The Transmission of Keynesian Supply Shocks*

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*This paper does not necessarily represent the views of the Bank of England or of any of its Committees.

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  - Excess demand for popcorn, price increases
- **Complementarity:** Nobody wants popcorn since people eat popcorn only at the movies
  - Deficient demand for popcorn, price falls
- Sectoral supply shocks can lead to aggregate demand deficiencies → **Keynesian Supply**

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- **Main Result:** Data consistent with Keynesian supply view
  * General feature of business cycles (not driven by Covid shock)
  * Key role of complementarities + heterogeneity in price stickiness and production network

Empirical Strategy: Intuition

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In practice

- Identify a shock that moves aggregate output and prices in same direction in a VAR
- Estimate response of sectoral output and prices to such shock to disentangle [1] vs. [2]

Literature and Contribution

- **Supply shocks and complementarities**
  - Corsetti, Dedola and Leduc (2008); Guerrieri, Lorenzoni, Straub and Werning (2020)
- **Granular fluctuations and production networks**
  - Gabaix (2011); Foerster, Sarte and Watson (2011); Smets, Tielens and Van Hove (2018); Baqaee and Farhi (2020a, 2020b); Gabaix and Koijen (2020)
- **Supply vs. demand shocks in the pandemic**
  - Bekaert, Engstrom and Ermolov (2020); Brinca, Duarte and Faria-e-Castro (2020); del Rio-Chanona, Mealy, Pichler, Lafond and Farmer (2020), Bilbiie and Melitz (2020)

A Multi-Sector Factor-Augmented VAR

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- Economy consists of N sectors indexed by $i = 1, 2, \ldots, N$
- Model sectoral output growth (y_{it}) and inflation (π_{it}) through a factor-augmented VAR(1)

$$x_{it} = \Phi_{i0} + \Phi_{i1} x_{it-1} + \Gamma_i f_t + u_{it} \qquad i = 1, 2, \ldots, N$$

All results extend to VAR(p)

where

  * $x_{it} \equiv [y_{it} \ \pi_{it}]'$
  * f_t is a vector of unobserved factors common across sectors
  * u_{it} is a vector of idiosyncratic (i.e. cross-sectionally weakly correlated) sectoral innovations

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Note: Common factors (elements of f_t) capture *all* cross-sectional comovement in x_{it} due to

[1] Truly aggregate shocks (e.g. TFP, aggregate demand, etc)

[2] Sector-specific shocks with aggregate effects (Foerster, Sarte and Watson, 2011)

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- Identification of f_t 'by aggregation' as in Cesa-Bianchi, Pesaran and Rebucci (2020)
  - Factors can be approximated by cross-sectional averages of observables

Skip derivations

Identification of the Common Factors

- **Notation:**
  - Consider set of sectoral weights $w = \{w_1, w_2, \ldots, w_N\}$
  - Denote weighted average of generic variable z_{it} across all sectors i with $\bar{z}_t = \sum_{i=1}^{N} w_i z_{it}$
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- **Key assumption:** Sectoral innovations u_{it} are cross-sectionally weakly correlated

$$\bar{u}_t = \sum_{i=1}^{N} w_i u_{it} = O_p\left(N^{-\frac{1}{2}}\right)$$

Details

Identification of the Common Factors

- Solve for x_{it} in terms of current and past aggregate and sectoral shocks

$$x_{it} = \mu_i + \sum_{\ell=0}^{\infty} \Phi_{i1}^{\ell} \Gamma_i f_t + \sum_{\ell=0}^{\infty} \Phi_{i1}^{\ell} u_{it}$$

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- Weak correlation (+ regularity conditions on Φ, Γ_i, and w) imply

$$\bar{x}_t = \bar{\mu} + \Omega(L) \Gamma f_t + O(N^{-\frac{1}{2}})$$

See all assumptions

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- Approximate common factors by inverting and truncating previous expression

$$f_t = \theta + \Theta_0 \bar{x}_t + \sum_{\ell=1}^{k} \Theta_\ell \bar{x}_{t-\ell} + O(N^{-\frac{1}{2}})$$

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- Unobserved factor model can be approximated by

$$x_{it} = \varphi_{i0} + \Phi_{i1} x_{it-1} + \Xi_{i0} \bar{x}_t + \sum_{\ell=1}^{k} \Xi_{i\ell} \bar{x}_{t-\ell} + u_{it}$$

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- But how to interpret loadings Ξ_{io} given elements of $\bar{x}_t$ are correlated?

