Leverage across the production network and the transmission of monetary policy

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Motivation

- **Production networks** important in shaping transmission of economic shocks
- **Financial frictions** acting as amplifier/accelerator of monetary policy shocks

Research Question

How do direct and indirect exposures to leverage across the production network affect monetary policy transmission?

Method

- Novel **up- and downstream leverage exposure measures**
- Study **non-linear effects on MP transmission** via panel local projections
- Rationalize empirical findings in **theoretical multi-sector model**

Data

- **Country-sector panel** (monthly) for 20 euro area countries
- Dataset composed of **five building blocks**:
  1. **Macroeconomic indicators** at country level
  2. **Monetary policy shocks** via high-frequency identification (Altavilla et al., 2019; Jarociński and Karadi, 2020)
  3. **Sector-specific PPI and activity measures** at NACE-2 level granularity (64 sectors for each country)
  4. Data on **input-output linkages** by sector/country
  5. **Firm-level balance sheet** data from Orbis
- Final dataset spanning **2002m1 to 2024m12** (approx 250.000 observations)

Appendix: Data

Econometric model

- MP shock interaction w/ **sector i's leverage ($\varphi_{ic,t}$)**
- MP shock interaction w/ sector i's exposure to **leverage position of suppliers ($\Phi_{ic,t}$) and customers ($\tilde{\Phi}_{ic,t}$)**

$$\Delta_h y_{ic,t+h} = \underbrace{\beta_1^h \varphi_{ic,t_{12}-1} \times s_t}_{\text{Direct leverage effect}} + \underbrace{\overbrace{\beta_2^h \Phi_{ic,t_{12}-1} \times s_t}^{\text{Upstream effect}} + \overbrace{\beta_3^h \tilde{\Phi}_{ic,t_{12}-1} \times s_t}^{\text{Downstream effect}}}_{\text{Indirect leverage effect}} + \tag{1}$$

$$+ \beta_4^h s_t + \cdots + \epsilon_{ic,t+h}$$

$$\Phi_{ic,t_{12}} = (1 - a_{ic,t_{12}}) \sum_{j,d} 1(j \neq i, d \neq c) \nu_{ic,jd,t_{12}} \times \varphi_{jd,t_{12}}$$

$$\tilde{\Phi}_{ic,t_{12}} = (1 - \tilde{a}_{ic,t_{12}}) \sum_{j,d} 1(j \neq i, d \neq c) \tilde{\nu}_{ic,jd,t_{12}} \times \varphi_{jd,t_{12}} \tag{2}$$

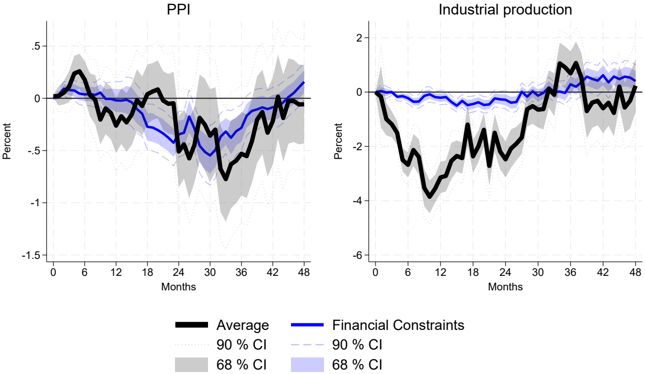
Appendix: Full model Appendix: Leverage measures

Empirical results

1. Overall response

- Prices and production fall in first 3 years after the MP shock
- Higher leverage (↑10% from mean) across the network implies additional dampening in prices and activity

Figure: Impulse responses to 25bp tightening shock

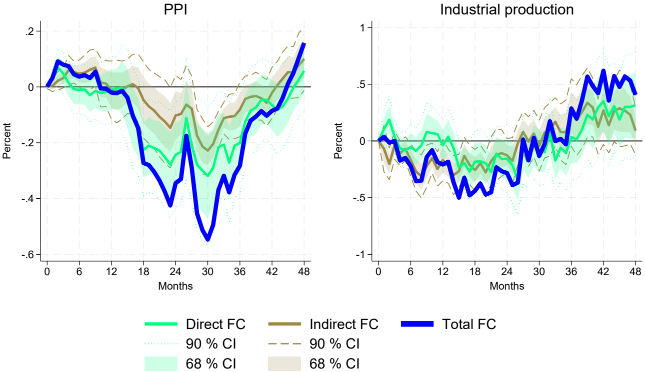


Empirical results

2. Direct vs. indirect network leverage effects

- Direct and indirect leverage exposures amplify transmission to prices and output
- Significant relative importance of indirect effects

