The Inflationary Implications of Sectoral Shock Transmission across the Global Production Network*

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Motivation

- Countries around the world have witnessed the highest inflation of the last four decades
- Driven by large swings in economic activity over time and across sectors over Covid-19:
  - Collapse and rebound in domestic demand, GDP, and international trade
  - Consumption substitution across sectors (goods for services and back)
  - Labor shortages across sectors/countries (pandemic/lockdowns and recovery)
- Global supply chains played a critical role in amplifying shocks within and across borders

$\Rightarrow$ Macro/central banks "woke up" to importance of supply shocks and production resilience

$\Rightarrow$ Future risks: geopolitical, climate change, fragmentation of production

Today

1. Provide a multicountry-multisector quantitative framework to quantify inflationary implications of shock transmission across countries
   - A simple approach to apply (à la Baqaee and Farhi (2022), *AER*) $\Rightarrow$ useful for policy
   - Endogenous non-linear adjustment of price and sector expenditure shares as a response to sectoral and aggregate shocks
   - Does *not* take into account persistence – essentially a "hat algebra" approach

2. Quantify contribution of multiple shocks to countries' inflation rates and spillovers

3. Model-based (reduced-form) analysis to ask how changes in global sourcing of goods impacts shock transmission and implications for inflation

Results from our Research Agenda so far

What are the sources of inflation in the US and Euro Area between 2019Q4–2021Q4?

1. "Global Supply Chain Presures, International Trade, and Inflation"
   (prepared for 2022 ECB Sintra conference)
   - Closed-econ quantification of Baqaee and Farhi (2022): network + sectoral shocks
   - Open-econ quantification of Çakmaklı, Demiralp, Kalemli-Özcan, Yeşiltaş, Yıldırım (2022)

2. "Quantifying the Inflationary Impact of Fiscal Stimulus under Supply Constraints"
   (ASSA P&P 2023)
   - Separate aggregate demand shock into fiscal stimulus and the rest, only for the US

Today: introduce a new multicountry-multisector model with full global network and shock transmission – think about fragmentation implications

Related literature

- **Theory-closed**: **Inflation, Production Networks, Sectoral Demand and Supply Shocks**

  Baqaee and Farhi (2022), La'O and Tahbaz-Salehi (2022), Rubbo (2022), Afrouzi and Bhattarai (2022), Pasten, Schoenle, and Weber (2020)

- **Theory-closed/open**: **Inflation, Demand and Supply Shocks**

  Guerrieri, Lorenzoni, Straub, and Werning (2021, 2022), Amiti, Heise, Karahan, and Sahin (2022), Ferrante, Graves, and Iacovello (2022), Blanchard and Bernanke (2023), Comin, Johnson, and Jones (2023)

- **Theory-open:**
  - Production Networks and Trade with Supply Shocks

    Bonadio, Huo, Levchenko, and Pandalai-Nayar (2021), Boehm and Pandalai-Nayar (2022)
  - Production Networks and Trade with Demand and Supply Shocks

    Çakmaklı, Demiralp, Kalemli-Özcan, Yeşiltaş, Yıldırım (2022), Gourinchas, Kalemli-Özcan, Penciakova, Sander (2021)

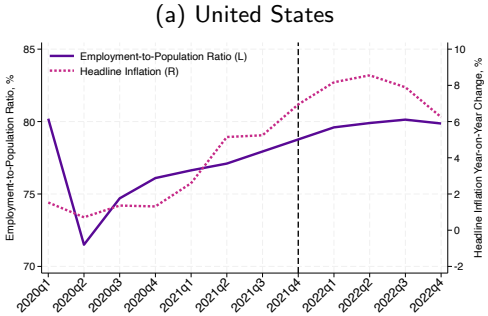
- **Existing Empirical Work on Inflation**: Reduced form regressions, VAR sign restrictions

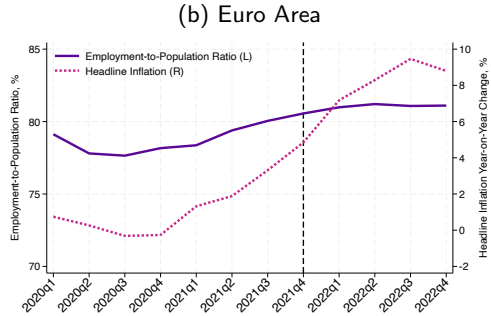
  Jorda, Liu, Nechio, and Rivera-Reyes (2022), LaBelle and Santacreu (2022), Shapiro (2022) ...