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- But how to interpret loadings Ξ_{io} given elements of $\bar{x}_t$ are correlated?
  - [1] Rotate $\bar{x}_t$ with a SVAR to extract orthogonal innovations to common factors

$$\bar{x}_t = A_0 + \sum_{\ell=1}^{k} A_\ell \bar{x}_{t-\ell} + Be_t$$

  - [2] Then plug rotated $\bar{x}_t$ back in sectoral VAR

Empirical Approach: Recap

- Compute cross-sectional averages of the observables $\bar{x}_t = \sum_{i=1}^{N} w_i x_{it}$

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Sectoral shocks with aggregate effects

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e_t → Sectoral shocks with aggregate effects

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$$x_{it} = \Psi_{i0} + \Phi_{i1} x_{i,t-1} + \Lambda_i \hat{e}_t + \sum_{\ell=1}^{k} \Psi_{i\ell} \bar{x}_{t-\ell} + u_{it}$$

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Main object of interest

Empirical Results

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  - 64 sectors (NAICS 3-digits, ex 'Oil and Petroleum'), from 2005Q1 to 2019Q1

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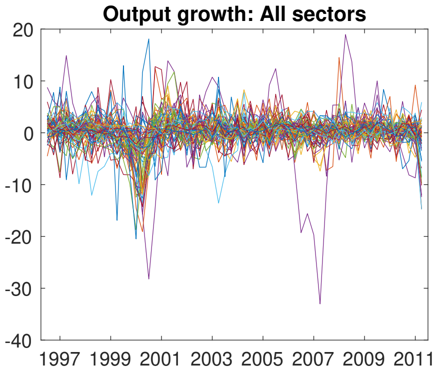
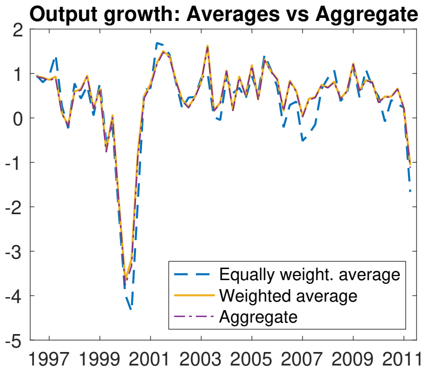
- **Sectoral output growth**





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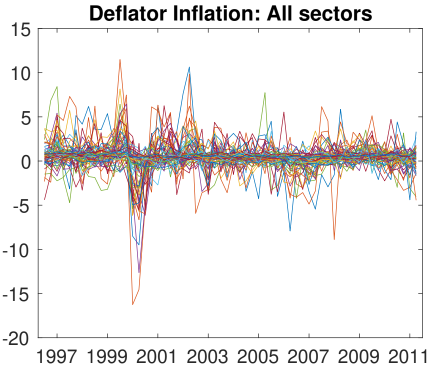
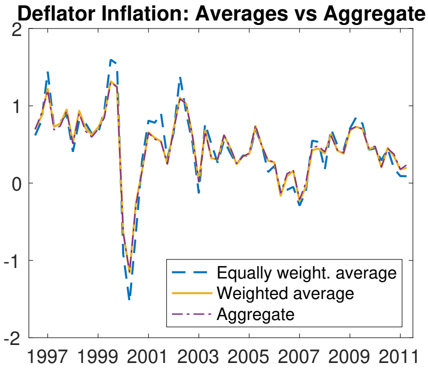
- **Sectoral inflation**





Identification of the Common Shocks e_t

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- Inference
  - Sign restrictions as in Uhligh(2005) and Rubio-Ramirez, Waggoner and Zha (2010)
  - Gaussian-inverse Wishart / Haar prior with 5,000 draws

