Inflation in Disaggregated Small Open Economies

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Motivation

1 2 3

1. Inflation rose everywhere in recent years
2. Most Central banks increased policy rates in response
3. Production networks relevance for macro outcomes and measurement

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3. Production networks relevance for macro outcomes and measurement

- Current debate
  - Closed economy with sectoral view

    Krugman vs. Summers, Bernanke and Blanchard (2023), Shapiro (2022), Ferrante et al. (2023), di Giovanni et al. (2022, 2023a), Rubbo (2023), Luo and Villar (2023)...
  - Open economy with sectoral view: focus on Euro Area and US

    di Giovanni et al. (2023b), Fornaro and Romei (2022), Comin and Johnson (2022)

This paper

- What? $\longrightarrow$ Inflation in disaggregated small open economies (SOEs)

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- Why? $\longrightarrow$ Covid19 scenario + most countries fall in this category
  - Small: do not affect world prices and quantities
  - Open: international trade of goods/services and financial markets

This paper

- What? $\longrightarrow$ Inflation in disaggregated small open economies (SOEs)
- Why? $\longrightarrow$ Covid19 scenario + most countries fall in this category
  - Small: do not affect world prices and quantities
  - Open: international trade of goods/services and financial markets
- How? $\longrightarrow$ Theory and Empirics
  1. Bring production network to a SOE model: change CPI elasticities
  2. Distinction matters quantitatively
  3. Application: United Kingdom and Chile's inflation during Covid-19

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    - Closed economy CPI elasticities with respect to:
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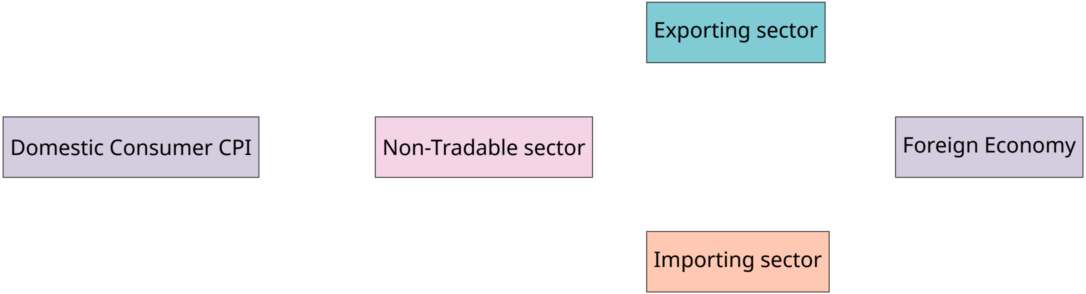
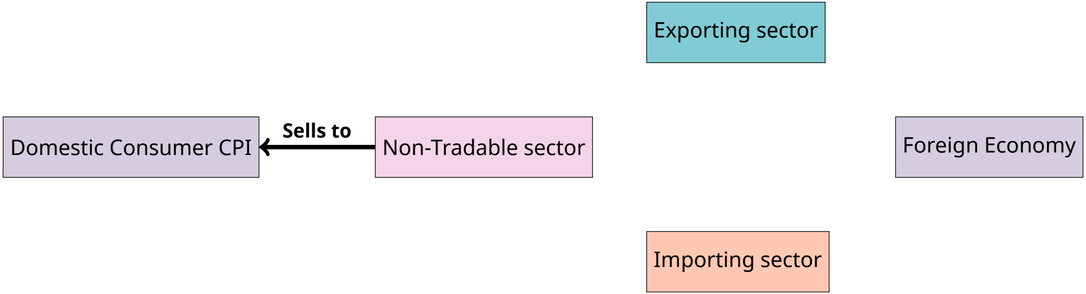
   - Small open economy CPI elasticities: sales and factor shares **adjusted**

   $\longrightarrow$ adjustment **requires** knowledge of the production network structure

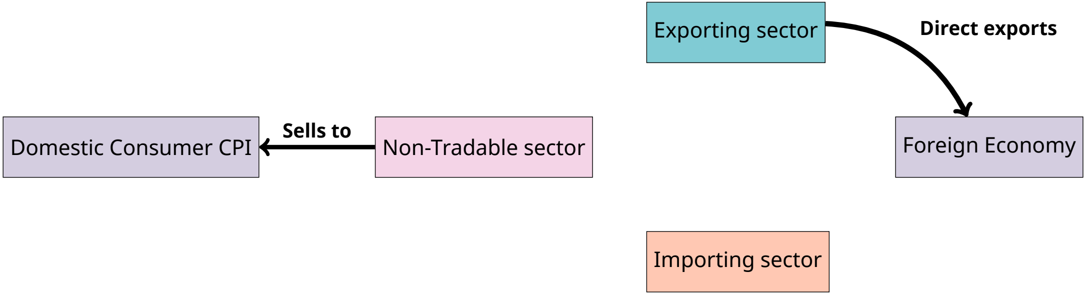
Overall idea of the paper in one diagram



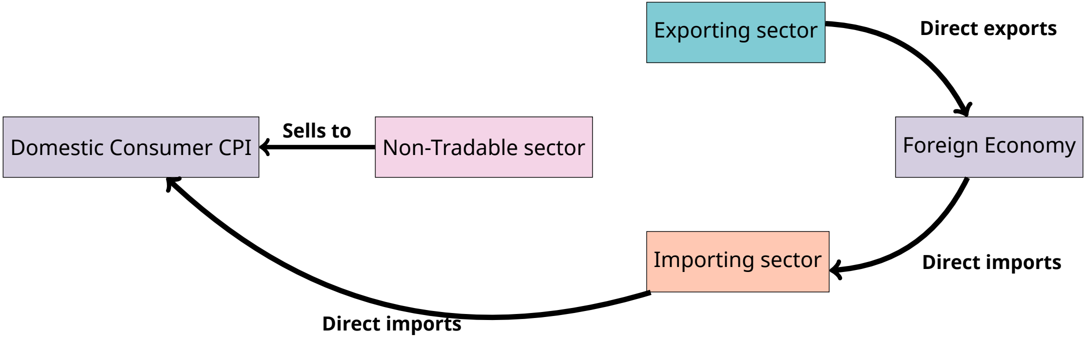
Non-tradable sells to domestic consumers only



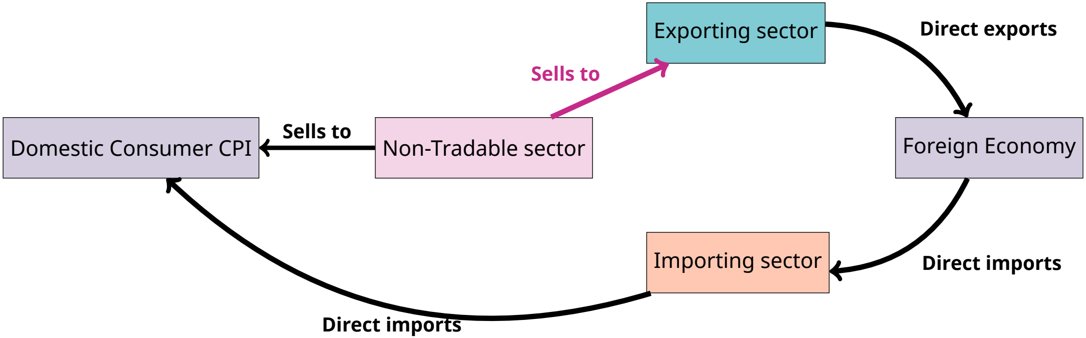
Exporters sells abroad



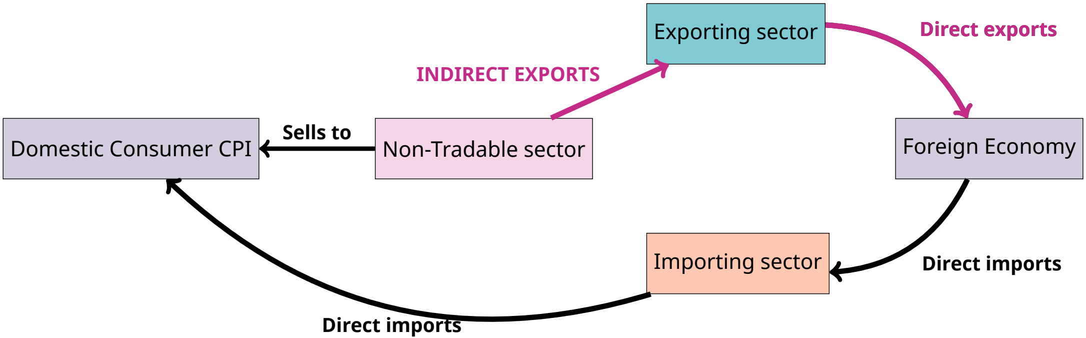
Imports from abroad to consume



By selling to exporting sector...

