The Transmission of Keynesian Supply Shocks*

Ambrogio Cesa-Bianchi
Bank of England, CEPR, and CfM

Andrea Ferrero
University of Oxford, CEPR & CfM

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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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Questions:

- Do the data support the notion of Keynesian supply shocks?
- Can we offer evidence on their transmission mechanism?

This Paper

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  - Aggregate output and prices move in the same direction

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  - * Identify a shock that moves aggregate output and prices in the same direction in a VAR
  - * Estimate response of sectoral output and prices to check whether [1] holds
  - * Evaluate empirical approach and interpretation with New Keynesian multi-sector DSGE

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- **What we find**
  - Data consistent with Keynesian supply view
  - General feature of business cycles, not driven by Covid shock
  - Important role for heterogeneity in price stickiness and production network

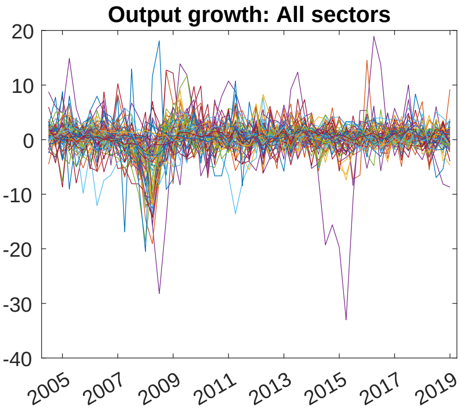
Literature and Contribution

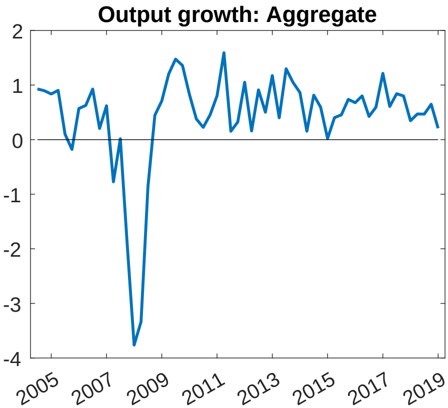
- **Supply shocks and complementarities**
  - Corsetti, Dedola and Leduc (2008); Atalay (2017); Guerrieri, Lorenzoni, Straub and Werning (2022)
- **Granular fluctuations and production networks**
  - Gabaix (2011); Foerster, Sarte and Watson (2011); Bouakez, Cardia, Ruge-Murcia (2014); Smets, Tielens and Van Hove (2018); Baqaee and Farhi (2020a, 2020b); Gabaix and Koijen (2020)
- **Supply vs. demand shocks during Covid-19 and its recovery**
  - Bekaert, Engstrom and Ermolov (2020); Brinca, Duarte and Faria-e-Castro (2021); del Rio-Chanona, Mealy, Pichler, Lafond and Farmer (2020), Bilbiie and Melitz (2020); Fornaro and Romei (2022)

Empirical Results

Data

- Aggregate and sectoral quarterly data on real gross output and its deflator (Source: BEA)
  - 64 sectors (NAICS 3-digits, ex 'Oil and Petroleum')
  - Sample period: 2005Q1 to 2019Q4





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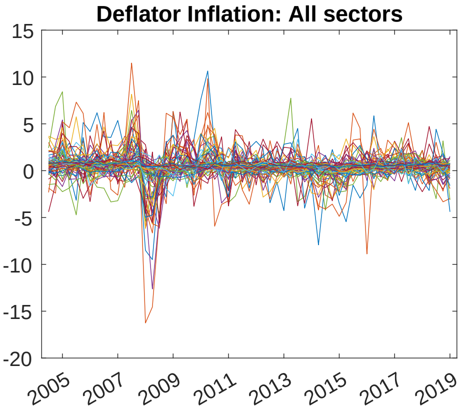

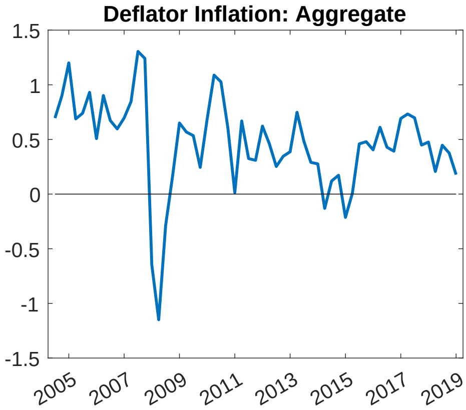

A Simple VAR

- VAR for aggregate output growth (y_t) and inflation rate of its deflator (π_t)

$$x_t = A_0 + A_1 x_{t-1} + B e_t$$

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- Identification of B with sign restrictions:

	Demand shock (e_t^{Dem})	Supply shock (e_t^{Sup})
Output growth	+	+
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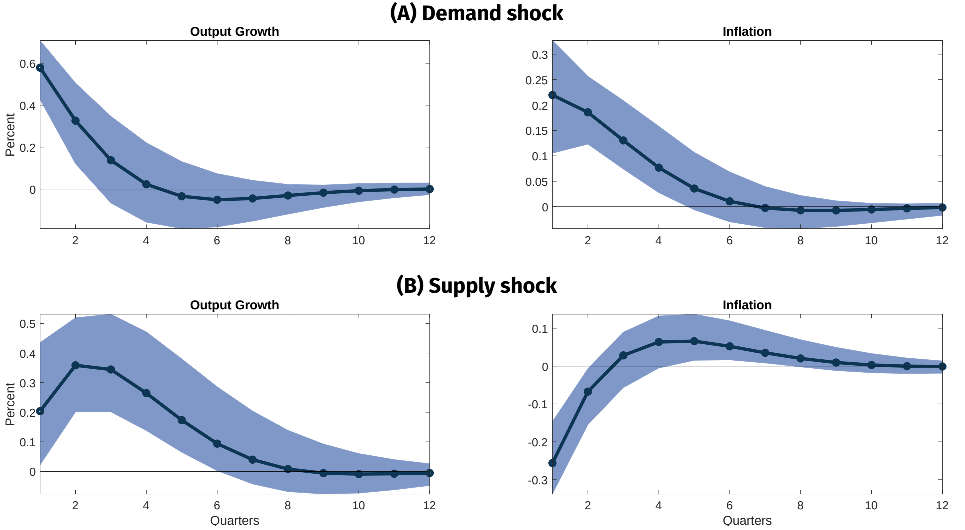
- Inference
  - Sign restrictions as in Uhlig (2005) and Rubio-Ramirez, Waggoner and Zha (2010)
  - Gaussian-inverse Wishart / Haar prior with $5,000$ draws

Impulse Responses



NOTE. The solid line in each panel depicts the median impulse response of the specified variable to a 1 standard deviation shock. Shaded bands denote the 90 percent pointwise credible sets.

