Price Rigidity and the Granular Origin of Aggregate Fluctuations

Ernesto Pasten
Central Bank of Chile & Toulouse SoE

Raphael Schoenle
Brandeis University

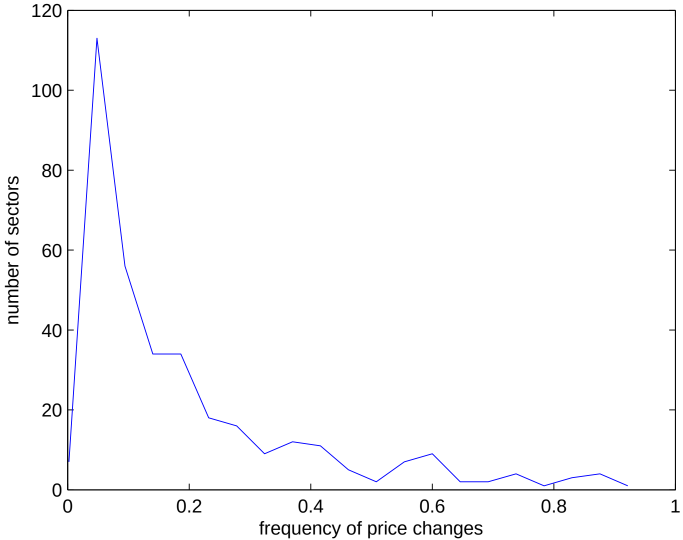
Michael Weber
University of Chicago & NBER

June 19, 2017

Motivation

- *Micro shocks may drive aggregate fluctuations* when
  - some sectors (or firms) are **large**
    (Gabaix, Ecma (2011))
  - some sectors (or firms) are **central** in the production network
    (Acemoglu et al, Ecma (2012))
- Shocks propagate through *prices*
- How does price rigidity affect the micro origin of agg. fluctuations?

Substantial Heterogeneity in Price Rigidity



Motivation cont.

- *Micro shocks may drive aggregate fluctuations* when
  - some sectors (or firms) are **large**
    (Gabaix, Ecma (2011))
  - some sectors (or firms) are **central** in the production network
    (Acemoglu et al, Ecma (2012)).
- shocks propagate through prices
- Large heterogeneity in price rigidity across sectors
- 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
- Multi-sector new-Keynesian model
- Heterogeneous GDP shares, I/O linkages, and price rigidity
  - Theoretically, with a simple form of price rigidity
  - Quantitatively, calibrated to the US to 348 sectors using *Calvo*

Preview: What we find

- Price rigidity changes **sectors** driving aggregate fluctuations
- Price rigidity distorts **rate** of convergence
- Price rigidity distorts **size** of aggregate volatility
  - 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 (Ecma 2011), Acemoglu et al. (various papers), Carvalho & Gabaix (AER 2013), Fouerst, Sarte and Watson (JPE 2011), Di Giovanni, Levchenko & Mejean (Ecma 2014), etc.

- **Monetary shocks**: Basu (AER 1995), Carvalho & Lee (mimeo), Nakamura & Steinsson (QJE 2010), Ozdagli & Weber (mimeo), Pasten, Schoenle & Weber (mimeo), etc.

- **Role of frictions**: Baqaee (mimeo), Bigio & La'O (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

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

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

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

- 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

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

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

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

Price rigidity and the Granular effect

Next: "Gabaix" effect revisited

- Take size heterogeneity as given
- Effect of homog / heterog price rigidity on output volatility

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 $\Pr[C_k > x] = \gamma x^{-\beta_c}$ 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,

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

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 from where aggregate fluctuations originate
- Price rigidity distorts the **size** of aggregate volatility from that which micro shocks generate

Price rigidity and the Network effect

Next: Network effect revisited

- Take network heterogeneity as given
- Effect of homog / heterog price rigidity on output volatility

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 $\Longrightarrow$ large level effects

- Empirically, 2^{nd} 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

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

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

- 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
  - $min\{\tilde{\beta}_d, \tilde{\beta}_q\} > min\{\beta_d, \beta_q\}$,
- then faster convergence than under homog 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 from where aggregate fluctuations originate
- 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 generates aggregate fluctuations from micro shocks
- Price rigidity strongly amplifies the Gabaix effect
- Price rigidity strongly amplifies 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:	11.0%	23.8%

- Price rigidity generates aggregate fluctuations from micro shocks
- Price rigidity strongly amplifies the Gabaix effect
- Price rigidity strongly amplifies 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:	11.0%	23.8%
hom GDP + het IO:	7.9%	11.5%

- Price rigidity generates aggregate fluctuations from micro shocks
- Price rigidity strongly amplifies the Gabaix effect
- Price rigidity strongly amplifies 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:	11.0%	23.8%
hom GDP + het IO:	7.9%	11.5%
het GDP + het IO:	17.4%	24.0%

- Price rigidity generates aggregate fluctuations from micro shocks
- Price rigidity strongly amplifies the Gabaix effect
- Price rigidity strongly amplifies the network effect
- Is there a frictional origin of aggregate fluctuations?

Price rigidity distorts the identity/relative contribution

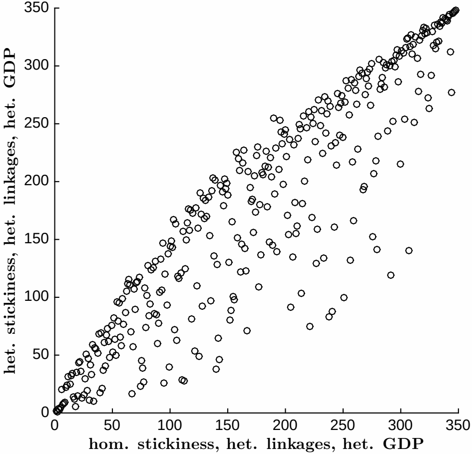
of the most important sectors for aggregate fluctuations

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 heterog in price stickiness on sector importance ranks

Robustness

- Add curvature to disutility of labor
- 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 **sectors** driving aggregate fluctuations
  - Monetary policy implications
- Price rigidity distorts the **size** of aggregate volatility
- Price rigidity distorts **rate** of convergence micro shocks generate
- Is there a *frictional* origin of aggregate fluctuations?