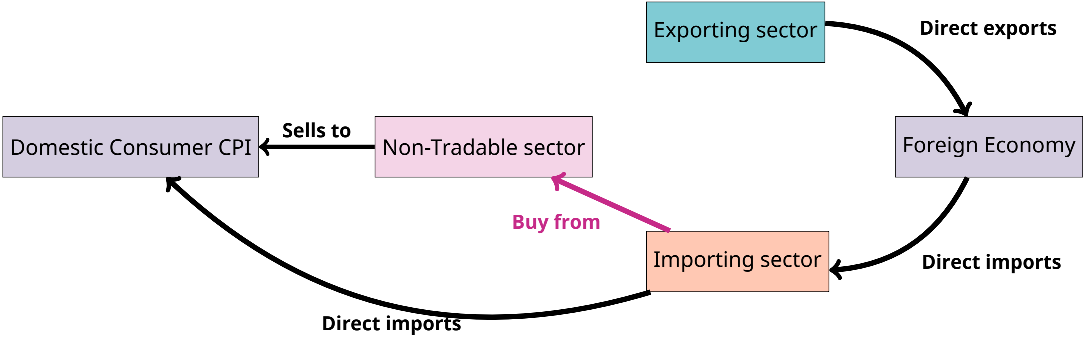


Non-tradable becomes an indirect exporter!

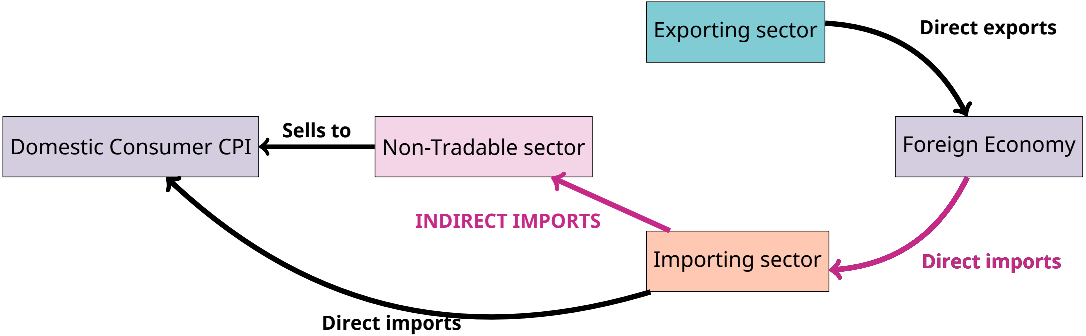


- Less exposed to changes affecting non-tradable sector price

By buying from importing sector...

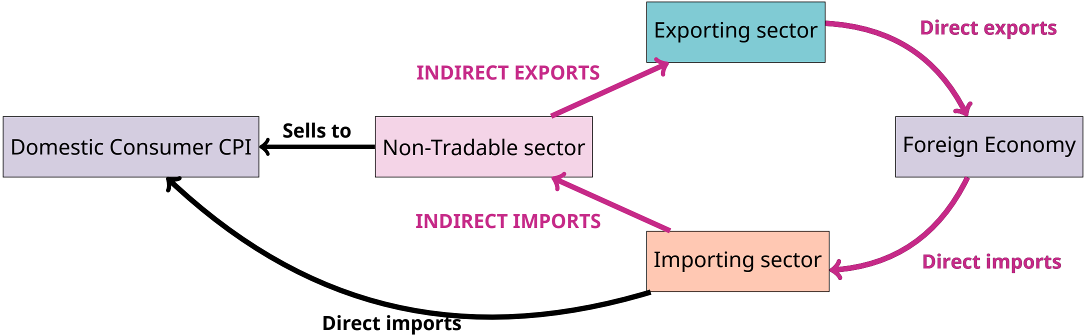


Non-tradable becomes an indirect importer!



- More exposed to import price changes

Production network amplifies trade



- Reducing CPI exposure to changes affecting non-tradable sector price
- Increasing CPI exposure to import price changes

This paper

2. Elasticity adjustment matters quantitatively
    - 10 % $\Downarrow$ productivity in UK electricity sector $\longrightarrow$ $\Uparrow$ CPI by

      0.59 % in a closed economy with production networks
      0.44 % in SOE with production network $\longrightarrow$ 25 % lower!

3. Application: UK and Chile inflation during COVID-19
    - Helps to quantitatively match inflation behavior

Related Literature

1. **Inflation in closed economy multi-sector models**

   Pasten et. al (2020), Guerrieri et. al (2021, 2022), Baqaee and Farhi (2022, 2023), La'O and Tahbaz-Salehi (2022), Rubbo (2023), Afrouzi and Bhattarai (2023), di Giovanni et al. (2022, 2023a), Ferrante et. al (2023), Luo and Villar (2023),...

   Contribution: Domestic production network relevant beyond shares + quantification

2. **Inflation in open economies**

   Gali and Monacelli (2005), Corsetti and Pesenti (2005), Comin and Johnson (2022), Fornaro and Romei (2022), Ho et. al (2022), di Giovanni et. al (2023b), Comin et. al (2023), Baqaee and Farhi (2023), Cardani et. al (2023) ...

   Contribution: Introduce production network and show how it alters CPI elasticities

3. **Supply-chain and indirect trade via production networks**

   Huneeus (2018), Dhyne et. al (2021), Adao et. al (2022), Antras and Chor (2022)

   Contribution: Why, and how much indirect trade matters for inflation

Outline

1. Model
2. Empirics
3. Application
4. Conclusion

Model

Small Open Economy with Production Networks

- Static setup
- Domestically produced goods: $i \in N \longrightarrow$ prices P_i^D
- Multiple (non-produced) factors: $f \in F \longrightarrow$ factor prices: W_f
- Imported goods: $m \in M \longrightarrow$ import prices: P_m^M
- Perfectly competitive goods and factor markets

Household

- Representative household with homothetic preferences

$$U(\{C_i^D\}_{i\in N}, \{C_m^M\}_{m\in M})$$

- Budget constraint

$$\underbrace{\sum_{i\in N} P_i^D C_i^D + \sum_{m\in M} P_m^M C_m^M}_{\equiv E} + T \leq \underbrace{\sum_{f\in F} W_f L_f + \sum_{i\in N} \Pi_i}_{\equiv nGDP}$$

T: net transfer to the rest of the world.

- Cash-in-advance constraint

$$\sum_{i\in N} P_i^D C_i^D + \sum_{m\in M} P_m^M C_m^M \leq \mathcal{M}$$

$\mathcal{M}$: money supply.

Firms

- Representative firm in each domestic sector $i \in N$

$$Q_i = Z_i F_i(\{L_{if}\}_{f\in F}, \{M_{ij}^D\}_{j\in N}, \{M_{im}^M\}_{m\in M})$$

- Given $(\boldsymbol{W}, \boldsymbol{P}_M, \boldsymbol{P}_D)$ and production function, firms solve

$$\min_{\{L_{if}\}_{f\in F}, \{M_{ij}^D\}_{j\in N}, \{M_{ij}^M\}_{m\in M}} \sum_{f\in F} W_f L_{if} + \sum_{j\in N} P_j^D M_{ij}^D + \sum_{m\in M} P_m^M M_{im}^M$$

$$\text{subject to} \quad Z_i F_i(\{L_{if}\}_{f\in F}, \{M_{ij}^D\}_{j\in N}, \{M_{im}^M\}_{m\in M}) \geq \bar{Q}_i$$

Market Clearing

- Factor markets clear

$$\bar{L}_f = \sum_{i \in N} L_{if} \quad f \in F$$

- Goods markets clear

$$Q_i = C_i^D + X_i + \sum_{j \in N} M_{ji}^D \quad i \in N$$

- Aggregate resource constraint

$$\sum_{i \in N} P_i^D X_i - \sum_{m \in M} P_m^M (C_m + \sum_{i \in N} M_{im}) = T$$

Equilibrium Detailed

- Households maximize utility s.t. budget and cash-in-advance constraint.
- Firms minimize costs.
- Goods and factor market clears.

Price changes

- Consider log-changes $(\widehat{\boldsymbol{W}},\ \widehat{\boldsymbol{Z}},\ \widehat{\boldsymbol{P}}_M)$ with $\widehat{\boldsymbol{Y}} = \mathrm{d}\log \boldsymbol{Y}$

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- Changes in domestic prices (to a first-order)

$$\widehat{P}_i^D = -\widehat{Z}_i + \sum_{f \in F} \underbrace{\frac{W_f L_{if}}{P_i^D Q_i}}_{\equiv \alpha_{if}} \widehat{W}_f + \sum_{j \in N} \underbrace{\frac{P_j^D M_{ij}}{P_i^D Q_i}}_{\equiv \Omega_{ij}} \widehat{P}_j^D + \sum_{m \in M} \underbrace{\frac{P_m^M M_{im}}{P_i^D Q_i}}_{\equiv \Gamma_{im}} \widehat{P}_m^M \tag{1}$$

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- Domestic price changes

$$\widehat{\boldsymbol{P}}_D = -\Psi \widehat{\boldsymbol{Z}} + \Psi \boldsymbol{A} \widehat{\boldsymbol{W}} + \Psi \Gamma \widehat{\boldsymbol{P}}_M \tag{2}$$

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- Domestic price changes

$$\widehat{\boldsymbol{P}}_D = -\Psi\widehat{\boldsymbol{Z}} + \Psi \boldsymbol{A}\widehat{\boldsymbol{W}} + \Psi\Gamma\widehat{\boldsymbol{P}}_M \tag{2}$$

- $\Psi = (\boldsymbol{I} - \Omega)^{-1} = \sum_{s=0}^{\infty} \Omega^s$: direct and indirect production network linkages across producers intuition det

