Production Networks, Nominal Rigidities and the Propagation of Shocks

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Motivation 1/2

Fact 1: Economic sectors are heterogeneous in their input-output relationships with other sectors within the 'production network'.

Fact 2: Economic sectors are heterogeneous in their degree of price rigidities.

This paper studies the interaction of these two forms of heterogeneity on the propagation of shocks.

But which shocks?
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Literature

- **Monetary policy shocks**: Basu (AER 1996), Carvalho (Frontiers, 2006), Nakamura and Steinsson (QJE, 2010), Carvalho and Lee (mimeo, 2011)

Setup

Households’ utility:

\[
\max \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left( \frac{C_t^{1-\sigma} - 1}{1 - \sigma} - \sum_{k=1}^{K} g_k \frac{L_{kt}^{1+\varphi}}{1 + \varphi} \right) \quad \text{s.t.} \quad BC
\]

where

\[
C_t \equiv \left[ \sum_{k=1}^{K} \omega_c^{k} C_k^{1-\eta} \right]^{\eta/(\eta-1)}
\]

\[
C_{kt} \equiv \left[ n_k^{-1/\theta} \int_{\mathbb{S}_k} C_k^{1-\theta} d\mu \right]^{\theta/(\theta-1)}
\]
**Setup**

**Firms’ production function:**

\[ Y_{kjt} = A_{kt} L_{kjt}^{1-\delta} Z_{kjt}^{\delta}, \]

where

\[ Z_{kjt} \equiv \left[ \sum_{r=1}^{K} \omega_{kr} Z_{kjt} (r)^{1-\frac{1}{\eta}} \right]^{\frac{\eta}{\eta-1}}, \]

\[ Z_{kjt} (r) \equiv \left[ n_r^{-1/\theta} \int_{\mathcal{S}_r} Z_{kjt} (r, j')^{1-\frac{1}{\theta}} \, dj' \right]^{\frac{\theta}{\theta-1}}. \]

**Benchmark model:** \( \delta = 0, \) so \( \omega_{ck} = n_k. \)
## Setup

### Demands for sector \( k \), firm \( k, j \):

<table>
<thead>
<tr>
<th>from households:</th>
<th>from some firm ( k'j' ):</th>
</tr>
</thead>
<tbody>
<tr>
<td>( C_{kt} = \omega_{ck} \left( \frac{P_{kt}}{P_{ct}} \right)^{-\eta} C_t ),</td>
<td>( Z_{k'j't} (k) = \omega_{k'k} \left( \frac{P_{kt}}{P_{k't}} \right)^{-\eta} Z_{k'j't} ),</td>
</tr>
<tr>
<td>( C_{kjt} = \frac{1}{n_k} \left( \frac{P_{kjt}}{P_{kt}} \right)^{-\theta} C_{kt} ).</td>
<td>( Z_{k'j't} (k, j) = \frac{1}{n_k} \left( \frac{P_{kjt}}{P_{kt}} \right)^{-\theta} Z_{k'j't} (k) ).</td>
</tr>
</tbody>
</table>

where price aggregators are:

<table>
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<th>for households:</th>
<th>for other firms:</th>
</tr>
</thead>
<tbody>
<tr>
<td>( P_{ct} = \left[ \sum_{r=1}^{K} \omega_{cr} P_{rt}^{1-\eta} \right]^{\frac{1}{1-\eta}} ),</td>
<td>( P_{k't} = \left[ \sum_{r=1}^{K} \omega_{k'r} P_{rt}^{1-\eta} \right]^{\frac{1}{1-\eta}} ),</td>
</tr>
<tr>
<td>( P_{kt} = \left[ \frac{1}{n_k} \int_{\mathbb{S}<em>k} P</em>{rjt}^{1-\theta} dj \right]^{\frac{1}{1-\theta}} ).</td>
<td>( P_{kt} = \left[ \frac{1}{n_k} \int_{\mathbb{S}<em>k} P</em>{kjt}^{1-\theta} dj \right]^{\frac{1}{1-\theta}} ).</td>
</tr>
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</table>
Setup