$\Longrightarrow$ **Our contribution:** a structural model with global I-O linkages and elasticities of substitution to quantify inflation drivers during Covid-19 collapse and recovery

Stylized Facts

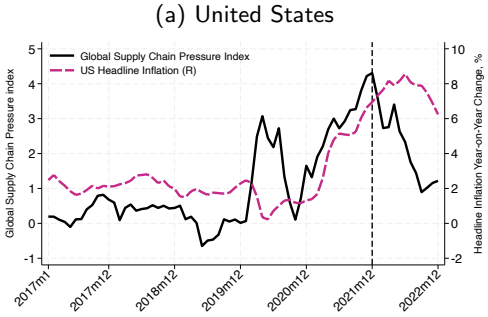
Simultaneous slack and inflation

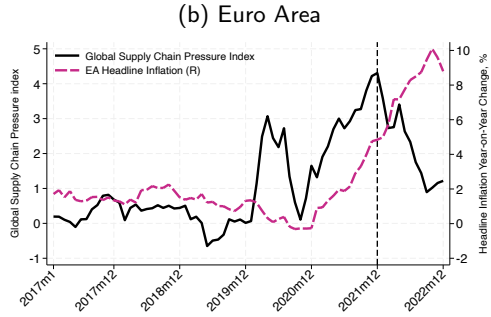




Source: FRED

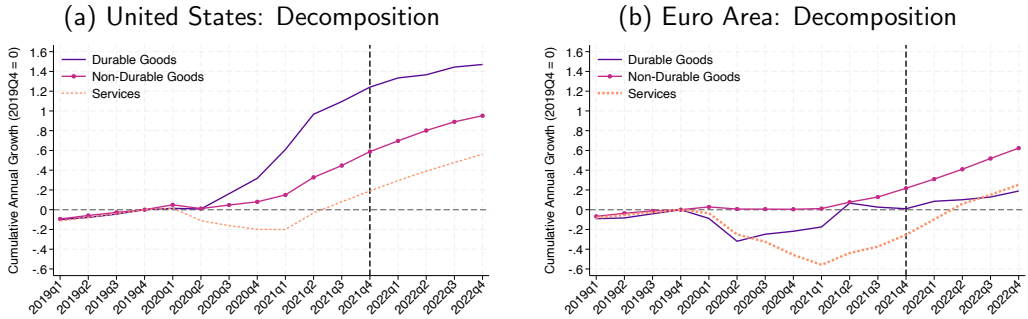
Simultaneous increase in inflation and supply chain pressures





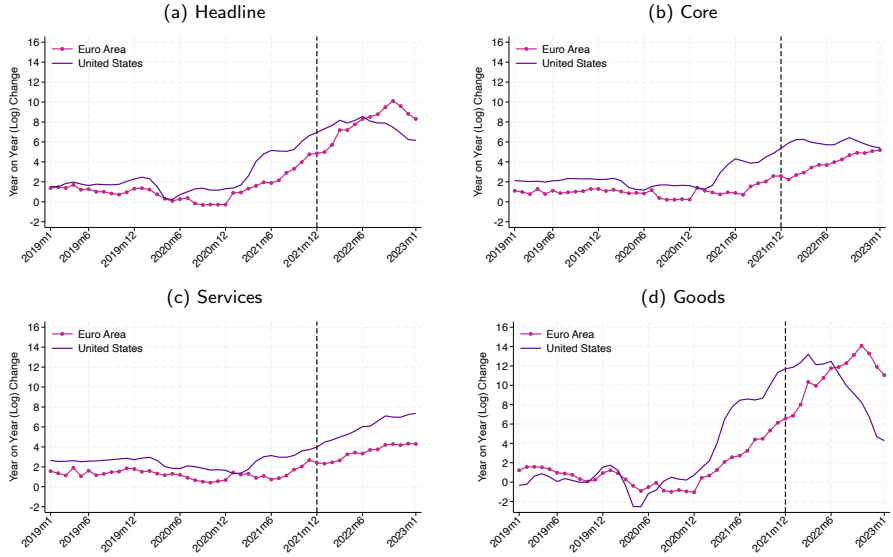
Source: FRBNY, FRED.