Sectoral Responses to Aggregate Demand Shocks

- Local projection of sectoral output growth (y_{it}) and inflation (π_{it}) to aggregate demand shock

$$x_{i,t+h} = \alpha_h + \beta_{i,h} e_t^{Dem} + \Gamma_{i,h} Z_{i,t-1} + u_{it+h}$$

where

  - $x_{it} \equiv [y_{it}\ \pi_{it}]'$
  - e_t^{Dem}: aggregate demand shock from VAR
  - $Z_{i,t-1}$: lags of output and prices (both sectoral and aggregate)

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- Estimate $\beta_{i,h}$ for each sector ($i = 1, 2, \ldots, 64$) and each of the $5,000$ sign restrictions draws

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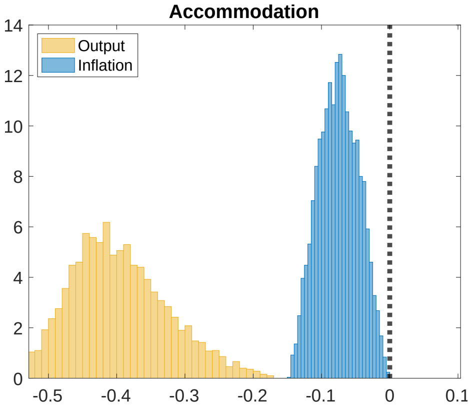
- Estimate $\beta_{i,h}$ for each sector ($i = 1, 2, \ldots, 64$) and each of the $5,000$ sign restrictions draws

- Plot distribution of impact responses $\beta_{i,0}$

  * Normalize output impact response to be negative (negative demand shock)

Sectoral Responses to Aggregate Demand Shocks

Two Examples: Accommodation sector vs. Apparel sector



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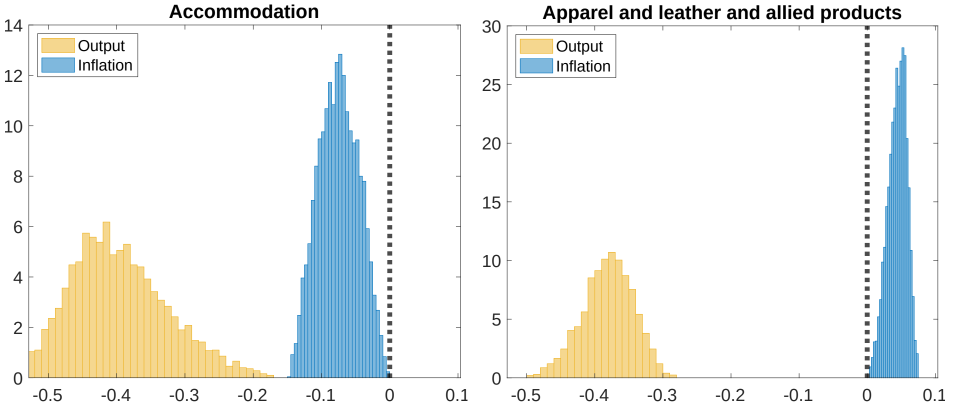

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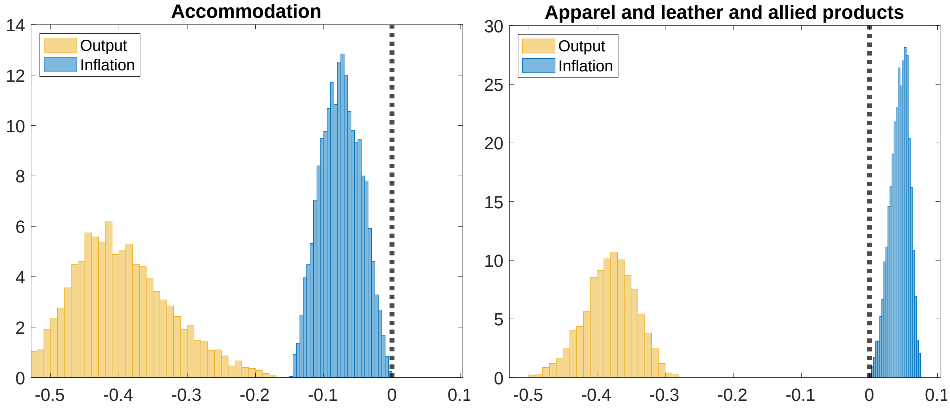
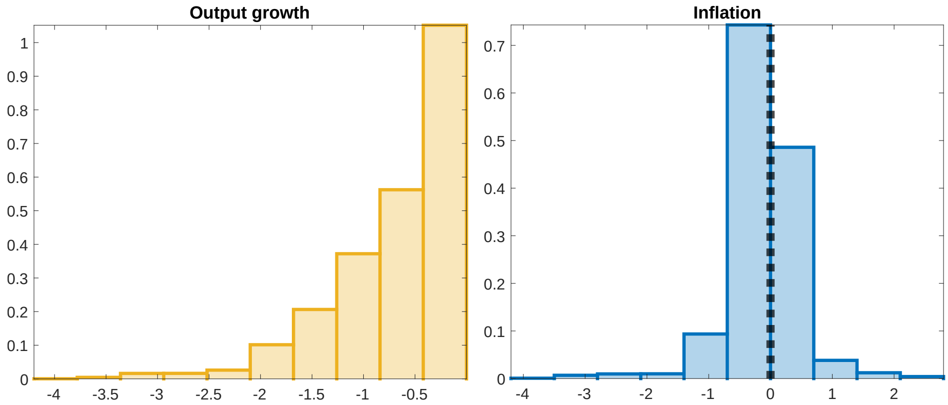


- In 16 sectors (of 64) not even one of 5, 000 impact responses behaves 'demand-like' List

Sectoral Responses to Aggregate Demand Shocks

All sectors



- Across all sectors, almost 40% of inflation impact responses do not behave ‘demand-like’