Equilibrium conditions:

\[ Y_{kjt} = C_{kjt} + \sum_{k' = 1}^{K} \int_{\Omega_{k'}} Z_{k'j't}(k, j) \, dj', \]

\[ Y_t = C_t + Z_t \]

+ the usual equations:

- sectoral Calvo pricing,
- sectoral labor supply,
- production efficiency condition,
- Taylor rule, and
- standard equilibrium conditions.
The log-linear system

We solve for value-added output $c_t$ and sectoral prices $\{p_{kt}\}_{k=1}^{K}$.

- The IS+ Taylor rule:
  $$\sigma E_t c_{t+1} - (\sigma + \phi_c) c_t + E_t p_{t+1}^c - (1 + \phi_\pi) p_t^c + \phi_\pi p_{t-1}^c = \mu_t$$

- $K$ equations for sectoral prices:
  $$\beta E_t p_{kt} - (1 + \beta) p_{kt} + p_{kt-1} = \kappa_k (p_t - mc_{kt})$$

where $\kappa_k (1 - \alpha_k) (1 - \beta \alpha_k) / \alpha_k$. 
The role of I/O linkages: The Channels

Aggregate prices:

\[ p^c_t = \sum_{k=1}^{K} \omega_{ck} p_{kt}, \]

\[ p^k_t = \sum_{k'=1}^{K} \omega_{kk'} p_{k't} \]

Sectoral participation in total production (note: \( \psi = Z/Y \)):

\[ n_k = (1 - \psi) \omega_{ck} + \psi \sum_{k'=1}^{K} n_{k'} \omega_{k'k} \zeta_k \] for all \( k \).
The role of I/O likages: The effects

- Direct effect on marginal costs:

\[ mc_{kt} = (1 - \delta) w_{kt} + \delta p^k_t - a_{kt} \]

so lower \( p_{k't} \) implies lower \( mc_{kt} \) as \( \omega_{kk} \) is larger.

- Effect on sectoral wages:

\[ w_{kt} = \frac{1}{1 + \delta \phi} \left[ \varphi (y_{kt} - a_{kt}) + \sigma c_t + \delta \phi \left( p^k_t - p^c_t \right) \right] + p^c_t \]

so lower \( p_{k't} \) implies lower \( w_{kt} \) when as \( \omega_{kk'} > \omega_{ck'} \) is larger.
Effect on sectoral demand:

\[ y_{kt} = y_t - \eta \left( p_{kt} - \left( (1 - \psi) p_t^c - \psi \tilde{p}_t \right) \right) \]

so lower \( p_{k't} \) implies smaller \( y_k \) relative to \( y_t \) as \( \zeta_{k'} > \omega_{ck'} \) is larger since

\[ \tilde{p}_t = \sum_{k=1}^{K} \zeta_k p_{kt} \]
The role of I/O likages: The effects 3/3

- Effect on total demand:

\[ y_t = (1 - \psi) c_t + \psi z_t \]

such that

\[ y_t = c_t + \psi \left[ \Gamma_c (\delta) c_t - \Gamma_a \sum_{k'=1}^{K} n_{k'} a_{k't} - \Gamma_p (\tilde{p}_t - p_t^c) \right] \]

so lower \( p_{k't} \) implies higher \( z_t \), so higher \( y_t \) as \( \zeta_{k'} > \omega_{ck'} \) is larger.
The role of heterogeneous price rigidity

Sectoral prices:

\[ \beta \mathbb{E}_t [p_{kt+1}] - (1 + \beta) p_{kt} + p_{kt-1} = \kappa_k (p_{kt} - mc_{kt}) \]

