PANDEMIC-ERA INFLATION DRIVERS AND GLOBAL SPILLOVERS

Julian di Giovanni

Federal Reserve Bank of New York and CEPR

Şebnem Kalemli-Özcan

University of Maryland, CEPR and NBER

Alvaro Silva

Federal Reserve Bank of Boston

Muhammed A. Yıldırım

Harvard & Koç University

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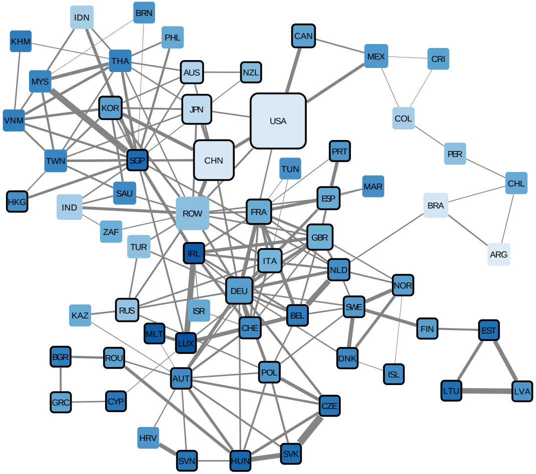
Motivation

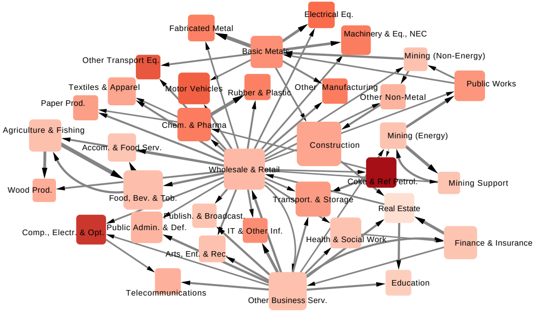
- Countries around the world have suffered the highest inflation of the last four decades
- Witnessing at the same time:
  - Collapse and rebound in domestic demand, GDP and international trade
  - Consumption substitution across sectors (goods for services and back)
  - Labor shortages (pandemic/lockdowns 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

Importance of Country-Sector Dimension: Production and Trade Network (65 by 44)





We quantify the well-known narrative

"Many viewed the sudden upturn in inflation as mostly a function of pandemic-related shifts in the composition of demand, a disruption of supply chains, and a sharp decline in labor supply.
The resulting supply and demand imbalances led to large increases in the prices of a range of items, especially goods ... But in the fourth quarter of 2021, the data clearly changed ... with only gradual progress in restoring global supply chains, and relatively few workers rejoining the labor force ... A new shock arrived in February 2022, when Russia invaded Ukraine, resulting in a sharp increase in energy and other commodity prices ... it was clear that bringing down inflation would depend both on the unwinding of the pandemic-related demand and supply distortions and on our tightening of monetary policy, which would slow the growth of aggregate demand, allowing supply time to catch up."

Remarks from Jay Powell, 24th Jacques Polak Annual Research Conference, IMF, 2023.

Develop a new global network model to quantify price effects of demand-supply imbalances

$\Rightarrow$ **open economy channels are important—transmission of cost-push and demand shocks**

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$\Rightarrow$ **open economy channels are important—transmission of cost-push and demand shocks**

- Once importance of supply side shocks are understood, inflation coming down quickly is basic economics
- But that happening without an increase in unemployment is not basic economics!
- Our paper can account for disinflation without a recession theoretically, while quantifying role of supply shocks (both supply chains and energy) and demand shocks on inflation

Our paper

- Estimate a multi-country multi-sector New Keynesian model to quantify the drivers of the pandemic-era inflation: Today 4 by 44—United States, Euro Area, Russia, China+RoW
- A rich set of sectoral and aggregate shocks that transmit through the global trade and production network.
- Can match observed headline inflation rates and changes in sector-level prices, wages, and exchange rates. (**nothing targeted**)

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- Can match observed headline inflation rates and changes in sector-level prices, wages, and exchange rates. (**nothing targeted**)
- Key Results:
  - Negative supply shocks to factors of production – labor and intermediate inputs – that can be of domestic or foreign origin, initially sparked inflation in **2020–2021.**
  - Positive aggregate demand shocks widened demand-supply imbalances and amplified inflation during **2021–2022.**
  - The reallocation of consumption between goods and service sectors transmitted the demand-supply imbalances across countries, impacting **current accounts**.
  - **Energy shocks** had differential impacts on the Euro Area relative to other countries' inflation rates, due to a higher foreign factor content of trade combined with complementarities between foreign and domestic factors of production.

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), Ferrante, Graves, and Iacovello (2023)

- **Theory-closed**: **Inflation, 2-sector, Demand and Supply Shocks**

  Guerrieri, Lorenzoni, Straub, and Werning (2021, 2022), Lorenzoni and Werning (2023)

- **Theory-closed**: **Inflation, 1-sector, Supply Shocks**

  Blanchard and Bernanke (2023), Gagliardone and Gertler (2023), Benigno and Eggertson (2023), Harding et al (2023), Fornaro and Wolf (2023)

- **Theory-open: Inflation, 2-sector, Demand and Supply (Energy) Shocks**

  Amiti, Heise, Karahan, and Sahin (2022), Comin, Johnson, and Jones (2023)

- **Empirical Work on Inflation, model-based**: di Giovanni et al (2021)—our earlier work prepared for ECB-Sintra conference is the first to quantify impact of supply chain disruptions
- **Empirical Work on Inflation, reduced form**: VAR sign restrictions

  Jorda, Liu, Nechio, and Rivera-Reyes (2022), LaBelle and Santacreu (2022), Shapiro (2022), de Soyres, Gaillard, Santacreu, and Moore (2024), Bai et al (2023)

