The Transmission of Foreign Shocks in a Networked Economy

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Motivation - I

Recent wave of supply-side **macroeconomic shocks with sectoral and international origins:**

- energy price increases
- supply bottlenecks
- Covid-19
- risks of trade fragmentation, import tariffs ...

Despite their different underlying causes, share key characteristic

- originate in specific sectors
- but quickly spread through complex production networks and international supply chains

Aim: understand how these shocks are transmitted through input-output (IO) linkages and spillover across countries and sectors

This Paper

Investigate the **transmission of supply-side shocks** through production networks

Particular focus on their impact on **inflation dynamics**

- increasing energy prices, key determinant of EA recent headline inflation

Build a **model that accommodates the disaggregated and international nature of shocks**:

- global economy with multiple countries
- **multi-sectoral** productive structure with **national and international production linkages**
- sectors subject to nominal price and wage rigidities

Calibrate the model to the main Euro-Area countries and their trade partners

Findings

- Focus on the **effects and transmission of imported energy prices shocks** in the Euro-Area
  1. **Contribution of input-output (IO) linkages**:
     - no IO: cumulative headline $\approx$ 60% of baseline, shorter lived, smaller pass-through to core
  2. **Cross-country heterogeneity**:
     - DE: more upstream industries and long production chains generate larger transmission to core and more persistent headline inflation
     - ES: higher CPI energy weights increase headline on impact but shorter-lived
  3. **Implications for monetary policy**:
     - weaker response mon. pol. to inflation: IO duplicates increase in inflation volatility
     - IO reduces impact of *mon. pol. shocks* (Nakamura and Steinsson, 2010; Rubbo, 2023)
     - *IO worsens the trade-off* faced by monetary policy: stabilizing inflation costlier in terms of output gap losses

Model

Model

1. **Model Overview**
2. Households
3. Firms
4. Monetary Authority
5. Market Clearing

Model Overview

- Global economy with **K countries**
  - International financial markets incomplete
  - Monetary arrangements:
    - $K^{\text{MU}} \subset K$ countries form part of **monetary union** with a common central bank
    - Remaining countries have monetary autonomy
- Within each country **k ∈ K**
  - **I sectors**: multi-sector productive structure with **national and international networks**
  - **Nominal rigidities** on *prices* (heterogeneous across sectors) and *wages* (homogeneous across sectors)

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Households - Intertemporal Problem

- Representative households' problem in country $k \in K$:

$$\max_{C_{k,t},\{B^l_{k,t}\}^K_{l=1}} \sum_{t=0}^{\infty} \beta^t \left(\frac{C_{k,t}^{1-\sigma} - 1}{1-\sigma} - \int_0^1 \frac{\mathcal{N}_{gk,t}^{1+\varphi}}{1+\varphi} dg \right) Z_{k,t} \quad \text{s.t.}$$

$$P_{kC,t}C_{k,t} + \sum_{l=1}^{K} B^l_{k,t}\left[1 - \Gamma(\mathcal{B}^l_{k,t})\right]^{-1} \mathcal{E}_{kl,t} \leq \sum_{l=1}^{K} B^l_{k,t-1}\mathcal{E}_{kl,t}(1+i_{l,t-1}) + \int_0^1 W_{gk,t}\mathcal{N}_{gk,t}dg + \Pi_{k,t} - T_{k,t} - \Xi_{k,t}$$

- $B^l_{k,t}$: Household holdings in country k of bonds issued by country l
- $\mathcal{E}_{kl,t}$: nominal exchange rate between country k and country l
- $\Gamma(\mathcal{B}^l_{k,t})$: portfolio adjustment costs to stabilize the model (Schmitt-Grohé and Uribe, 2003)

Households – Consumption Baskets

- Consumption C_k: aggregator of energy ($C_{kE,t}$) and non-energy ($C_{kM,t}$) baskets:

$$C_{k,t} = \left[\widetilde{\beta}_k^{\frac{1}{\gamma}} C_{kE,t}^{\frac{\gamma-1}{\gamma}} + (1-\widetilde{\beta}_k)^{\frac{1}{\gamma}} C_{kM,t}^{\frac{\gamma-1}{\gamma}} \right]^{\frac{\gamma}{\gamma-1}}$$