Substitution between goods and services consumption



Notes: Seasonally-adjusted real private consumption. Source: OECD Quarterly National Accounts.

Inflation in goods picked up earlier than inflation in services



Source: FRED.

Model Sketch

Inflation in a multicountry network-macro model

- We build on Baqaee and Farhi (2022) w/simplifications:
  - Two-period multicountry model ($n = 1, \ldots, \mathcal{C}$)
  - Ricardian households with perfect foresight
  - Multiple sectors ($i = 1, \ldots, \mathcal{J}$) produce using factors and intermediate inputs
  - Perfect competition in factors and good markets
  - Downward nominal wage rigidity + sector-specific labor, zero-lower bound
- Model allows for rich set of shocks:
  - Country level aggregate demand
  - Country-sector demand shifts
  - Country-sector factor supply and productivity (including energy shocks eventually...)

Households

Inter-temporal maximization problem

$$\max_{\{C_{n,0}, C_{n,*}\}} (1-\beta_n)\log U(C_{n,0}) + \beta_n \log U(C_{n,*})$$

s.t.

$$P_{n,0}C_{n,0} + \frac{P_{n,*}C_{n,*}}{1+i_n} = I_{n,0} + \frac{I_{n,*}}{1+i_n}$$

$$U(C_n) = \frac{C_n^{1-\sigma}-1}{1-\sigma}; \qquad C_n = \prod_{j=1}^{\mathcal{J}} C_{nj}^{\Omega_{nj}}, \quad \sum_{j=1}^{\mathcal{J}} \Omega_{nj} = 1$$

$$C_{nj} = \left[\sum_{m=1}^{\mathcal{C}} \Omega_{nj,m} X_{nj,m}^{\frac{1-\xi}{\xi}}\right]^{\frac{\xi}{1-\xi}}$$

Note: Future variables (denoted by $*$) are exogenous

Production

Cost minimization

$$\min_{\{VA_{ni}, M_{ni}\}} P_{ni}^{VA} VA_{ni} + P_{ni}^{M} M_{ni}$$

s.t.

$$Y_{ni} = A_{ni} \left[\Omega_{ni,VA} VA_{ni}^{\frac{1-\theta}{\theta}} + \Omega_{ni,M} M_{ni}^{\frac{1-\theta}{\theta}} \right]^{\frac{\theta}{1-\theta}}$$

$$VA_{ni} = \left[\Omega_{niVA,L} L_{ni}^{\frac{1-\gamma}{\gamma}} + \Omega_{niVA,K} \overline{K}_{ni}^{\frac{1-\gamma}{\gamma}} \right]^{\frac{\gamma}{1-\gamma}}$$

Intermediate goods' aggregation

Across sectors: $M_{ni} = \left[\sum_{j=1}^{\mathcal{J}} \Omega_{nj,i} X_{nj}^{\frac{1-\epsilon}{\epsilon}} \right]^{\frac{\epsilon}{1-\epsilon}}$ Across countries: $X_{nj} = \left[\sum_{m=1}^{\mathcal{C}} \Omega_{nj,m} X_{nj,m}^{\frac{1-\xi}{\xi}} \right]^{\frac{\xi}{1-\xi}}$

