Price Rigidity and the Granular Origin of Aggregate Fluctuations

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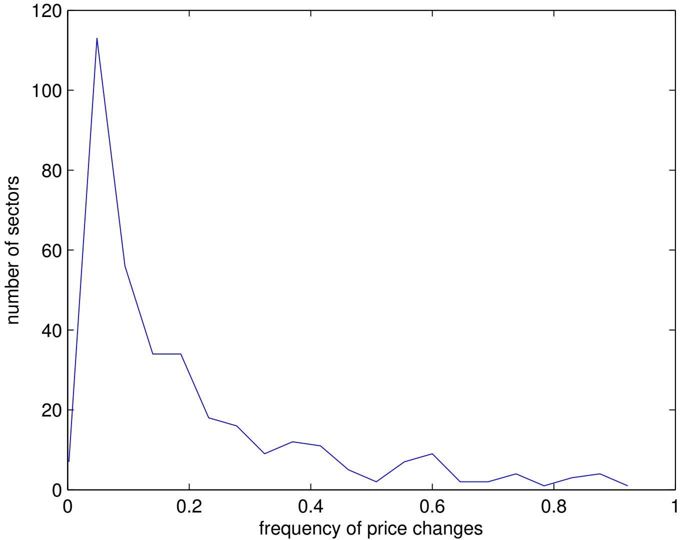
Motivation

- *Micro shocks may drive aggregate fluctuations* when
  - some sectors (or firms) are **large** [Gabaix, Ecta '11].
  - some sectors (or firms) are **central** in the production network [Acemoglu et al, Ecta '12].
  - shocks propagate through prices
  - How does price ridigity affect potency of idiosyncratic shocks to contribute to aggregate fluctuations?

There is substantial heterogeneity in price rigidity



Motivation

- *Micro shocks may drive aggregate fluctuations* when
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  - some sectors (or firms) are **central** in the production network [Acemoglu et al, Ecta '12].
  - shocks propagate through prices
- **Sectors also have substantial heterogeneous price rigidity...**

How does price rigidity affect the micro origin of agg. fluctuations?

Motivation: Abstract level

- How does the interaction of heterogeneity of agents and frictions affect the propagation of shocks into economic aggregates? (Related: How useful is a representative agent model?)
- Shocks:
  - Idiosyncratic
  - Aggregate
- This paper: effect of idiosyncratic shocks on GDP through lens of heterogeneous size + networks + price rigidity

Preview: What we do

- Study the effect of sectoral productivity shocks on GDP volatility in a multi-sector new-Keynesian model with heterogeneous GDP shares, I/O linkages, and price rigidity (measurable friction).
  - Theoretically, with a simple form of price rigidity.
  - Quantitatively, calibrated for the US to 348 sectors using *Calvo*.

Preview: What we find

- Price rigidity distorts the **identity** of sectors from which aggregate fluctuations originate.

- Price rigidity distorts the **size** of aggregate volatility and **rate** of convergence that micro shocks generate:

  Size increase between 38% and 116%.

- Is there a *frictional* origin of aggregate fluctuations?

Literature review

- **Aggregate fluctuations**: Long and Plosser (JPE 1983), Horvath (RED 1998, JME 2000), Dupor (JME 1999), Gabaix (Ecta 2011), Acemoglu et al. (various papers), Carvalho & Gabaix (AER 2013), Fouerst, Sarte and Watson (JPE 2011), Di Giovanni, Levchenko & Mejean (Ecta 2014), etc.
- **Monetary shocks**: Basu (AER 1995), Carvalho & Lee (mimeo), Nakamura & Steinsson (QJE 2010), Ozdagli & Weber (2016), Pasten, Schoenle & Weber (2016), etc.
- **Role of frictions**: Baqaae (mimeo), Bigio & Lao (mimeo), Carvalho & Grassi (mimeo).

Main idea (simplified model)

- Continuum of differentiated goods $j \in [0,1]$.
- One firm produces one good; firms belong to K sectors.
- Households: $u(C_t, L_t) = \log(C_t) - L_t$ where

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

- Firms: $Y_{jkt} = A_{kt} L_{jkt}^{1-\delta} Z_{jkt}^{\delta}$ where

$$Z_{jkt} \equiv \left[\sum_{k'=1}^{K} \omega_{kk'}^{\frac{1}{\eta}} Z_{jkt}(k')^{1-\frac{1}{\eta}}\right]^{\frac{\eta}{\eta-1}} \to Z_{jkt}(k') = \omega_{kk'}\left(\frac{P_{k't}}{P_t^k}\right)^{-\eta} Z_{jkt}$$

- Monetary policy is $\overline{P_t^c C_t}$.