$\Longrightarrow$ **Our contribution:** a structural network NK-GE model with global I-O linkages and endogenous exchange rates to quantify inflation drivers and spillovers

Model Sketch

Inflation in a multicountry network-macro model

- Open economy version of Baqaee and Farhi (2022) w/simplifications:
  - Two-period multicountry model ($n, m = 1, \ldots, \mathcal{N}$)
  - Ricardian households with perfect foresight
  - Have access to a domestic and a world bond
  - Multiple sectors ($i, j = 1, \ldots, \mathcal{J}$) produce using factors and intermediate inputs
  - Perfect competition in factors and good markets
  - Monetary policy: Zero-lower bound

- Frictions:
  - Downward nominal wage rigidity
  - Segmented factor markets

Households in Country “n”: Inter-temporal Problem

$$\max_{\{C_{n,0},C_{n,1},F_{n,0},B_{n,0}\}} (1-\beta_{n,0})\frac{C_{n,0}^{1-\sigma}}{1-\sigma} + \beta_{n,0}\frac{C_{n,1}^{1-\sigma}}{1-\sigma}$$

s.t.

$$P_{n,0}C_{n,0} + B_{n,0} + \mathcal{E}_{n,0}F_{n,0} \leq \sum_i (W_{ni,0}L_{ni,0} + R_{ni,0}K_{ni,0}),$$

$$P_{n,1}C_{n,1} \leq \mathcal{E}_{n,1}\sum_i (W_{ni,1}L_{ni,1} + R_{ni,1}K_{ni,1}) + (1+i_{n,0})B_{n,0} + \mathcal{E}_{n,1}(1+i_{US,0})F_{n,0},$$

- B_n: domestic bond denominated in local currency units (lcu). Traded domestically.
- F_n: world bond denominated in US dollars. Internationally traded.
- $\mathcal{E}_n$: exchange rate between country n and the US (lcu per dollar)
- i_n: domestic interest rate
- i_{US}: US interest rate
- $\beta_{n,0}$: intertemporal shifter.

Households in Country "n": Intertemporal Optimality

- Optimality conditions

$$\phi_{n,0}\frac{C_{n,0}^{-\sigma}}{P_{n,0}} = \frac{C_{n,1}^{-\sigma}(1+i_{n,0})}{P_{n,1}} \qquad \text{(Euler Equation)}$$

$$(1+i_{n,0}) = (1+i_{US,0})\frac{\mathcal{E}_{n,1}}{\mathcal{E}_{n,0}} \qquad \text{(Interest Parity Condition)}$$

- $\phi_{n,0} = (1-\beta_{n,0})/\beta_{n,0}$
- X: steady-state value. 0 present where shocks happen, 1 future.
- $\hat{X}_t = X_t/X$: deviation from steady-state.
- From now on, assume future variables are at steady state and $\sigma = 1$.

Monetary policy and exchange rates

- World expenditure (in US dollars) is *endogenous* and determined by intertemporal shifters $(\phi_{n,0})$ and US interest rate

$$\widehat{E}^{\$}_{W,0} = \frac{1}{(1+i_{US,0})} \sum_n \alpha_n \hat{\phi}_{n,0}; \qquad \alpha_n = (P_n C_n / \mathcal{E}_n) \Big/ \sum_m P_m C_m / \mathcal{E}_m$$

- Bilateral exchange rates depend only on stance of domestic monetary policies

$$\frac{\mathcal{E}_{n,0}}{\bar{\mathcal{E}}_n} = \frac{(1+i_{US,0})}{(1+i_{n,0})}$$

- We use data on expenditure E_n and interest rates, $1+i_n(0)$, to back out discount factor changes

$$\hat{\phi}_{n,0} = \widehat{E}_{n,0}(1+i_{n,0})$$

  - If no change in domestic interest rates $\longrightarrow$ Exchange rates vis-a-vis the US do not change
  - $\uparrow \phi_{n,0} \longrightarrow \hat{E}_{n,0}$: given $(1+i_{n,0})$

Disaggregated Consumption

- Consumption Bundle consists of Country-specific Sectoral Consumption Bundles:

$$C_n = \prod_{j=1}^{\mathcal{J}} C_{n,j}^{\Omega_{n,j}^{C}}, \quad \sum_{j=1}^{\mathcal{J}} \Omega_{n,j}^{C} = 1$$

- Country-specific Sectoral Consumption Bundles are formed by varieties (Armington aggregator)

$$C_{n,j} = \left[\sum_{m=1}^{\mathcal{C}} (\Omega_{n,mj}^{CB})^{\frac{1}{\xi}} C_{n,mj}^{\frac{\xi-1}{\xi}} \right]^{\frac{\xi}{\xi-1}}, \quad \sum_{m=1}^{\mathcal{N}} \Omega_{n,mj}^{CB} = 1$$

Disaggregated Production

- Sectors produce by combining the factors (value-added) and intermediate bundle.

$$\min_{\{\mathsf{VA}_{ni}, M_{ni}\}} P_{ni}^{\mathsf{VA}} \mathsf{VA}_{ni} + P_{ni}^{M} Z_{ni}$$

s.t.

$$Y_{ni} = A_{ni} \left[(\Omega_{ni,\mathsf{VA}}^{Y})^{\frac{1}{\theta}} \mathsf{VA}_{ni}^{\frac{\theta-1}{\theta}} + (\Omega_{ni,Z}^{Y})^{\frac{1}{\theta}} Z_{ni}^{\frac{\theta-1}{\theta}} \right]^{\frac{\theta}{\theta-1}} \quad \text{with} \quad \Omega_{ni,\mathsf{VA}}^{Y} + \Omega_{ni,Z}^{Y} = 1$$