Identification of the Sectoral Loadings Λ_i

- For each draw and associated sign restriction rotation estimate

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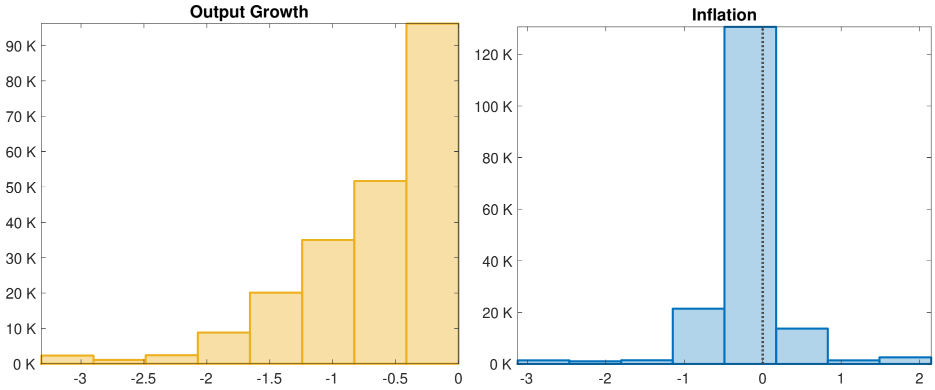
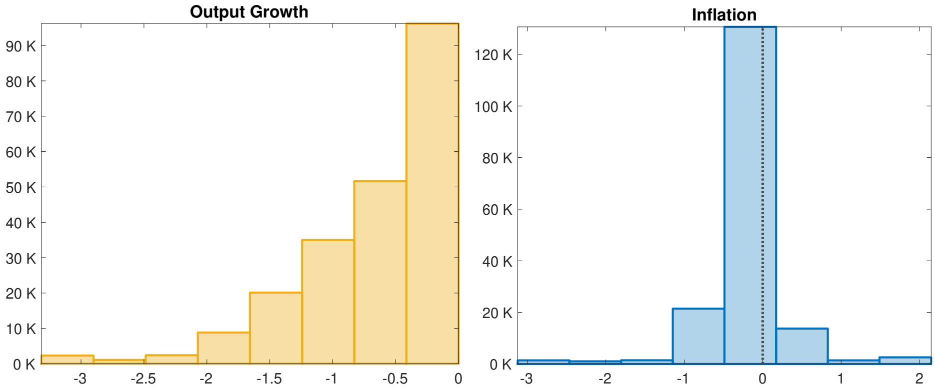
  - Plot distribution of inflation loadings $\lambda_{i,\pi}$ associated with normalized $\lambda_{i,y}$

Distribution of the Sectoral Loadings Λ_i



- Almost 40% of inflation loadings $\lambda_{i,\pi}$ lie on 'wrong' side of distribution
  - Not consistent with a *strict view* of aggregate demand shocks

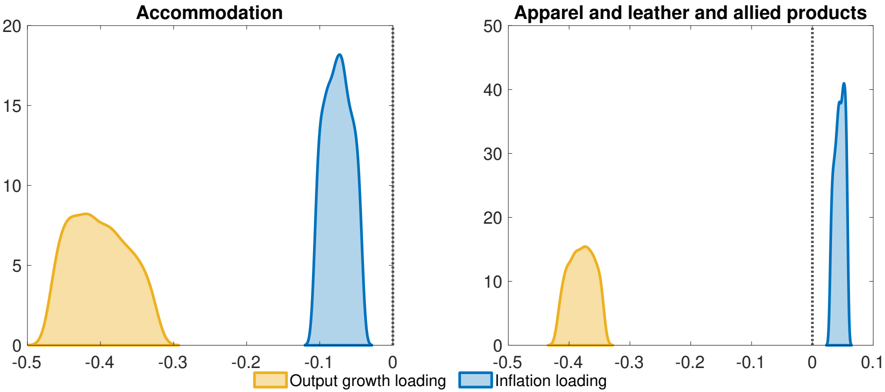
Distribution of the Sectoral Loadings Λ_i



- **Interpretation:** Evidence supportive of Keynesian supply transmission mechanism
  - VAR mis-classifies sectoral supply shock ($+$ complementarities) as aggregate demand shock

Two Examples

- Distributions of estimated loadings in response to a demand shock in two sectors
  - * Results not driven by tail observations
  - * In 16 sectors, not even one out of 5, 000 loadings behaves ‘demand-like’



Robustness

- Including 2020Q1 Go
- Value added instead of gross output Go
- Richer dynamics (4 lags) Go
- Specification in levels (4 lags) Go
- Identify oil shocks alongside demand and supply Go
- Adding EBP to aggregate/sectoral VARs Go