Main idea [in log-deviations]

- Marginal costs of firms in sector k are

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

where

$$p_t^k \equiv \sum_{k'=1}^{K} \omega_{kk'} p_{k't}, \qquad \omega_{kk'} \equiv \frac{Z_k\,(k')}{Z_k}$$

- Since labor disutility is linear

$$w_t = p_t^c + c_t$$

where

$$p_t^c \equiv \sum_{k'=1}^{K} \omega_{ck'} p_{k't}, \qquad \omega_{ck'} \equiv \frac{C\,(k')}{C}$$

Main idea [in log-deviations]

- Monetary policy is such that

$$p_t^c + c_t = 0 = w_t$$

- The price of a firm j in sector k ($\beta = 0$) is such

$$p_{jkt} = \begin{cases} p_{kt}^* & \text{prob. } 1 - \lambda_k \\ \mathbb{E}_{t-1}\left[p_{kt}^*\right] & \text{prob. } \lambda_k \end{cases}$$

- If sectoral shocks $\{a_k\}$ are iid, $p_{kt}^* = mc_{kt}$, so

$$p_{kt} = (1 - \lambda_k)\left[\delta p_t^k - a_{kt}\right]$$

$$\rightarrow c_t = \Omega_c' \left[\mathbb{I} - \delta\left(\mathbb{I} - \Lambda\right)\Omega\right]^{-1}\left(\mathbb{I} - \Lambda\right) a_t = \chi' a_t$$

$\Omega_c \equiv \left[\omega_{ck}\right]'$: vector of GDP shares.
$\Omega \equiv \left[\omega_{kk'}\right]$: matrix of I/O linkages.
$\Lambda \equiv \{\lambda_k\}$: diag matrix of price rigidity.

Price rigidity and the Granular effect

Next: "Gabaix" effect revisited

Effect of homogeneous/heterogeneous price rigidity on output volatility given size heterogeneity

Price rigidity and the Granular effect 1/4

- Assume $\delta = 0$ and $\lambda_k = \lambda$ for all k,

$$\chi = (1 - \lambda)\,\Omega_c \rightarrow \sigma_c = (1 - \lambda)\,\sigma_a \sqrt{\sum_{k=1}^{K} \omega_{ck}^2}$$

  so, if $\omega_{ck} = C_k / C = 1/K$ for all k,

$$\sigma_c = \frac{(1 - \lambda)\,\sigma_a}{K^{1/2}}$$

- Level effect of price flexibility.

Price rigidity and the Granular effect 2/4

- More generally, $\omega_{ck} = C_k / C$ so that

$$\sigma_c = \frac{(1-\lambda)\sigma_a \sqrt{\sigma_{ck} + {\mu_{ck}}^2}}{K^{1/2}\mu_{ck}}$$

  As in Gabaix: sector size distribution affects GDP volatility.

- Rate of convergence: if $\Pr\left[C_k > x\right] = \gamma x^{-\beta_c}$ for $x \geq \gamma^{1/\beta_c}$, $\gamma > 0$,

$$\sigma_c \sim \begin{cases} \frac{u_0}{K^{1/2}} & \text{for } \beta_c > 2 \\ \frac{u_0}{K^{1-1/\beta_c}} & \text{for } \beta_c \in (1,2) \\ \frac{u_0}{\log K} & \text{for } \beta_c = 1 \end{cases}$$

- No effect of price rigidity on convergence.

Price rigidity and the Granular effect 3/4

- Assume now that $\delta = 0$ and $\{\lambda_k\}$ are heterogeneous,

$$\chi = (\mathbb{I} - \Lambda)\,\Omega_c \to \sigma_c = \sigma_a \sqrt{\sum_{k=1}^{K} \left[(1-\lambda_k)\,\omega_{ck}\right]^2}$$

so, if $\omega_{ck} = C_k / C = 1/K$ for all k,

$$\sigma_c = \frac{\sigma_a}{K^{1/2}} \sqrt{\sum_{k=1}^{K} (1-\lambda_k)^2}$$

- Price rigidity distorts "Gabaix" effect (e.g. $\lambda_k = 1$) + changes identity of sectoral contribution.
- Dispersion increases volatility.

Price rigidity and the Granular effect 4/4

- More generally, now convolution determines GDP volatility

$$\sigma_c = \frac{\sigma_a \sqrt{\sigma_{ck \times \lambda_k} + [(1-\bar{\lambda})\mu_{ck} - cov(\lambda_k, C_k)]^2}}{K^{1/2}\mu_{ck}}$$

- Rate of convergence: if $\Pr\left[(1-\lambda_k)\, C_k > x\right] = \gamma x^{-\beta_{\lambda c}}$,

$$\sigma_c \sim \begin{cases} \frac{u_1}{K^{1/2}} & \text{for } \beta_{\lambda c} > 2 \\ \frac{u_1}{K^{1-1/\beta_{\lambda c}}} & \text{for } \beta_{\lambda c} \in (1,2) \\ \frac{u_1}{\log K} & \text{for } \beta_{\lambda c} = 1 \end{cases}$$

- Price rigidity affects convergence
- Exact effect: complicated.
  - In case of independence, there is no effect of price rigidity on convergence/tail (λ_k bounded).