- Value-added bundle is composed of Labor and Capital:

$$\mathsf{VA}_{ni} = \left[(\Omega_{ni,L}^{\mathsf{VA}})^{\frac{1}{\gamma}} (L_{ni})^{\frac{\gamma-1}{\gamma}} + (\Omega_{ni,K}^{\mathsf{VA}})^{\frac{1}{\gamma}} (\bar{K}_{ni})^{\frac{\gamma-1}{\gamma}} \right]^{\frac{\gamma}{\gamma-1}} \quad \text{with} \quad \Omega_{ni,L}^{\mathsf{VA}} + \Omega_{ni,K}^{\mathsf{VA}} = 1$$

Intermediate goods' aggregation

- Intermediate bundle consists of country specific sectoral bundles:

$$Z_{ni} = \left[\sum_{j=1}^{\mathcal{J}} (\Omega^{Z}_{ni,j})^{\frac{1}{\varepsilon}} X_{ni,j}^{\frac{\varepsilon-1}{\varepsilon}} \right]^{\frac{\varepsilon}{\varepsilon-1}} \quad \text{with} \quad \sum_{j=1}^{\mathcal{J}} \Omega^{Z}_{ni,j} = 1$$

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Steel (j) comes from country $m = 1 \ldots \mathcal{N}$ into the U.S. $= X_{n,mj}$ as an intermediate input
U.S. (n) creates a steel bundle $= X_{n,j}$ to use in different industries such as U.S. car industry $= Z_{ni}$

Market clearing

- Goods market clearing (as consumption or intermediate goods): for each country n sector i:

$$Y_{ni} = \sum_{m=1}^{\mathcal{N}} (X_{m,ni} + C_{m,ni})$$

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- Segmented labor markets: the labor market in country n, sector i

$$\frac{W_{ni}^{\$}}{E_W^{\$}} \geq \frac{\overline{W}_{ni}}{\mathcal{E}_n E_W^{\$}}, \quad \overline{L}_{ni} \geq L_{ni}, \qquad (\overline{L}_{ni} - L_{ni}) \left(\frac{W_{ni}^{\$}}{E_W^{\$}} - \frac{\overline{W}_{ni}}{\mathcal{E}_n E_W^{\$}} \right) = 0$$

  - Downward wage limit is given in the local currency but the model solves in relative terms (e.g. Schmitt-Grohe-Uribe)
  - Labor cannot go beyond the available labor and one of the constraints should be binding

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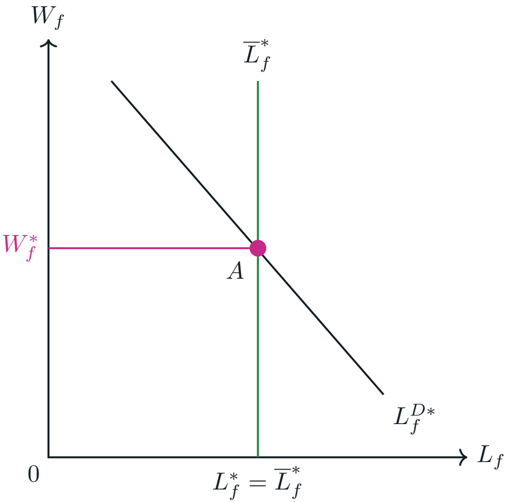
- Asset Markets clear: $\sum_n F_{n,t} = 0$
  - $F_{n,t}$, allows for endogenous current account/trade balance movements

Segmented factor markets during collapse and recovery

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



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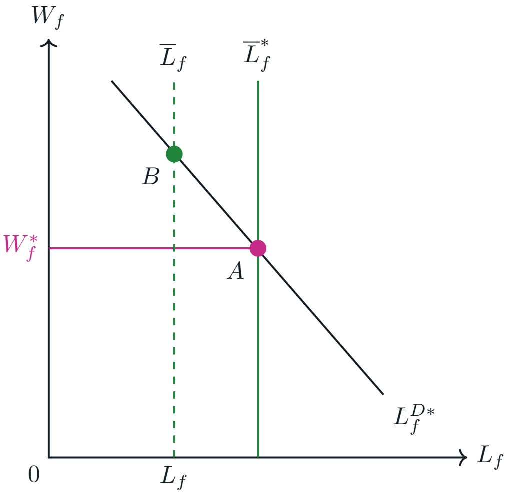

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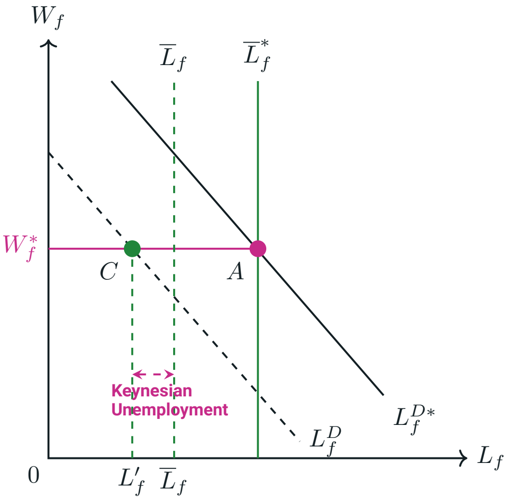

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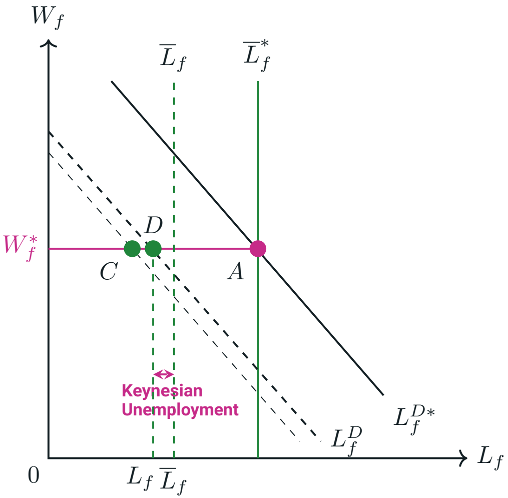