Consumer Price Index Changes

$$\widehat{CPI} = \sum_{i \in N} \bar{b}_i \, \widehat{P}_i^D + \sum_{m \in M} \bar{b}_m \, \widehat{P}_m^M \tag{3}$$

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- Can show

$$\widehat{CPI} = -\left(\bar{\boldsymbol{\lambda}}^T - \tilde{\boldsymbol{\lambda}}^T\right) \widehat{\boldsymbol{Z}} + \left(\bar{\boldsymbol{\Lambda}}^T - \tilde{\boldsymbol{\Lambda}}^T\right) \widehat{\boldsymbol{W}} + \left((\bar{\boldsymbol{b}}^M)^T + (\tilde{\boldsymbol{b}}^M)^T\right) \widehat{\boldsymbol{P}}_M$$

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$$\longrightarrow \bar{\lambda}_i = \frac{P_i^D Q_i}{E}; \quad \bar{\Lambda}_f = \frac{W_f \bar{L}_f}{E}; \quad \bar{b}_i = \frac{P_i^D C_i}{E}; \quad \bar{b}_m^M = \frac{P_m^M C_m}{E}; \quad \bar{x}_i = \frac{P_i^D X_i}{E}$$

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Baqaee and Farhi, 2022

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- Closed economy: $\widehat{CPI} = -\boldsymbol{\lambda}^T \widehat{\boldsymbol{Z}} + \boldsymbol{\Lambda}^T \widehat{\boldsymbol{W}}$ Baqaee and Farhi, 2022
- **Open economy + production networks changed relevant elasticities!**

$$\widehat{CPI} = -\left(\bar{\boldsymbol{\lambda}}^T - \tilde{\boldsymbol{\lambda}}^T\right)\widehat{\boldsymbol{Z}} + \left(\bar{\Lambda}^T - \tilde{\Lambda}^T\right)\widehat{\boldsymbol{W}} + \left((\bar{\boldsymbol{b}}^M)^T + (\tilde{\boldsymbol{b}}^M)^T\right)\widehat{\boldsymbol{P}}_M$$

Dampening impact of sectoral technology shocks

$$\widehat{CPI} = -\left(\bar{\boldsymbol{\lambda}}^T - \tilde{\boldsymbol{\lambda}}^T\right)\hat{\boldsymbol{Z}}$$

Model	Market Clearing	Vector	Adjustment
Closed Economy			
Small Open Economy			

Dampening impact of sectoral technology shocks

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Closed Economy			
Without prod. networks	$Q_i = C_i$	$\bar{\boldsymbol{\lambda}}^T = \bar{\boldsymbol{b}}^T$	$\tilde{\boldsymbol{\lambda}}^T = \mathbf{0}_N^T$
Small Open Economy			

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With prod. networks	$Q_i = C_i + \sum_{j \in N} M_{ji}$	$\bar{\boldsymbol{\lambda}}^T = \bar{\boldsymbol{b}}^T \boldsymbol{\Psi}$	$\tilde{\boldsymbol{\lambda}}^T = \mathbf{0}_N^T$
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Dampening impact of factor price changes

$$\widehat{CPI} = \left(\bar{\Lambda}^T - \tilde{\Lambda}^T\right)\widehat{\boldsymbol{W}}$$

- Recall $\bar{\Lambda}^T = \bar{\lambda}^T \boldsymbol{A}$

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Small Open Economy		

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Amplifying impact of import prices

$$\widehat{CPI} = \left((\bar{\boldsymbol{b}}^M)^T + (\tilde{\boldsymbol{b}}^M)^T \right) \widehat{\boldsymbol{P}}_M$$

- $\bar{\boldsymbol{b}}^M$: **not** relevant elasticities of CPI to import prices.

Amplifying impact of import prices

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- $\bar{\boldsymbol{b}}^M$: **not** relevant elasticities of CPI to import prices.
- CPI depends on import prices
  - Directly: $(\bar{\boldsymbol{b}}^M)^T$
  - Indirectly : $(\tilde{\boldsymbol{b}}^M)^T = \bar{\boldsymbol{b}}^T \boldsymbol{\Psi} \boldsymbol{\Gamma}$

Networks matter beyond aggregate shares

$$\widehat{CPI} = -\left(\bar{\boldsymbol{\lambda}}^T - \tilde{\boldsymbol{\lambda}}^T\right)\widehat{\boldsymbol{Z}} + \left(\bar{\boldsymbol{\Lambda}}^T - \tilde{\boldsymbol{\Lambda}}^T\right)\widehat{\boldsymbol{W}} + \left((\bar{\boldsymbol{b}}^M)^T + (\tilde{\boldsymbol{b}}^M)^T\right)\widehat{\boldsymbol{P}}_M$$

- $(\bar{\boldsymbol{\lambda}}, \bar{\boldsymbol{\Lambda}}, \bar{\boldsymbol{b}}^M)$ are **not** the relevant elasticities.
- **Need** production network structure to compute $\tilde{\lambda}_i, \tilde{\Lambda}_f, \tilde{b}_m$
- Next step: measure these in the data

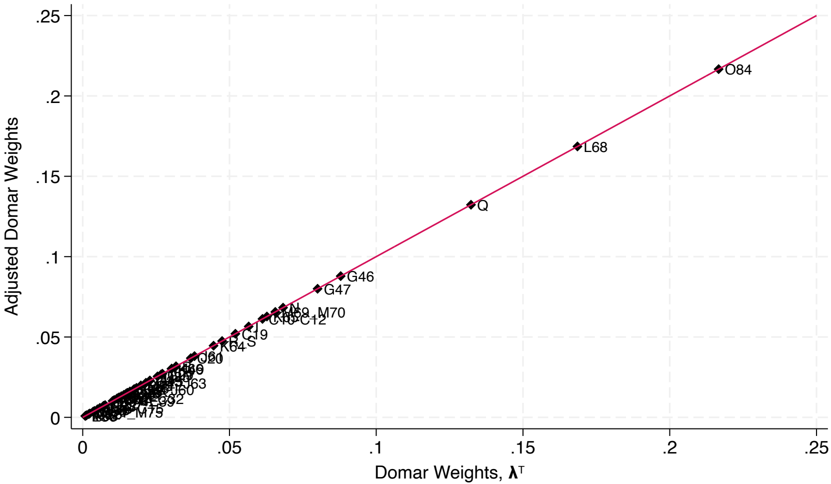
Aggregate demand

Empirics

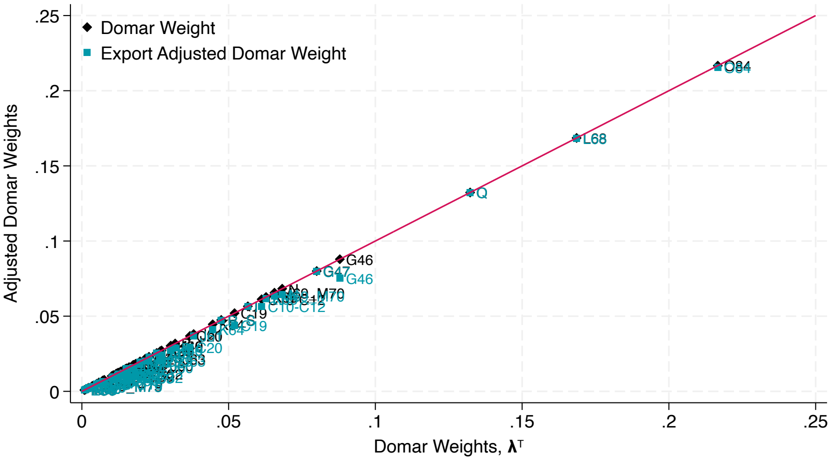
Data

- Data from the World Input-Output Table Release 2016
  - 56 sectors and 43 countries.
  - Detailed information on intermediate input usage, exports, imports, sales.
  - Domestic Input-Output Tables.
- Penn-World Table 9.0. Small Open Economies (1990 – 2019)
  - Share of World GDP $\leq 5\%$
  - Openness ((Exports + Imports)/nGDP) $\geq 30\%$
- All cross-sectional plots based on the year 2014 (last year available).

