Small and large price changes and the propagation of monetary shocks

Fernando Alvarez , Hervé Le Bihan , Francesco Lippi

University of Chicago & NBER , Banque de France , EIEF & University of Sassari

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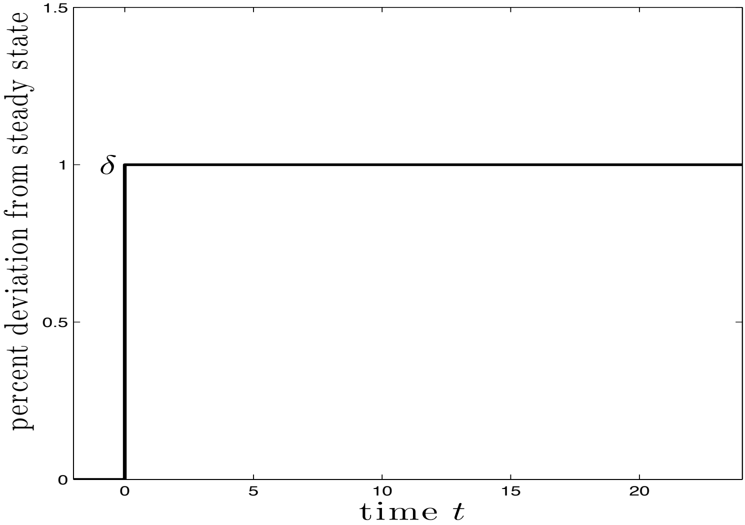
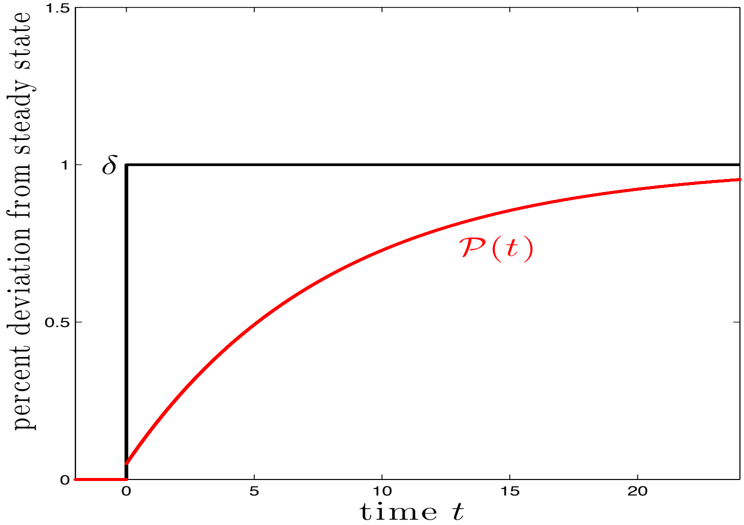
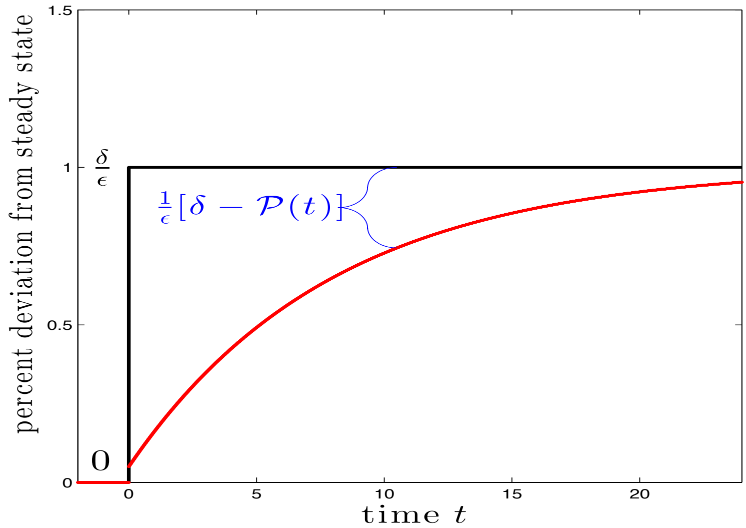
Once and for all monetary shock at $t = 0$.