Robustness

- Richer dynamics (4 lags) Go
- Specification in levels (4 lags) Go
- Including Covid data Go
- Value added instead of gross output Go
- Identify oil shocks alongside demand and supply Go
- Adding EBP to aggregate VAR and LPs Go

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- **Conjecture:**
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- **Interpretation:**
  - Evidence supportive of Keynesian supply transmission mechanism
- **Next:** Evaluate conjecture and interpretation with a structural model

A Multi-Sector DSGE Model

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

Households

- Representative household maximizes present discounted value of utility

$$\mathbb{V}_t^h = \mathbb{E}_t \left[\sum_{s=0}^{\infty} \beta^s \Delta_{t+s-1} \left(\ln C_{t+s} - \frac{\sum_{k=1}^{K} N_{kt+s}^{1+\varphi}}{1+\varphi} \right) \right]$$

subject to

$$P_t C_t + \mathbb{E}_t(Q_{t,t+1} D_{t+1}) = D_t + \sum_{k=1}^{K} (W_{kt} N_{kt} + \mathcal{P}_{kt})$$

Consumption bundle

- The overall consumption index is a CES aggregate of sectoral consumption bundles

$$C_t \equiv \left[\sum_{k=1}^{K} (e^{m_{kt}} \omega_{ck})^{\frac{1}{\eta_c}} C_{kt}^{\frac{\eta_c - 1}{\eta_c}} \right]^{\frac{\eta_c}{\eta_c - 1}}$$

- In turn, each sectoral bundle is a CES aggregator of diversified varieties

$$C_{kt} \equiv \left[f_k^{-\frac{1}{\theta}} \int_0^{f_k} C_{kt}(j)^{\frac{\theta - 1}{\theta}} dj \right]^{\frac{\theta}{\theta - 1}}$$

Production

- The technology for firm j in sector k is

$$Y_{kt}(j) = e^{a_{kt}} Z_{kt}(j)^{\alpha_k} N_{kt}(j)^{1-\alpha_k}$$

- Composite intermediate input that combines goods from all sectors of the economy

$$Z_{kt}(j) \equiv \left[\sum_{r=1}^{K} \omega_{kr}^{\frac{1}{\eta_z}} Z_{krt}(j)^{\frac{\eta_z - 1}{\eta_z}} \right]^{\frac{\eta_z}{\eta_z - 1}}$$

- In turn, the sectoral intermediate inputs are aggregators of varieties produced by firms

$$Z_{krt}(j) \equiv \left[f_r^{-\frac{1}{\theta}} \int_0^{f_r} Z_{krt}(j, \ell)^{\frac{\theta-1}{\theta}} d\ell \right]^{\frac{\theta}{\theta-1}}$$

Price Stickiness

- Firms set prices on a staggered basis as in Calvo (1983)
- Probability of not being able to reset prices in t for a firm in sector k is $\xi_k \in (0, 1)$
- A firm that can reset its price at time t solves

$$\mathbb{V}_t^f = \max_{P_{kt}^*(j)} \mathbb{E}_t \left\{ \sum_{s=0}^{\infty} \xi_k^s Q_{t,t+s} \left[P_{kt}^*(j) Y_{kt+s}(j) - W_{t+s} N_{kt+s} - P_{t+s}^k Z_{kt+s}(j) \right] \right\}$$

subject to the demand for its own good (P_t^k is the price of the intermediate input bundle)

Monetary policy & Equilibrium

- Central bank sets monetary policy following an interest rate rule

$$\frac{R_t}{R} = \left(\frac{R_t}{R}\right)^{\rho_i} \left[\left(\frac{P_t}{P_{t-1}}\right)^{\phi_\pi} \left(\frac{Y_t}{Y_{t-1}}\right)^{\phi_y}\right]^{1-\rho_i}$$

- Labor markets are competitive and clear at the sectoral level

$$N_{kt} = \int_0^{f_k} N_{kt}(j)dj$$

- Goods market clearing implies

$$Y_{kt}(j) = C_{kt}(j) + \sum_{r=1}^{K} \int_0^{f_r} Z_{rkt}(\ell, j)d\ell$$

Model-Based Validation Exercise

[1] Calibrate model to same 64 sectors as in empirical analysis

- Input/output linkages and intermediates intensity (BEA)
- Frequency of price adjustment stickiness (BLS)

} Pasten, Schoenle and Weber (2020)

- Elasticity of substitution across intermediates $\eta^Z = 0.5$
- Elasticity of substitution across goods $\eta^C = 1$

} Baqaee and Farhi (2020a,b)

- Standard values for remaining parameters Table

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[3] Apply our empirical methodology to simulated data

Experiment #1: Sectoral TFP Shocks

- Simulated data driven exclusively by sectoral (uncorrelated) TFP shocks

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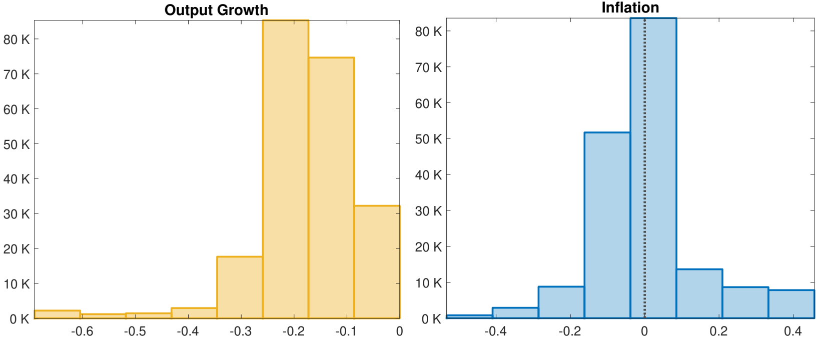
- **Step #1**: Aggregate VAR with sign restrictions
  - Aggregate demand-like shocks explain 50% of output forecast error variance

Experiment #1: Sectoral TFP Shocks

- Simulated data driven exclusively by sectoral (uncorrelated) TFP shocks
- **Step #2**: Estimation of sectoral impact responses
  - * Share of wrong responses 41%, number of sectors with wrong responses 21



