ECB FORUM ON CENTRAL BANKING

26–28 June 2023

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CROSS-SECTIONAL DYNAMICS UNDER NETWORK STRUCTURE

EUROPEAN CENTRAL BANK

EUROSYSTEM

Cross-Sectional Dynamics Under Network Structure: Theory & Macroeconomic Applications

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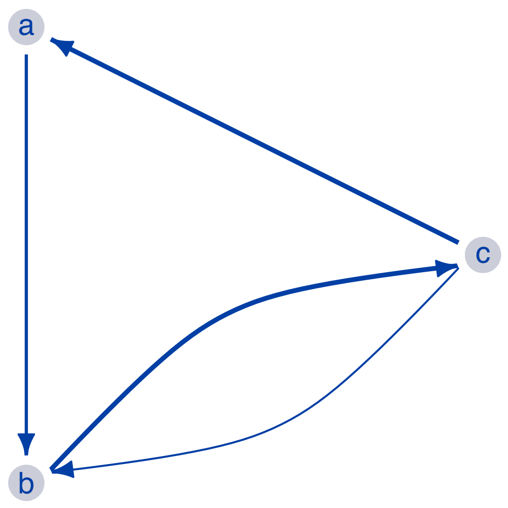
Motivation

- Common in economics:
  cross-section linked by bilateral ties
  - countries linked by trade, capital flows, geopolitical ties
  - sectors linked by supply chains
  - individuals linked by acquaintance
- Theory & empirics: networks amplify unit-level shocks, lead to comovement in cross-sectional variables
- **How does this amplification play out over time?**



$$A = \begin{bmatrix} 0 & 0 & .8 \\ .7 & 0 & .6 \\ 0 & .8 & 0 \end{bmatrix}$$

shows direct links
e.g. suppliers

$$A^2 = \begin{bmatrix} 0 & .64 & 0 \\ 0 & .48 & .56 \\ .56 & 0 & .48 \end{bmatrix}$$

shows 2nd order connections
e.g. suppliers of suppliers

Contribution

- Build econometric framework that can speak to dynamics implied by networks
- Estimate how sectoral TFP shocks transmit through supply chain network and drive sectoral prices over time
- Forecast industrial production of 44 countries by assuming and estimating network underlying dynamics

Model: Network-VAR

NVAR(p,q): $\quad x_\tau = \boldsymbol{\alpha_1 A}\, x_{\tau-1} + \ \ldots + \boldsymbol{\alpha_p A}\, x_{\tau-p} + v_\tau \,, \qquad \boldsymbol{y_t} = x_{tq} \qquad$ (x_τ observed every q periods)

- VAR in which innovations transmit cross-sectionally only via bilateral links in network A
- Can accommodate general patterns on how innovations travel through network over time

  Dynamic impact of y_j on y_i, h periods into the future, is composed of network-connections from i to j of order $\underline{k}, \underline{k}+1, \ldots, h, \ldots, hq$:

$$\frac{\partial y_{i,t+h}}{\partial y_{j,t}} \,|\, \mathcal{F}_t = c^h_{\underline{k}}(\alpha)\, \left(A^{\underline{k}}\right)_{ij} + \ \ldots + c^h_{hq}(\alpha)\, \left(A^{hq}\right)_{ij}$$

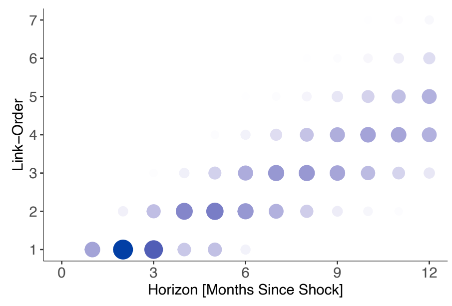
Two assumptions:

1. At some (high) frequency, network interactions happen with lags (nothing is contemporaneous!)
2. Frequency of observation possibly differs from (is lower than) frequency of network interactions