Impulse response of Price Level

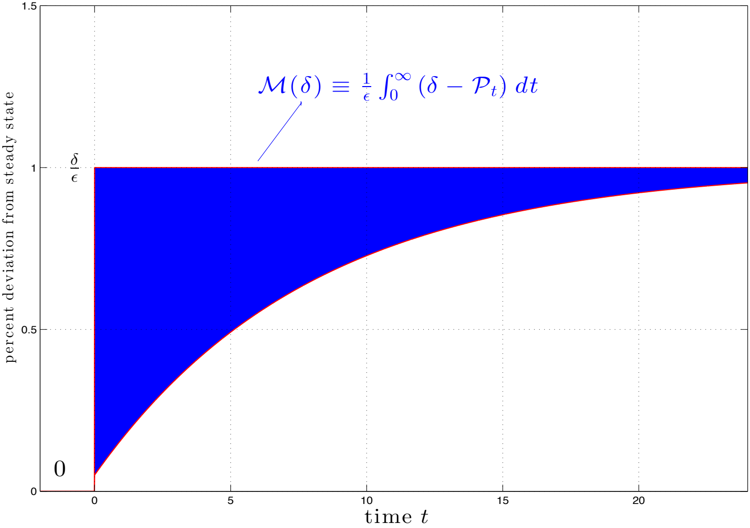


Impulse response of output $d \log c_t = \frac{1}{\epsilon} d \log(M_t / P_t)$

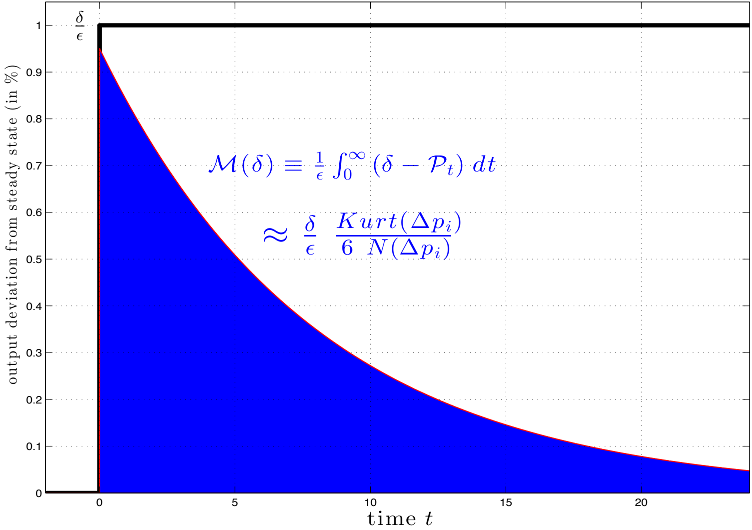


Area under impulse response of output: $\mathcal{M}$

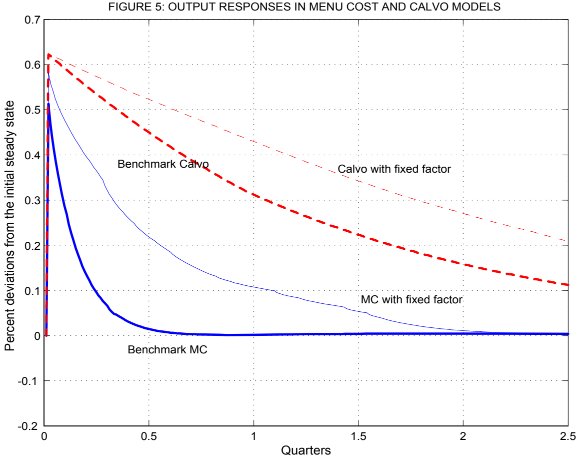
back



Area under impulse response of output: $\mathcal{M}$



Range of effects: $\mathcal{M}_{Calvo} \;/\; \mathcal{M}_{GL} \;\approx\; 6$



source: Golosov-Lucas 2008

More Models: Reis / Taylor 1980, Nakamura-Steinsson 2010, Midrigan 2011

All models same $N(\Delta p_i)$; differences due to "selection" effects (Kurtosis)

Our contribution

- Class of stylized menu-cost models:

  (random) menu cost, multi-product, rational inattentiveness.

- $\mathcal{M}(\delta) \equiv$ cumulative IRF of output to a (small) monetary shock δ

$$\mathcal{M}(\delta) \approx \frac{\delta}{\epsilon} \, \frac{Kurt(\Delta p_i)}{6 \, N(\Delta p_i)}$$

  - Frequency of price changes $N(\Delta p_i)$ has a first order effect,
  - Kurtosis price changes $Kurt(\Delta p_i)$ has a first order effect.

- Result in the spirit of “Sufficient Statistic Approach" (useful to macro)

- Gather and evaluate empirical measures of $Kurt(\Delta p_i) \approx 4.5$
- Evaluate magnitude of implied adjustment/menu cost.

Micro evidence: overview

- We explore several datasets

  CPI (French, US, Norway), scanner price (US), Internet scraped data

- Excess Kurtosis due to small and large $\Delta p_{i,j,t}$ (Kashyap, 1995)

- Excess Kurtosis attenuated but still positive after correcting for:

  (1) heterogeneity $\rightarrow$ standardize price changes: $\frac{\Delta p_{i,j,t} - m_{i,j}}{\sigma_{i,j}}$

  standardization at the good-i $\times$ store-j level

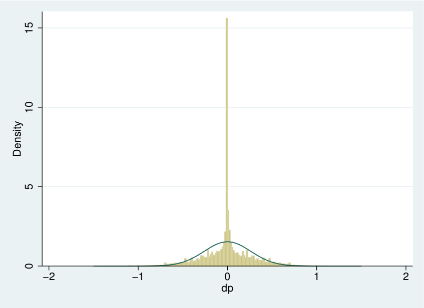
  (2) measurement error $\rightarrow$ compare datasets and trimming

  CPI vs scanner data , or trim $\Delta p_i < 1$ ct

Same scanner data as Eichenbaum et al (2011)

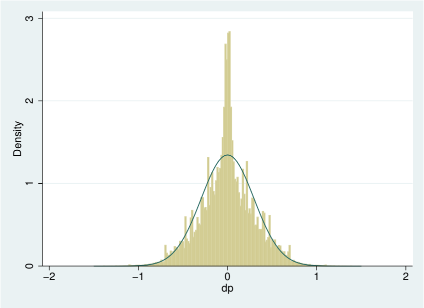
Size distribution of non-zero Δp_i (based on average weekly prices)

All Δp_i



kurtosis = 4.9 ; 11 million obs.

trim $|\Delta p_i| < 1$ dollar cent

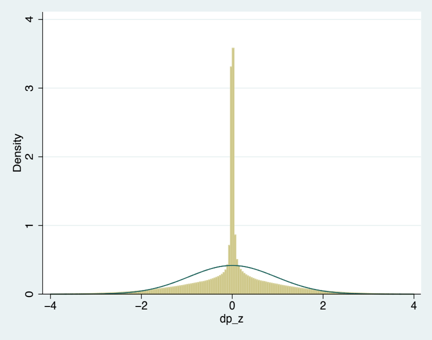


kurtosis = 3.8 ; 8.5 million obs.