- Energy and non-energy: goods produced by energy and non-energy industries

$$C_{kE,t} = \left[\sum_{i \in I_E} \widetilde{\nu}_{ki}^{\frac{1}{\eta}} C_{ki,t}^{\frac{\eta-1}{\eta}} \right]^{\frac{\eta}{\eta-1}}, \quad C_{kM,t} = \left[\sum_{i \in I_M} \widetilde{\upsilon}_{ki}^{\frac{1}{\iota}} C_{ki,t}^{\frac{\iota-1}{\iota}} \right]^{\frac{\iota}{\iota-1}}$$

- Each energy and non-energy good combines varieties produced by different countries:

$$C_{ki,t} = \left[\sum_{l=1}^{K} \widetilde{\zeta}_{kli}^{\frac{1}{\delta}} C_{kli,t}^{\frac{\delta-1}{\delta}} \right]^{\frac{\delta}{\delta-1}}$$

Wage Setting

- In each country k, nominal wages are infrequently reset by a union (Erceg *et al.*, 2000)
  - Wages are different across countries
  - But common across sectors within a country
- **Wage NKPC** for country k (log-linearized):

$$\pi_{wk,t} = \kappa_{wk}\left(\sigma\widehat{c}_{k,t} + \varphi\widehat{n}_{k,t} - \widehat{w}_{k,t}\right) + \beta\mathbb{E}_t\pi_{wk,t+1} + u^w_{k,t}$$

- Where $u^w_{k,t}$ is a wage cost-push shock that follows an AR(1) process

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Firms - Production I

- Firm f (sector i, country k) combines labor and intermediates:

$$Y_{fki,t} = A_{ki,t}\left[\widetilde{\alpha}_{ki}^{\frac{1}{\psi}} N_{fki,t}^{\frac{\psi-1}{\psi}} + \widetilde{\vartheta}_{ki}^{\frac{1}{\psi}} X_{fki,t}^{\frac{\psi-1}{\psi}}\right]^{\frac{\psi}{\psi-1}}$$

- Intermediates X_{fki} combines energy $X_{fkiE,t}$ and non-energy baskets $X_{fkiM,t}$:

$$X_{fki,t} = \left[\widetilde{\beta}_{ki}^{\frac{1}{\phi}} X_{fkiE,t}^{\frac{\phi-1}{\phi}} + (1-\widetilde{\beta}_{ki})^{\frac{1}{\phi}} X_{fkiM,t}^{\frac{\phi-1}{\phi}}\right]^{\frac{\phi}{\phi-1}}$$

- Energy and non-energy baskets: goods produced by energy and non-energy industries

$$X_{fkiE,t} = \left[\sum_{j\in I_E} \widetilde{\nu}_{kij}^{\frac{1}{\chi}} X_{fkij,t}^{\frac{\chi-1}{\chi}}\right]^{\frac{\chi}{\chi-1}}, \quad X_{fkiM,t} = \left[\sum_{j\in I_M} \widetilde{\upsilon}_{kij}^{\frac{1}{\xi}} X_{fkij,t}^{\frac{\xi-1}{\xi}}\right]^{\frac{\xi}{\xi-1}}$$

- Energy and non-energy goods combines varieties produced by different countries:

$$X_{kij,t} = \left[\sum_{j=1}^{I} \widetilde{\zeta}_{klij}^{\frac{1}{\mu}} X_{klij,t}^{\frac{\mu-1}{\mu}}\right]^{\frac{\mu}{\mu-1}}$$

Firms – Price Setting I

- Firms set prices à la Calvo in the **currency of destination** (LCP, Devereux and Engel 2003)
- **Price NKPC** of sector i in country k **selling to foreign country** l (log-linearized):

$$\pi_{lki,t} = \kappa_{ki}(\widehat{\mathrm{mc}}_{ki,t} - \widehat{p}_{lki,t} - \widehat{q}_{kl,t}) + \beta \mathbb{E}_t \pi_{lki,t+1} + u^p_{ki,t}$$