Domar weights in the United States

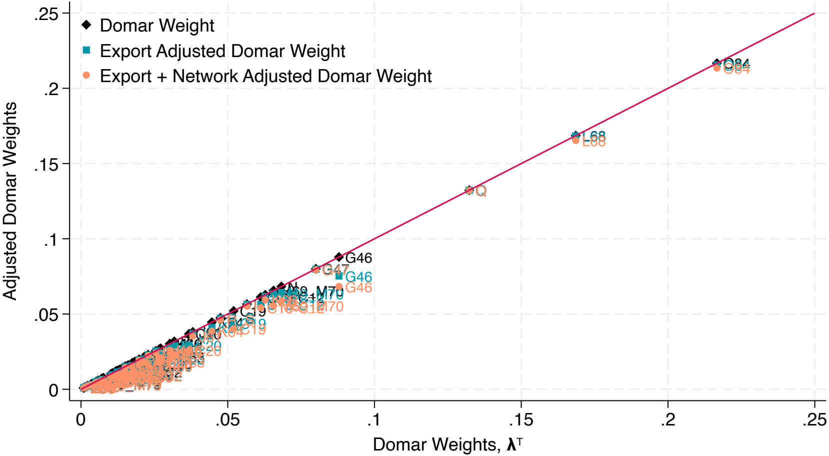


Export adjustment? Not much



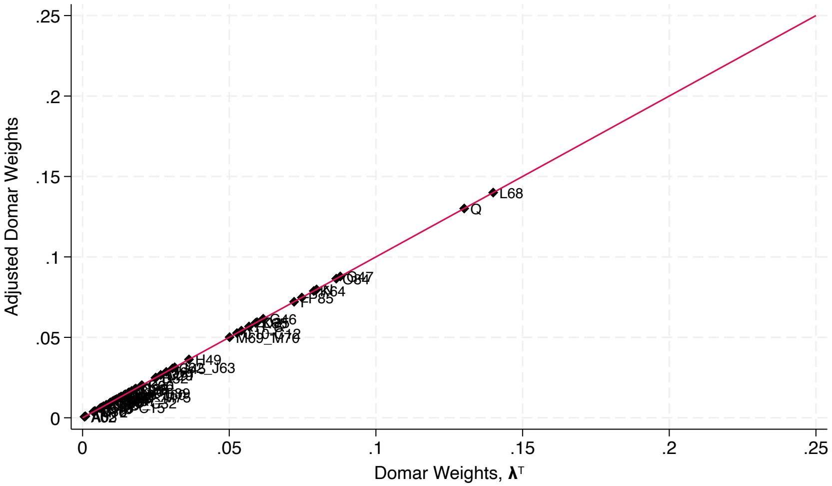
R-squared=0.996

Production network? Not much either

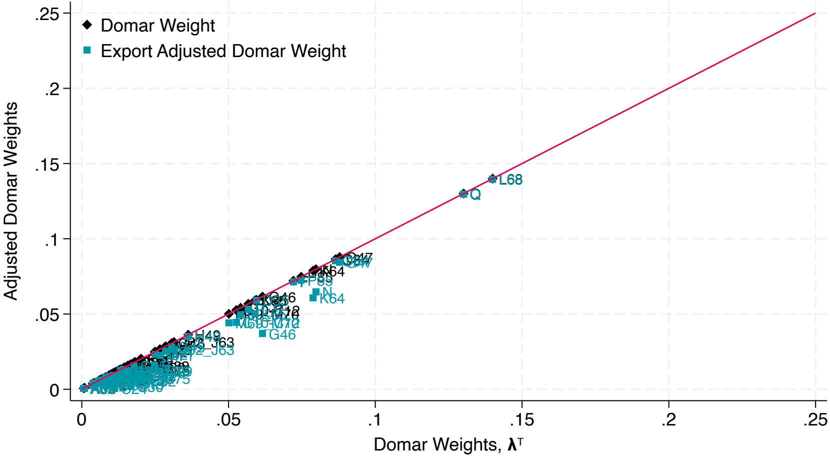


R²(Export adjusted)=0.996, R²(Full adjustment)=0.991

Domar weights in United Kingdom

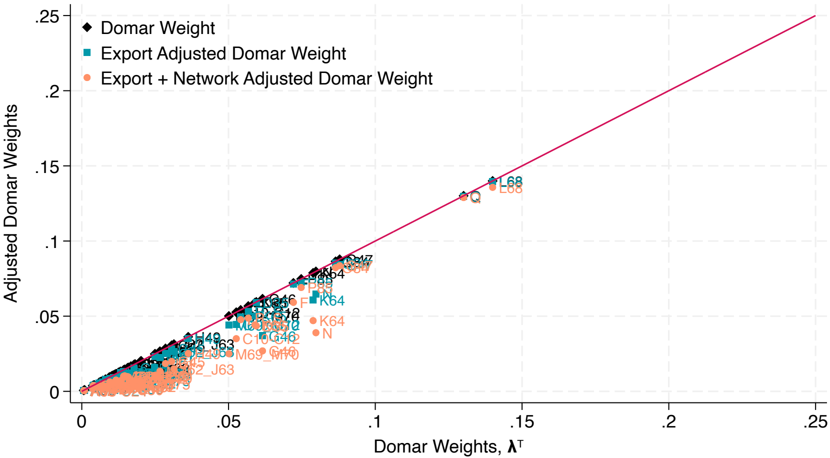


Export adjustment? Matters!



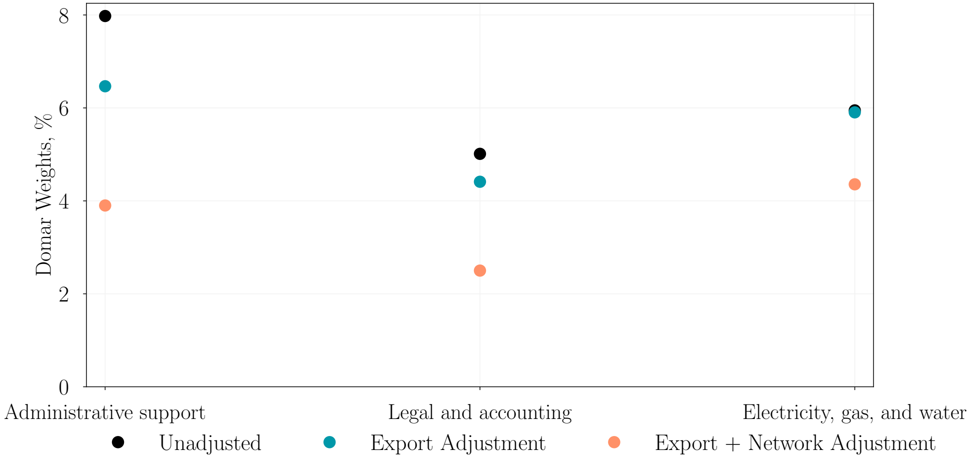
R-squared=0.973

Production network adjustment? Also matters!



R²(Export adjusted)=0.973, R²(Full adjustment)=0.930

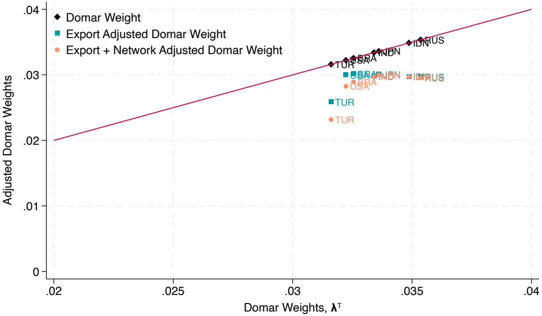
UK: 3 largest export adjustment + network



- Electricity: **5.95%** $\xrightarrow{\text{Export Adjustment}}$ **5.90%** $\xrightarrow{\text{Production Network Adj.}}$ **4.4%**

Average adjustments across countries

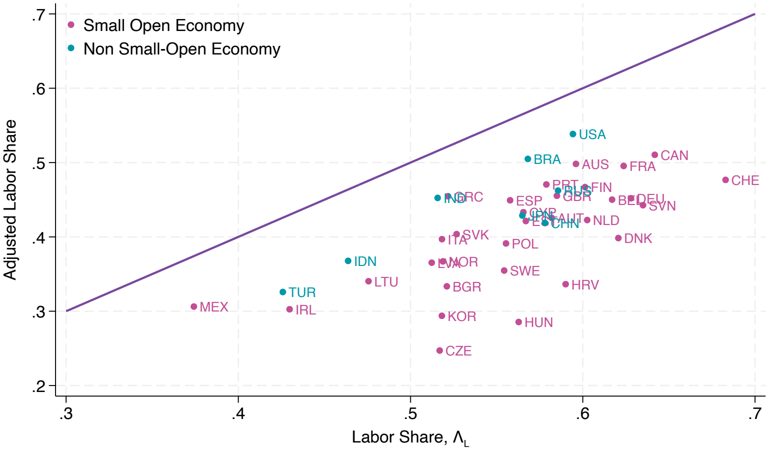
(a) Non Small Open Economies



(b) Small Open Economies

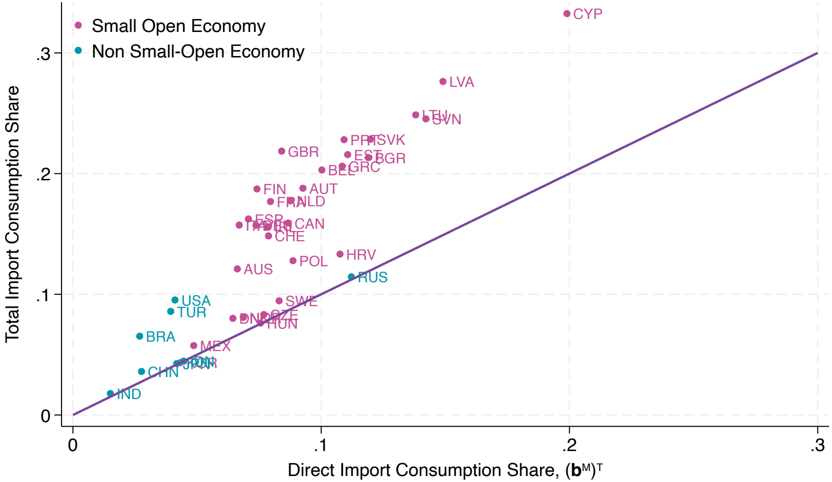
- Full adjustment is small in non-SOEs but quantitatively important in SOEs

Elasticity to factor prices: $(\Lambda^T - \tilde{\Lambda}^T)\widehat{W}$



- Adjustment matters more for SOEs.