- Based upon: Average Weekly prices.
- Lots of price changes smaller than 1 cent! (left panel)

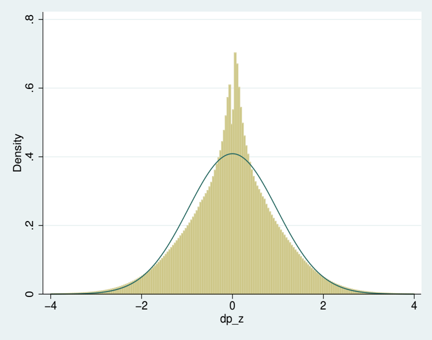
US: IRI-Symphony scanner data

All Δp_i



kurtosis = 34.3 ; 820 million obs.

Standardized & trimmed

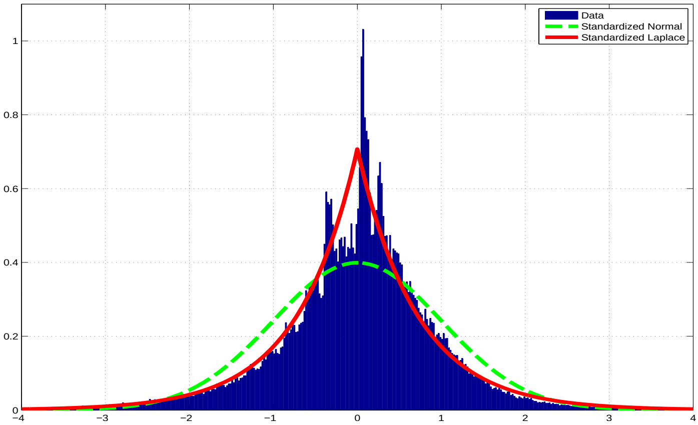


kurtosis = 4.3 ; 610 million obs.

- Large data set: 3,000 stores x 40,000 products x 10 years
- Average weekly prices

French CPI data 2003-2011

size distribution; Standardized and trimmed; 1.5 million obs.



$Std(\Delta p_i) = 16\%$; kurtosis = 8.9

Measurement error: CPI vs Scraped Data (France)

- CPI very broad, but subject to measurement error:

  Eichenbaum et all: spurios small price changes in CPI and scanner data.

- Our approach:
  - Compare “error free" data for selected products with CPI.
  - Use internet scrapped data for France.
  - Match type of goods/outlet with CPI.
  - Use simple measurement error model to extrapolate to whole CPI.

- Conclusion: kurtosis is about half.

Summary of evidence

Once x-section heterogeneity removed, the data show

- evidence of measurement error (“spurious” Δp_i)
  overestimate Kurtosis on CPI data
- distribution of Δp_i peaked in both the US and France
  between Normal (kurt $\approx$ 4 in US) and Laplace (kurt $\approx$ 5 in FR)
- no big differences between sales vs no-sales size distribution

▸ Sales-vs-nonsales ▸ US-vs-France ▸ CPI-vs-scraped data ▸ CPI-vs-scanner data

The model economy

Lifetime Utility : $$\int_0^{\infty} e^{-r\,t} \left(\frac{c(t)^{1-\epsilon} - 1}{1-\epsilon} - \alpha\, \ell(t) + \log \frac{M(t)}{P(t)} \right) dt$$

CES aggregate : $$c(t) = \left(\int_0^1 \sum_{i=1}^{n} (\, Z_{ki}(t)\, c_{ki}(t)\,)^{1-\frac{1}{\eta}} dk \right)^{\frac{\eta}{\eta-1}}$$

- Intratemporal η (= for firms k & products i).
- Linear technology $c_{ki}(t) = \ell_{ki}(t) \,/\, Z_{ki}(t)$ and $Z_{ki}(t) = \exp(\sigma\, \mathcal{W}_{ki}(t))$.
- Household problem:
  - demand for monopolist competitive firms, idiosyncratic pref. shocks $Z_{ki}(t)$
  - money demand: determination of interest rate (forward looking)
  - Inter-temporal and labor supply elasticity = $1/\epsilon$
- Firm's adjustment cost: if ψ_ℓ units of labor paid, n prices can be changed.

  Random menu cost: w/pr. $\lambda\, dt$ adjust without paying ψ_ℓ (Poisson).

- Equilibrium: constant nominal interest rate & wages $W(t) \propto M(t)$.

  Simplify firm's problem: nominal cost are known.

- Discounted nominal profit of product i as function of (log) price gap p_i:

$$
\begin{aligned}
\Pi\left(p_i, c(t)\right) &\propto W(0)\, e^{-r\,t}\, c(t)^{1-\eta\epsilon} e^{-\eta\, p_i} \left[e^{p_i} \frac{\eta}{\eta - 1} - 1 \right] \\
0 &= \frac{\partial \Pi\left(0, c(t)\right)}{\partial p_i} = \frac{\partial^2 \Pi\left(0, c(t)\right)}{\partial p_i \partial c(t)}
\end{aligned}
$$

- Same reason why consumption and nominal interest rates do not "enter into" the simple NK Phillips curve.