A Multi-Sector DSGE Model

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- Multi-sector DSGE model with production network
  - Similar to Pasten, Schoenle and Weber (2020) and Ghassibe (2021)
  - Heterogeneity in price stickiness
  - Asymmetric input-output linkages
  - Complementarities in consumption and production

Model details

Model-Based Validation Exercise

- Calibrate model to same 64 sectors as in empirical analysis
  - Input/output linkages and intermediates intensity (BEA)
  - Frequency of price adjustment stickiness (BLS)
  - Elasticity of substitution across intermediates $\eta^Z = 0.5$
  - Elasticity of substitution across goods $\eta^C = 1$

Pasten, Schoenle and Weber (2020)

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Pasten, Schoenle and Weber (2020) [input/output linkages; price stickiness]

Baqaee and Farhi (2020a,b) [elasticities]

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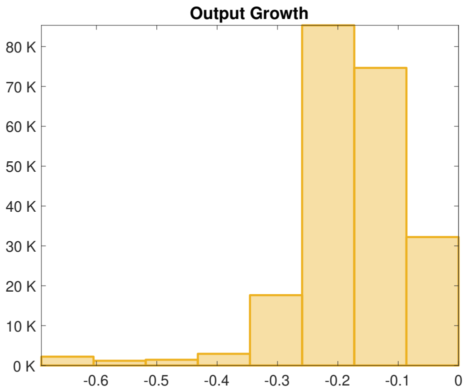
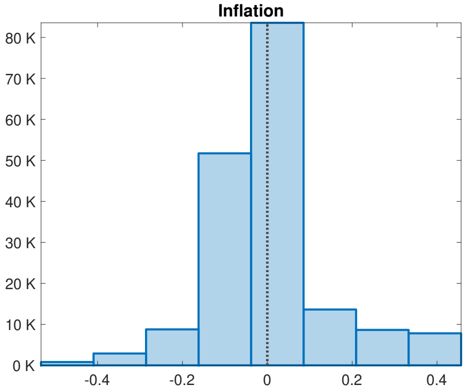
- **Experiments** Exogenous processes driving model's dynamics
  1. Sectoral TFP shocks
  2. Sectoral demand shocks (weights in consumption bundle)
  3. Aggregate demand shocks

Simulated Data Driven by Sectoral TFP Shocks

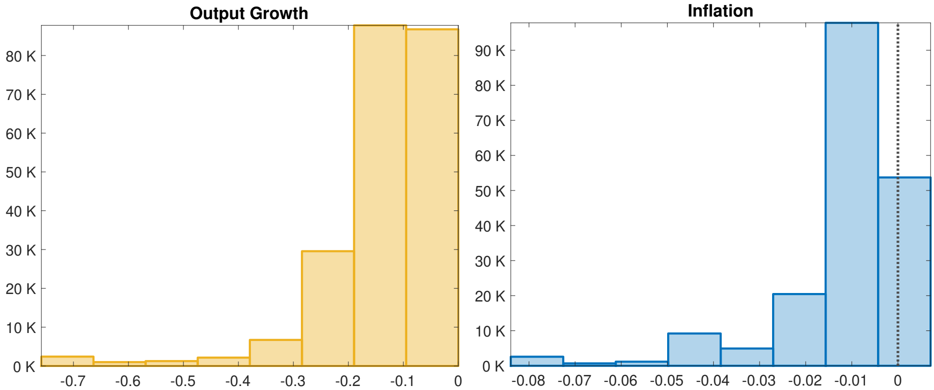
- Distribution of loadings in line with empirical evidence
  - Share of wrong loadings 41%
  - Number of sectors with wrong loadings 21





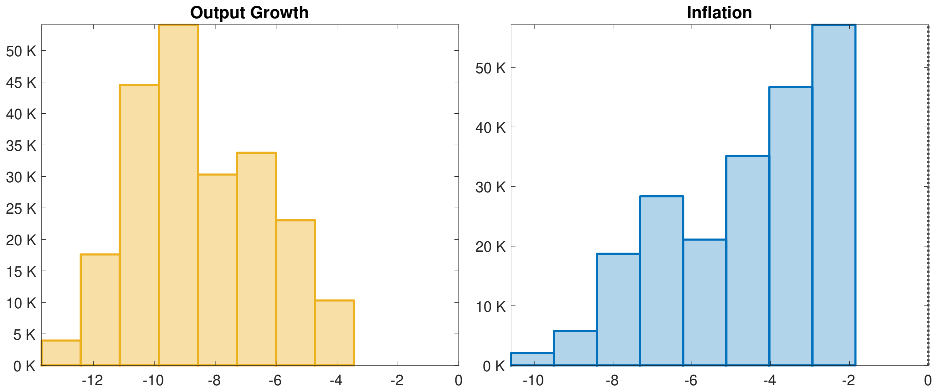
Simulated Data Driven by Sectoral Demand Shocks