Figure: Impulse responses to 25bp tightening shock

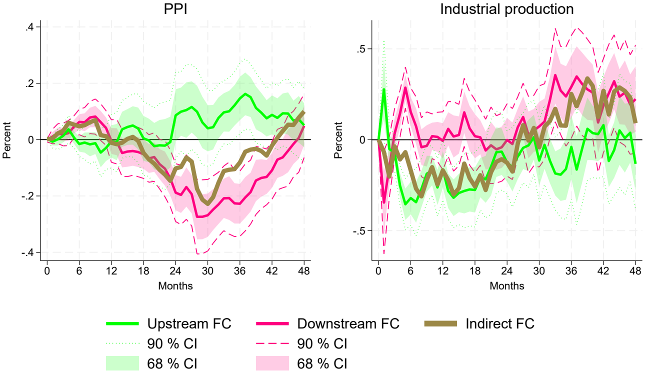


Empirical results

3. Up- and downstream network leverage effects

- Exposure to upstream suppliers' (downstream customers') leverage mitigates (reinforces) transmission to prices
  - ⇒ **Downstream demand vs. upstream cost-channel**

Figure: Impulse responses to 25bp tightening shock



Overview

Model:

- Static multi-sector model (Bigio and La'O, 2020):
  - ⇒ Two agents: firms and households
  - ⇒ Firms operate in different sectors ⇒ production network
- Sector-specific working capital constraints:
  - ⇒ Capture sectoral heterogeneity in monetary policy (i) effects
  - ⇒ Link sector-specific impact to sectoral financial positions via φ_i
  - ⇒ Financial friction introduces a sector-specific "cost channel"

Analysis:

- Derive theoretical counterparts of empirical leverage measures
  - ⇒ Assess importance of sector-specific financial constraints for monetary policy transmission
  - ⇒ Take potential amplification effects from production network into account

Theoretical model appendix

Key equations

- Firm profit equation:

$$\pi_i = p_i y_i - (1 + i\varphi_i)(l_i + \sum_{j \in K} p_j x_{i,j}) \tag{3}$$

- Sectoral (firm) optimality conditions:

$$p_i = (1 + i\varphi_i) mc_i, \tag{4}$$

$$mc_i = \frac{1}{z_i} \frac{(1-\alpha_i)^{\alpha_i - 1}}{\alpha_i^{\alpha_i}} \left(\prod_{i \in K} p_i^{\nu_{i,j}} \right)^{1-\alpha_i} \tag{5}$$

- Derivative of **sectoral prices**:

$$\frac{d}{di} \log(p_i) \approx \varphi_i + \sum_{j \neq i} \nu_{i,j} \varphi_j \quad \textbf{(direct + upstream)} \tag{6}$$

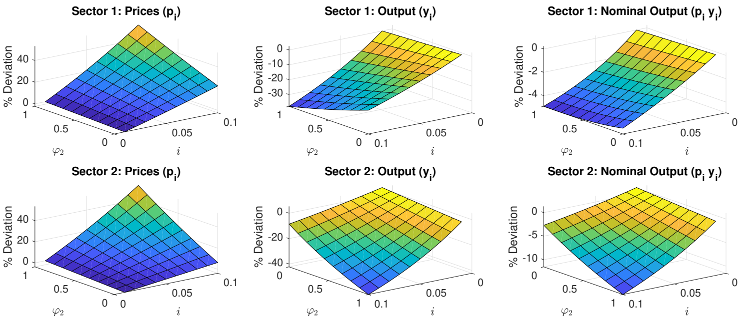
- Interest-rate sensitivity of **sectoral nominal output**:

$$p_i y_i = P^c \nu_{ci} C + \sum_{j \neq i} \frac{\nu_{j,i}(1-\alpha_j)}{(1+\varphi_j i)} P^c \nu_{cj} C \quad \textbf{(downstream)} \tag{7}$$