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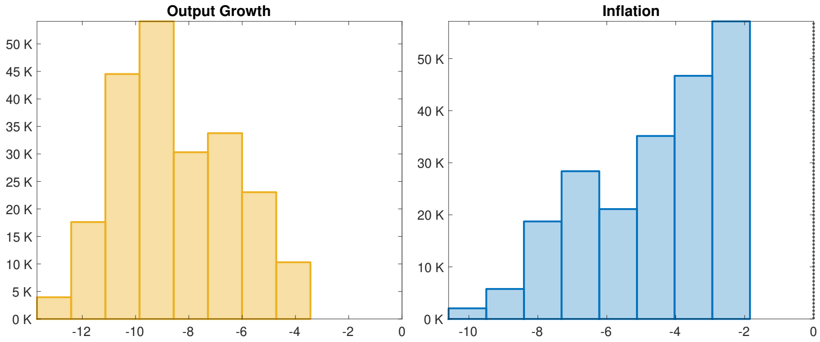
Experiment #2: Aggregate Demand Shocks

- Simulated data driven exclusively by aggregate demand shocks
- **Step #2**: Estimation of sectoral impact responses
  - Share of wrong responses 0%, number of sectors with wrong responses 0



Experiment #3: Sectoral Demand Shocks

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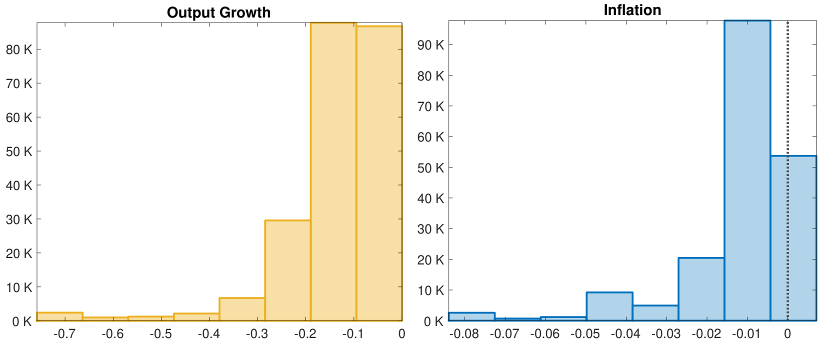
    - Aggregate demand-like shocks explain 93% of output forecast error variance

Experiment #3: Sectoral Demand Shocks

- Simulated data driven exclusively by sectoral (uncorrelated) demand shocks
- **Step #2**: Estimation of sectoral impact responses
  - Share of wrong responses 6%, number of sectors with wrong responses 3



Inspecting the Mechanism

What drives the Keynesian supply transmission mechanism?

- Four dimensions of sectoral heterogeneity:
  - **Price stickiness**: probability of being able to reset the price in each period
  - **Downstreamness**: other sectors' reliance on a sector's intermediate goods
  - **Upstreamness**: a sector's reliance on other sectors' intermediate goods
  - **Intermediates intensity**: exponent of intermediates in the production function

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- Model exercise
  - [1] Consider a negative sectoral TFP shock for each of the 64 sectors separately
  - [2] Compute the impact response of aggregate inflation to each sectoral TFP shock
  - [3] Scatter plot aggregate inflation response against dimensions of heterogeneity

Inspecting the Mechanism

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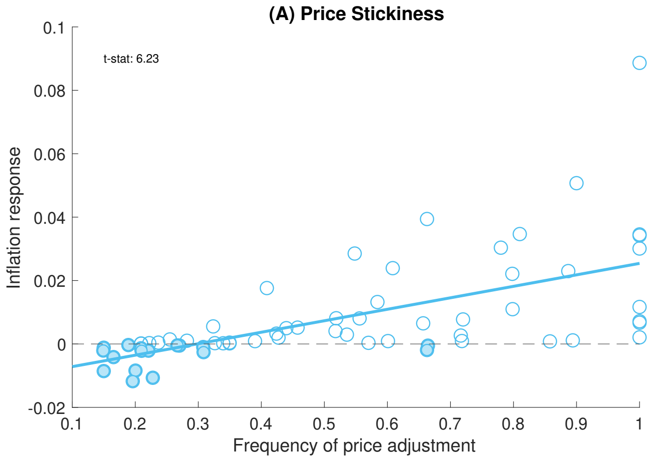
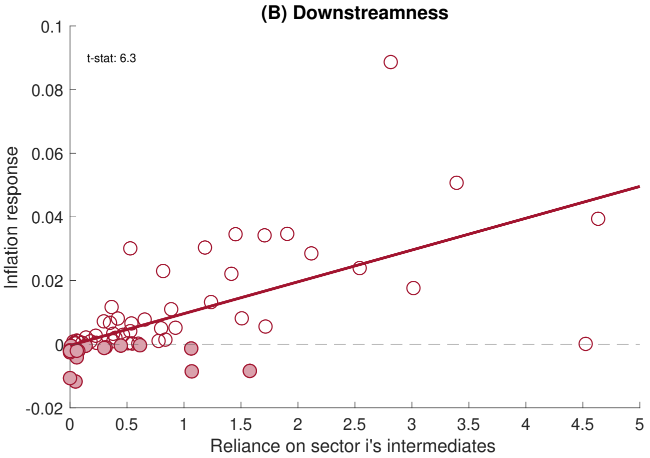