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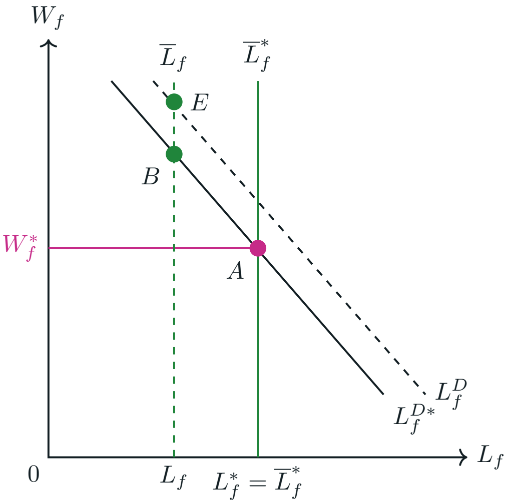
- During recovery: unemployment gaps are closed (heterogeneous across sectors, may not be back to 2019 but still inflationary)



Model solution method

- Calibrate the model with ICIO 2018 Table from OECD
  - Final use shares
  - Input shares
  - Value added shares
  - Expenditures
  - Allow for initial trade imbalances
- Normalize all prices, wages and rents to 1 at steady state
- From this stable equilibrium (2019 pre-pandemic) 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

Calculating Inflation – Auxiliary Matrices

- Industry shares in consumption baskets:

$$\Omega^{CS} \equiv \Omega^{C}\Omega^{CB}.$$

- Industry to industry flows:

$$\Omega^{SS} \equiv \Omega^{Y}\Omega^{Z}\Omega^{X}.$$

- All direct and indirect flows from industry to industry (Leontief Inverse):

$$\Psi = \left[I - \Omega^{SS}\right]^{-1}$$

- Factor shares (for all factors, including labor and capital):

$$\Omega^{F} \equiv \Omega^{Y}\Omega^{\mathsf{VA}}.$$

Domestic CPI inflation in a global economy

1. Prices in dollars ($\mathrm{d}\log P^{\$}$):

$$\mathrm{d}\log P^{\$} = -\Psi \mathrm{d}\log A + \Psi\Omega^{F}\mathrm{d}\log W^{\$}$$

2. Country's n CPI changes

$$\mathrm{d}\log CPI_n = (\Omega_n^{CS})^T \mathrm{d}\log P^{LC,n} = \mathrm{d}\log \mathcal{E}_n + (\Omega_n^{CS})^T \mathrm{d}\log P^{\$}$$

3. Relate factor price f to its factor share at the *world level* $\Lambda_f = W_f^{\$} L_f / E_W^{\$}$

$$\mathrm{d}\log W_f^{\$} = \mathrm{d}\log E_W^{\$} + \mathrm{d}\log \Lambda_f - \mathrm{d}\log L_f$$

Domestic CPI inflation in a global economy

- CPI changes (where $(\lambda^n)^T = (\Omega_n^{CS})^T \Psi$ and $(\Lambda^n)^T = (\lambda^n)^T \Omega^F$)

$$\mathrm{d}\log \text{CPI}_n = \underbrace{\mathrm{d}\log E_W^{\$}}_{\text{World Expenditure}} + \underbrace{\mathrm{d}\log \mathcal{E}_n}_{\text{Exchange Rate}} - \underbrace{(\lambda^n)^T \mathrm{d}\log A}_{\text{Productivity Shocks}} - \underbrace{(\Lambda^n)^T \mathrm{d}\log L}_{\text{Factor Changes}} + \underbrace{(\Lambda^n)^T \mathrm{d}\log \Lambda}_{\substack{\text{Local-Global} \\ \text{D-S Imbalance}}}$$

- *World Expenditure* ($\mathrm{d}\log E_W^{\$}$): US interest rate and countries intertemporal shifters.
- *Exchange Rate Term* ($\mathrm{d}\log \mathcal{E}_n$): country interest rate relative to the US.
- *Productivity shock* ($(\lambda^n)^T \mathrm{d}\log A$): Productivity changes weighted by the importance of sector in consumption basket of country n.
- *Factor Changes* ($(\Lambda^n)^T \mathrm{d}\log L$): Labor changes weighted by the importance of factor in providing for the consumption basket of country n.
  - An endogenous object due to downward-wage rigidity.

Domestic CPI inflation in a global economy

$$\mathrm{d}\log \mathsf{CPI}_n = \underbrace{\mathrm{d}\log E_W^{\$}}_{\text{World Expenditure}} + \underbrace{\mathrm{d}\log \mathcal{E}_n}_{\text{Exchange Rate}} - \underbrace{(\lambda^n)^T \mathrm{d}\log A}_{\text{Productivity Shocks}} - \underbrace{(\Lambda^n)^T \mathrm{d}\log L}_{\text{Factor Changes}} + \underbrace{\color{red}{(\Lambda^n)^T \mathrm{d}\log \Lambda}}_{\substack{\text{Local-Global} \\ \text{D-S Imbalance}}}$$

- *Local-Global Demand-Supply Imbalance Term* ($\color{red}{(\Lambda^n)^T \mathrm{d}\log \Lambda}$): Changes in global factor shares and local factor shares.
  - Global factor shares in terms of local factor shares:

$$\Lambda_f \equiv \frac{W_f^{\$} L_f}{E^W} = \sum_n \frac{E_n/\mathcal{E}_{n,US}}{E^W} \Lambda_f^n.$$

  - If $\mathrm{d}\log \Lambda = \mathrm{d}\log \Lambda^n$:

$$(\Lambda^n)^T d\log \Lambda^n = \sum_f \Lambda_f^n d\log \Lambda_f^n = \sum_f d\Lambda_f^n = d\underbrace{\sum_f \Lambda_f^n}_{=1} = 0.$$

  - Endogenous object: integrates changes in demand and supply factors.
  - If world demand increases in factors that also country n demands a lot, then inflationary.