- Distribution of loadings weakly in line with empirical evidence
  - Share of wrong loadings 6%
  - Number of sectors with wrong loadings 3



Simulated Data Driven by Aggregate Demand Shocks

- Distribution of loadings inconsistent with empirical evidence
  - Share of wrong loadings 0%
  - Number of sectors with wrong loadings 0



Inspecting the Mechanism

- Compute the response of aggregate inflation to each sectoral TFP shock
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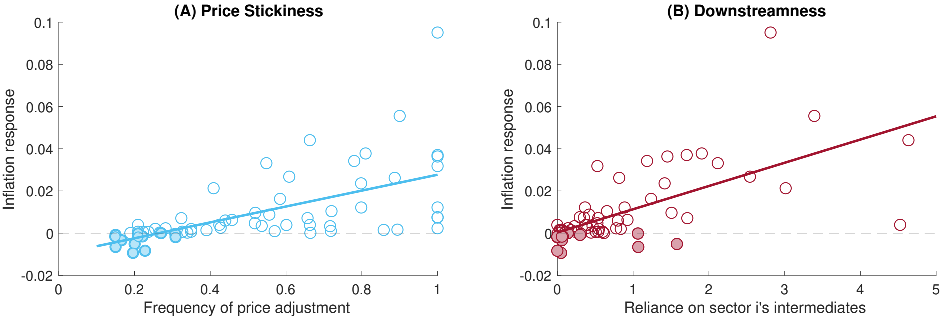

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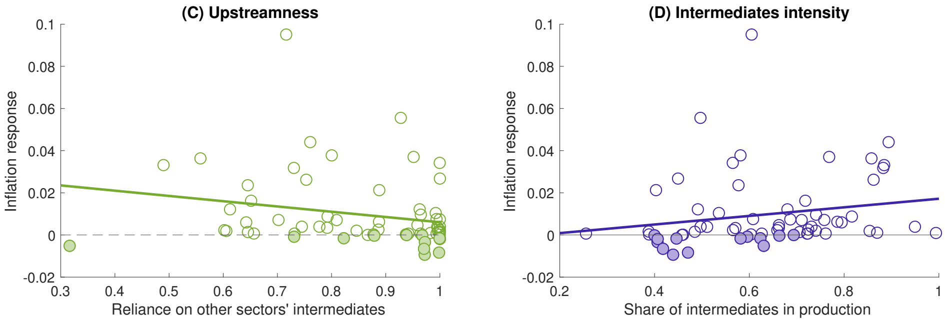

Conclusions

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  - Beyond pandemic, debate about sources of business cycle fluctuations
    - Granular shocks and production networks (Gabaix, 2011; Baqaee and Farhi, 2020a, b)

Conclusions

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  - Beyond pandemic, debate about sources of business cycle fluctuations
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- **Future research:** Identification of sectoral shocks
  - Estimation of multi-sector DSGE model
  - Cross-country analysis

Appendix

A1: Assumptions

Weights and Sectoral Innovations: Theory

- **Weights** satisfy smallness conditions

$$||w|| = O(N^{-1}) \qquad \text{and} \qquad \frac{w_i}{||w||} = O(N^{-1/2})$$

- **Sectoral innovations** u_{it} are cross-sectionally weakly correlated

$$\varrho_{\max}(\Sigma_u) = O(1)$$

where $\varrho_{\max}(\Sigma_u)$ denotes largest eigenvalue of covariance matrix $\Sigma_u = Var([u_{1t}\ u_{2t}\ \dots\ u_{Nt}]')$