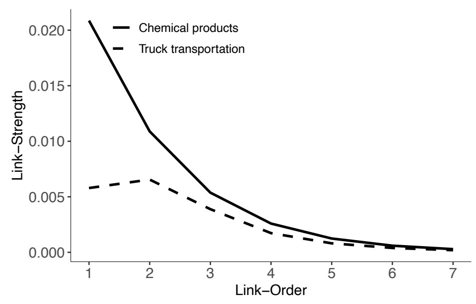
App. 1: Supply Chain Linkages & Sectoral Price Dynamics

- Macro literature: shocks to more central sectors have stronger aggregate effects
  - RBC economy, firms use inputs produced in same period
  - → Sectoral prices & output: $y = A\,y + \varepsilon$ (static model, contemp. network interactions)
- **How does network-position impact timing of effects?**
  - RBC economy where firms use inputs produced in past periods (Long & Plosser (1983), generalized)
  - → Sectoral prices & output follow NVAR
- Estimate α (timing of network effects) given A (US supply chain network)

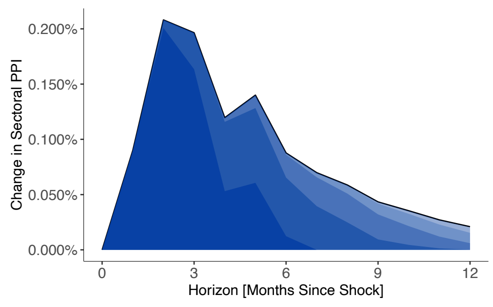
Timing of Network Effects



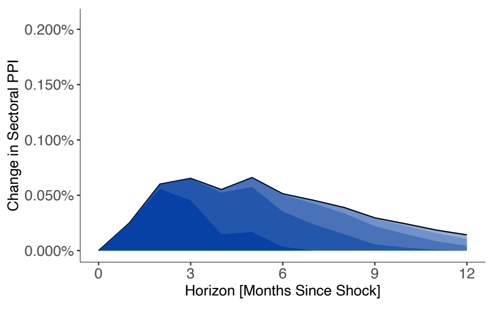
Network Links to Utilities Sector



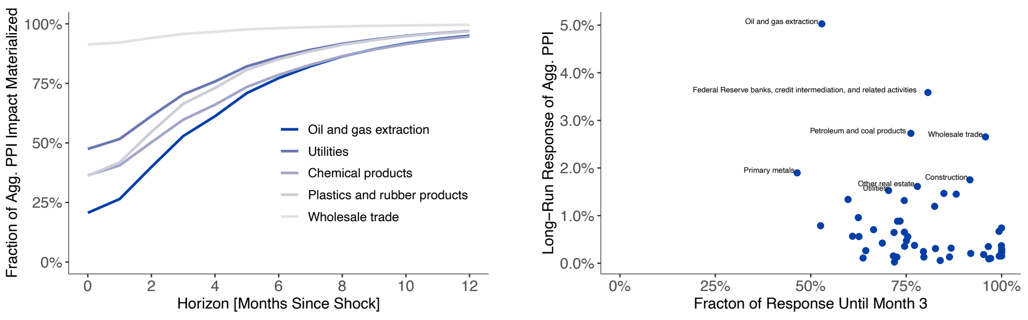
Price Chemicals ← Price Utilities



Price Truck Transp. ← Price Utilities



Size & Timing of Aggregate Price Response to Sectoral Shocks



- Shocks in sectors on top of supply chains (e.g. energy) take time to affect aggregate prices
- No clear relationship between strength and timing of effects

App. 2: Forecasting Cross-Country Industrial Production

- Unrestricted VAR not feasible (44 countries)
- **Use NVAR as sparse & flexible dimensionality-reduction technique** (estimate (α, A) jointly)
  - All dynamics driven by bilateral links
  - A can be sparse; even if $a_{ij} = 0$, dependence through $(A^2)_{ij}, (A^3)_{ij}, \ldots$
- NVAR captures cross-sectional dynamics better when driven by many micro links (not necessarily few influential units)
  - Equivalence result to factor models: # factors = rank(A)
- Beats PC factor model for IP growth, in particular for horizons < 6 months (MSE reductions up to -23%)

Out-of-Sample Forecasting Performance