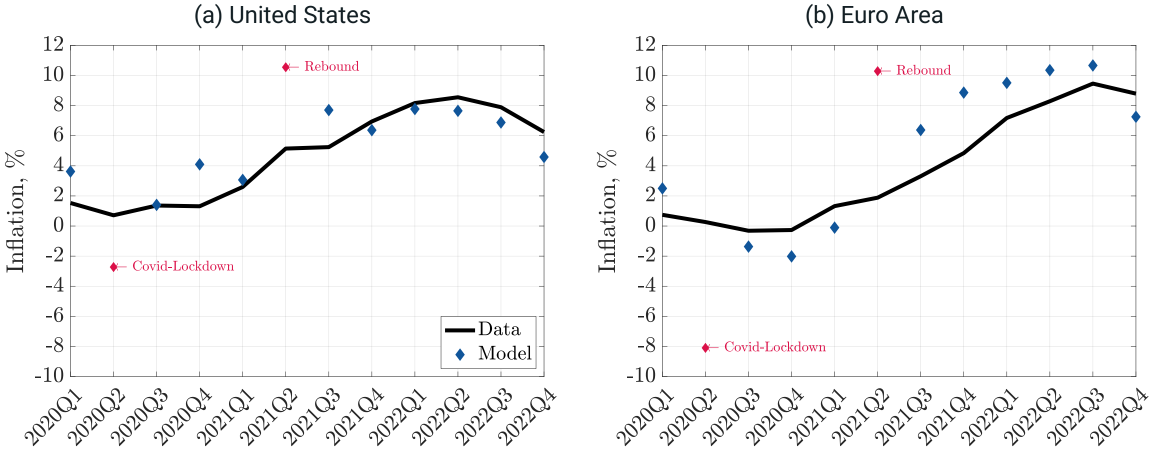
Quantification Exercises

Shocks and Parameters

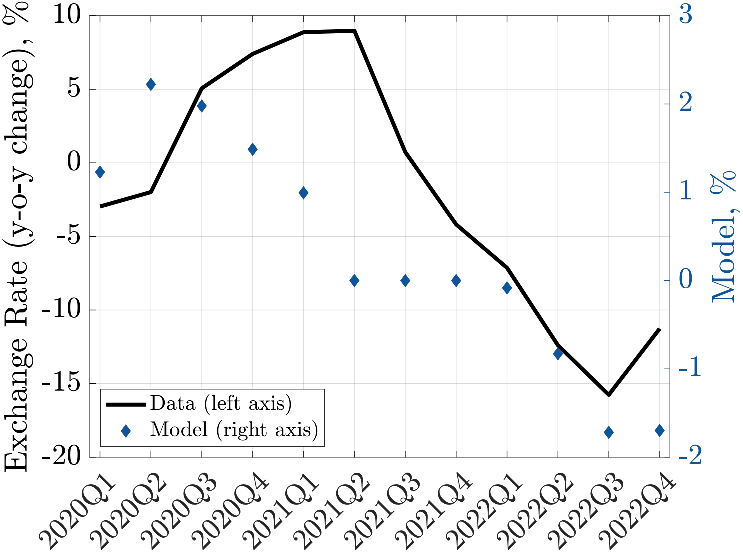
- Shocks
  1. Sectoral demand shocks: Sectoral expenditure shares changes in country n with $\sum_{j \in \mathcal{J}} d\Omega_{nj} = 0$
  2. Country-sectoral potential supply shocks: Observed Δ in total hours worked in country n, sector i
  3. Country-level aggregate demand shocks: discount factor changes using Nominal (l.c.) expenditure changes and interest rates
  4. Energy shocks: IMF commodity price index
- 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: $\xi = 0.6$ (Boehm, Levchenko and Pandalai-Nayar (2023)
- We set country-sector productivity changes to zero throughout
  - Recent evidence: little changes in aggregate/sectoral productivity w/no labor reallocation across sectors in the US (Fernald and Li, 2022)

Results

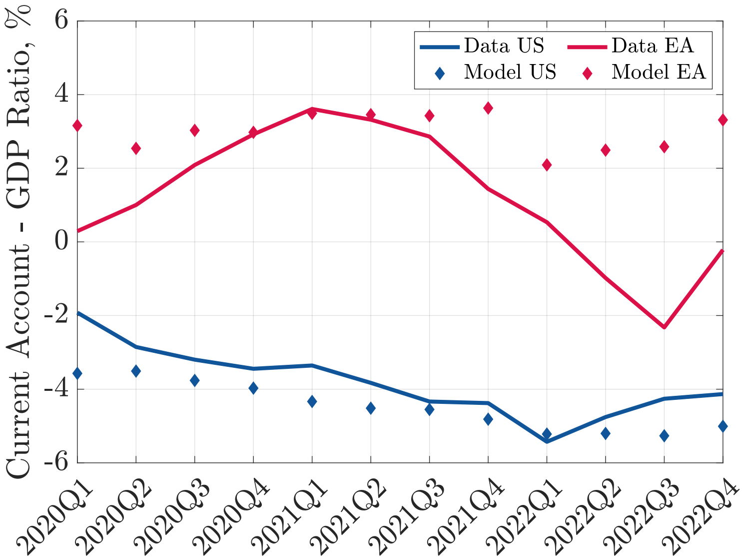
Model with all shocks: Headline Inflation