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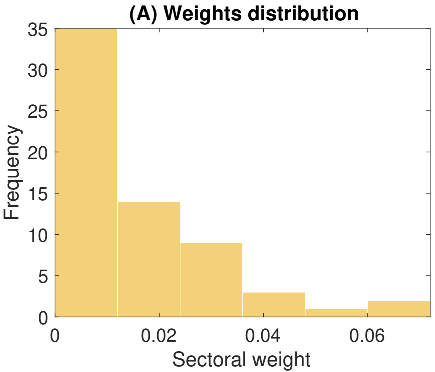
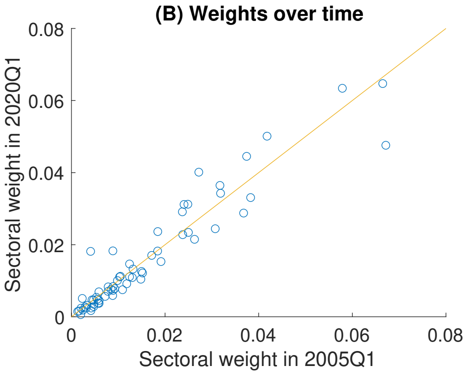
Weights and Sectoral Innovations: Data





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Common Factors, Factor Loadings and Coefficients

- The unobservable **common factors** f_t have zero means and finite variances, are serially uncorrelated, and are distributed independently of sector-specific shocks u_{it} for all i and t

- The **factor loadings** (i.e. the elements of Γ_i for $i = 1, 2, \ldots, N$) are distributed independently across i and from f_t for all i and t. Denoting a generic element of Γ_i by γ_i, the loadings satisfy

$$\gamma = \sum_{i=1}^{N} w_i \gamma_i \neq 0 \qquad \text{and} \qquad \sum_{i=1}^{N} \gamma_i^2 = O(N).$$

  In addition, $\Gamma \equiv \mathbb{E}[\Gamma_i]$ is invertible

- **Coefficients:** The constants Φ_{i0} are bounded, the autoregressive coefficients Φ_{i1} are independently distributed for all i, the support of $\varrho\left(\Phi_{ij}\right)$ lies strictly inside the unit circle, for $i = 1, 2, \ldots, N$, and the inverse of the polynomial $\Omega(L) = \sum_{\ell=0}^{\infty} \Omega_\ell L^\ell$, where $\Omega_\ell = \mathbb{E}\left(\Phi_i^\ell\right)$, exists and has exponentially decaying coefficients, namely $\|\Omega_\ell\| \leq C_0 \rho^\ell$, with $0 < \rho < 1$

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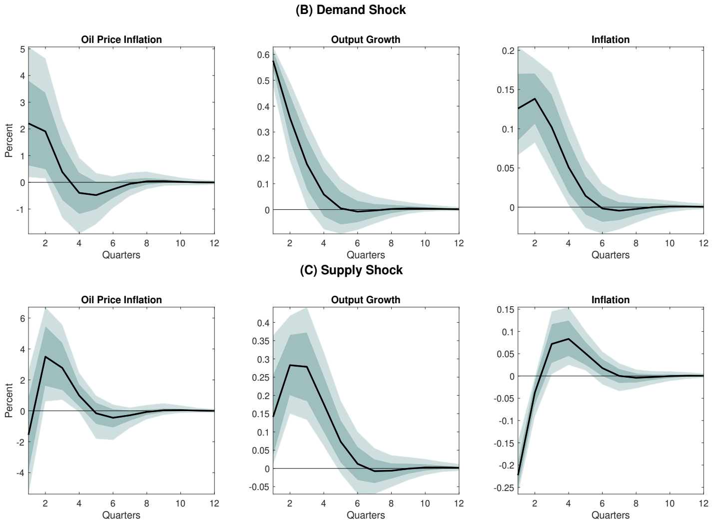
A2: Additional Results

Aggregate VAR: IRFs



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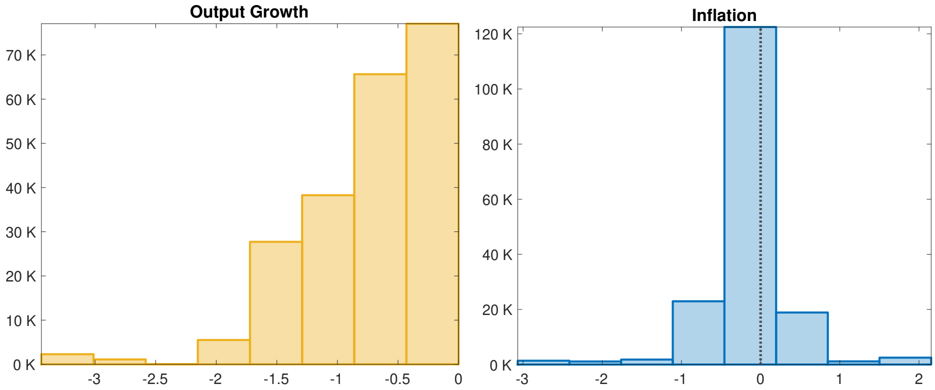
Factor Loadings to 'Demand-Like' Shock (2020Q1)