- This means we can consider simple steady state problem for the firm

Model has 4 primitive parameters $\frac{\psi}{B}$, λ, σ^2 and n

- multi-product: simultaneous adjustment of n products sold by firm.
- random menu cost:

$$\text{adjust } n \text{ prices paying} = \begin{cases} \psi & \text{with probability } 1 - \lambda\, dt \text{ or} \\ 0 & \text{with probability } \lambda\, dt. \end{cases}$$

  where menu cost ψ is measured relative to steady state profits.
- production cost each product: $\mathcal{W}_{ki}(t)$ random walk w/volatility $\sigma^2\, dt$.
- $p_i(t)$ (log) percentage deviation from static optimal markup over cost.
- 2nd order approx. to period profit gives: $-\sum_{i=1}^{n} B\, [p_i\,(t)]^2$

  $B = (1/2)\,\eta\,(\eta - 1)$ where η elasticity of demand.
- Firm maximizes expected net discounted (at rate r) profits.

Simplest case when $n = 1$ and $\lambda \geq 0$

Bellman equation

$$r\ V(p) = B\,p^2 + \lambda\,(\ V(0) - V(p)\ ) + \frac{\sigma^2}{2}\ V''(p), \quad \text{for } p \in (-\bar{p}, \bar{p})\ ,$$

value matching and smooth pasting conditions are:

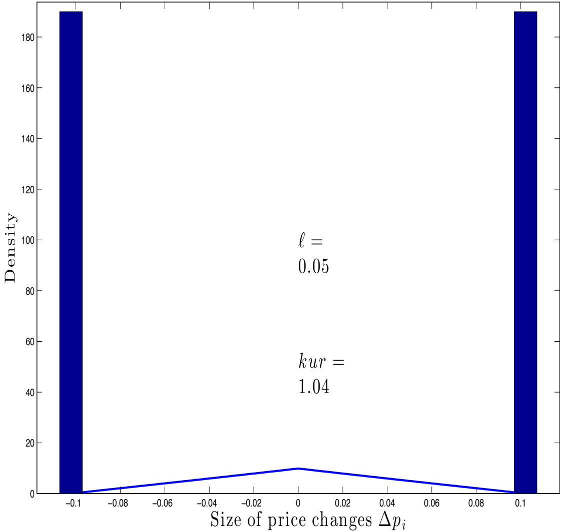
$$V(\bar{p}) = V(0) + \psi\ \ ,\ \ V'(\bar{p}) = 0\ \ ,\ \ \bar{p} \approx \begin{cases} \left(\frac{6\,\psi\,\sigma^2}{B}\right)^{\frac{1}{4}} & \text{if } \frac{\psi}{B}\sigma^2(r+\lambda)^2 \text{ is small} \\ \frac{\psi}{B}\,(r+\lambda) & \text{if } \frac{\psi}{B}\sigma^2(r+\lambda)^2 \text{ is large} \end{cases}$$

Threshold rule $\bar{p}$ yields cross-sectional model predictions

Frequency of adjustment: $N(\Delta p_i)$ or $\ell = \lambda / N$

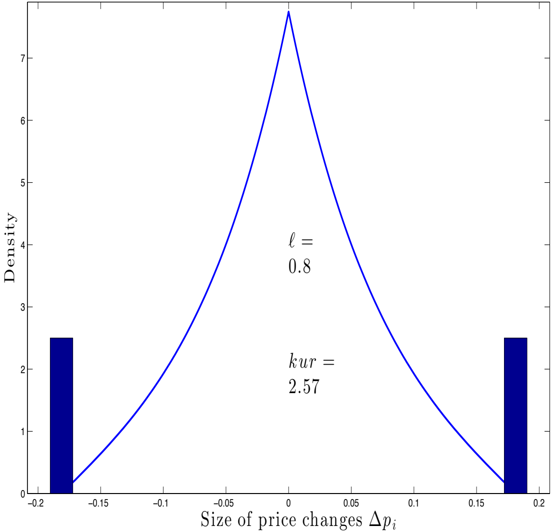
Shape of size-distribution of price changes $w(\Delta p_i)$ depends only on ℓ.

for $n = 1$, $\ell = \lambda / N = 0.05$



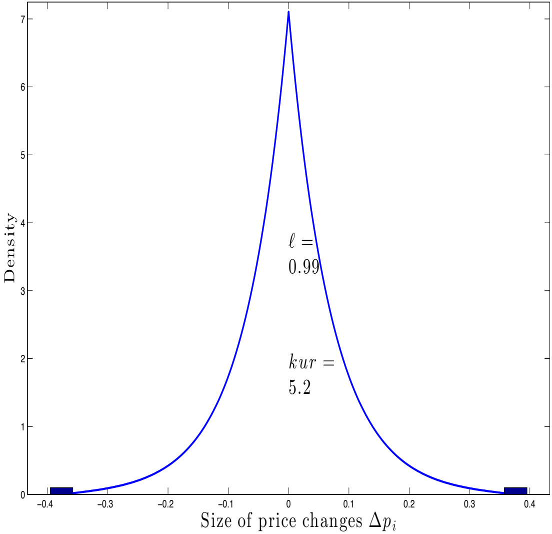
Size distribution $w(\Delta p_i)$ for $n = 1$ model ; shape depends ONLY on ℓ