Two-sector comparative statics

- Calibrated two-sector version ⇒ industry vs. services
- **Exercise**: Vary **policy rate** and sector 2's **financial position**
- **Results:**
  - ⇒ Higher i increases prices and reduces output across sectors
  - ⇒ Increasing φ_2 increases prices and reduces output in both sectors ⇒ **network transmission**

Figure: Policy rate and sectoral financial position



Conclusion

Research Question

How do direct and indirect exposures to leverage across the production network affect monetary policy transmission?

Key results

- Network leverage exposure important amplifier of disinflationary impact
- Up- and downstream leverage exposure affect prices in opposite directions
- Rationalize in a multi-sector "cost-channel" model

Thank you very much for your attention!

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Appendix
Overview

Introduction

Appendix
Literature

1. Theoretical studies on **production networks**:
   Acemoglu et al. (2012); La'O and Tahbaz-Salehi (2022); Rubbo (2023); Bigio and La'O (2020)
2. Empirical studies on **sectoral monetary policy transmission**
   Ghassibe (2021); Durante et al. (2022); Borağan Aruoba and Drechsel (2024)
3. **Financial frictions and monetary policy transmission:**
   Bernanke and Gertler (1995); Bernanke et al. (1999); Ottonello and Winberry (2020); Jeenas (2018); Gilchrist et al. (2017); Adelino et al. (2023)
4. **Monetary policy shocks in local projections:**
   Borağan Aruoba and Drechsel (2024); Jordà and Taylor (2024); Ramey (2016); Ramey and Zubairy (2018); BarthIII and Ramey (2002)

Country-sector euro area panel

- 2-digit NACE info on producer price index, industrial production, turnover and employment, by country. From STS Eurostat dataset

Input-output data

- FIGARO tables at 2-digit NACE level (from 2010 to 2022).

Firm-level financial constraints measures

- Information on firm level balance sheet data from ORBIS (using the cleaning method from Kalemli-Ozcan et al. (2015))

Data

- Annual input-output (IO) linkages from Eurostat's FIGARO database (2010-2023)

Table: Simplified Multi-Country Input-Output Table

		Intermediate use				
		1A	**2A**	**1B**	**2B**	**Final use**
Intermed. input	**1A**	$z_{11}^{A,A}$	$z_{12}^{A,A}$	$z_{11}^{A,B}$	$z_{12}^{A,B}$	y_1^A
	2A	$z_{21}^{A,A}$	$z_{22}^{A,A}$	$z_{21}^{A,B}$	$z_{22}^{A,B}$	y_2^A
	1B	$z_{11}^{B,A}$	$z_{12}^{B,A}$	$z_{11}^{B,B}$	$z_{12}^{B,B}$	y_1^B
	2B	$z_{21}^{B,A}$	$z_{22}^{B,A}$	$z_{21}^{B,B}$	$z_{22}^{B,B}$	y_2^B
	VA+Labor	VA_1^A	VA_2^A	VA_1^B	VA_2^B	
	Taxes	T_1^A	T_2^A	T_1^B	T_2^B	

Appendix
Data - Input-output linkages

$$a_{1A} = \frac{y_1^A}{z_{11}^{A,A} + z_{12}^{A,A} + z_{11}^{A,B} + z_{12}^{A,B} + y_1^A} \tag{8}$$

$$\tilde{a}_{1A} = \frac{VA_1^A + T_1^A}{z_{11}^{A,A} + z_{21}^{A,A} + z_{11}^{B,A} + z_{21}^{B,A} + VA_1^A + T_1^A} \tag{9}$$

- Square IO matrix:

$$\boldsymbol{A} = \begin{bmatrix} z_{11}^{A,A} & z_{12}^{A,A} & z_{11}^{A,B} & z_{12}^{A,B} \\ z_{21}^{A,A} & z_{22}^{A,A} & z_{21}^{A,B} & z_{22}^{A,B} \\ z_{11}^{B,A} & z_{12}^{B,A} & z_{11}^{B,B} & z_{12}^{B,B} \\ z_{21}^{B,A} & z_{22}^{B,A} & z_{21}^{B,B} & z_{22}^{B,B} \end{bmatrix} \tag{10}$$