Market clearing

- Goods market clearing: for each country n sector i:

$$Y_{ni} = \sum_{m \in \mathcal{C}} X_{mi,n}$$

- Segmented labor markets: the labor market in country n, sector i, with wage W_{ni} in *local currency*, satisfies

$$\overline{L}_{ni} \geq L_{ni}, \qquad W_{ni} \geq \overline{W}_{ni}, \qquad \left(\overline{L}_{ni} - L_{ni}\right)\left(W_{ni} - \overline{W}_{ni}\right) = 0$$

- Segmented capital markets with *no* price rigidities:

$$K_{ni} = \overline{K}_{ni}$$

Monetary policy and the inter-temporal budget

- Monetary policy: assume all countries at zero-lower bound ($i = 0$)
- Inter-temporal budget constraint becomes:

$$P_{n,0} C_{n,0} + P_{n,*} C_{n,*} = I_{n,0} + I_{n,*}$$

- Set $P_{n,*} = 1$ and $I_{n,*}$ to the steady-state expenditure level
- Inter-temporal optimization yields:

$$I_{n,0} = P_{n,0} C_{n,0} = \frac{1 - \beta_n}{\beta_n} I_{n,*}$$

- Note that the aggregate shock is driven by a change in β_n. Corresponding expenditure is given in local currencies

The current account

- At the world level: Expenditure = GDP, but for individual countries: $I_n \neq \text{GDP}_n$

$$I_n = \text{GDP}_n + \underbrace{\text{Imports}_n - \text{Exports}_n}_{-\text{Current Account}}$$

- Define bilateral trade balance between countries m and n as:

$$D_{nm} \equiv \text{Exports}_{m \to n} - \text{Exports}_{n \to m}$$

- Assume that the bilateral trade balance is financed by the ownership of factors / industries of country m in country n:

$$\chi_{nm} \equiv \begin{cases} \frac{D_{nm}}{\text{GDP}_m} & \text{if } D_{nm} > 0 \\ 0 & \text{otherwise} \end{cases}$$

- Then the total income of country n is:

$$I_n = \text{GDP}_n - \underbrace{\sum_m \chi_{mn} \text{GDP}_n}_{\text{Factors owned by foreigners in } n} + \underbrace{\sum_m \chi_{nm} \text{GDP}_m}_{\text{Factors owned abroad by } n}$$

Exchange rates

- In terms of factor income, the GDP of country n can be written as:

$$\text{GDP}_n = \sum_i (W_{ni} L_{ni} + R_{ni} \overline{K}_{ni})$$

- This is given in the common world currency. Hence the income of country n is given in the common currency
- We know the expenditure in the local currency from the inter-temporal budget constraint
- The exchange rate of country n is then:

$$e_n \equiv \frac{\text{Local currency Income}}{\text{Common currency Income}} = \frac{(1-\beta_n) I_n / \beta_n}{(1 - \sum_m \chi_{mn}) \text{GDP}_n + \sum_m \chi_{nm} \text{GDP}_m}$$

- Downward wage limit is given in the local currency but the wage the model solves is in common currency. Therefore, the downward wage rigidity is given by:

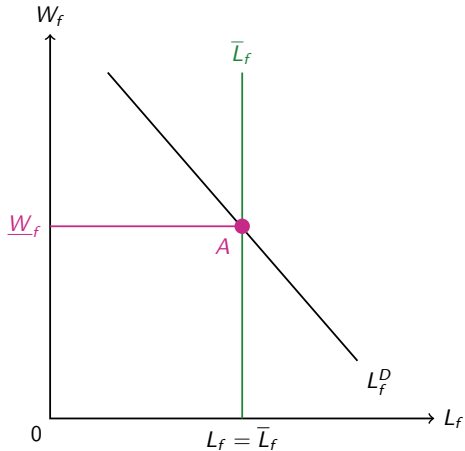
$$e_n W_{ni} \geq \overline{W}_{ni} \Rightarrow W_{ni} \geq \frac{\overline{W}_{ni}}{e_n}$$

Model solution method

- Calibrate the model with ICIO 2018 Table from OECD
  - Final use shares
  - Input shares
  - Value added shares
  - Expenditures
- Normalize all prices, wages and rents to 1 at steady state
- From this stable equilibrium introduce shocks
- AMPL / Knitro optimizer
- Calculate the relative changes in common currency
- Convert the common currency price changes to local currency by multiplying with the model-consistent exchange rate

Segmented factor (e.g., labor) markets during collapse and recovery

- $\overline{L}_f$: Potential level for factor f. Decrease due to sick workers, shutdowns, etc.