Consumption aggregate prices:

\[ \beta \mathbb{E}_t [p^c_{t+1}] - (1 + \beta) p^c_t + p^c_{t-1} = \sum_{k=1}^K \kappa_k \omega_{ck} (p_{kt} - mc_{kt}) \equiv x_t \]

where

\[ \kappa_k = \frac{(1 - \alpha_k)(1 - \beta \alpha_k)}{\alpha_k} \]
Monetary shocks: Building intuition

\[-x_t = \Lambda_0 (\delta) \sum_{k=1}^{K} (\bar{\kappa} - \kappa_k) \omega_{ck} p_{kt} + \delta \Lambda_1 (\delta) \sum_{k=1}^{K} \kappa_k \omega_{ck} (p_t^k - p_t^c) + \psi \Lambda_2 (\delta) \bar{\kappa} \sum_{k=1}^{K} (\zeta_k - \omega_{ck}) p_{kt} + \Lambda_3 (\delta) \bar{\kappa} c_t \]

Monetary non-neutrality is stronger when

- Production needs intermediate inputs (Basu, 1995)
- Prices have heterogeneous price rigidities (Carvalho, 2006)
- Stickiest sectors are large suppliers of the most flexible sectors.
- Stickiest sectors are large suppliers in the economy.
### Monetary shocks: Calibration

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
</tr>
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<tbody>
<tr>
<td>$\beta = .9975$</td>
<td>Monthly disc factor to get 3% annual riskless int. rate</td>
</tr>
<tr>
<td>$\sigma = 1$</td>
<td>Relative risk aversion</td>
</tr>
<tr>
<td>$\varphi = 2$</td>
<td>Inverse of Frisch elasticity</td>
</tr>
<tr>
<td>$\delta = .5$</td>
<td>Average int inputs share in production function</td>
</tr>
<tr>
<td>$\eta = 2$</td>
<td>Elasticity of substitution across sectors</td>
</tr>
<tr>
<td>$\theta = 6$</td>
<td>Elasticity of substitution across firms within sectors</td>
</tr>
<tr>
<td>$\phi_{\pi} = 1.24$</td>
<td>Responsiveness of monetary policy to consumption infl.</td>
</tr>
<tr>
<td>$\phi_c = .33/12$</td>
<td>Responsiveness of monetary policy to GDP variations</td>
</tr>
<tr>
<td>$\rho = .9$</td>
<td>Persistence of shocks (the same to all of them)</td>
</tr>
</tbody>
</table>

Monetary shock: IRF for $\mu_t = 1$
Monetary shocks: Micro data

- I-O data: From the Input-Output tables (BEA) which reports the input share industry by industry.

- Prices data: From microdata underlying the PPI Index (BLS) matching goods in the BEA’s industry category.
Monetary shocks: Quantitative assessment

case1: flex prices; case0: hom. with $\delta = 0$, case2: hom. with $\delta = .5$, case3: het Calvo, Others: combinations of heterogeneity
Monetary shocks: Why?

Black: Term 1; Blue: Term 2; Red: Term 3.
Making the Taylor rule more sensitive to inflation

**case1**: flex prices; **case0**: hom. with $\delta = 0$, **case2**: hom. with $\delta = .5$, **case3**: het Calvo, **Others**: combinations of heterogeneity
Idiosyncratic shocks: A sketch

- Aggregate volatility depends on the distribution of \( \{ \omega_{ck} \}_{k=1}^K \)

- Aggregate volatility depends on the distribution of \( \{ \zeta_k \}_{k=1}^K \)

- These two dimensions interact with the distribution of price stickiness.

- Quantitative result: The effect of \( \{ \omega_{ck} \}_{k=1}^K \) dominates.
Final remarks

- Monetary non-neutrality: Everything is about heterogeneity of price stickiness (in an economy where intermediate inputs are needed for production.)

- Monetary non-neutrality: I/O linkages have bolder role when monetary policy reacts strongly to inflation.

- Aggregate volatility from idiosyncratic shocks: Everything is about the distribution of $\{\omega_{ck}\}_{k=1}^{K}$