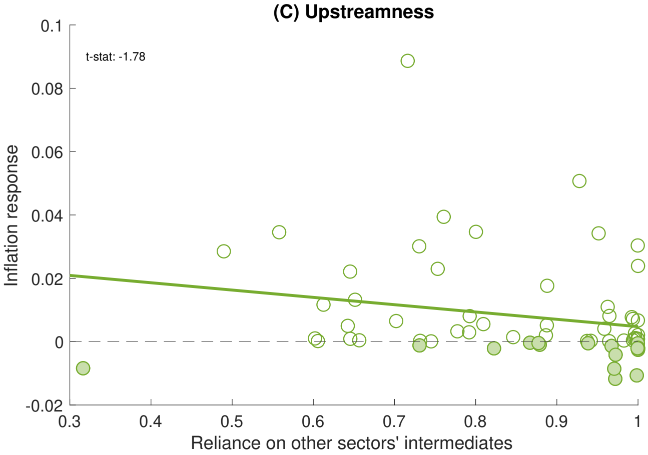
Inspecting the Mechanism

- **Downstreamness**: Other sectors' reliance on a sector's intermediate goods



Inspecting the Mechanism

- **Upstreamness**: a sector's reliance on other sectors' intermediate goods



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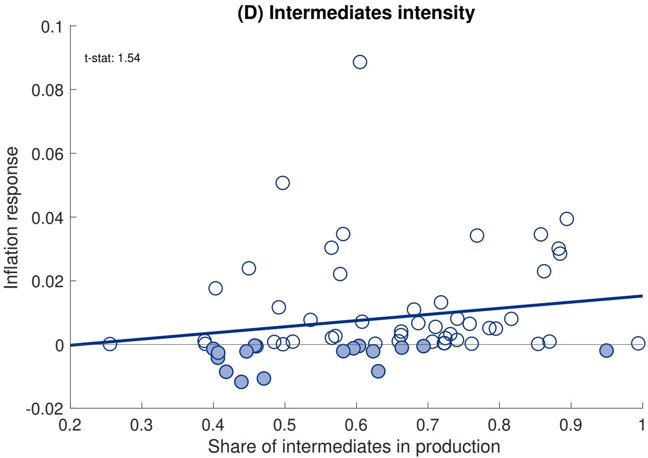

Conclusions

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  - Demand-like shocks derived from aggregate data contaminated by Keynesian supply shocks

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  - Demand-like shocks derived from aggregate data contaminated by Keynesian supply shocks
- **Model highlights key ingredients for Keynesian supply transmission**
  - Price stickiness and a sector's position in the production network

Conclusions

- **Why do we care?**
  - Optimal policy mix in response to sectoral shocks (like Covid-19)
    - Tilt balance in favor of fiscal policy? (Guerrieri, Lorenzoni, Straub and Werning, 2020; Woodford, 2020)
  - Beyond pandemic, debate about sources of business cycle fluctuations
    - Granular shocks and production networks (Gabaix, 2011; Baqaee and Farhi, 2020a, b)

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- **Future research:**
  - Identification of sectoral shocks
  - Cross-country analysis

Appendix

A1: A Multi-Sector Factor-Augmented VAR

A Multi-Sector Factor-Augmented VAR

All results extend to VAR(p)

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

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

where

  - $x_{it} \equiv [y_{it} \ \pi_{it}]'$

A Multi-Sector Factor-Augmented VAR

- Economy consists of N sectors indexed by $i = 1, 2, \ldots, N$

- Model sectoral output growth (y_{it}) and inflation (π_{it}) through a VAR(1) with a factor structure

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where

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  * f_t is a vector of unobserved factors common across sectors
  * u_{it} is a vector of unobserved 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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$$x_{it} = \Phi_{i0} + \Phi_{i1} x_{it-1} + \Gamma_i f_t + u_{it} \qquad i = 1, 2, \ldots, N$$

  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 unobserved cross-sectionally weakly correlated sectoral innovations

- Recover f_t 'by aggregation' as in Cesa-Bianchi, Pesaran and Rebucci (2020)
  - Factors can be approximated by cross-sectional averages of observables ($\bar{x}_t$) Skip derivations

Recovering 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 $\bar{z}_t = \sum_{i=1}^{N} w_i z_{it}$
  - Denote vector of cross-sectional weighted averages with $\bar{x}_t \equiv [\bar{y}_t \ \bar{\pi}_t]'$

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  - Denote vector of cross-sectional weighted averages with $\bar{x}_t \equiv [\bar{y}_t \; \bar{\pi}_t]'$

- **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

Recovering the Common Factors

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

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

Recovering the Common Factors

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

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

- Pre-multiply both sides by w_i and sum equation by equation over i

$$\bar{x}_t = \bar{\mu} + \sum_{\ell=0}^{\infty} \sum_{i=0}^{N} w_i \Phi_i^{\ell} \Gamma_i f_{t-\ell} + \sum_{\ell=0}^{\infty} \sum_{i=0}^{N} w_i \Phi_{i1}^{\ell} u_{it}$$

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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

Recovering the Common Factors

- Solve for x_{it} in terms of current and past common 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

- Approximate common factors by inverting and truncating previous expression

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

A Multi-Sector Factor-Augmented VAR

- Economy consists of N sectors indexed by $i = 1, 2, \ldots, N$

- Model sectoral output growth (y_{it}) and inflation (π_{it}) through a VAR(1) with a factor structure

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

  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 unobserved cross-sectionally weakly correlated sectoral innovations

- Unobserved factor model can be approximated by plugging expression for f_t

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

$\approx \Gamma_i f_t$

Identification of the Common Factors

- Factors are always identified up to a rotation matrix

- Rotate $\bar{x}_t$ with a SVAR to obtain aggregate structural shocks e_t

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

Identification of the Common Factors

- Factors are always identified up to a rotation matrix

- Rotate $\bar{x}_t$ with a SVAR to obtain aggregate structural shocks e_t

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

- Plug rotated $\bar{x}_t$ back in sectoral VAR

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

Identification of the Common Factors

- Factors are always identified up to a rotation matrix

- Rotate $\bar{x}_t$ with a SVAR to obtain aggregate structural shocks e_t

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

- Plug rotated $\bar{x}_t$ back in sectoral VAR

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

Main object of interest

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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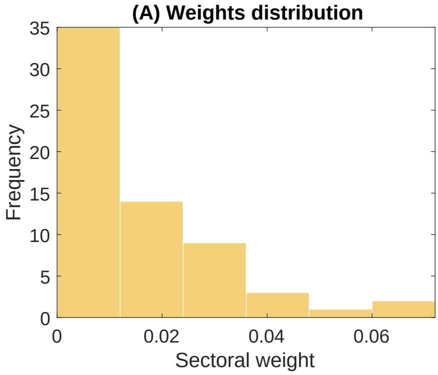
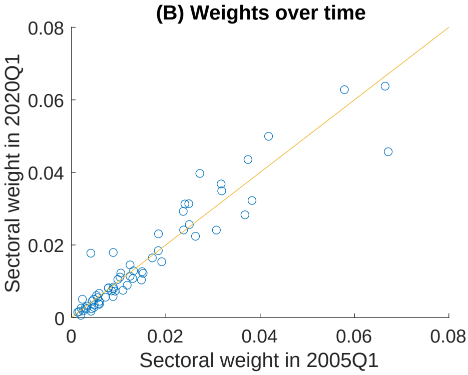
Weights and Sectoral Innovations: Data





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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 $\left\|\Omega_\ell\right\| \leq C_0 \rho^\ell$, with $0 < \rho < 1$