Appendix
Data - Input-output linkages

- Matrix of technical coefficients $\boldsymbol{B}$: divide each element of $\boldsymbol{A}$ by total of respective column:

$$\boldsymbol{B} = \begin{bmatrix} \nu_{11}^{A,A} & \nu_{12}^{A,A} & \nu_{11}^{A,B} & \nu_{12}^{A,B} \\ \nu_{21}^{A,A} & \nu_{22}^{A,A} & \nu_{21}^{A,B} & \nu_{22}^{A,B} \\ \nu_{11}^{B,A} & \nu_{12}^{B,A} & \nu_{11}^{B,B} & \nu_{12}^{B,B} \\ \nu_{21}^{B,A} & \nu_{22}^{B,A} & \nu_{21}^{B,B} & \nu_{22}^{B,B} \end{bmatrix} \tag{11}$$

- Matrix of allocation coefficients $\boldsymbol{C}$: divide each element of $\boldsymbol{A}$ by the total of the rows:

$$\boldsymbol{C} = \begin{bmatrix} \tilde{\nu}_{11}^{A,A} & \tilde{\nu}_{12}^{A,A} & \tilde{\nu}_{11}^{A,B} & \tilde{\nu}_{12}^{A,B} \\ \tilde{\nu}_{21}^{A,A} & \tilde{\nu}_{22}^{A,A} & \tilde{\nu}_{21}^{A,B} & \tilde{\nu}_{22}^{A,B} \\ \tilde{\nu}_{11}^{B,A} & \tilde{\nu}_{12}^{B,A} & \tilde{\nu}_{11}^{B,B} & \tilde{\nu}_{12}^{B,B} \\ \tilde{\nu}_{21}^{B,A} & \tilde{\nu}_{22}^{B,A} & \tilde{\nu}_{21}^{B,B} & \tilde{\nu}_{22}^{B,B} \end{bmatrix} \tag{12}$$

Appendix
Data - Input-output linkages

- Account for higher-order effects by deriving Leontief and Gosh inverses (Acemoglu et al., 2016)

$$\boldsymbol{L} \equiv (\boldsymbol{I} - \boldsymbol{B})^{-1} = \begin{bmatrix} \omega_{11}^{A,A} & \omega_{12}^{A,A} & \omega_{11}^{A,B} & \omega_{12}^{A,B} \\ \omega_{21}^{A,A} & \omega_{22}^{A,A} & \omega_{21}^{A,B} & \omega_{22}^{A,B} \\ \omega_{11}^{B,A} & \omega_{12}^{B,A} & \omega_{11}^{B,B} & \omega_{12}^{B,B} \\ \omega_{21}^{B,A} & \omega_{22}^{B,A} & \omega_{21}^{B,B} & \omega_{22}^{B,B} \end{bmatrix} \tag{13}$$

$$\boldsymbol{G} \equiv (\boldsymbol{I} - \boldsymbol{C})^{-1} = \begin{bmatrix} \tilde{\omega}_{11}^{A,A} & \tilde{\omega}_{12}^{A,A} & \tilde{\omega}_{11}^{A,B} & \tilde{\omega}_{12}^{A,B} \\ \tilde{\omega}_{21}^{A,A} & \tilde{\omega}_{22}^{A,A} & \tilde{\omega}_{21}^{A,B} & \tilde{\omega}_{22}^{A,B} \\ \tilde{\omega}_{11}^{B,A} & \tilde{\omega}_{12}^{B,A} & \tilde{\omega}_{11}^{B,B} & \tilde{\omega}_{12}^{B,B} \\ \tilde{\omega}_{21}^{B,A} & \tilde{\omega}_{22}^{B,A} & \tilde{\omega}_{21}^{B,B} & \tilde{\omega}_{22}^{B,B} \end{bmatrix} \tag{14}$$