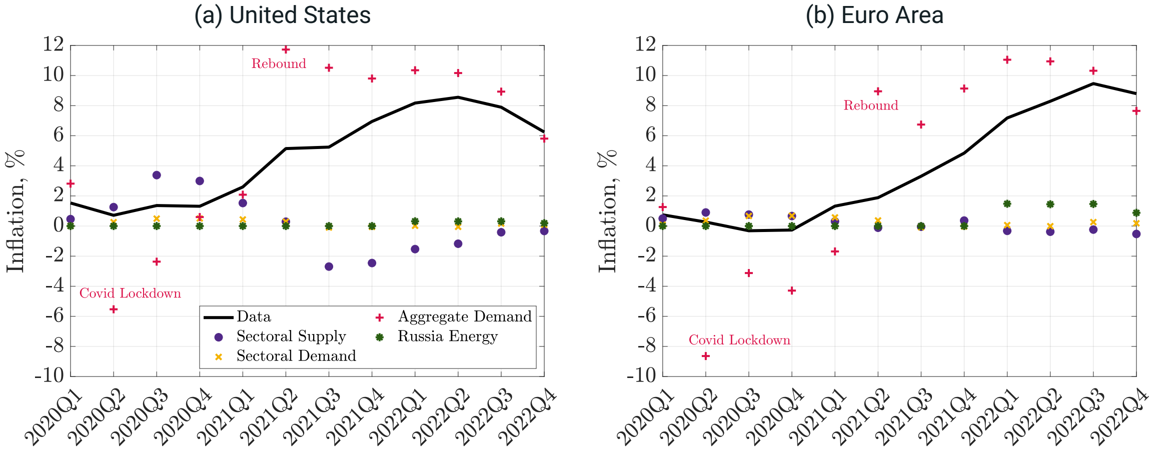
Model implied exchange rate changes and data