Elasticity to import prices: $(\bar{b}^M + \tilde{b}^M)\widehat{P}_M$



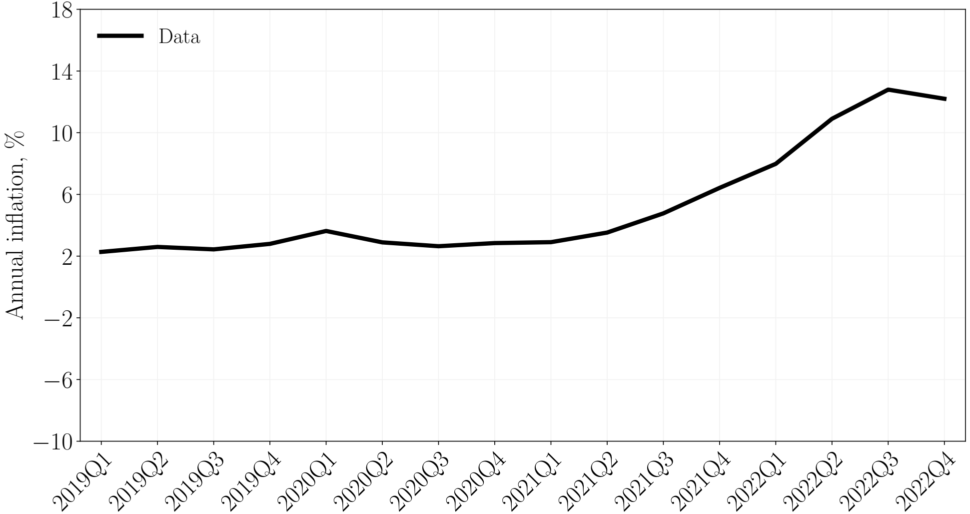
- Indirect consumption share as important as direct consumption share!

Application

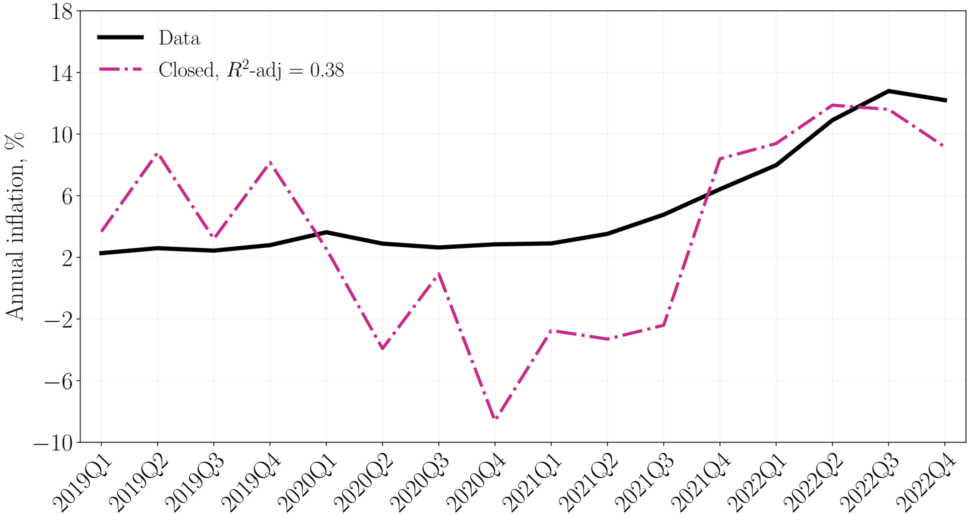
Inflation during COVID19: Application

- Collect data on sectoral wages, labor productivity, and import price
  - Two small open economies $\longrightarrow$ Chile and UK
  - UK caveat: only good enough data on import price and sectoral wages.
- Calibrate relevant elasticities using Input-Output tables.
  - Model to data assumption: sector-specific labor and capital.
  - 20 sectors: SIC2 classification.
- Use data on $\hat{\boldsymbol{W}}, \hat{\boldsymbol{Z}}, \hat{P}_M$ + elasticities to construct model implied inflation.
  - Three scenarios: Closed, Open - No Network, and Open - Network