Price rigidity and the Granular effect: Take-Away

- Price rigidity has a **level** effect on aggregate volatility.
- Price rigidity distorts the **identity** of sectors where aggregate fluctuations originate from.
- Price rigidity distorts the **size** of aggregate volatility from that which micro shocks generate.

Price rigidity and the Network effect

Next: Network effect revisited

Effect of homogeneous/heterogeneous price rigidity on output volatility given network heterogeneity

Price rigidity and the Network effect 1/5

- Assume $\omega_{ck} = 1/K$ and $\lambda_k = \lambda$ for all k,

$$\chi = \frac{1}{K}(1-\lambda)\left[\mathbb{I} - \delta(1-\lambda)\Omega'\right]^{-1}\iota$$

so, if Ω is homogeneous, $\Omega_{kk'} = 1/K$,

$$\sigma_c = \frac{(1-\lambda)\sigma_a}{(1-\delta(1-\lambda))K^{1/2}}$$

- Level effect of price flexibility, additional network multiplier.
- More generally, for unconstrained Ω:

$$\chi \geq \frac{1}{K}(1-\lambda)\left[\iota + \delta(1-\lambda)d + \delta^2(1-\lambda)^2 q\right],$$

$$\text{(outdegrees)} \quad d_k \equiv \sum_{k'=1}^{K} \omega_{k'k},$$

$$\text{(2nd-order outdegrees)} \quad q_k \equiv \sum_{k'=1}^{K} d_{k'}\omega_{k'k}$$

Price rigidity and the Network effect 2/5

$$\chi \geq \frac{1}{K}(1-\lambda)\left[\iota + \delta(1-\lambda)\, d + \delta^2 (1-\lambda)^2\, q\right]$$

- Since $\sigma_c = \|\chi\|\,\sigma_a$, price rigidity has a level effect on the contribution via the outdegrees and (quadratically) via the 2nd-order outdegrees on aggregate volatility.
- Quantitatively, large network asymmetries imply large level effects of price flexibility.
- Empirically, second-order outdegrees interact strongest with price flexibility ($\hat{q} > \hat{d}$).

Price rigidity and the Network effect 3/5

- Rate of convergence: if $\Pr\left[d_k > x\right] = \gamma_d x^{-\beta_d}$ and $\Pr\left[q_k > x\right] = \gamma_q x^{-\beta_q}$

$$\sigma_c \sim \begin{cases} \frac{u_2}{K^{1/2}} & \text{for } \min\left\{\beta_d, \beta_q\right\} > 2 \\ \frac{u_2}{K^{1-1/\min\left\{\beta_d,\beta_q\right\}}} & \text{for } \min\left\{\beta_d, \beta_q\right\} \in (1,2) \\ \frac{u_2}{\log K} & \text{for } \min\left\{\beta_d, \beta_q\right\} = 1 \end{cases}$$

- Price rigidity does not affect the rate of convergence.

Price rigidity and the Network effect 4/5

- Assume now $\{\lambda_k\}$ are heterogeneous,

$$\chi \geq \frac{1}{K} (\mathbb{I} - \Lambda) \left[\iota + \delta \widetilde{d} + \delta^2 \widetilde{q} \right]$$

where

$$\text{(mod. outdegrees)} \quad \widetilde{d}_k \equiv \sum_{k'=1}^{K} (1 - \lambda_{k'}) \, \omega_{k'k},$$

$$\text{(mod. 2nd-order outdegrees)} \quad \widetilde{q}_k \equiv \sum_{k'=1}^{K} (1 - \lambda_{k'}) \, \widetilde{d}_{k'} \omega_{k'k}.$$

- Recall that $\sigma_c = \|\chi\| \, \sigma_a$, so price rigidity affects aggregate volatility given K.
- Price rigidity affects the identity of sectoral contributions.

Price rigidity and the Network effect 5/5

Complicated expression for $\|\chi\|_2$, containing functions of:

- $\tilde{q}$: large suppliers of most flexible sectors?
- $\tilde{d}$: large suppliers of most flexible sectors who are large suppliers of most flexible sectors?
- Covariance terms between flexibility and $\tilde{q}_k$, $\tilde{d}_k$.

Rate of convergence:

- If sectors with the most sticky prices are also the most central such that $min\{\tilde{\beta}_d, \tilde{\beta}_q\} > min\{\beta_d, \beta_q\}$, then faster convergence than under homogeneous prices or independence of centrality measures.

Price rigidity and the Network effect: Take-Away

- Price rigidity has a **level** effect on aggregate volatility.
- Price rigidity distorts the **identity** of sectors where aggregate fluctuations originate from.
- Price rigidity distorts the **rate** of convergence.