  - $\widehat{q}_{kl,t}$ is the real exchange rate between country k and country l, equal to 1 if sold at home; $u^p_{ki,t}$ is a sectoral cost-push shock that follows AR(1) process
  - mc_{ki}: **marginal cost** of sector i that will depend on: domestic wages w_k; prices charged by domestic (p_{kj}) and international suppliers (p_{klj}) on intermediate goodsM costs of suppliers (wages, intermediate goods' prices...) through input-output linkages
- We assume there is an exogenous **price wedge** $\tau_{klj,t}$ between the *price set by the exporting firm* $P_{klj,t}$ and the *actual price paid by the importing firm*: $(1 + \tau_{klj,t})P_{klj,t}$

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Monetary Authority

- **Countries not members of a currency union**: Taylor rule that targets *domestic* headline inflation and domestic GDP:

$$i_{k,t} = \rho_{kr} i_{k,t-1} + \left(1 - \rho_{kr}\right) \phi_{k\pi} \pi_{k,t} + \left(1 - \rho_{kr}\right) \phi_{ky} \widehat{y}_{k,t} + \varepsilon^{r}_{k,t} \tag{1}$$

- **Member countries of a currency union** (K^{MU}):
  - Country $k^{MU} \in K^{MU}$ sets interest rates responding *union-wide* headline inflation and GDP:

$$i_{k^{MU},t} = \rho_{\mathrm{MU}r} i_{k^{MU},t-1} + \left(1 - \rho_{\mathrm{MU}r}\right) \phi_{\mathrm{MU}\pi} \pi^{\mathrm{MU}}_{t} + \left(1 - \rho_{\mathrm{MU}r}\right) \phi_{\mathrm{MU}y} \widehat{y}^{\mathrm{MU}}_{t} + \varepsilon^{r}_{\mathrm{MU},t}$$

  - Remaining countries in K^{MU} *peg* their nominal exchange rate to k^{MU}:

$$\mathcal{E}_{k,k^{MU},t} = \mathcal{E}_{k,k^{MU}} \quad \forall k \in K^{MU}$$

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Market Clearing & GDP

- Labor market clears:

$$N_{k,t} = \sum_{i=1}^{I} N_{ki,t}$$

- Goods' market clears:

$$Y_{ki,t} = \sum_{l=1}^{K} \left(C_{lki,t} + \sum_{j=1}^{I} X_{lkji,t} \right) \quad \forall i \in I$$

- Bonds' market clears:

$$\sum_{l} B_{l,t}^{k} = 0, \quad \forall k \in K$$

- Nominal GDP $\mathscr{Y}_{k,t}$:

$$\mathscr{Y}_{k,t} = P_{kC,t} C_{k,t} + P_{k\text{EXP},t} \text{EXP}_{k,t} - P_{k\text{IMP},t} \text{IMP}_{k,t}$$

- Real GDP:

$$Y_{k,t} = \frac{\mathscr{Y}_{k,t}}{P_{kY,t}}$$

Calibration

Calibration – I

- Calibrate the model to **6 countries** ($K = 6$) and **44 sectors** within each country ($I = 44$):
  - Euro-Area: Spain (ES), Germany (DE), Italy (IT), France (FR), Rest of the Euro Area (REA)
  - Rest of the World
- Calibrate heterogeneous **price frequency adjustments** for each sector and country using data from Gautier *et al.* (2024)
- We linearize the model *by hand* so we can **read input-output matrix, labor shares, and consumption shares directly from the data** (ICIO Input-Output Tables, OECD; and Figaro, Eurostat)