Econometric model

Appendix
Indirect leverage measures

Combine **sectoral leverage information** with **input-output data** to construct **sectoral up- and downstream leverage exposure measures**

$$\Phi_{ic,t_{12}} = (1 - a_{ic,t_{12}}) \sum_{j,d} 1(j \neq i, d \neq c)\nu_{ic,jd,t_{12}} \times \lambda_{jd,t_{12}}$$
$$\tilde{\Phi}_{ic,t_{12}} = (1 - \tilde{a}_{ic,t_{12}}) \sum_{j,d} 1(j \neq i, d \neq c)\tilde{\nu}_{ic,jd,t_{12}} \times \lambda_{jd,t_{12}} \qquad (15)$$

Econometric model

Appendix
Econometric model - full specification

$$\Delta_h y_{ic,t+h} = y_{ic,t+h} - y_{ic,t-1} = \tag{16}$$

$$\underbrace{\beta_1^h \varphi_{ic,t_{12}-1} \times s_t}_{\substack{\text{Direct financial constraints}\\ \text{effect}}} + \underbrace{\overbrace{\beta_2^h \Phi_{ic,t_{12}-1} \times s_t}^{\text{Upstream effect}} + \overbrace{\beta_3^h \tilde{\Phi}_{ic,t_{12}-1} \times s_t}^{\text{Downstream effect}}}_{\substack{\text{Indirect financial constraints}\\ \text{effect}}} + \tag{17}$$

$$\underbrace{\beta_4^h a_{ic,t_{12}-1} \times s_t + \beta_5^h \tilde{a}_{ic,t_{12}-1} \times s_t + \beta_6^h s_t}_{\text{Non-network effect}}$$

$$+ \sum_{l=0}^{L} \gamma^{\boldsymbol{h}} \boldsymbol{H_{t-l}} + \sum_{l=1}^{L} \delta^{\boldsymbol{h}} \boldsymbol{K_{t-l}} + \sum_{l=0}^{L} \eta^{\boldsymbol{h}} \boldsymbol{\Delta X_{t-l}} + \theta_{t_{12}} + \kappa_{t+h} + \epsilon_{ic,t+h}$$

Appendix
Econometric model

- Matrix $\boldsymbol{H_t}$: sector-level variables unrelated to the monetary shock
- Matrix $\boldsymbol{K_t}$: lags of the dependent variables and shock variables
- Matrix $\boldsymbol{X_t}$: set of macro-financial controls

$$\boldsymbol{H_t} = \begin{bmatrix} a_{ic,t_{12}-1} \\ \tilde{a}_{ic,t_{12}-1} \\ \varphi_{ic,t_{12}-1} \\ \Phi_{ic,t_{12}-1} \\ \tilde{\Phi}_{ic,t_{12}-1} \end{bmatrix}, \quad \boldsymbol{K_t} = \begin{bmatrix} \Delta y_{ic,t} \\ \varphi_{ic,t_{12}-1} \times s_t \\ a_{ic,t_{12}-1} \times s_t \\ \tilde{a}_{ic,t_{12}-1} \times s_t \\ \Phi_{ic,t_{12}-1} \times s_t \\ \tilde{\Phi}_{ic,t_{12}-1} \times s_t \\ s_t \end{bmatrix} \quad \boldsymbol{X_t} = \begin{bmatrix} \text{EA OIS3m rate} \\ \text{10y comp. EA sov. yield} \\ \text{EUR-USD FX rate} \\ \log(\text{CISS}) \\ \log(\text{Commodities PI}) \\ \log(\text{EA HICP}) \\ \log(\text{EA unempl. rate}) \\ \log(\text{sectoral empl.}) \end{bmatrix}$$

Appendix
Econometric model - details

Estimation Method:

- Model estimated in long-differences:

$$\Delta_h x_{t+h} = x_{t+h} - x_{t-1},$$
$$\Delta x_t = x_t - x_{t-1}$$

- Results are robust to levels estimation
- Interaction term scaling: one-unit change in coefficients refers to a 10 percent deviation of leverage from the mean
- Shock scaling: 25bp peak effect in first year