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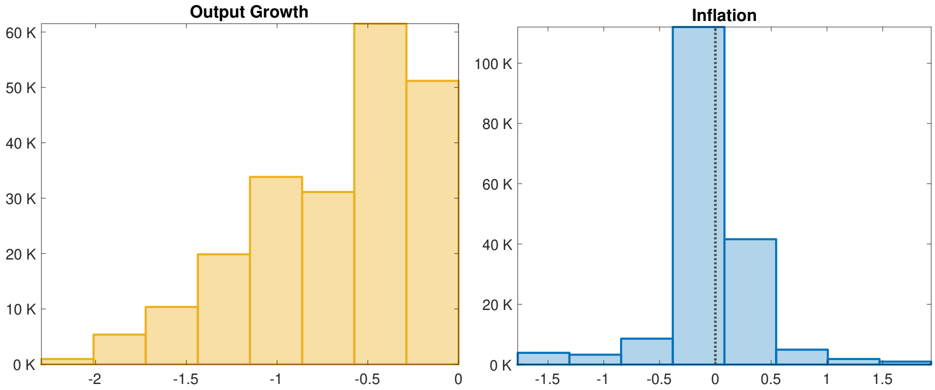
Factor Loadings to ‘Demand-Like’ Shock (Value Added)



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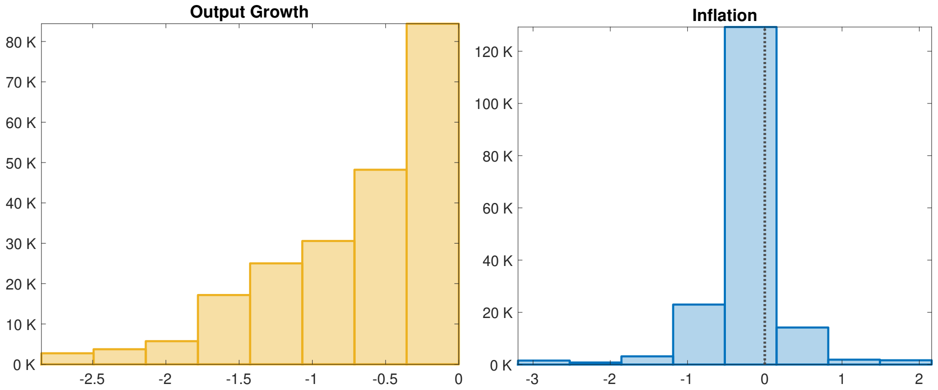
Factor Loadings to ‘Demand-Like’ Shock (4 lags)



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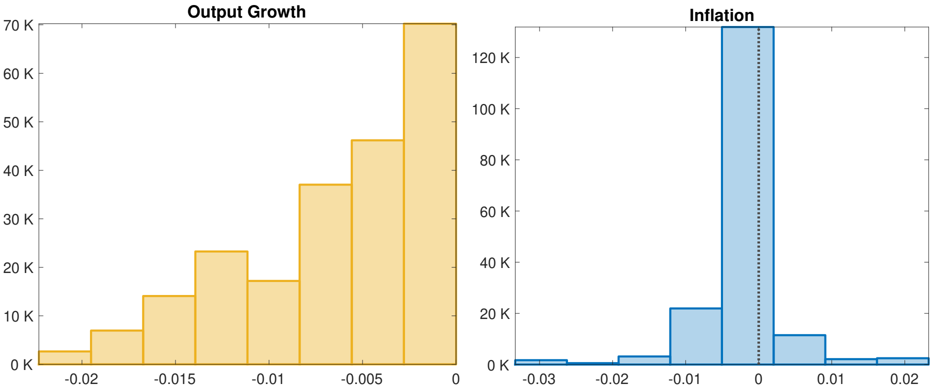
Factor Loadings to ‘Demand-Like’ Shock (4 lags, Levels)