for $n = 1$, $\ell = \lambda / N = 0.80$



Size distribution $w(\Delta p_i)$ for $n = 1$ model ; shape depends ONLY on ℓ

for $n = 1$, $\ell = \lambda/N = 0.99$

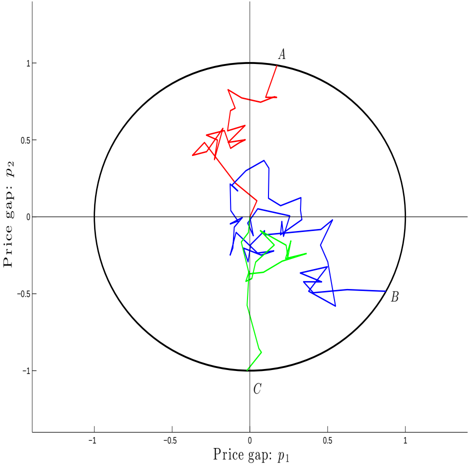


Size distribution $w(\Delta p_i)$ for $n = 1$ model ; shape depends ONLY on ℓ

Key for $n > 1$: summarize state by scalar $y \equiv ||p||^2$

$y \equiv ||p||^2$ square of a **Bessel** process: : $\quad dy = n\,\sigma^2\,dt + 2\,\sigma\sqrt{y}\,d\mathcal{W}$

Inaction region = sphere: $\quad \mathcal{I} = \{p : ||p||^2 \le \bar{y}\}$.



$v(y) = v\left(||p||^2\right) = V(p_1, ..., p_n)$

derivation of y process
ODE for $v(y)$

Cross section predictions for $n > 1$

All prices change if $||p(\tau)||^2$ hits $\bar{y}$ or when free-chance arrives.

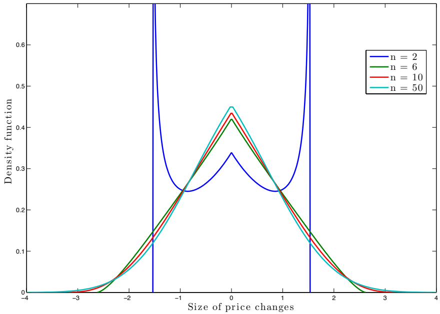
- At such times price changes are $\Delta p_i(\tau) = -p_i(\tau)$, i.e. reset gaps to zero.

Use properties of $||p(\tau)||^2 \in [0, \bar{y})$ and statistical tools to characterize:

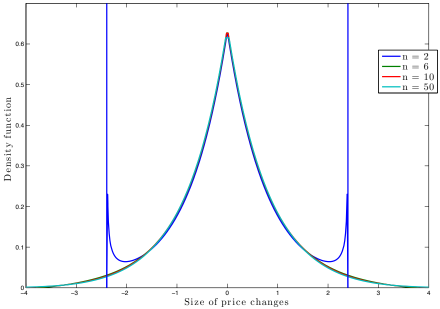
- scale and frequency of Δp_i: $Std(\Delta p_i)$, $N(\Delta p_i)$ $\implies \ell \equiv \frac{\lambda}{N(\Delta p_i)}$
- size-distribution of Δp_i: $w(\Delta p_i)$: shape depends ONLY on n and ℓ
- one-to-one mapping $(n, \lambda, \psi/B, \sigma^2)$ and $(n, \ell, Std(\Delta p_i), N(\Delta p_i))$.

Density of price changes $w(\Delta p_i)$, for $n > 1$

fraction of free adjustments: $\ell = 0.2$

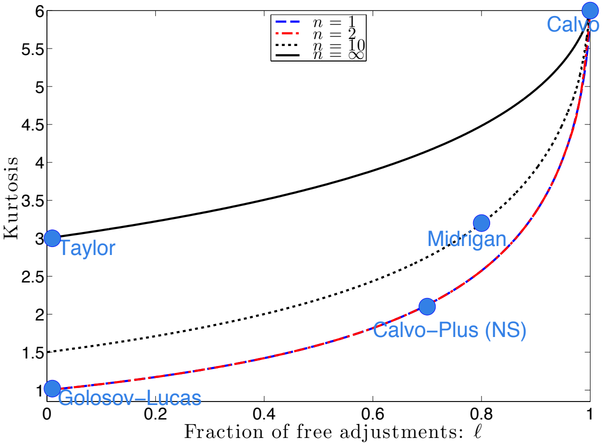


fraction of free adjustments: $\ell = 0.8$



- $\ell > 0$ *and* large n: avoid mass points (or high density) for large $|\Delta p_i|$.
- The shape of the distributions only depends on n, ℓ.