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A2: Additional Results

List of Sectors with Wrong Loadings

```
{'Farms'                                    }
{'Motor vehicles, bodies and trailers [..]' }
{'Other transportation equipment'           }
{'Apparel and leather and allied products'  }
{'Food and beverage stores'                 }
{'Transit and ground passenger transport.'  }
{'Publishing industries, except internet [..]'}
{'Motion picture and sound recording [..]'  }
{'Broadcasting and telecommunications'      }
{'Data processing, internet publishing [..]'}
{'Fed banks, credit intermed. [..]'         }
{'Insurance carriers [..]'                  }
{'Housing'                                  }
{'Administrative and support services'      }
{'Performing arts, spectator sports [..]'   }
{'Food services and drinking places'        }
```

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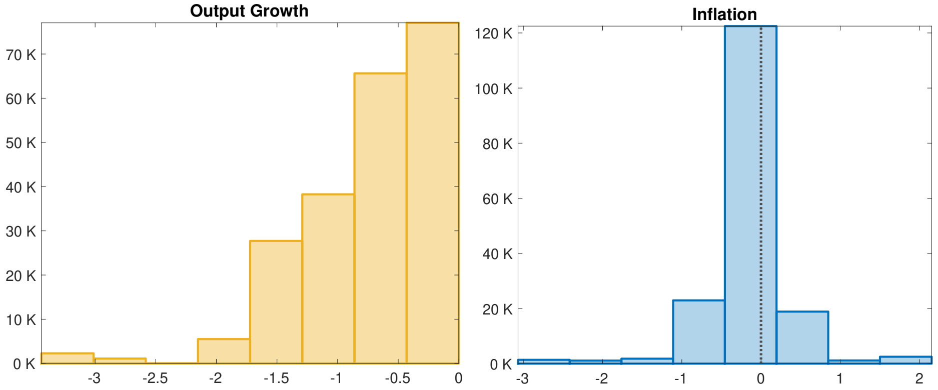
Factor Loadings to 'Demand-Like' Shock (2020Q1)



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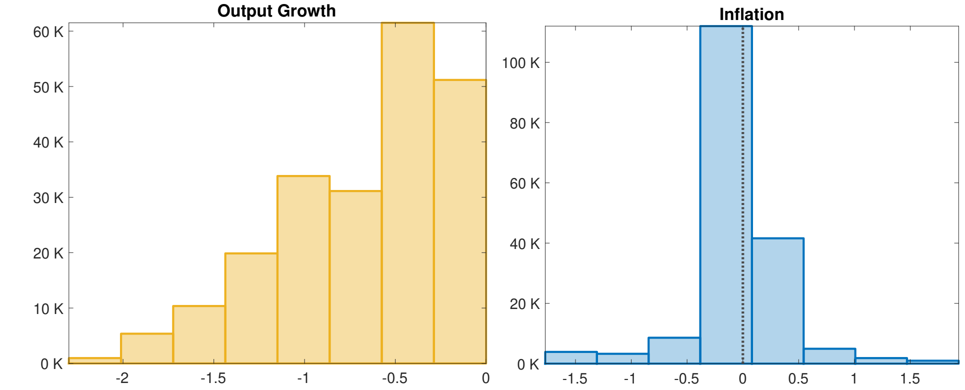
Factor Loadings to ‘Demand-Like’ Shock (Value Added)



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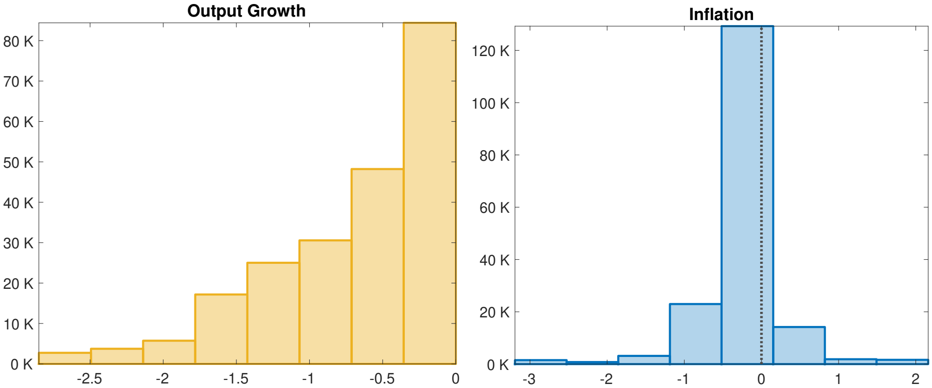
Factor Loadings to ‘Demand-Like’ Shock (4 lags)



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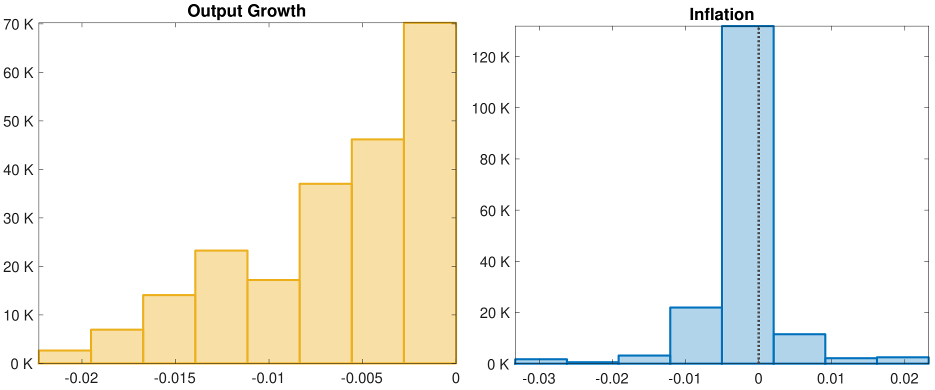
Factor Loadings to ‘Demand-Like’ Shock (4 lags, Levels)