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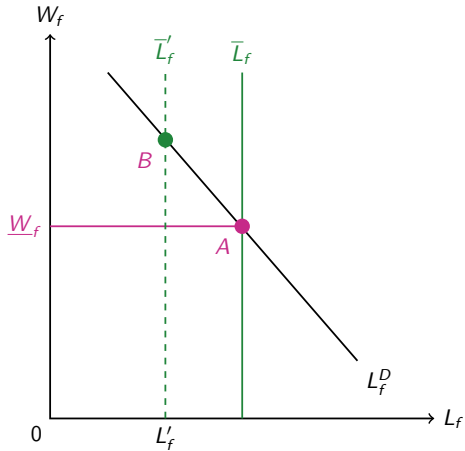

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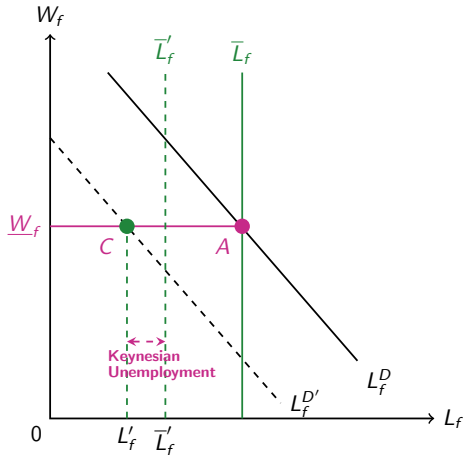
- L_f: Equilibrium employment level for factor f
  - Demand effects+downward wage rigidity $\Rightarrow$ workers employed might be lower than *potential*
- Difference between $\overline{L}_f$ and L_f: Keynesian unemployment



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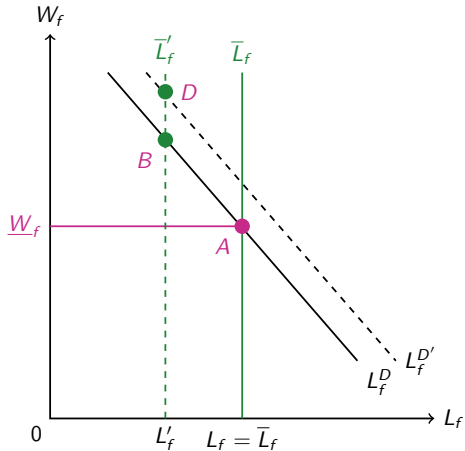
- Difference between $\overline{L}_f$ and L_f: Keynesian unemployment
- During recovery – point D: where these unemployment gaps are closed (heterogeneous across sectors, may not be back to 2019 but still inflationary)



First-order approximation of domestic CPI inflation: closed economy

Domar Weights:

$$\lambda_i \equiv \frac{P_i Y_i}{GDP} \quad \text{and} \quad \Lambda_f \equiv \frac{W_f L_f}{GDP}$$

CPI:

$$\mathrm{d}\log CPI = \underbrace{\mathrm{d}\log \zeta}_{\text{Domestic AD shock}} - \boldsymbol{\Lambda}^T \mathrm{d}\log \boldsymbol{L} - \boldsymbol{\lambda}^T \mathrm{d}\log \boldsymbol{A}$$

- Same result as in Baqaee & Farhi (2022)
- Relative strength of sector-level labor or productivity shocks determined by the influence vector of sector-level factor or output shares, respectively