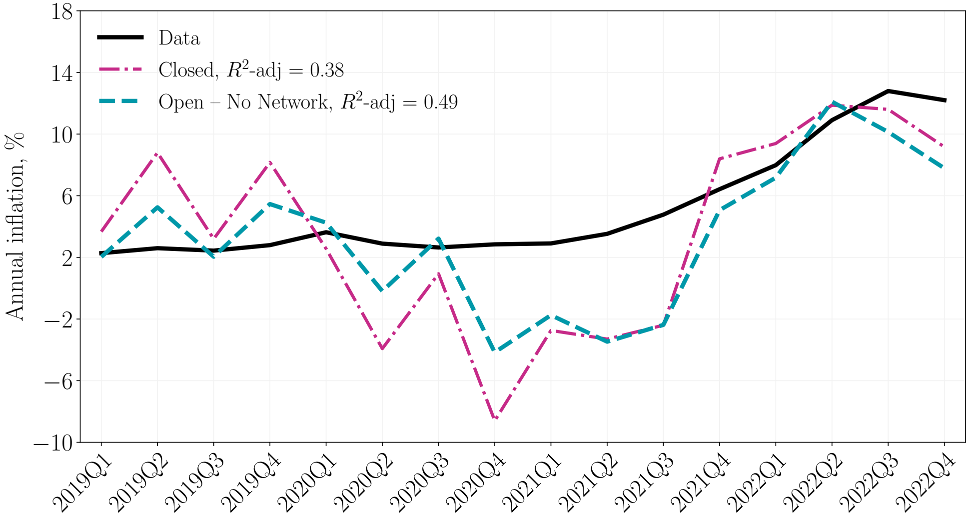
Inflation during COVID19: Chile



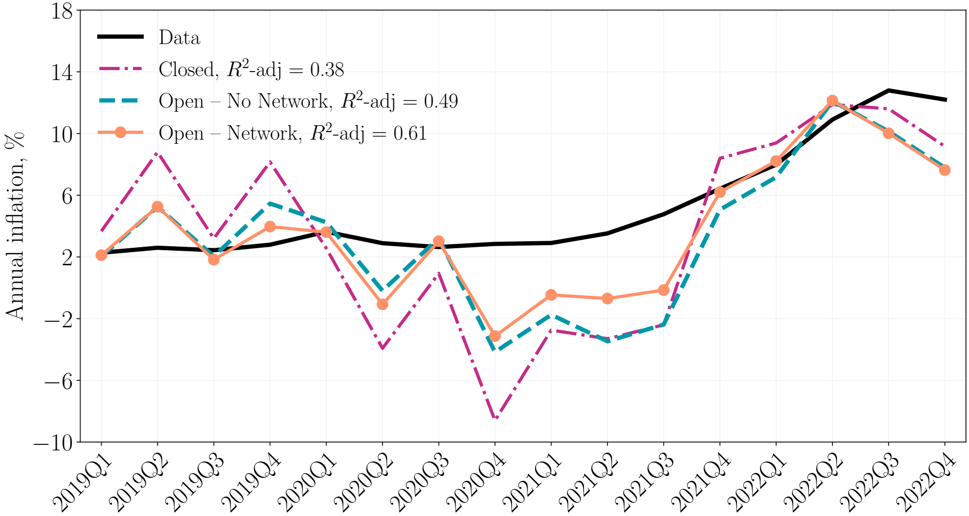
Inflation during COVID19: Chile



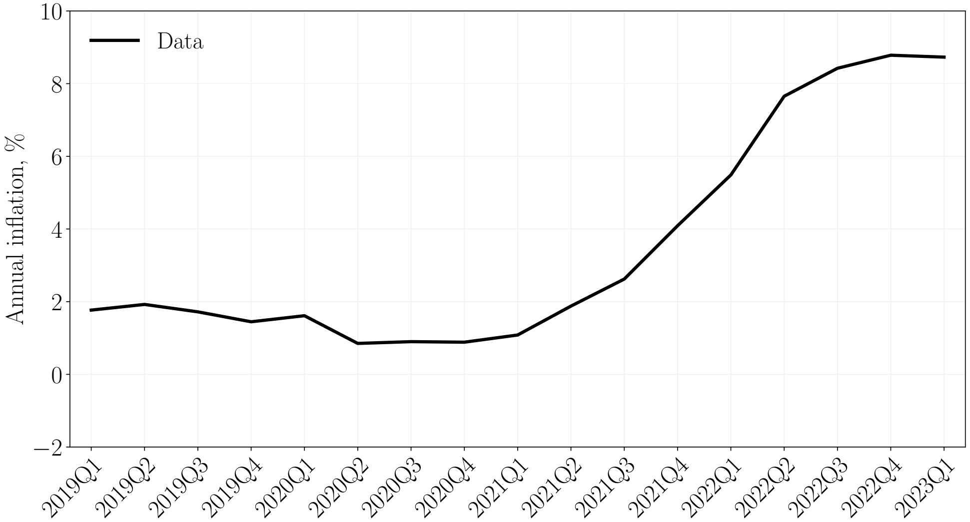
Inflation during COVID19: Chile



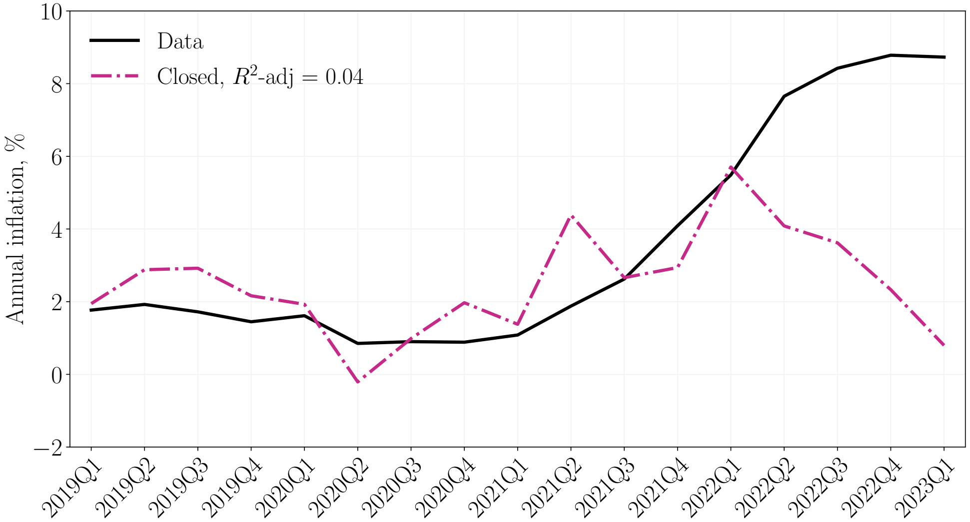
Inflation during COVID19: Chile



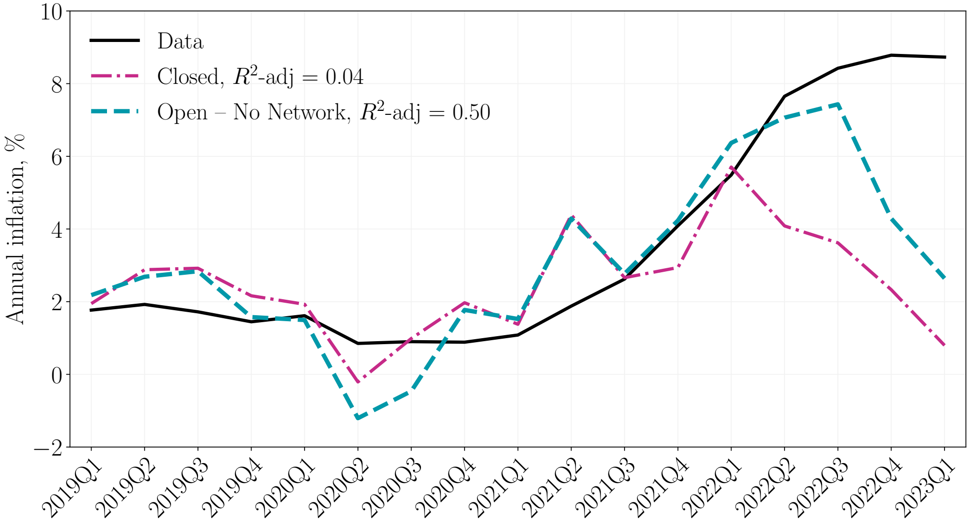
Inflation during COVID19: United Kingdom



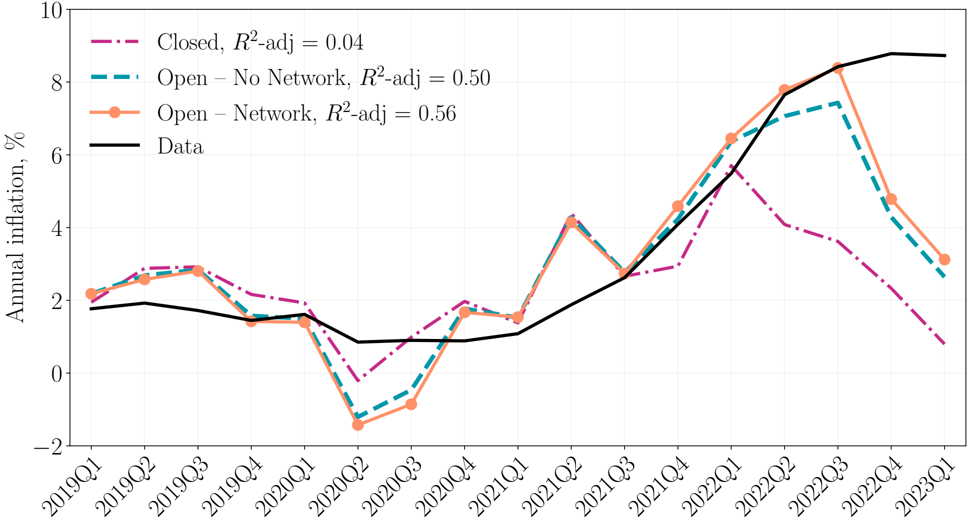
Inflation during COVID19: United Kingdom



Inflation during COVID19: United Kingdom



Inflation during COVID19: United Kingdom



Conclusion

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1. Production network amplifies trade affecting CPI elasticities
2. Quantitatively important for small open economies
3. Helps to match inflation during Covid-19 in United Kingdom and Chile

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4. Upcoming work and research agenda
    - Incorporate your comments and suggestions (this paper)

Conclusion

1. Production network amplifies trade affecting CPI elasticities
2. Quantitatively important for small open economies
3. Helps to match inflation during Covid-19 in United Kingdom and Chile
4. Upcoming work and research agenda
   - Incorporate your comments and suggestions (this paper)
   - Sticky prices/wages
     - "*Pandemic-era inflation drivers and global spillovers*"
       (with di Giovanni, Kalemli-Özcan, and Yıldırım)
     - "*Optimal monetary policy in small open economies with production networks*"
       Gali and Monacelli (2005) meet La'O and Tahbaz-Salehi (2022), Rubbo (2023)

Thank you!

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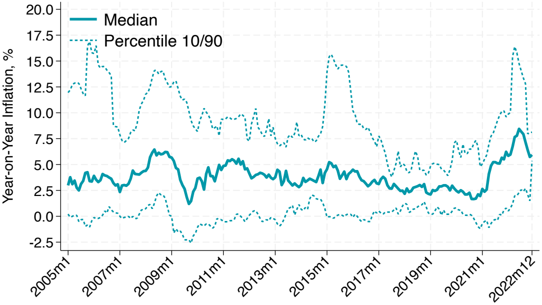
asilvub@umd.edu

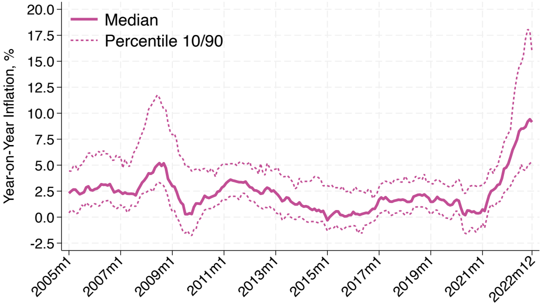
Fact 1: Inflation strikes back

Back

(a) Non Small Open Economies



(b) Small Open Economies



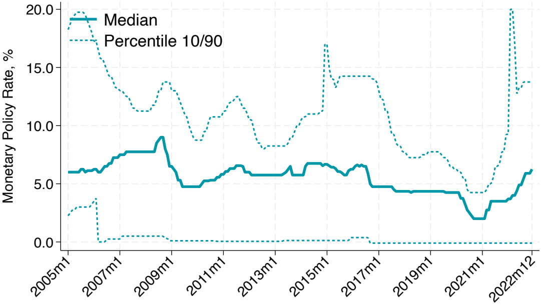
Source: Bank for International Settlements. Non SOE: 9, SOE: 47.

SOE criteria: trade openness ≥ 30 % and share of world GDP ≤ 5 %.

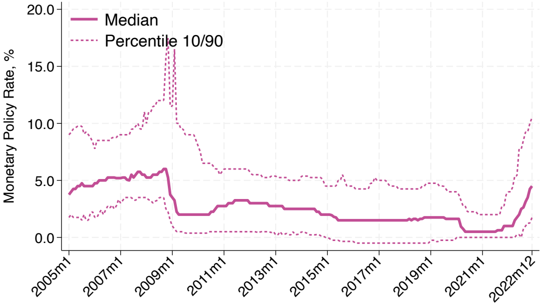
Fact 2: Median Central Bank hiked

Back

(a) Non-Small Open Economies



(b) Small Open Economies

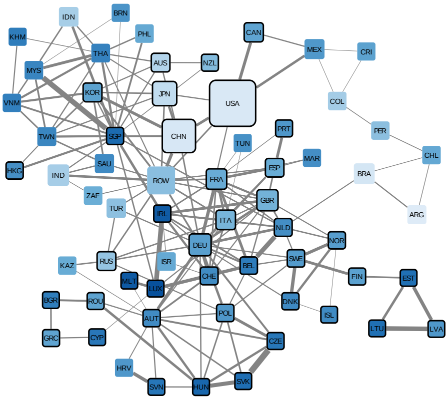


Source: Bank for International Settlements. Non SOE: 9, SOE: 25.