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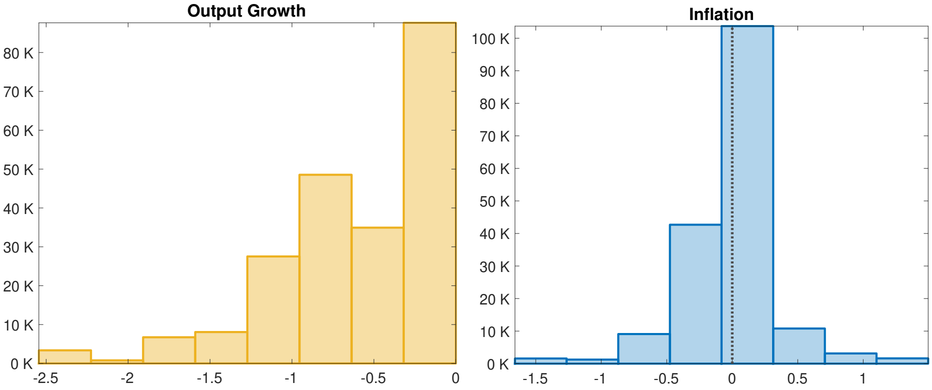
Factor Loadings to ‘Demand-Like’ Shock (Oil Shock)



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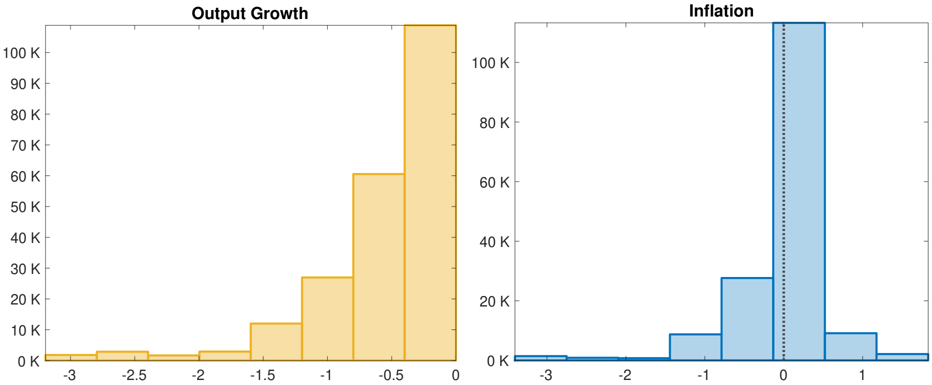
Factor Loadings to ‘Demand-Like’ Shock (EBP)



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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}	Pasten et al. (2020)	Consumption shares
ω_{kr}	Pasten et al. (2020)	Input-Output coefficients
α_k	Pasten et al. (2020)	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	0.975	Persistence of shocks

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References I

Baldwin, R. and B. Weder di Mauro (2020): *Economics in the Time of COVID-19*, CEPR Press.

Balleer, A., S. Link, M. Menkhoff, and P. Zorn (2020): "Demand or Supply? Price Adjustment during the Covid-19 Pandemic," IZA Working Paper 13568, -.

Baqaee, D. and E. Farhi (2020a): "Nonlinear Production Networks with an Application to the Covid-19 Crisis," NBER Working Paper 27281, -.

——— (2020b): "Supply and Demand in Disaggregated Keynesian Economies with an Application to the Covid-19 Crisis," NBER Working Paper 27152, -.

Bayer, C., B. Born, R. Luetticke, and G. Müller (2020): "The Coronavirus Stimulus Package: How Large is the Transfer Multiplier?" Discussion Paper 14600, Centre for Economic Policy Research.

Bekaert, G., E. Engstrom, and A. Ermolov (2020): "Aggregate Demand and Aggregate Supply Effects of COVID-19: A Real-time Analysis," Board of Governors of the Federal Reserve System Finance and Economics Discussion Series 2020-049, -.

Benigno, P. (2004): "Optimal Monetary Policy in a Currency Area," *Journal of International Economics*, 63, 293–320.

Benmelech, E. and N. Tzur-Ilan (2020): "The Determinants of Fiscal and Monetary Policies During the Covid-19 Crisis," NBER Working Paper 27461, -.

Bodenstein, M., G. Corsetti, and L. Guerrieri (2020): "Social Distancing and Supply Disruptions in a Pandemic," Cambridge-INET Institute Working Paper Series 2020/17, Cambridge-INET Institute.

Brinca, P., J. Duarte, and M. Faria-e-Castro (2020): "Measuring Labor Supply and Demand Shocks during COVID-19," Federal Reserve Bank of St. Louis Working Paper 2020-011D, -.

Caballero, R. and A. Simsek (2020): "Asset Prices and Aggregate Demand in a "Covid-19"Shock: A Model of Endogenous Risk Intolerance and LSAPs," Discussion Paper 14627, Centre for Economic Policy Research.

Calvo, G. (1983): "Staggered Pricing in a Utility-Maximizing Framework," *Journal of Monetary Economics*, 12, 383–398.

Carvalho, C., J. W. Lee, and W. Y. Park (2021): "Sectoral Price Facts in a Sticky-Price Model," *American Economic Journal: Macro*, 13, 216–256.

References II

Cavallo, A. (2020): "Inflation with Covid Consumption Baskets," Working Paper 27352, National Bureau of Economic Research.

Cesa-Bianchi, A. and A. Ferrero (2020): "The Transmission of Keynesian Supply Shocks," Unpublished manuscript.

Cesa-Bianchi, A., H. Pesaran, and A. Rebucci (2020): "Uncertainty and Economic Activity: A Multicountry Perspective," *Review of Financial Studies*, 33, 3393–3445.

Cesa-Bianchi, A. and A. Sokol (2017): "Financial Shocks, Credit Spreads, and the International Credit Channel," Bank of England Working Paper 693, -.

Chudik, A. and H. Pesaran (2014): "Aggregation in Large Dynamic Panels," *Journal of Econometrics*, 178, 273–285.

——— (2015): "Common Correlated Effects Estimation of Heterogeneous Dynamic Panel Data Models with Weakly Exogenous Regressors," *Journal of Econometrics*, 188, 393–420.

Chudik, A., M. H. Pesaran, and K. Mohaddes (2020): "Identifying Global and National Output and Fiscal Policy Shocks Using a GVAR," in *Essays in Honor of Cheng Hsiao*, ed. by T. Li, M. H. Pesaran, and D. Terrell, Emerald Publishing, vol. 41 of *Advances in Econometrics*, 143–189.

Cochrane, J. (2020): "Coronavirus Monetary Policy," in *Economics in the Time of COVID-19*, ed. by R. Baldwin and B. Weder di Mauro, CEPR Press.