Calibration – II

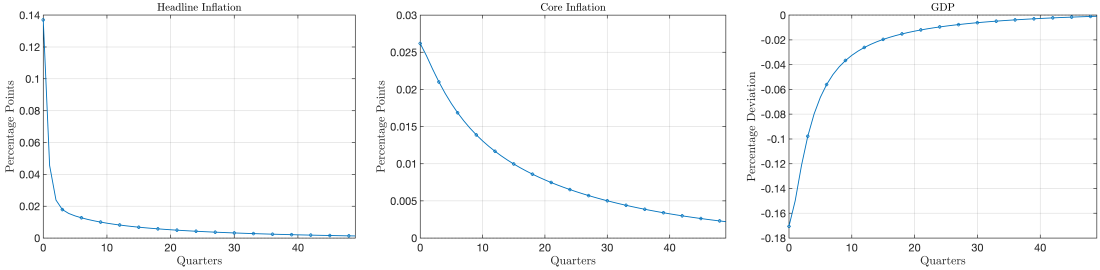
Parameter	Description	Value	Target / Source
Households			
β	Discount factor	0.99	$R = 4.5\%$ p.a.
σ	Inv. Intertemp. Elast. Subs.	1	Standard Value
φ	Inv. Frisch Elasticity	1	Chetty *et al.* (2011)
γ	Elast. Subst. E and M	0.4	Böhringer and Rivers (2021)
η	Elast. Subst. E	0.9	Atalay (2017)
ι	Elast. Subst. M	0.9	Atalay (2017)
δ	Trade Elasticity	1	Standard value
$\{\widetilde{\beta}_k, \widetilde{\nu}_{ki}, \widetilde{\upsilon}_{ki}, \widetilde{\zeta}_{kli}\}$	Quasi-shares consumption		ICIO tables (OECD)
θ_k^w	Calvo wage prob.	0.75	Christoffel *et al.* (2008)
Monetary Policy			
$\rho_{k,r}$	Interest Rate Smoothing	0.7	Standard Value
$\phi_{k,\pi}$	Reaction to Inflation	1.5	Galí (2015)
$\phi_{k,y}$	Reaction to real GDP	0.125	Galí (2015)

Calibration – III

Parameter	Description	Value	Target / Source
Firms			
ψ_{ki}	Returns to scale	1	Constant returns to scale
ψ	Elast. Subst. N and X	0.5	Atalay (2017)
ϕ	Elast. Subst. E and M	0.4	Böhringer and Rivers (2021)
χ	Elast. Subst. M	0.2	Atalay (2017)
ξ	Elast. Subst. E	0.2	Atalay (2017)
μ	Trade Elasticity	1	Standard value
$\{\widetilde{\alpha}_{ki}, \widetilde{\vartheta}_{ki}, \widetilde{\beta}_{ki}, \widetilde{\nu}_{kij}, \widetilde{\upsilon}_{kij}, \widetilde{\zeta}_{kij}\}$	Quasi-shares production		ICIO tables (OECD)
$\mathscr{M}_{ki}$	Markups		Labor shares (Eurostat)
θ^p_{ki}	Calvo price prob.		Gautier *et al.* (2024)
Exogenous Shock Processes			
$\rho^\tau_{1,kli}$	Persistence price wedge shock	1.17	Brent crude oil
$\rho^\tau_{2,kli}$	Persistence price wedge shock	-0.2	Brent crude oil
σ^τ_{kli}	Std. Dev. price wedge shock	1	Standard Value

Results

The Transmission of an Increase of Energy Prices

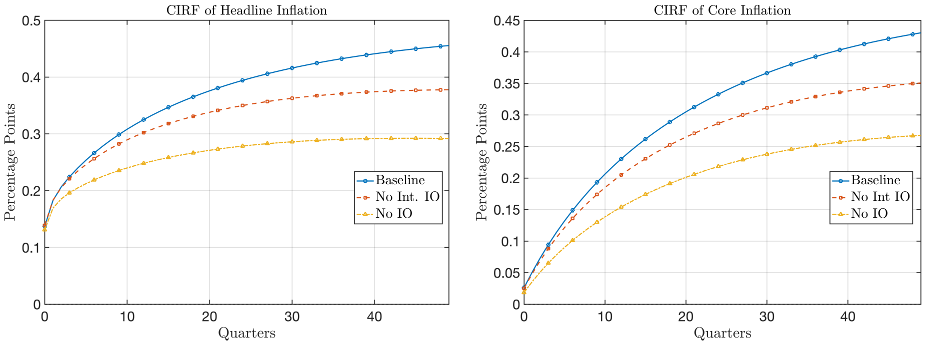


Notes: IRFs to a 10% increase in import energy prices for Euro-Area wide variables.