Kurtosis $Kur(\Delta p_i)$ function only of (n, ℓ)

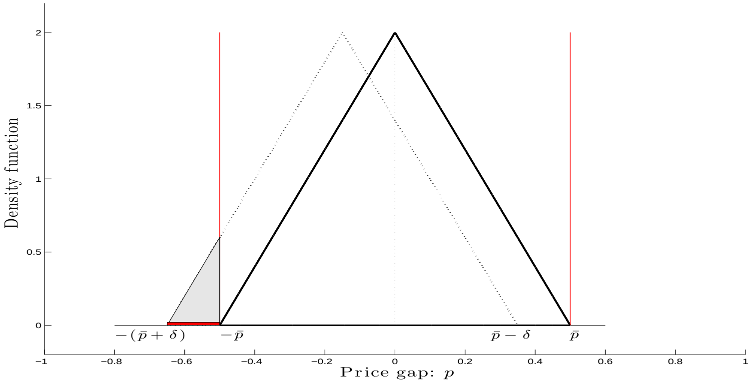


$Kur(\Delta p_i) \in [1\ ,\ 6]$, an increasing function of (n, ℓ)

Cumulative Output Response to a Monetary Shock

- Unexpected permanent increase in money of size δ starting at steady st.
- Start at steady state with distribution of price gaps across firms.
- Keep decision rules ($\bar{y}$) at steady state (as Caballero-Engel)
  - Numerically small GE feedback effects (Golosov-Lucas ▸)
  - Alvarez-Lippi (2014) prove GE effects are second-order on $\bar{y}$ for small δ

Example: canonical menu cost example $n = 1, \ell = 0$



- Start from Steady State distribution of desired price adjustments (p. gaps)
- size of shock matters
- selection effect: in size and time

Two useful, general, simplifying results:

- No need to characterize whole evolution of p distribution after the shock

  Only compute the firms' effect on CPI until *first time they adjust prices*,

  Result due to symmetry after adjustment.

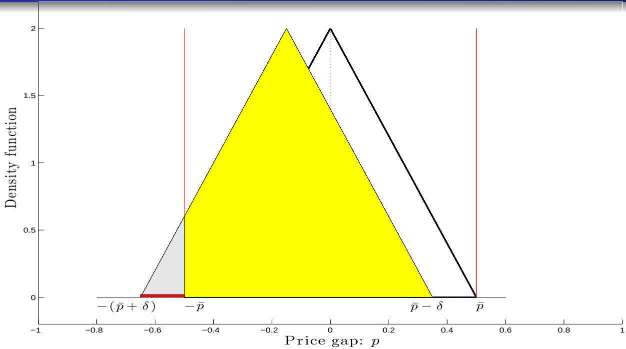
- The decision rule in the transition $\bar{y}$ is the same one as in the st. st.

  No GE effect due to multiplicative profit function: $\Pi(p, c) = \hat{\Pi}(p)\ c$,

  Interest rates and wages solved independently of prices.

Gol-Lucas figure

Key idea to solve the problem analytically ($n = 1$)



$$m(p) = \mathbb{E}\left[\int_0^{\tau} -p(t)\,dt \mid p_0 = p\right] \quad \text{then} \quad \mathcal{M}(\delta) = \frac{1}{\epsilon}\int_{-\bar{p}}^{\bar{p}} m(p-\delta)\,g(p)\,dp$$

useful because we have ODE for $m(p)$: $\lambda m(p) = -p + m''(p)\frac{\sigma^2}{2}$

with boundary conditions $m(0) = m(\bar{p}) = 0$ and known $g(p)$

Example: two famous models ($n = 1$)

From the definition $\mathcal{M}(\delta) = \frac{1}{\epsilon} \int_{-\bar{p}}^{\bar{p}} m\,(p - \delta)\; g(p)\, dp$

Using the approximation $\mathcal{M}(\delta) \cong \delta\, \mathcal{M}'(0) = -\frac{\delta}{\epsilon} \int_{-\bar{p}}^{\bar{p}} m'(p)\, g(p)\, dp$

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From the definition $\mathcal{M}(\delta) = \frac{1}{\epsilon} \int_{-\bar{p}}^{\bar{p}} m\,(p - \delta)\; g(p)\, dp$

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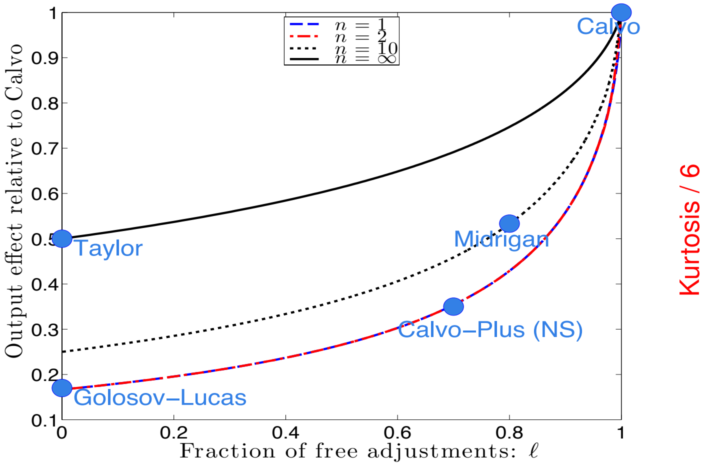
and the closed form expressions for $m(p)$ and $g(p)$ we get

$$\delta \mathcal{M}'(0) = \begin{cases} \frac{\delta}{\epsilon} \frac{1}{6\, N(\Delta p_i)} = \frac{\delta}{\epsilon} \frac{kur(\Delta p_i, \ell)}{6\, N(\Delta p_i)} & \text{if} \quad \ell = 0 \quad \text{(Gol-Luc)} \\ \frac{\delta}{\epsilon} \frac{6}{6\, N(\Delta p_i)} = \frac{\delta}{\epsilon} \frac{kur(\Delta p_i, \ell)}{6\, N(\Delta p_i)} & \text{if} \quad \ell \to 1 \quad \text{(Calvo)} \end{cases}$$

More analysis shows this generalizes to any $n \geq 1$and $\ell \in [0, 1]$

Cumulated output effect relative to Calvo

details



- One curve for each n, no other parameters; infinite slope at $\ell = 1$
- Differences are due to *selection* on “time" and “size" of adjustments.

