Production Networks, Nominal Rigidities and the Propagation of Shocks

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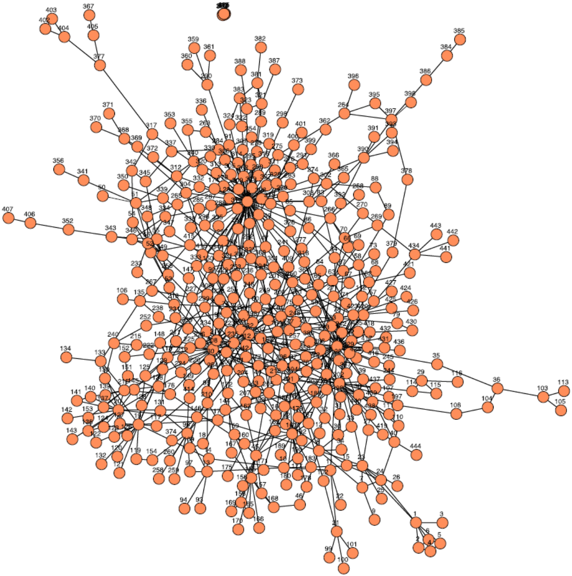
Motivation 1/2

- 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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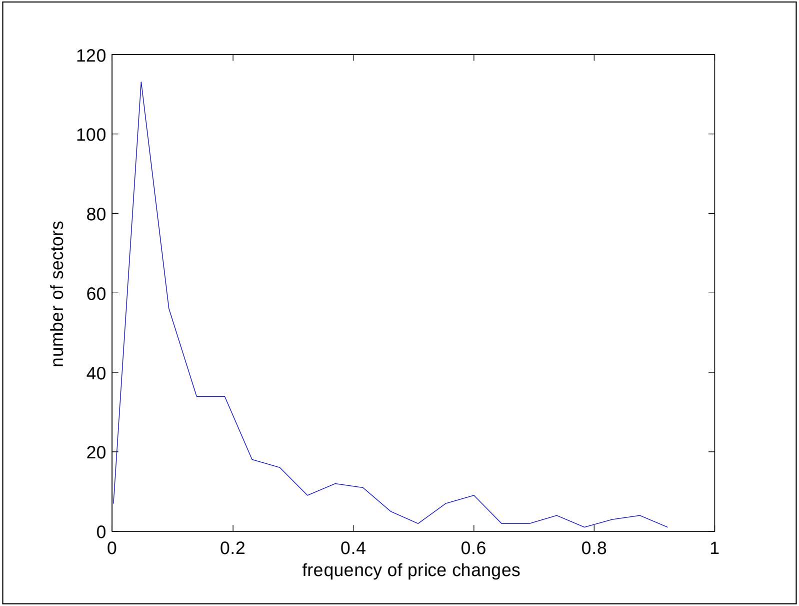

120
100
80
60
40
20
0
number of sectors
0
0.2
0.4
0.6
0.8
1
frequency of price changes

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Literature

- **Monetary policy shocks**: Basu (AER 1996), Carvalho (Frontiers, 2006), Nakamura and Steinsson (QJE, 2010), Carvalho and Lee (mimeo, 2011)
- **Aggregate volatility due to idiosyncratic volatility**: Lucas (Carnegie-Rochester CPP, 1977), Gabaix (Etrca, 2011), Acemoglu et al (Etrca, 2012), Acemoglu (mimeo, 2015).

Setup

Households' utility:

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

where

$$C_t \equiv \left[\sum_{k=1}^{K} \omega_{ck}^{\frac{1}{\eta}} C_{kt}^{1-\frac{1}{\eta}} \right]^{\frac{\eta}{\eta-1}},$$

$$C_{kt} \equiv \left[n_k^{-1/\theta} \int_{\Im_k} C_{kjt}^{1-\frac{1}{\theta}} dj \right]^{\frac{\theta}{\theta-1}}.$$

Setup

Firms' production function:

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

where

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

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

Benchmark model: $\delta = 0$, so $\omega_{ck} = n_k$.

Setup

Demands for sector k, firm k,j :

from households:	from some firm $k'j'$:
$C_{kt} = \omega_{ck} \left(\frac{P_{kt}}{P_t^c} \right)^{-\eta} C_t,$ $C_{kjt} = \frac{1}{n_k} \left(\frac{P_{kjt}}{P_{kt}} \right)^{-\theta} C_{kt}.$	$Z_{k'j't}(k) = \omega_{k'k} \left(\frac{P_{kt}}{P_t^{k'}} \right)^{-\eta} Z_{k'j't},$ $Z_{k'j't}(k,j) = \frac{1}{n_k} \left(\frac{P_{kjt}}{P_{kt}} \right)^{-\theta} Z_{k'j't}(k)$

where price aggregators are:

for households:	for other firms:
$P_t^c = \left[\sum_{r=1}^{K} \omega_{cr} P_{rt}^{1-\eta} \right]^{\frac{1}{1-\eta}},$ $P_{kt} = \left[\frac{1}{n_k} \int_{\Im_k} P_{rjt}^{1-\theta} dj \right]^{\frac{1}{1-\theta}}.$	$P_t^{k'} = \left[\sum_{r=1}^{K} \omega_{k'r} P_{rt}^{1-\eta} \right]^{\frac{1}{1-\eta}},$ $P_{kt} = \left[\frac{1}{n_k} \int_{\Im_k} P_{kjt}^{1-\theta} dj \right]^{\frac{1}{1-\theta}}.$

Setup

Equilibrium conditions:

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

$$Y_t = C_t + Z_t$$

$+$ 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 ouput c_t and sectoral prices $\{p_{kt}\}_{k=1}^{K}$.