- Energy shock: large spike of headline inflation on impact which *dies out slowly*
- Significant **pass-through to core inflation** ($\approx$ 20% of headline) responsible for inflation persistence (Adolfsen *et al.*, 2024)

The Role of Production Networks

The Role of Production Networks - I



Notes: Cumulative IRF of headline (left panel) and core (right panel) inflation for the baseline and turning off the full, international, or national input-output structure. When turning off the IO structure, we always keep the use of energy as an intermediate input.

- **Without IO**: inflation dies much faster, responding $\approx 60\%$ (cumulative) of baseline with full IO
- Both *national* and *international* production networks important in driving the effects

The Role of Production Networks - II

- For intuition: domestic currency pricing, fixed nominal exchange rates, and $\tau_{klijt} = \tau_{ljt}$.
- With sticky prices, intermediate goods' prices inherit persistence from past inflations and shocks, amplified through IO linkages:

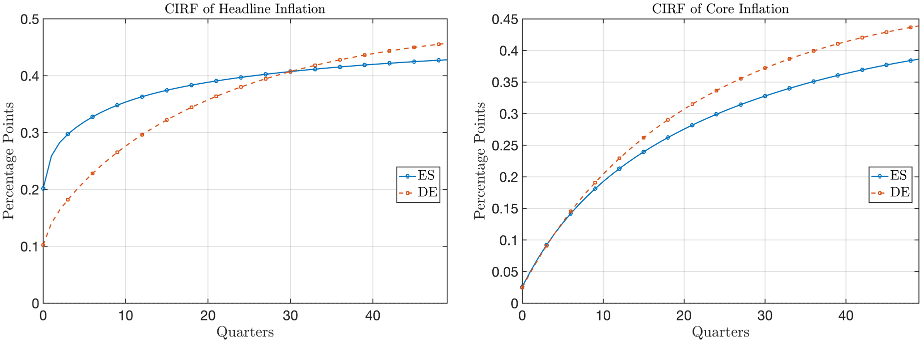
$$\boldsymbol{p}_{t+h} = (\boldsymbol{I} - \boldsymbol{\Delta\Omega})^{-1} \left[\boldsymbol{\Delta\Omega R}^{h} \boldsymbol{\tau}_t + (\boldsymbol{I} - \boldsymbol{\Delta}) \sum_{s=1}^{h} \boldsymbol{\pi}_{t+h-s} + \boldsymbol{\Delta\alpha} \sum_{s=0}^{h} \boldsymbol{\pi}^{w}_{t+h-s} + \boldsymbol{\Delta K}^{-1} \beta \mathbb{E}_t \boldsymbol{\pi}_{t+h+1} \right]$$

$\boldsymbol{\Omega} \equiv$ input-output, $\boldsymbol{K} \equiv$ Slope PC, $\boldsymbol{\Delta} = (\boldsymbol{I} - \boldsymbol{K})^{-1}\boldsymbol{K}$, $\boldsymbol{\alpha} \equiv$ labor share, $\boldsymbol{R} \equiv$ Shock persistence,

- Rigidity-adjusted Leontief inverse $(\boldsymbol{I} - \boldsymbol{\Delta\Omega})^{-1}$ **amplifies**
  - The impact and **exogenous persistence** of shock $\boldsymbol{\Delta\Omega R}^{h} \boldsymbol{\tau}_t$
  - ...and the **intrinsic persistence** induced by staggered price– and wage–setting
- More persistent dynamics of prices feed into firms' marginal costs and hence inflation:

$$\widehat{\mathbf{mc}}^{n}_{t} = \boldsymbol{\alpha w}_t + \boldsymbol{\Omega} \left(\boldsymbol{\tau}_t + \boldsymbol{p}_t \right)$$

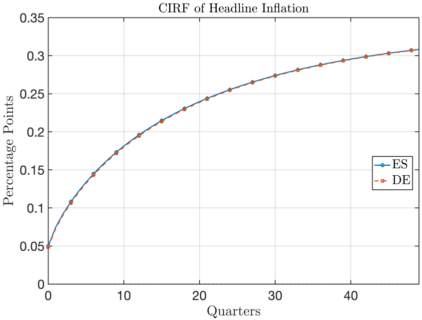
Cross-Country Heterogeneity - I



Notes: Cumulative IRF of headline (left panel) and core (right panel) inflation for Spain (ES) and Germany (DE).