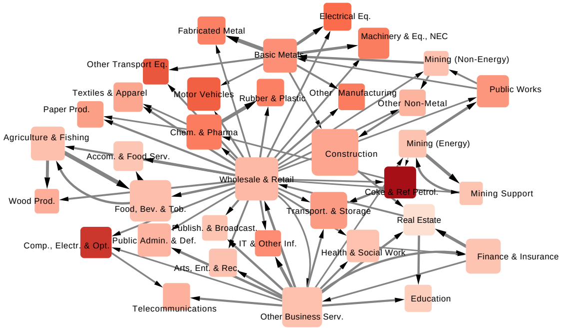
SOE criteria: trade openness ≥ 30 % and share of world GDP ≤ 5 %.

Fact 3: Economies are networks! Back

(a) International Production Network



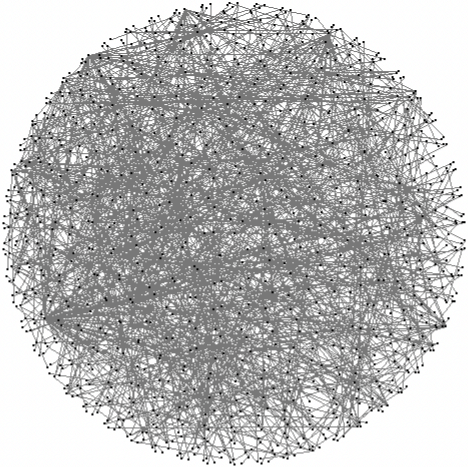
(b) Sectoral Production Network



Source: Cakmakli, Demiralp, Kalemli-Özcan, Yeşiltaş, and Yıldırım (2022) based on OECD Input-Output Tables 2018.

Fact 3: Economies are networks! Back

(c) Chile's Firm-to-Firm Level Production Network



Note: Chilean firm-to-firm level network 2019Q4: 2000 firms random sample, intermediate input sales represent at least 10% of client's total intermediate input purchases. Source: Miranda-Pinto, Silva, and Young (2023).

Leontieff-Inverse Intuition

Back

$$\downarrow Z_A \longrightarrow \uparrow P_A \longrightarrow \uparrow P_{B_1} = \Omega_{B_1,A} d\log P_A \text{ (1st round)} \rightarrow P_{B_2} = \Omega_{B_2,B_1} d\log P_{B_1} \text{ (2nd round)}$$

$$\Psi = \sum_{s=0}^{\infty} \Omega^s \text{ takes into account all these higher order effects!}$$

Equilibrium Back

1. Given sequences $(\boldsymbol{W}, \boldsymbol{P}_D, \Pi, \boldsymbol{P}_M)$ and exogenous parameters $(T, \mathcal{M})$, the household chooses $(\boldsymbol{C}_D, \boldsymbol{C}_M)$ to maximize its utility subject to its budget constraint and the cash-in-advanced constraint.
2. Given $(\boldsymbol{W}, \boldsymbol{P}_D, \boldsymbol{P}_M)$ and production technologies, firms choose $(\boldsymbol{L}_i, \boldsymbol{M}_i)$ to minimize their cost of production.
3. Given $\boldsymbol{X}$, goods and factor markets clears.

Role of aggregate demand Back

- Closed economy with production networks

$$\widehat{CPI} = \widehat{\mathcal{M}} - \boldsymbol{\lambda}^T \hat{\boldsymbol{Z}} - \boldsymbol{\Lambda}^T \hat{\boldsymbol{L}}$$

Baqaee and Farhi, 2022

Role of aggregate demand Back

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$$\widehat{CPI} = \widehat{\mathcal{M}} - \boldsymbol{\lambda}^T \hat{\boldsymbol{Z}} - \boldsymbol{\Lambda}^T \hat{\bar{\boldsymbol{L}}}$$

Baqaee and Farhi, 2022

- Small open economy with production networks

$$\widehat{CPI} =$$

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Baqaee and Farhi, 2022

- Small open economy with production networks

$$\widehat{CPI} = -\left(\boldsymbol{\lambda}^T - \tilde{\boldsymbol{\lambda}}\right) \widehat{\boldsymbol{Z}} + \left((\boldsymbol{b}^M)^T + \boldsymbol{b}^T \boldsymbol{\Psi} \boldsymbol{\Gamma}\right) \widehat{\boldsymbol{P}}_M$$

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- Lower effect of aggregate demand forces

Role of aggregate demand Back

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Baqaee and Farhi, 2022

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$$-\left(\bar{\boldsymbol{\Lambda}}^T - \tilde{\boldsymbol{\Lambda}}^T\right)\widehat{\bar{\boldsymbol{L}}}$$

- Dampens factor supply shocks effect through factor content of exports.

Role of aggregate demand Back

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$$\widehat{CPI} = \widehat{\mathcal{M}} - \boldsymbol{\lambda}^T \widehat{\boldsymbol{Z}} - \boldsymbol{\Lambda}^T \widehat{\bar{\boldsymbol{L}}}$$

Baqaee and Farhi, 2022

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$$-\left(\bar{\boldsymbol{\Lambda}}^T - \tilde{\boldsymbol{\Lambda}}^T\right)\widehat{\bar{\boldsymbol{L}}} - \tilde{\boldsymbol{\Lambda}}^T \widehat{\bar{\boldsymbol{\Lambda}}}$$

- Factor share reallocation term: dampens inflation from factor prices

Role of aggregate demand Back

- Closed economy with production networks

$$\widehat{CPI} = \widehat{\mathcal{M}} - \boldsymbol{\lambda}^T \widehat{\boldsymbol{Z}} - \boldsymbol{\Lambda}^T \widehat{\bar{\boldsymbol{L}}}$$

Baqaee and Farhi, 2022

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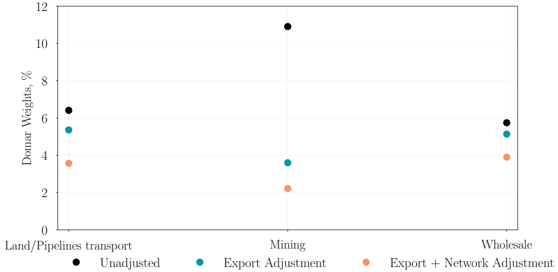
$$\widehat{CPI} = -\left(\boldsymbol{\lambda}^T - \tilde{\boldsymbol{\lambda}}\right)\widehat{\boldsymbol{Z}} + \left((\boldsymbol{b}^M)^T + \boldsymbol{b}^T \Psi \Gamma\right)\widehat{\boldsymbol{P}}_M + (1 - \tilde{\boldsymbol{\Lambda}}^T 1_F)\widehat{\mathcal{M}} + \frac{\mathrm{d}T}{E}$$
$$-\left(\bar{\boldsymbol{\Lambda}}^T - \tilde{\boldsymbol{\Lambda}}^T\right)\widehat{\bar{\boldsymbol{L}}} - \tilde{\boldsymbol{\Lambda}}^T \widehat{\bar{\boldsymbol{\Lambda}}}$$

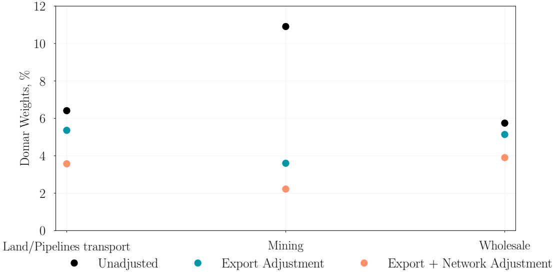
- Bottom line: **network + openness do matter for inflation!**