Robustness and extensions

- Non-zero but small inflation, same result. ▸ details
- Free vs Cheap random cost, same result ▸ details
- Rational Inattentiveness: (observation cost), same result. ▸ details
- Aggregation across sectors with different $Kur(\Delta p_i)$, $N(\Delta p_i)$ ▸ details
- Implied menu costs, reasonable for $\ell < 0.9$ and large n. ▸ details
- Fat-tailed (discontinuous) shocks, different result (identification?) ▸ details
- Large Monetary Shocks, different results. ▸ details

Lack of sensitivity to Inflation μ

- Inflation has only second order effect around $\mu = 0$ on
  - entire *hazard rate* h and *frequency* of price changes $N(\Delta p_i)$,
  - marginal distribution of *absolute value of price changes* $w(|\Delta p_i|)$,
  - all centered *even moments* of marginal price changes (e.g. $Kurt(\Delta p_i)$).
  - area under output IRF small monetary shock: $\mathcal{M}'(0)$
  - results on $\mathcal{M}'(0)$ due to symmetry of μ around zero & of (μ, δ) around (0,0).
- Thus expression for holds for *small* inflation rates:

$$\mathcal{M}(\delta;\mu) \approx \frac{\delta}{\epsilon} \frac{Kurt(\Delta p_i\,;\mu)}{N(\Delta p_i;\mu)\ 6}$$

back

Lack of sensitivity to Inflation μ

- Static “target" prices have drift μ, all price gaps drift down

  $p_i(t) = -\mu\, t + \sigma W_i(t) + \sum_{j:\tau_j<t} \Delta p_i(\tau_j)$ all $t \geq 0, i = 1, ..., n.$

- Optimal decision rule are different (no closed form)
  - State is entire vector p, not just $y = ||p||^2$.
  - Prices are not reset to static target at adjustment.
  - Inaction set $\mathcal{I}$ is *not* a hyper-sphere.
  - GE model: nominal rate $r + \mu$, wages grow at μ.

back

Cheap vs free adjustment cost: Nakumura-Steinsson

- Take the case of $n = 1$ product.
- cheap random menu cost:

$$\text{adjust the price paying} = \begin{cases} \psi & \text{with probability } 1 - \lambda\, dt \text{ or} \\ b\,\psi & \text{with probability } \lambda\, dt. \end{cases}$$

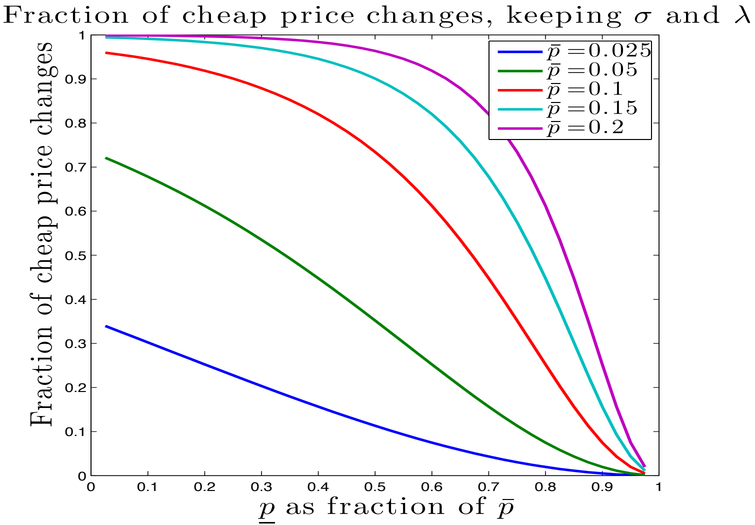
- Cheap adjustment fraction $b \in [0\,,\,1)$ of normal cost ψ.
- Optimal policy: two thresholds $0 < \underline{p} < \bar{p}$, adjust price if

$$\text{abs. value price gap} = |\, p(t) \,| \geq \begin{cases} \bar{p} & \text{and cost } \psi \\ \underline{p} & \text{and cost } b\,\psi \end{cases}$$

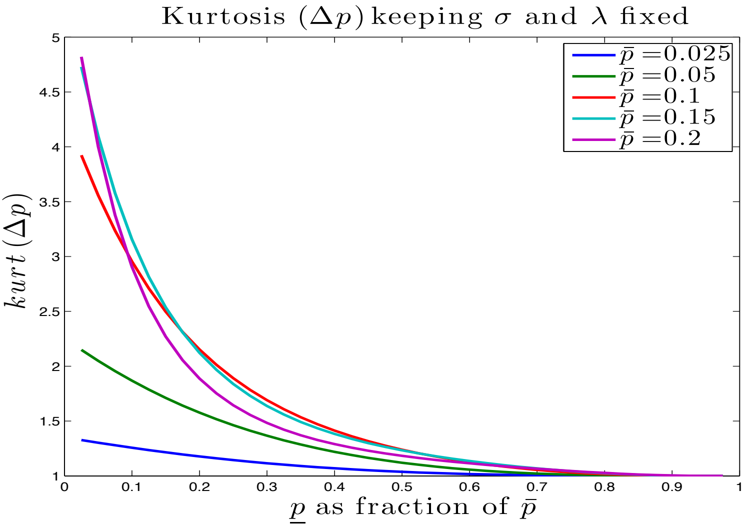
- Eliminates price changes smaller than $\underline{p}$, & hence decreases $Kurt(\Delta p_i)$.
- Result $\mathcal{M} \approx \frac{\delta}{\epsilon} \frac{Kurt(\Delta p_i)}{6\ N(\Delta p_i)}$ still holds.