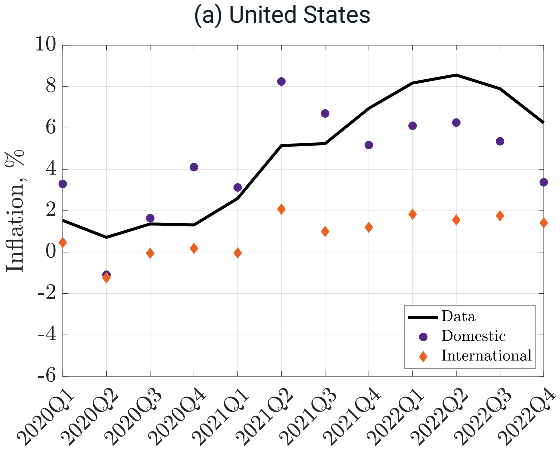
Current Account

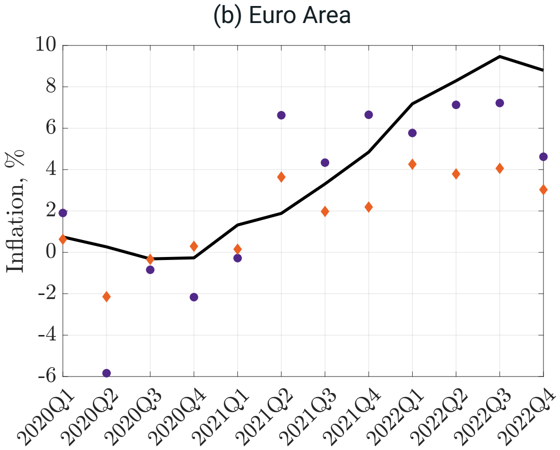


Counterfactuals with single shock

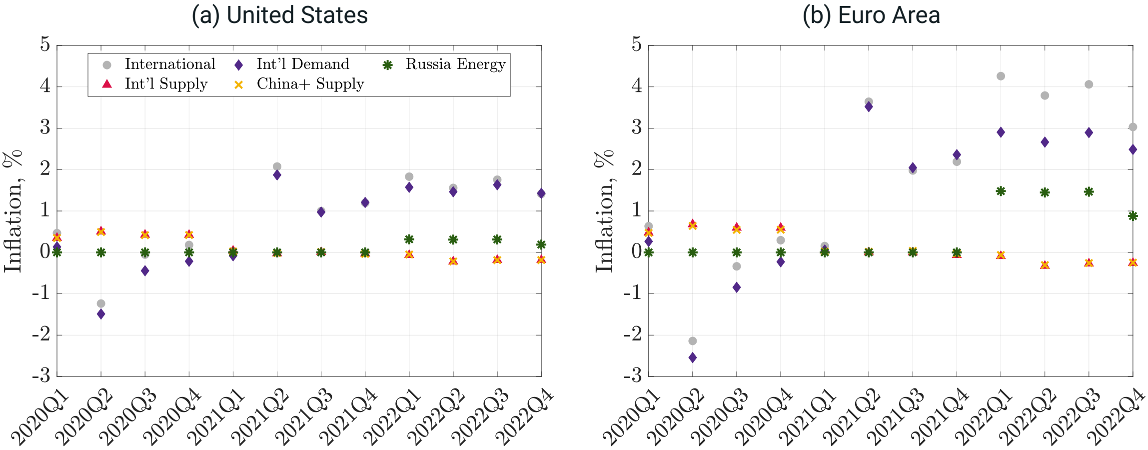


Domestic and International Shocks

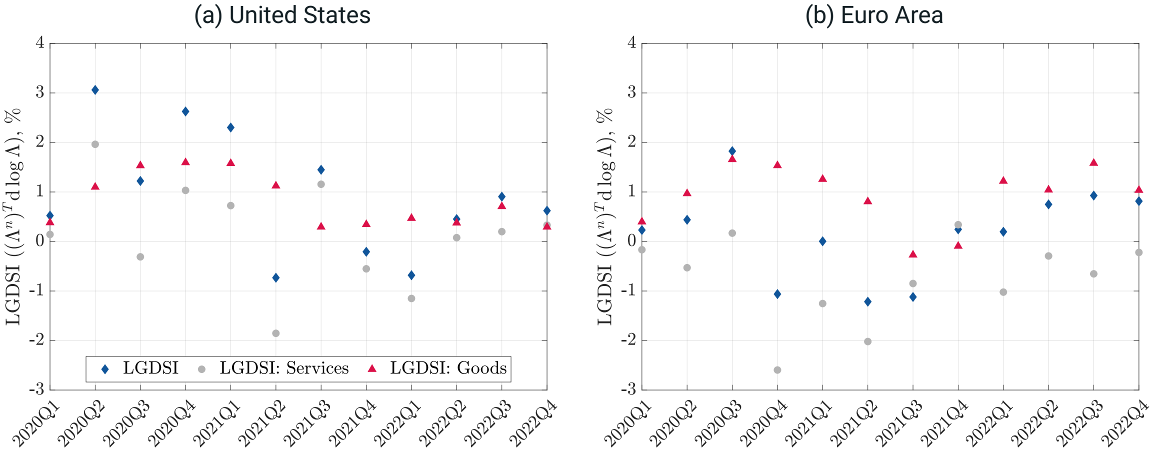




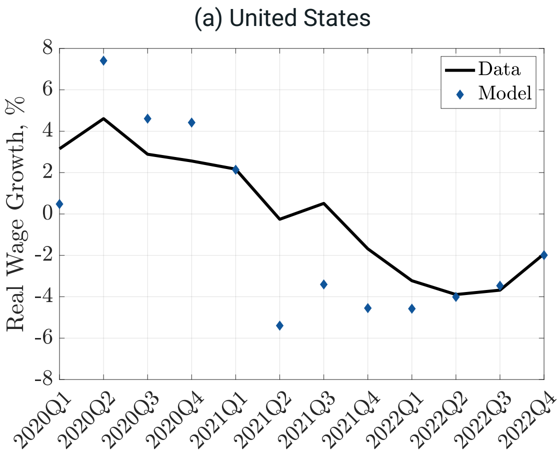
Transmission of International Shocks

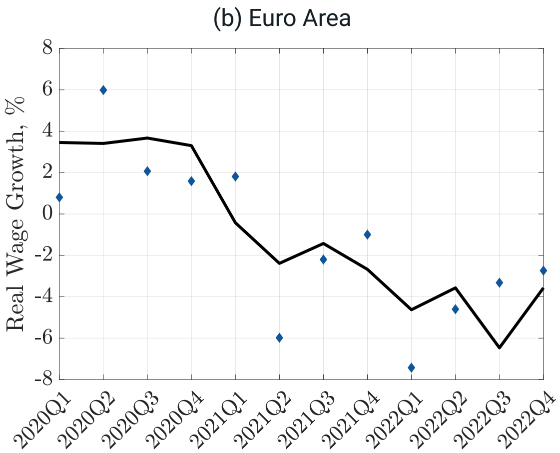


Local-Global Demand-Supply Imbalance

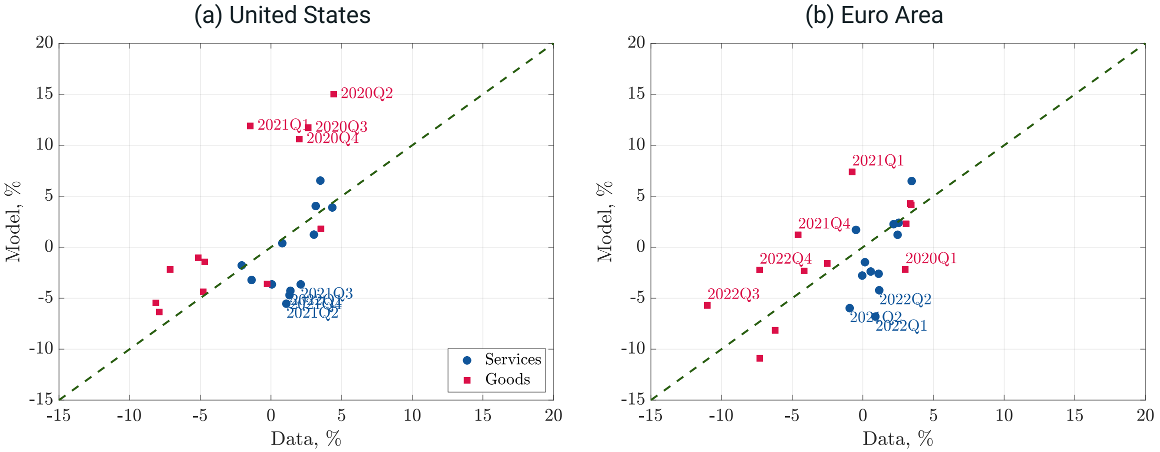


Aggregate Real Wages

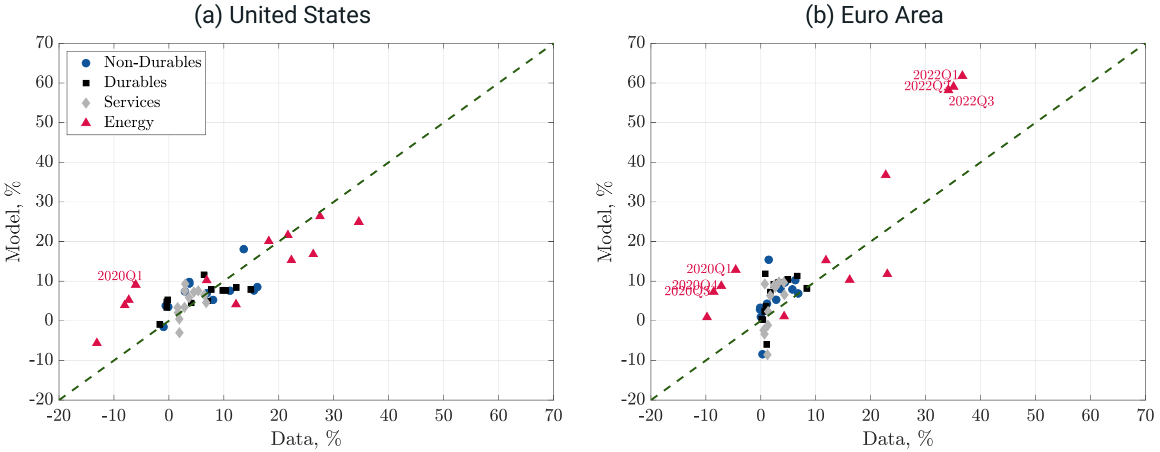




Real Wages: Cross Section



Sectoral Prices: Cross Section



Conclusion

Difficult to Quantify Drivers of Inflation and Disinflation: Real Shocks and Policies