Open-economy Domar weights

- We can relate the final consumption to production via global Leontieff inverse ($\mathbf{\Psi}$). Denote the total output of all industries globally with $\boldsymbol{Y}$, the total consumption of all industries with $\boldsymbol{C}$, then:

$$\boldsymbol{Y} = \mathbf{\Psi}\boldsymbol{C}$$

- Denote the consumption of country n in all industries globally with $\boldsymbol{C}^n$ and assign the portion of production to country n by

$$\boldsymbol{Y}^n = \mathbf{\Psi}\boldsymbol{C}^n$$

- Write the local Domar weights for country n using Y^n_{mi}:

$$\lambda^n_{mi} \equiv \frac{P_{mi}Y^n_{mi}}{I_n}$$

First-order approximation of domestic CPI inflation: open economy

Factor shares are governed by $\boldsymbol{\Omega}^F$. We can define country-level Domar weights for all factors globally as:

$$\boldsymbol{\Lambda^n} \equiv (\boldsymbol{\Omega}^F)^T \boldsymbol{\lambda^n}$$

Then the (local currency) CPI in country n can be written as:

$$\mathrm{d}\log CPI^n = \underbrace{\mathrm{d}\log \zeta^n}_{\text{AD shock}} - (\boldsymbol{\Lambda^n})^T \mathrm{d}\log \boldsymbol{L} - (\boldsymbol{\lambda^n})^T \mathrm{d}\log \boldsymbol{A}$$

- Labor shortages, at home and abroad, are inflationary domestically
- Positive productivity changes everywhere, $\mathrm{d}\log \boldsymbol{A}$, are deflationary
- Country n's AD shock includes both domestic AD shock and exchange rate change

Quantification Exercises

Data aggregation

- Three countries:
  - United States
  - Euro Area
  - Rest of the world
- Three sectors:
  - Durable
  - Non-durable
  - Services

Mapping data to model shocks

1. Sectoral demand shocks ($\mathrm{d}\Omega_{nj}$): Observed sectoral expenditure shares changes in country n with $\sum_{j \in \mathcal{J}} d\Omega_{nj} = 0$
   - United States: BEA sectoral personal consumption expenditure
   - Euro Area: OECD Quarterly National Accounts
   - Rest of the world: estimates based on infection levels

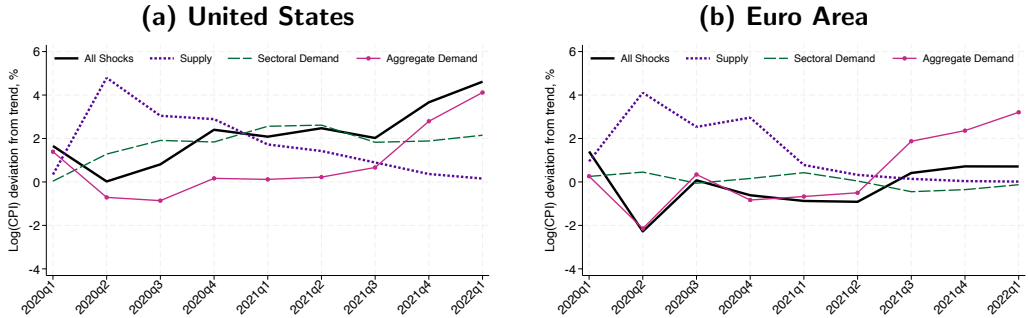
2. Country-sectoral potential supply shocks ($\mathrm{d} \log \overline{L}_{ni}$): Observed changes in total hours worked in country n, sector i
   - United States: BLS tables B1 and B2
   - Euro Area: EuroStat
   - Rest of the world: estimates based on infection levels

3. Country-level aggregate demand shocks ($\mathrm{d} \log \zeta^n$): Nominal (l.c.) expenditure changes
   - United States: Gross national income
   - Euro Area: Gross national income
   - Rest of the world: country-weighted nominal GDP growth