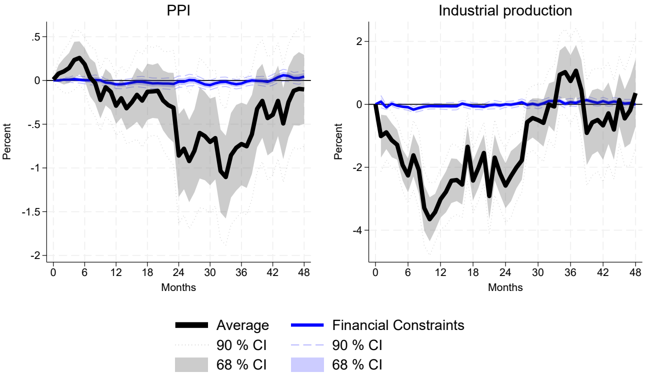
Controls:

- Lags for dependent/control and shock variables (baseline: 3 months)
- Fixed effects: monthly (θ_t) and Covid-19 dummy (κ_{t+h})
- Cluster-robust standard errors (country-sector)

Main

Appendix
1. Overall financial constraints effect - Working Capital

Figure: Impulse responses to 25bp tightening shock - working capital

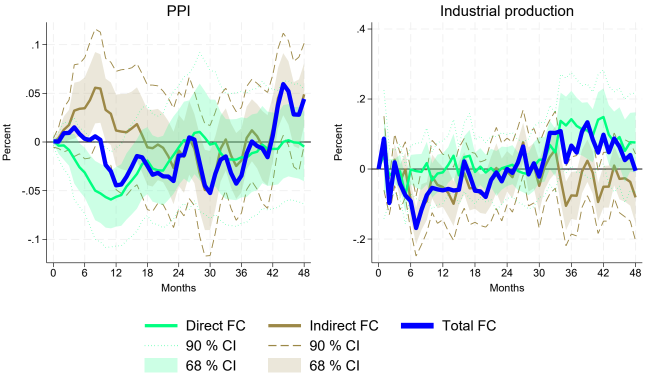


Appendix

2. Direct vs. indirect network financial constraints effects - Working Capital

- Heterogeneous direct and indirect working capital effects
- Indirect effects particularly important for prices

Figure: Impulse responses to 25bp tightening shock - working capital

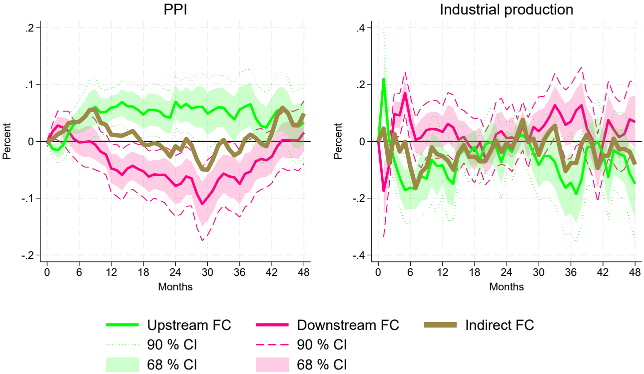


Appendix

3. Up- and downstream network financial constraints effects - WC

- Downstream working capital constraints reinforce drop in prices and output
- Upstream constraints dampen drop in prices and output

Figure: Impulse responses to 25bp tightening shock - working capital



Appendix
Theoretical model: overview

- Multi-sector static model with production networks and sector-specific working capital constraint
- Builds on Bigio and La'O (2020), extended to:
  - ⇒ capture sectoral heterogeneity in monetary policy (i) effects
  - ⇒ link transmission strength to sectoral financial positions via φ_i.
- Firm profit equation

$$\pi_i = p_i y_i - (1 + i\varphi_i)(l_i + \sum_{j \in K} p_j x_{i,j})$$

Sector optimality conditions

$$p_i = (1 + i\varphi_i) mc_i,$$

$$mc_i = \frac{1}{z_i} \frac{(1-\alpha_i)^{\alpha_i - 1}}{\alpha_i^{\alpha_i}} \left(\prod_{i \in K} p_i^{\nu_{i,j}} \right)^{1-\alpha_i} .$$