- **The pandemic temporarily disrupted economies:** Lockdowns and general fear of infection kept many people from working, a shift in demand away from in-person services to goods, supply chain bottlenecks.

- **Russia's invasion of Ukraine:** drove up food and energy prices worldwide, made economies temporarily poorer.

- **Fiscal and Monetary Stimulus:** Governments intervened to help the unemployed, subsidies to firms to maintain their payrolls—The purchasing power was sustained even as economies' abilities to supply goods and services temporarily fell.

  $\Rightarrow$ Inflation was the natural consequence

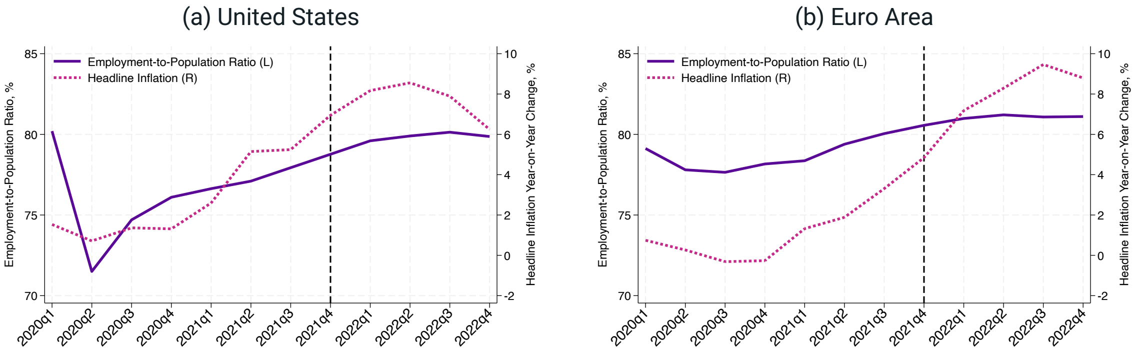
  $\Rightarrow$ Price increases via global factor shortages lead to domestic wage increases.

Need a global macro-network model to understand and quantify the 2020–2023 inflation and disinflation

Appendix

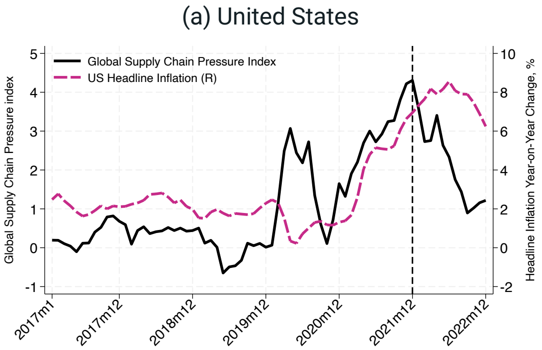
Stylized Facts

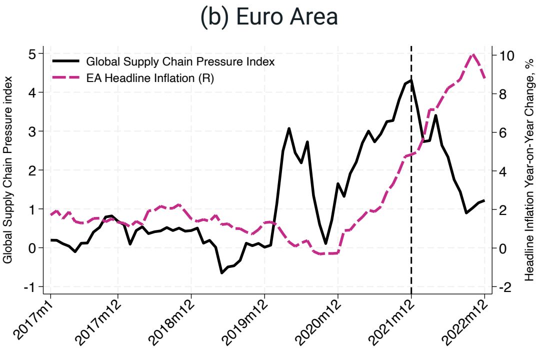
Simultaneous slack and inflation



Source: FRED

Simultaneous increase in inflation and supply chain pressures

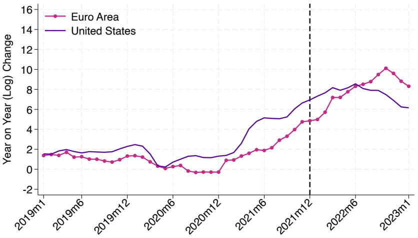




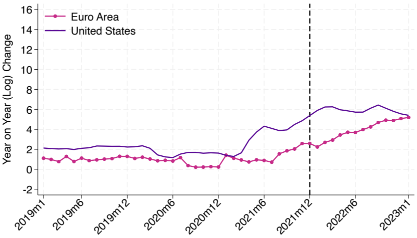
Source: FRBNY, FRED.

Inflation in goods picked up earlier than inflation in services

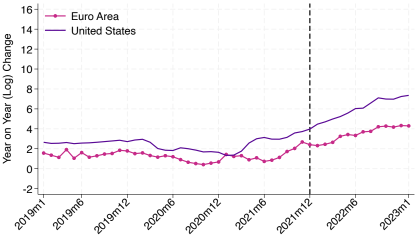
(a) Headline



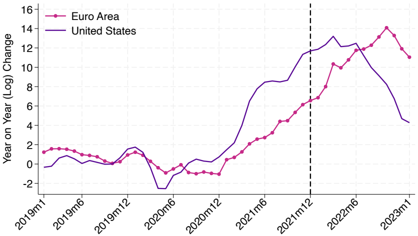
(b) Core



(c) Services



(d) Goods



Source: FRED.