Parametrization

- Model requires initial consumption and input-output shares
  - We use the cross-country input-output database from the OECD year 2018
- Elasticities:
  - Between value added and intermediate inputs: $\theta = 0.6$ (Atalay, 2017; Carvalho et. al, 2021)
  - Between labor and capital: $\gamma = 0.6$ (Raval, 2019; Oberfield and Raval, 2021)
  - Among intermediates: $\varepsilon = 0.2$ (Atalay, 2017; Boehm, Flaaen, and Pandalai-Nayar, 2019)
  - Cross-country Armington: $\xi = 4.55$ (Caliendo & Parro, 2015)
- We set country-sector productivity changes to zero throughout
  - Recent evidence on pandemic suggests little changes in aggregate/sectoral productivity w/no labor reallocation across sectors in the US (Fernald and Li, 2022)
  - Want to give full chance to sectoral labor shocks to mimic the reality of sectoral shortages and demand-supply imbalances

Baseline results: all shocks

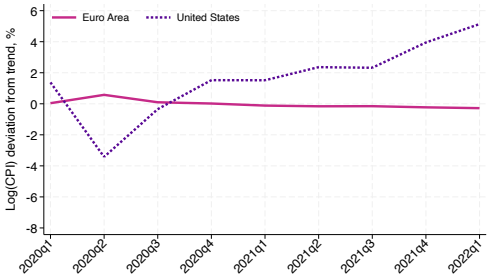


Key takeaways:

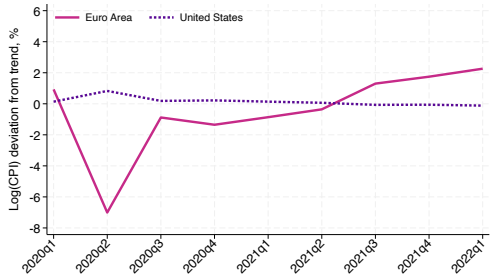
- Supply shocks play large role early on
- Aggregate demand shocks dominate latter part of the sample period
- Sectoral demand more relevant for the US

Baseline spillover results: all shocks

(a) United States shocks



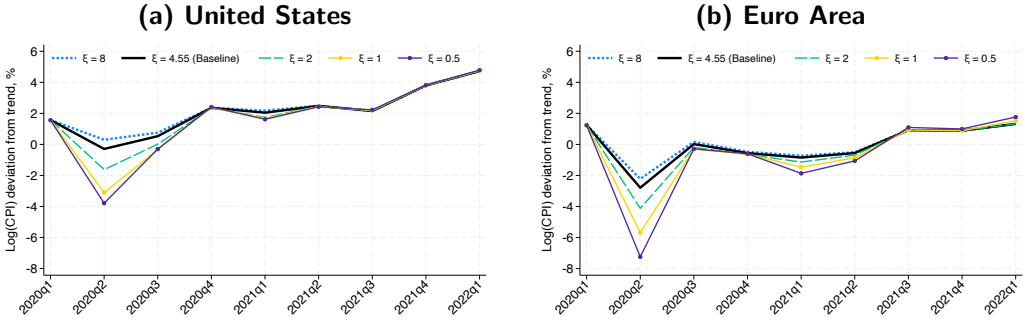
(b) Euro Area shocks



Spillovers are small:

- Exchange rate effect cancels out AD shocks
- Relatively small international component of IO matrix leads limited supply spillovers

Global sourcing: all shocks different trade elasticities



Decreasing elasticity:

- Impact of supply shocks quantitatively unimportant
- Amplifies deflationary impact of sectoral demand shocks

Conclusion and open questions

- New multicountry-multisector framework to quantity how supply-demand imbalances that were generated by multiple types of shocks over Covid-19 period spilled over across countries and impacted inflation
- Many avenues to further explore with the framework + future work needed
  - Expanding sample to many more countries/sectors
  - Embed energy price shocks and extend time series to war period
  - Possible to generate greater spillover effect in a tractable quantifiable framework?

  $\Rightarrow$ Common problem in these types of models
  - How to incorporate *micro* findings on breakdowns in GVCs into a *macro* framework?
  - More generally, how will potential changes in firms' sourcing decisions impact transmission of shocks and macro volatility?