- **ES** strongest headline response on impact but dies out the quickest: *large weight of energy in CPI* but with more *upstream production structure* core inflation raises the least
- **DE** shows the opposite: less weight of energy in CPI but with *downstream and long production chains*

Cross-Country Heterogeneity - II

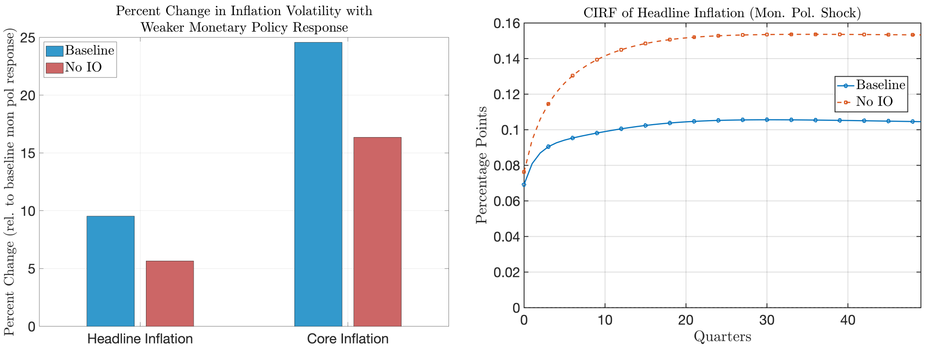


Notes: Cumulative IRF of headline inflation under common IO structure for Spain (ES) and Germany (DE).

- **Homogenizing** the IO structure reduces the gap between headline inflation dynamics in ES vs. DE
- Remaining difference explained through (slightly) **more flexible prices** in DE

Monetary Policy Implications

The Interaction Between Monetary Policy and Production Networks



Notes: Left panel: percent change in inflation volatility (conditional on energy price shocks) with a lower coefficient on inflation in the Taylor rule. Right panel: CIRF of headline inflation to a monetary policy shock (easing) in the baseline and without IO.

- **Production networks amplify the increase of inflation volatility** from a weaker mon. pol. response
- Despite production networks generating *more* monetary non-neutrality (Nakamura and Steinsson, 2010)

Monetary Policy Trade-offs (Simplified framework)

Monetary policy trade-offs between stabilizing inflation and output gap $\widetilde{y}_t$

- One-sector economy (Gali and Monacelli, 2005): "divine coincidence" holds

$$\pi_t^H = \kappa(1+\varphi)(\alpha+\omega_F)\widetilde{y}_t + \beta \mathbb{E}_t \pi_{t+1}^H, \tag{2}$$

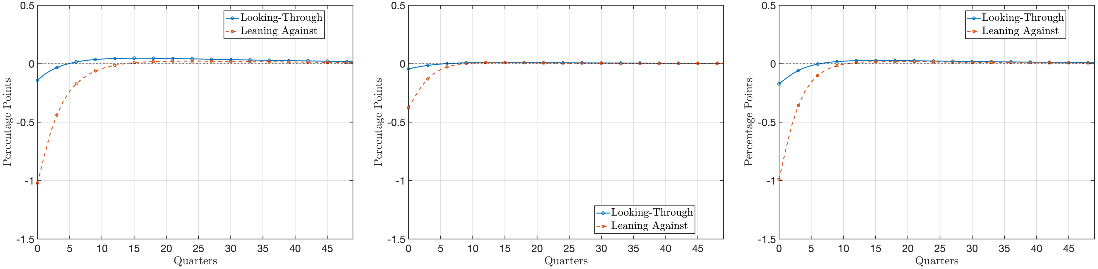
- Baseline with production networks: trade-off between stabilizing inflation and output gap