HH consumption and market clearing

$$y_i = c_i + \sum_{j \in K} x_{j,i} \quad \forall \ i$$

$$c_i = \frac{P^c}{p_i} \nu_{ci} C \tag{18}$$

Appendix
Theoretical model: empirical mapping

- Model-implied derivative of sectoral prices:

$$\frac{d}{di}\log(p_i) \approx \varphi_i + \sum_{j\neq i} \nu_{i,j}\varphi_j \quad \text{(direct + upstream)}$$

- Model-implied interest-rate sensitivity of sectoral nominal output:

$$p_i y_i = P^c \nu_{ci} C + \sum_{j\neq i} \frac{\nu_{j,i}(1-\alpha_j)}{(1+\varphi_j i)} P^c \nu_{cj} C \quad \text{(downstream)}$$

Appendix
Theoretical model: comparative statics

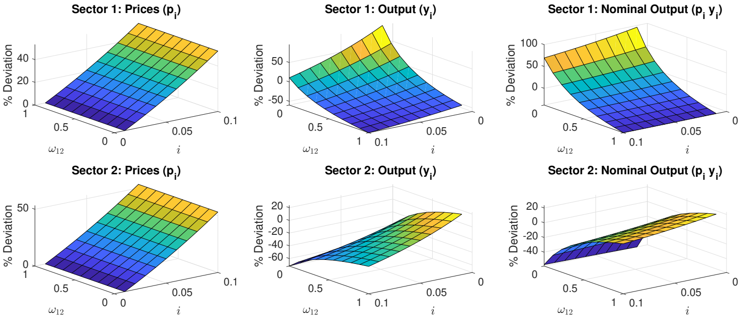
- Two-sector model calibrated to match European **industry** (sector 1) and **services** (sector 2).
- Input-output shares ($\nu_{i,j}$) calibrated to Eurostat FIGARO data:
  - $\Rightarrow$ Industry: 60% industry, 40% services inputs
  - $\Rightarrow$ Services: 20% industry, 80% services inputs
- Final consumption shares (ν_{ci}): 55% goods, 45% services (COICOP).
- Other parameters (e.g. φ_i, α_i) set uniformly across sectors.

Main exercise

Appendix
Theoretical model: comparative statics

- Vary ν_{12} to capture sector 1's reliance on sector 2
  - $\Rightarrow$ Higher ν_{12} raises sector 2 output, lowers sector 1 output
  - $\Rightarrow$ No sectoral price effect $\Rightarrow$ price sensitivity tied to financing conditions

Figure: Policy rate and sectoral input shares

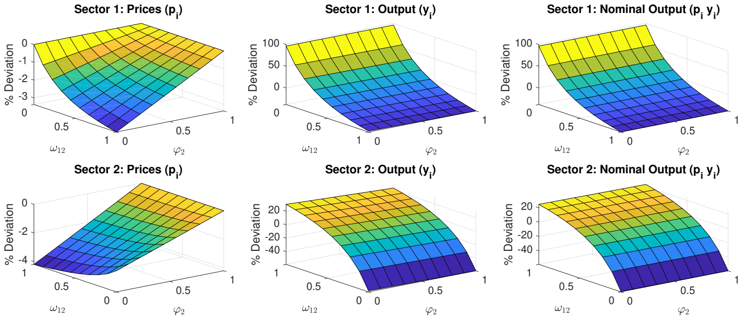


Main exercise

Appendix
Theoretical model: comparative statics

- Vary sector 2's **financial position** φ_2 and sector 1's reliance on services via **input share** ν_{12}
- Tightening in φ_2 and higher ν_{12} amplify contraction in sector 1 output

Figure: Sectoral financial position and input shares



Main exercise

Appendix

Theoretical model: comparative statics - network amplification

- **Full vs. isolationist economy** w/o input linkages ($\alpha_i = 1$)
- In most adverse financial scenario ($i = 0.1$, $\varphi_2 = 1$):
  - ⇒ Upward effect on sector 1's prices is 44 ppt. lower in isolationist economy (baseline: 53%)
  - ⇒ Output drop is mitigated by 34 ppt. in the isolationist model (baseline: -38%)

Figure: Policy rate and sectoral financial friction - network amplification