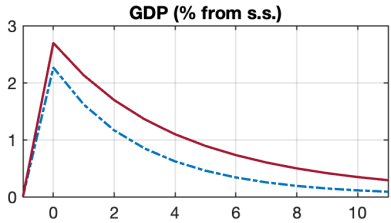
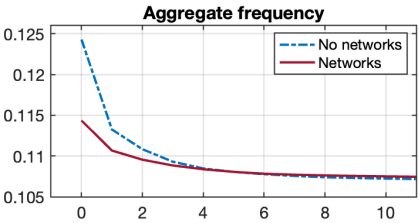
## Inflation decomposition and network effects

- Make use of the following inflation decomposition:

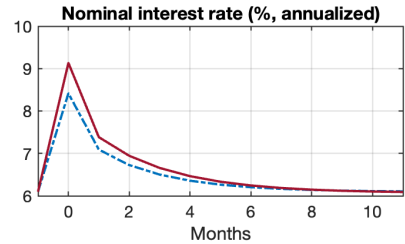
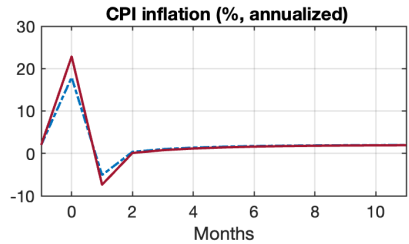
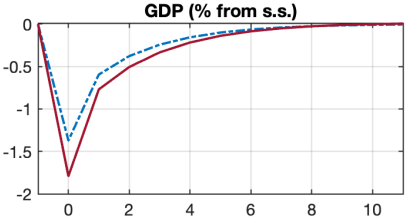
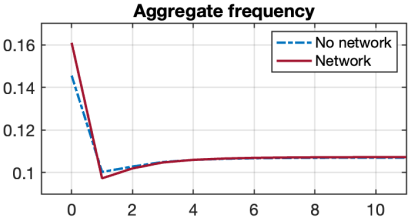
$$\Delta\pi = \Delta\pi^{\text{Calvo}} + \Delta\pi^{\text{Extensive}} + \Delta\pi^{\text{Selection}}$$



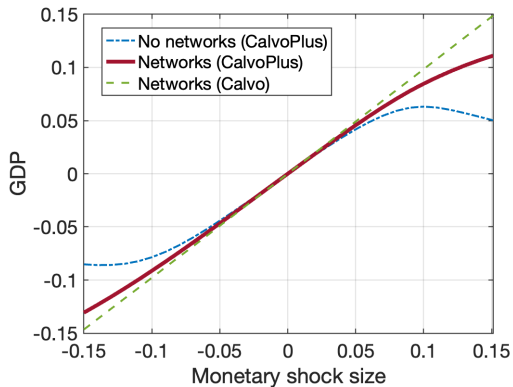
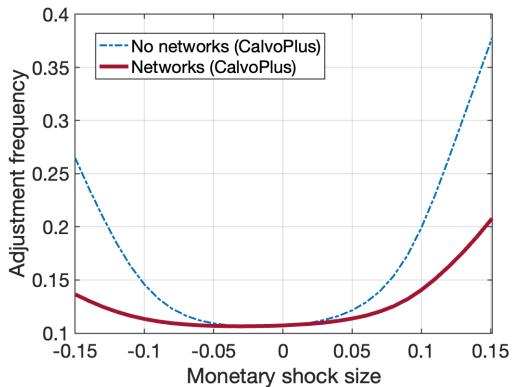
# Cascades dampening following monetary shocks: Taylor rule



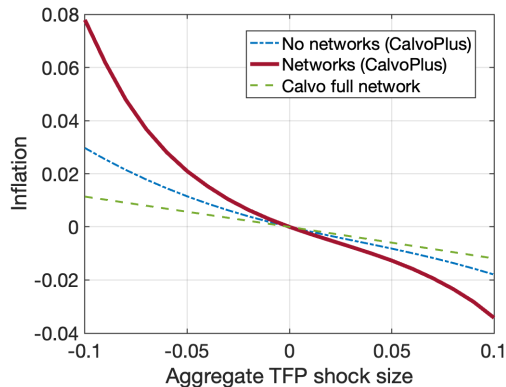
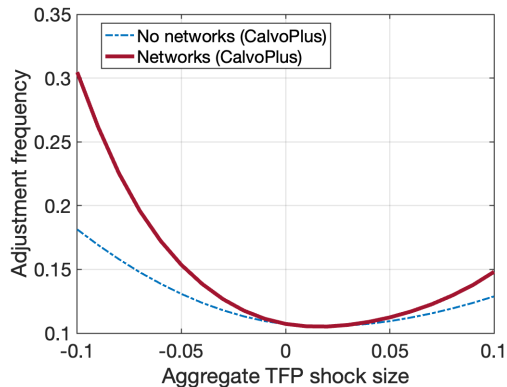
# Cascades amplification following TFP shocks: Taylor rule



## Cascades dampening following monetary shocks: CalvoPlus

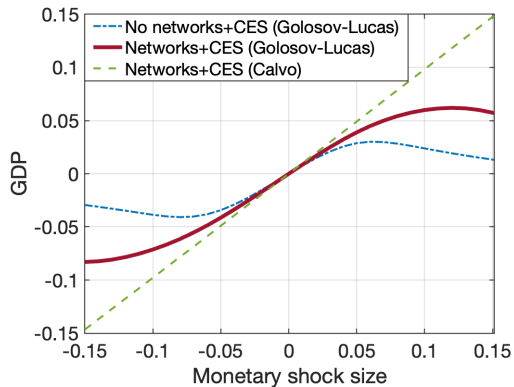
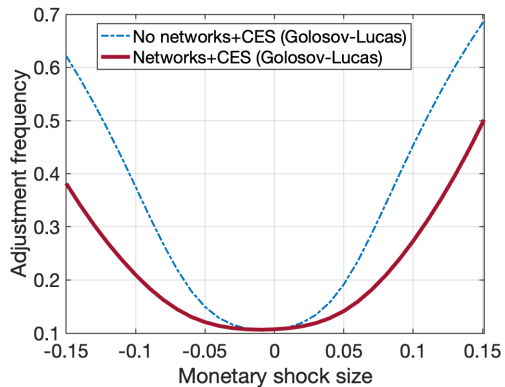


## Cascades amplification following TFP shocks: CalvoPlus





## Cascades dampening following monetary shocks: CES aggregation



## Cascades amplification following TFP shocks: CES aggregation