$$\boldsymbol{\pi}_t^H = \mathscr{B}\left(1+\varphi+\varphi\omega_X\right)\widetilde{y}_t + \mathscr{B}\boldsymbol{\lambda}^\intercal \boldsymbol{\Omega}_F \widetilde{\boldsymbol{n}}_t + \mathscr{V}(\boldsymbol{I}-\boldsymbol{\Omega})^{-1}\boldsymbol{\Omega}_F \widetilde{\boldsymbol{s}}_t - \mathscr{V}\boldsymbol{\chi}_t + \beta(\boldsymbol{I}-\mathscr{V})\mathbb{E}_t \boldsymbol{\pi}_{t+1}^H, \tag{3}$$

$\boldsymbol{\chi}_t \equiv \boldsymbol{p}_{t-1}^H - (\boldsymbol{I}-\boldsymbol{\Omega}_H)^{-1}\boldsymbol{\Omega}_F \boldsymbol{\tau}_t$: open-economy version of Rubbo (2023)

Sectoral terms-of-trade gaps ($\widetilde{\boldsymbol{s}}_t$) and **sectoral employment gaps** ($\widetilde{\boldsymbol{n}}_t$): specific to open economies

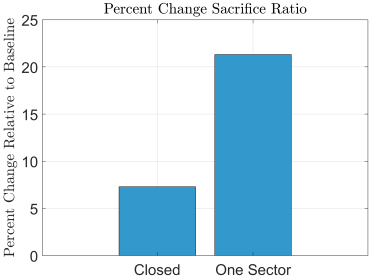
Monetary Policy Trade-offs - Output Gap Responses



Output Gap in Baseline Economy, One-Sector Economy, Closed Economy

- Tighter monetary policy induces larger output gap losses relative to a one-sector economy or a “closed-economy” with IO and only imported energy

Monetary Policy Trade-offs - Sacrifice Ratio



Notes: Change in the sacrifice ratio in the one-sector and closed-economy frameworks relative to the baseline.

- *Differential* Sacrifice Ratio: units of excess fall in the output gap (after implementing a more restrictive monetary stance) for each unit reduction in inflation
- Input-ouput linkages translate into larger sacrifice ratios: each percentage point reduction in inflation requires larger output gap losses

Conclusions

Conclusions

- We provide an international multi-sector macroeconomic model with input-output linkages that can accommodate the disaggregated and international nature of macroeconomic shocks
- We analyze the impact and transmission of rising imported energy prices:
  - Production networks important transmission channel to core inflation, increasing persistence of inflation dynamics
  - Heterogeneity in production structures gives rise to cross-country heterogeneity in inflation developments
  - Production networks amplify the increase in inflation volatility resulting from a weaker systematic response of monetary policy to inflation and worsen the trade-off faced by monetary policy

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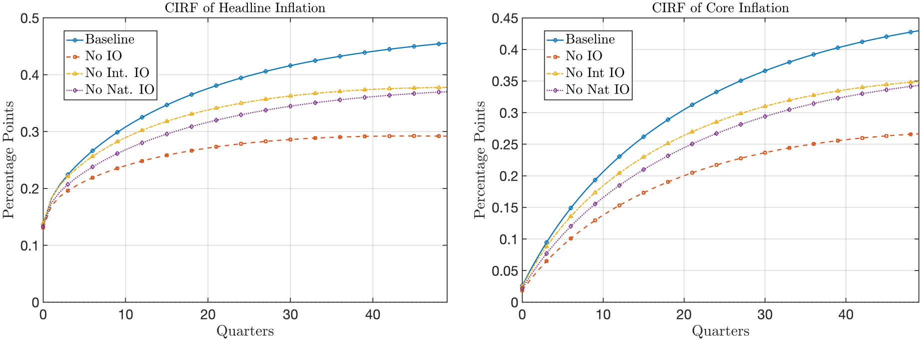
The Role of Production Networks - AI



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