- The IS+ Taylor rule:

$$\sigma \mathbb{E}_t c_{t+1} - (\sigma + \phi_c) c_t + \mathbb{E}_t p^c_{t+1} - (1 + \phi_\pi) p^c_t + \phi_\pi p^c_{t-1} = \mu_t$$

- K equations for sectoral prices:

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

where $\kappa_k (1 - \alpha_k)(1 - \beta\alpha_k) / \alpha_k$.

The role of I/O linkages: The Channels

Aggregate prices:

$$p_t^c = \sum_{k=1}^{K} \omega_{ck} p_{kt},$$

$$p_t^k = \sum_{k'=1}^{K} \omega_{kk'} p_{k't}$$

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

$$n_k = (1-\psi)\,\omega_{ck} + \psi \underbrace{\sum_{k'=1}^{K} n_{k'}\omega_{k'k}}_{\zeta_k} \text{ for all } k.$$

The role of I/O likages: The effects

- Direct effect on marginal costs:

$$mc_{kt} = (1 - \delta) w_{kt} + \delta p_t^k - a_{kt}$$

so lower $p_{k't}$ implies lower mc_{kt} as ω_{kk} is larger.

- Effect on sectoral wages:

$$w_{kt} = \frac{1}{1 + \delta\varphi} \left[\varphi (y_{kt} - a_{kt}) + \sigma c_t + \delta\varphi \left(p_t^k - p_t^c \right) \right] + p_t^c$$

so lower $p_{k't}$ implies lower w_{kt} when as $\omega_{kk'} > \omega_{ck'}$ is larger.

The role of I/O likages: The effects 2/3

- Effect on sectoral demand:

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

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

$$\widetilde{p}_t = \sum_{k=1}^{K} \zeta_k p_{kt}$$

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

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

so lower $p_{k't}$ implies higher z_t, so higher y_t as as $\zeta_{k'} > \omega_{ck'}$ is larger.

The role of heterogeneous price rigidity

Sectoral prices:

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

Consumption aggregate prices:

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

where

$$\kappa_k = \frac{(1-\alpha_k)(1-\beta\alpha_k)}{\alpha_k}$$

Monetary shocks: Building intuition

$$
\begin{aligned}
-x_t \quad = \quad & \Lambda_0 (\delta) \sum_{k=1}^{K} (\overline{\kappa} - \kappa_k) \omega_{ck} p_{kt} + \delta \Lambda_1 (\delta) \sum_{k=1}^{K} \kappa_k \omega_{ck} \left(p_t^k - p_t^c \right) \\
& + \psi \Lambda_2 (\delta) \overline{\kappa} \sum_{k=1}^{K} (\zeta_k - \omega_{ck}) p_{kt} + \Lambda_3 (\delta) \overline{\kappa} c_t
\end{aligned}
$$

Monetary non-neutrality is stronger when

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

Monetary shocks: Calibration

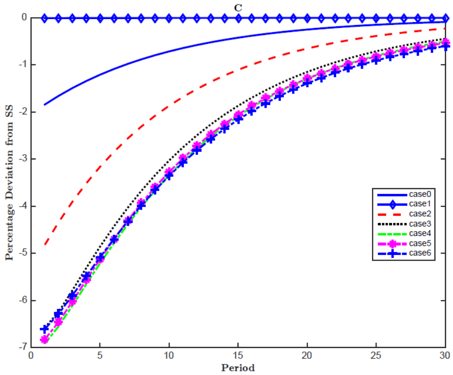
$\beta = .9975$	:	Monthly disc factor to get 3% annual riskless int. rate
$\sigma = 1$	:	Relative risk aversion
$\varphi = 2$	:	Inverse of Frisch elasticity
$\delta = .5$	:	Average int inputs share in production function
$\eta = 2$	:	Elasticity of substitution across sectors
$\theta = 6$	:	Elasticity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

Monetary shock: IRF for $\mu_t = 1$

Monetary shocks: Micro data

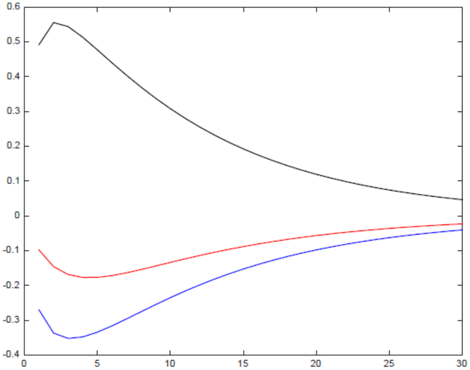
- I-O data: From the Input-Output tables (BEA) which reports the input share industry by industry.
- Prices data: From microdata undelying the PPI Index (BLS) matching goods in the BEA's industry category.

Monetary shocks: Quantitative assessment



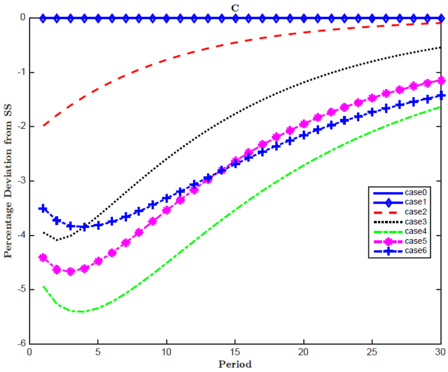
case1: flex prices; **case0:** hom. with $\delta = 0$, **case2**: hom. with $\delta = .5$,
case3: het Calvo, **Others**: combinations of heterogeneity

Monetary shocks: Why?



Black: Term 1; **Blue**: Term 2; **Red**: Term 3.

Making the Taylor rule more sensitive to inflation



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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 $\{\omega_{ck}\}_{k=1}^{K}$