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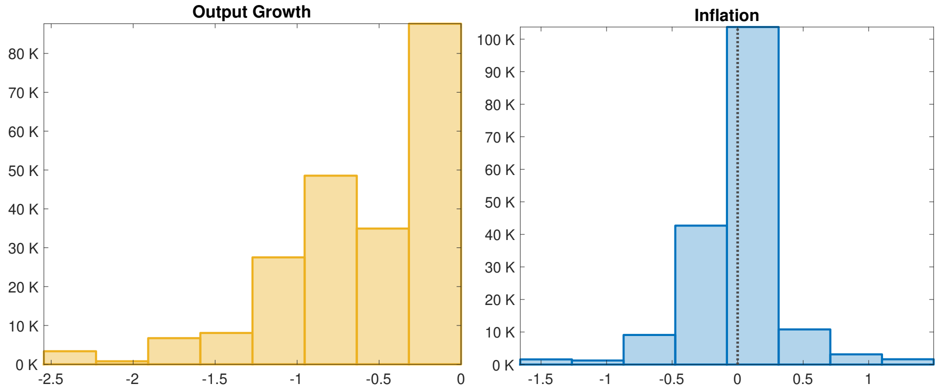
Factor Loadings to ‘Demand-Like’ Shock (Oil Shock)



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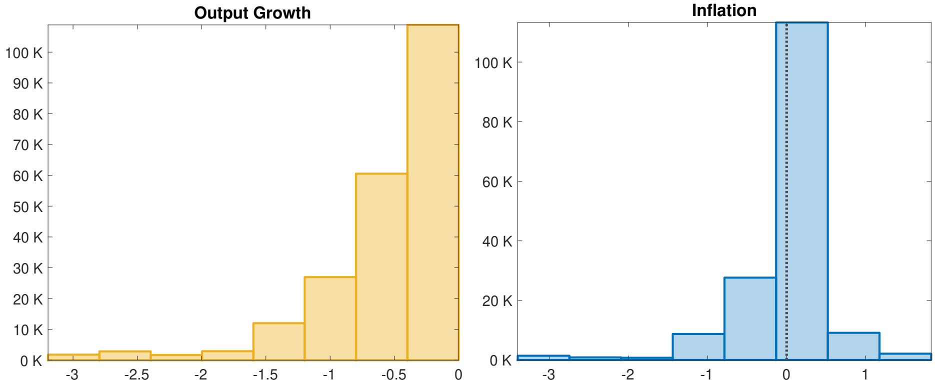
Factor Loadings to 'Demand-Like' Shock (EBP)



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A3: Model

Multi-Sector DSGE Model: Ingredients

- Continuum of monopolistically competitive firms j in sector k produce one variety
- Varieties bundled into sectoral intermediate input and sectoral consumption good
- Each firm j employs CES aggregate of sectoral intermediate bundles
  - Weights calibrated using input-output matrix
- Representative household consumes CES aggregate of sectoral consumption bundles
  - Weights calibrated using sectoral data
- Intermediate good producers set prices on a staggered basis (Calvo, 1983)
- Competitive labor markets clear at sectoral level
- Complete financial markets
- Central bank sets interest rate according to feeback rule (Taylor, 1993)

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Multi-Sector DSGE Model: Calibration

Parameter	Value/Source	Description
β	0.995	Individual discount factor
φ	2	Inverse Frisch elasticity of labor supply
ω_{ck}	Ghassibe (2021)	Consumption shares
ω_{kr}	Ghassibe (2021)	Input-Output coefficients
α_k	Ghassibe (2021)	Sectoral input shares
ξ_k	Pasten et al. (2020)	Price rigidity parameters
θ	6	Elasticity of substitution among varieties
η	0.5	Elasticity of substitution across sectors (intermediates)
η	1	Elasticity of substitution across sectors (final good)
ρ_i	0.75	Interest rate rule inertia
ϕ_π	1.5	Interest rate rule inflation feedback
ϕ_y	0.125	Interest rate rule output growth feedback
ρ_a	0.975	Persistence of sectoral TFP shocks
ρ_b	0.95	Persistence of aggregate demand shocks