Conley, T. and B. Dupor (2003): "A Spatial Analysis of Sectoral Complementarity," *Journal of Political Economy*, 111, 311–352.

Corsetti, G., L. Dedola, and S. Leduc (2008): "International Risk Sharing and the Transmission of Productivity Shocks," *Review of Economic Studies*, 75, 443–473.

——— (2014): "The International Dimension of Productivity and Demand Shocks in the US Economy," *Journal of the European Economic Association*, 12, 153–176.

del Rio-Chanona, M., P. Mealy, A. Pichler, F. Lafond, and D. Farmer (2020): "Supply and Demand Shocks in the COVID-19 Pandemic: An Industry and Occupation Perspective," *Oxford Review of Economic Policy*, 36, S94–S137.

Elenev, V., T. Landvoigt, and S. V. Nieuwerburgh (2020): "Can the Covid Bailouts Save the Economy?" Working Paper 27207, National Bureau of Economic Research.

References III

Eusepi, S., B. Hobijn, and A. Tambalotti (2011): “CONDI: A Cost-of-Nominal-Distorsions Index,” *American Economic Journal: Macroeconomics*, 3, 53–91.

Faria-e-Castro, M. (2020): “Fiscal Policy during a Pandemic,” Working Paper 14600, -.

Favara, G., S. Gilchrist, K. F. Lewis, and E. Zakrajšek (2016): “Updating the Recession Risk and the Excess Bond Premium,” Board of Governors of the Federal Reserve System FEDS Notes 2016-10-06, -.

Ferrero, A. and S. Giglioli (2020): “How Did Central Banks Respond to the Coronavirus Crisis?” Working paper, Economics Observatory.

Foerster, A. T., P.-D. G. Sarte, and M. W. Watson (2011): “Sectoral versus Aggregate Shocks: A Structural Factor Analysis of Industrial Production,” *Journal of Political Economy*, 119, 1–38.

Fornaro, L. and M. Wolf (2020): “Covid-19 Coronavirus and Macroeconomic Policy: Some Analytical Notes,” Unpublished, -.

Gabaix, X. (2011): “The Granular Origins of Aggregate Fluctuations,” *Econometrica*, 79, 733–772.

Gabaix, X. and R. Koijen (2020): “Granular Instrumental Variables,” NBER Working Paper 28204, -.

Galí, J. (2015): *Monetary Policy, Inflation, and the Business Cycle*, Princeton University Press.

Gertler, M. and P. Karadi (2015): “Monetary Policy Surprises, Credit Costs, and Economic Activity,” *American Economic Journal: Macroeconomics*, 7, 44–76.

Ghassibe, M. (2021): “Monetary Policy and Production Networks,” *Journal of Monetary Economics*, 119, 21–39.

Gilchrist, S. and E. Zakrajsek (2012): “Credit Spreads and Business Cycle Fluctuations,” *American Economic Review*, 102, 1692–1720.

Glover, A., J. Heathcote, D. Krueger, and J. Ríos-Rull (2020): “Health versus Wealth: On the Distributional Effects of Controlling a Pandemic,” Working paper, -.

Gourinchas, P. (2020): “Flattening the Pandemic and Recession Curves,” Unpublished.

References IV

GUERRIERI, V., G. LORENZONI, L. STRAUB, AND I. WERNING (2020): "Macroeconomic Implications of COVID-19: Can Negative Supply Shocks Cause Demand Shortages?" NBER Working Paper 26918.

HANSEN, L. AND T. SARGENT (1991): "Two Difficulties in Interpreting Vector Autoregressions," in *Rational Expectations Econometrics*, ed. by L. Hansen and T. Sargent, Westview Press, 77–119.

HORVATH, M. (2000): "Sectoral Shocks and Aggregate Fluctuations," *Journal of Monetary Economics*, 45, 69–106.

JORDÁ, O., S. SINGH, AND A. TAYLOR (2020): "Longer-Run Economic Consequences of Pandemics," Working Paper 26934, National Bureau of Economic Research.

KANZIG, D. (2021): "The Macroeconomic Effects of Oil Supply News: Evidence from OPEC Announcements," *American Economic Review*, 111, 1092–1125.

KAPLAN, G., B. MOLL, AND G. VIOLANTE (2020): "The Great Lockdown and the Big Stimulus: Tracing the Pandemic Possibility Frontier for the U.S." NBER Working Paper 27794, -.

LA'O, J. AND A. TAHBAZ-SALEHI (2020): "Optimal Monetary Policy in Production Networks," NBER Working Paper 27464, -.

LENZA, M. AND G. PRIMICERI (2020): "How to Estimate a VAR after March 2020," NBER Working Paper 27771, -.

MATTHES, C. AND F. SCHWARTZMAN (2021): "The Consumption Origins of Business Cycles: Lessons from Sectoral Dynamics," Federal Reserve Bank of Richmond Working Paper 19-09R, -.

MERTENS, K. AND M. RAVN (2013): "The Dynamic Effects of Personal and Corporate Income Tax Changes in the United States," *American Economic Review*, 103, 1212–1247.

PASTEN, E., R. SCHOENLE, AND M. WEBER (2020): "The Propagation of Monetary Policy Shocks in a Heterogeneous Production Economy," *Journal of Monetary Economics*, 116, 1–22.

SMETS, F., J. TIELENS, AND J. VAN HOVE (2018): "Pipeline Pressures and Sectoral Inflation Dynamics," National Bank of Belgium Working Papers 351, -.

References V

Smets, F. and R. Wouters (2007): "Shocks and Frictions in US Business Cycles: A Bayesian DSGE Approach," *American Economic Review*, 97, 586–606.

Stock, J. and M. Watson (2012): "Disentangling the Channels of the 2007-2009 Recession," *Brookings Papers on Economic Activity*, Spring, 81–135.

——— (2016): "Dynamic Factor Models, Factor-Augmented Vector Autoregressions, and Structural Vector Autoregressions in Macroeconomics," in *Handbook of Macroeconomics*, ed. by J. Taylor and H. Uhlig, North Holland, vol. 2A, chap. 8, 415–525.

Uhlig, H. (2005): "What Are the Effects of Monetary Policy on Output? Results from an Agnostic Identification Procedure," *Journal of Monetary Economics*, 52, 381–419.

Woodford, M. (2020): "Effective Demand Failures and the Limits of Monetary Stabilization Policy," NBER Working paper 27768, -.