Canada

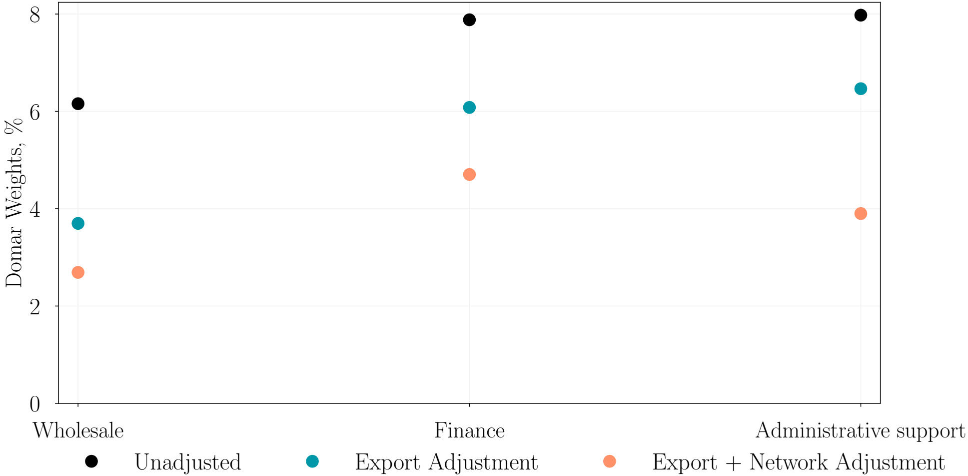
(a) Full adjustment



(b) Full adjustment

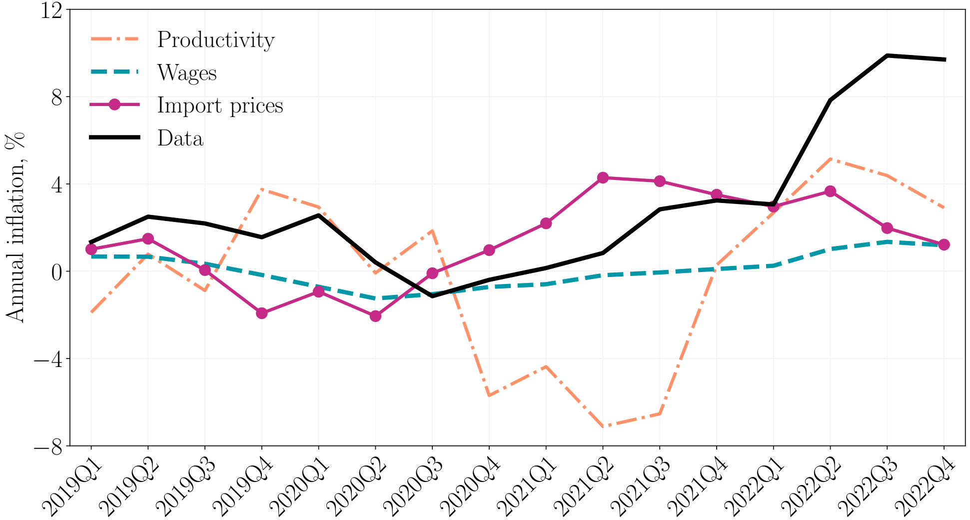


UK: 3 largest export adjustment

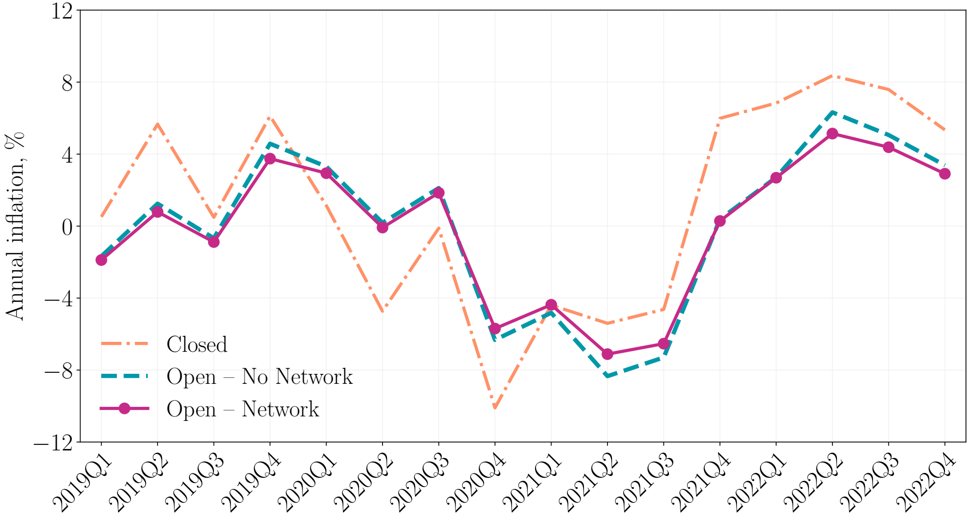


- Wholesale: **6.2%** $\xrightarrow[\text{Export Adjustment}]{}$ **3.7%** $\xrightarrow[\text{Production Network Adj.}]{}$ **2.7%**

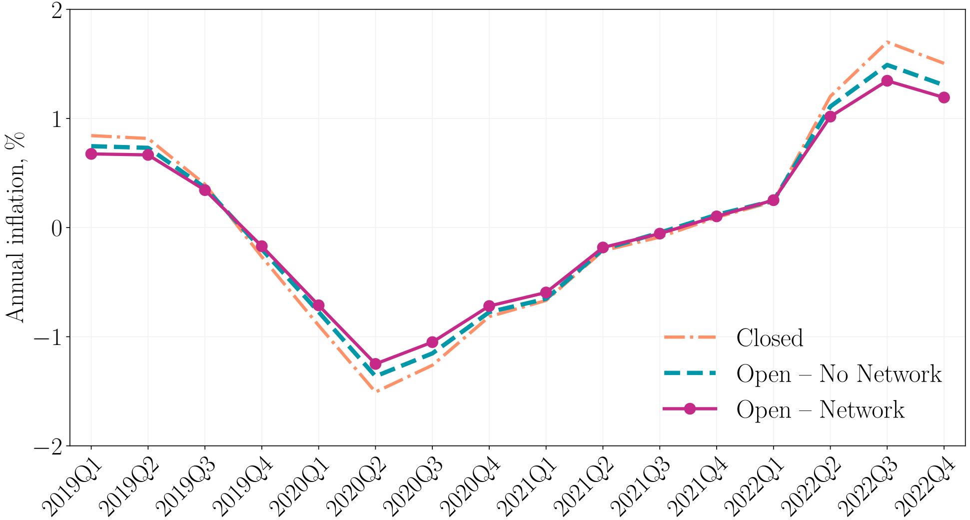
Chile Model Decomposition



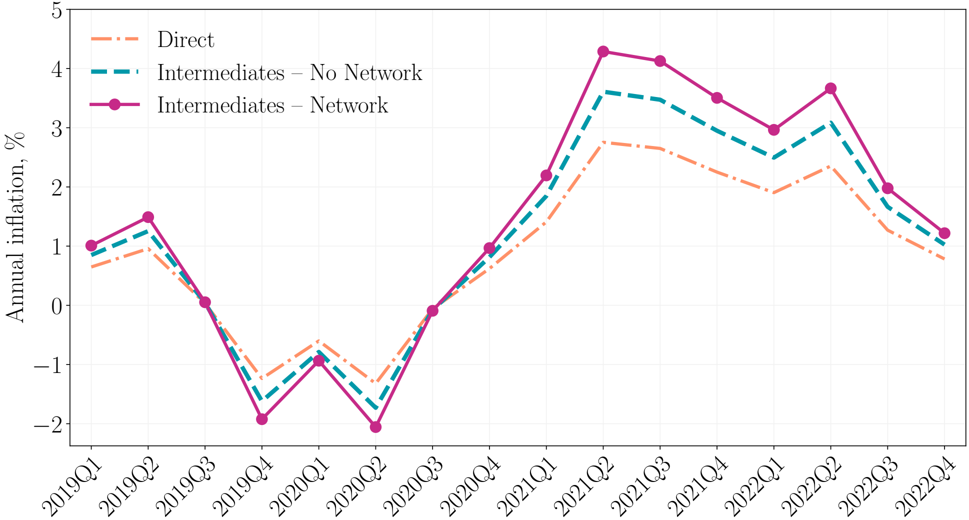
Chile: Productivity Comparison



Chile: Wages Comparison



Chile: Import Price Comparison



Extension

Gali-Monacelli meet production networks

- Start from Gali and Monacelli (2005) small open economy model
- Continuum of small open economies in $[0, 1]$
- Household block
  - Identical but restricted to one imported good.
  - Complete financial markets
- Production block
  - Intersectoral linkages + price stickiness

    as in La'o and Tahbaz-Salehi (2020), Rubbo (2023)
  - Multiple sectors $\longrightarrow$ sectoral "terms of trade".
- Policy block
  - $i_t = r_t^n + \phi\bar{\pi}_t + \phi_y\tilde{y}_t$

Production block setup

- One factor of production (labor) and an imported intermediate good.
- N sectors with a continuum of firms.
- Constant returns to scale production function: $Q_{if} = Z_i F(L_{if}, \{M_{ifj}\}_{j \in N}, M_{ifM})$
- δ_i: probability of firm in sector i of adjusting the price.
- Key objects

$$\mathbf{\Delta} = diag(\hat{\boldsymbol{\delta}})$$
$$\mathbf{\Psi}^{\text{Sticky}} = (\boldsymbol{I} - \mathbf{\Delta}\mathbf{\Omega})^{-1}\mathbf{\Delta}$$

- One Phillips curve per sector: how do they look like?

Sectoral Phillips curves in open economy

$$\boldsymbol{\pi}_t = \boldsymbol{K}\varphi \underbrace{\tilde{y}_t}_{\text{Output gap}} + \underbrace{\boldsymbol{\Psi}^{\text{Sticky}}(\boldsymbol{I} - \boldsymbol{\Omega})\mathbf{1}_N \pi_t^M - \boldsymbol{\Psi}^{\text{Sticky}}(\boldsymbol{I} - \boldsymbol{\Omega})\tilde{\boldsymbol{s}}_{t-1}}_{\text{Cost-push}} + \beta \boldsymbol{\Psi}^{\text{Sticky}}(\boldsymbol{I} - \boldsymbol{\Delta})E_t \boldsymbol{\pi}_{t+1}$$

where

$$\boldsymbol{\Psi}^{\text{Sticky}} = (\boldsymbol{I} - \boldsymbol{\Delta\Omega})^{-1}\boldsymbol{\Delta}$$

$$\boldsymbol{K} = \boldsymbol{\Psi}^{\text{Sticky}}\boldsymbol{\alpha}$$

- Cost-push shocks
  - $\tilde{\boldsymbol{s}}_{t-1}$: past sectoral terms of trade, $\tilde{s}_{it-1} = \tilde{p}_{it-1} - \tilde{p}_{t-1}^M$
  - Import price inflation, π_t^M
- Indirect linkages + openness flattens the Phillips curves even more!