Ultimately an empirical question.

Quantitative model

- Replace simple rigidity with Calvo.
- Data sources: 2002 National Accounting (BEA) + PPI data (BLS):
  - Total number of sectors: **348**.
  - Ω_c matches **sectoral fraction of total value-added output**.
  - Ω matches the **input-output matrix**.
  - Calvo parameters match the **frequency of price changes**.
- Other parameters: $\beta = .9975$, $\delta = .5$, $\eta = 2$, $\theta = 6$.

Price rigidity amplifies the effect of micro shocks

on aggregate volatility relative to aggregate shocks

	flex prices	het prices
hom GDP + hom IO:	5.4%	10.8%

- Price rigidity strongly amplifies the Gabaix effect; a bit less the network effect.
- Is there a frictional origin of aggregate fluctuations?

Price rigidity amplifies the effect of micro shocks

on aggregate volatility relative to aggregate shocks

	flex prices	het prices
hom GDP + hom IO:	5.4%	10.8%
het GDP + hom IO:	11%	23.8%

- Price rigidity strongly amplifies the Gabaix effect; a bit less the network effect.
- Is there a frictional origin of aggregate fluctuations?

Price rigidity amplifies the effect of micro shocks

on aggregate volatility relative to aggregate shocks

	flex prices	het prices
hom GDP + hom IO:	5.4%	10.8%
het GDP + hom IO:	11%	23.8%
hom GDP + het IO:	7.9%	11.5%

- Price rigidity strongly amplifies the Gabaix effect; a bit less the network effect.
- Is there a frictional origin of aggregate fluctuations?

Price rigidity amplifies the effect of micro shocks

on aggregate volatility relative to aggregate shocks

	flex prices	het prices
hom GDP + hom IO:	5.4%	10.8%
het GDP + hom IO:	11%	23.8%
hom GDP + het IO:	7.9%	11.5%
het GDP + het IO:	17.4%	24%

- Price rigidity strongly amplifies the Gabaix effect; a bit less the network effect.
- Is there a frictional origin of aggregate fluctuations?

Price rigidity distorts the identity/relative contribution

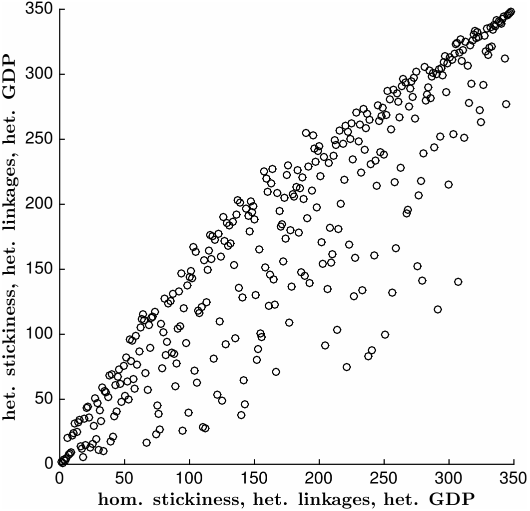
of the most important sectors for aggregate fluctuations

hom GDP + het IO		hom GDP + het IO + het prices	
25.2%	(Real estate)	6.7%	(Petroleum Ref)
9.4%	(Retail trade)	6.5%	(Oil & gas extraction)
3.6%	(Wholesale trd)	5.9%	(Cattle ranch & farm'g)

het GDP + het IO		het GDP + het IO + het prices	
33.9%	(Real estate)	32.8%	(Wholesale trd)
16.7%	(Wholesale trd)	19.3%	(Real estate)
10.27%	(Retail trade)	12.1%	(credit interm.)

- Network: Strong effect on identity.
- Gabaix/Overall: Strong effect on relative contribution.

Effect on Identity



Large effect of heterogeneity in price stickiness on sector importance ranks.

Robustness

- Add curvature to disutility of labor such that inverse Frisch elasticity equals 2.
- Allow for sectorally segmented labor markets.
- Replace simple monetary policy rule $\overline{P_t^c C_t}$ by standard Taylor rule.

Results remain unchanged.

Powerful mechanism

$$corr(\Omega_c, FPA) = 5.1\% \quad (6.7\%)$$

$$corr(out, FPA) = 18.8\% \quad (22.6\%)$$

$$corr(out2, FPA) = 22.2\% \quad (33.3\%)$$

More complicated mechanism than simple correlations suggest.

Final Remarks

- Price rigidity has a **level** effect on aggregate volatility.
- Price rigidity distorts the **identity** of sectors where aggregate fluctuations originate from.
  - Monetary policy implications.
- Price rigidity distorts the **size** of aggregate volatility and **rate** of convergence that micro shocks generate.
- Is there a *frictional* origin of aggregate fluctuations?