back

Fraction of cheap price changes for several $\bar{p}$ and $\underline{p}$



Kurtosis for several $\bar{p}$ and $\underline{p}$



Rational Inattentiveness (no menu cost):

- Caballero, Reis, Carvalho-Schwartzman, Alvarez-Lippi-Paciello.
- Firms observe price gap *only* if they pay a *random* observation costs.
- Optimal decision rules:
  - set times τ until next review = and price adjustment
  - decision cannot depend on (unobserved) current price gaps.
- Randomness of expected observation cost implies random times τ.
- Models with $n = \infty$ have similar formal properties.

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- Randomness of expected observation cost implies random times τ.
- Models with $n = \infty$ have similar formal properties.
- Monetary shock δ learned only at times when firms observe their cost.
- Allows for any value of $Kurt(\Delta p_i)$, even larger than 6.
- Result $\mathcal{M} \approx \frac{\delta}{\epsilon} \frac{Kurt(\Delta p_i)}{6 \; N(\Delta p_i)}$ still holds.

back

Implied menu costs (for $r \downarrow 0$)

- Fixing n and $\ell \in (0,1)$, the menu cost $\psi \geq 0$:

$$\text{Menu cost per product} = \frac{\psi}{n} = B \, \frac{Var(\Delta p_i)}{N(\Delta p_i)} \, \Psi(n, \ell)$$

- $\Psi(n, \ell)$ is only a function of (n, ℓ).

- Total cost: $B = \eta(\eta - 1)/2$ or markup $\mathfrak{m} \equiv 1/(\eta - 1)$ then

$$\frac{\text{Yearly costs of price adjustment}}{\text{Yearly revenues}} = \frac{1}{2} \, \frac{Var(\Delta p_i)}{\mathfrak{m}} \, (1 - \ell) \, \Psi(n, \ell)$$

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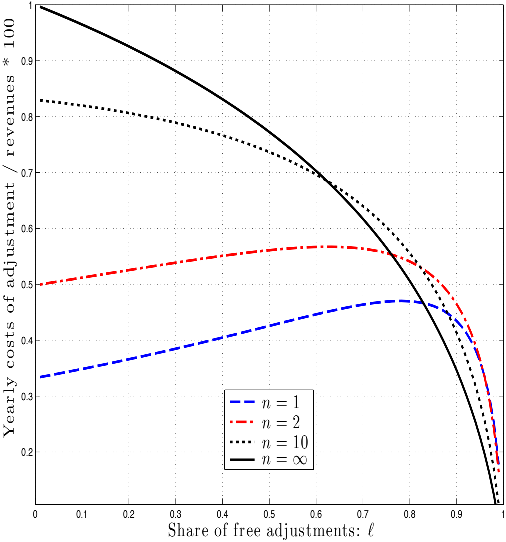
The cost of price adjustment



Levy et al (QJE, 1997) avg. cost per year around 0.7% of revenues.

back

Aggregation across heterogeneous sectors

- Let $e(s)$ the expenditure share of sector s with different parameters.
- Allow different, $N(s)$, $Std(s)$ and $Kurt(s)$ by sector s
- For small δ shocks aggregation across sectors yields:

$$\mathcal{M}(\delta) \approx \frac{1}{6} \frac{\delta}{\epsilon} \sum_{s \in S} \frac{e(s)}{N(s)} Kurt(s)$$

- If $Kurt(s)$ the same across sectors: the model aggregates using expenditure weighted by duration.
- If $Kurt(s)$ varies across sectors: needs to consider its covariation. In French data we found about 15% higher effect due to this effect.

back

Model with fat tailed shocks

- Process for cost: BM W + Poisson counter N w/ intensity λ

$$dp_i(t) = \sigma\, dW_i(t) \,+\, \xi_i(t)\, dN(t) \quad \text{for } i = 1, ..., n$$

- distribution of fat-tailed shock:

$$0 < \underline{\xi} \equiv \inf ||\xi|| \ \text{ with } \Gamma \text{ probability } = 1$$

- Results:

1. If the $\underline{\xi}$ large enough, then threshold $\bar{y}$ is the same as in baseline model.
2. Fat tails contributes to kurtosis by mostly adding large price changes.
3. "Lack of identification". (almost) anything goes if Γ unrestricted and ψ small .

back

Effect depends on size of the monetary shock δ

- $\underline{\delta}$ smallest once-and-for-all monetary shock that gives full price flexibility.
- Depends on $Std(\Delta p_i)$ and ℓ:

$$\underline{\delta} = 2\sqrt{\frac{\bar{y}}{n}} = 2\, Std(\Delta p_i)\, \sqrt{\frac{\mathcal{L}^{-1}(\ell; n)}{\ell}},$$

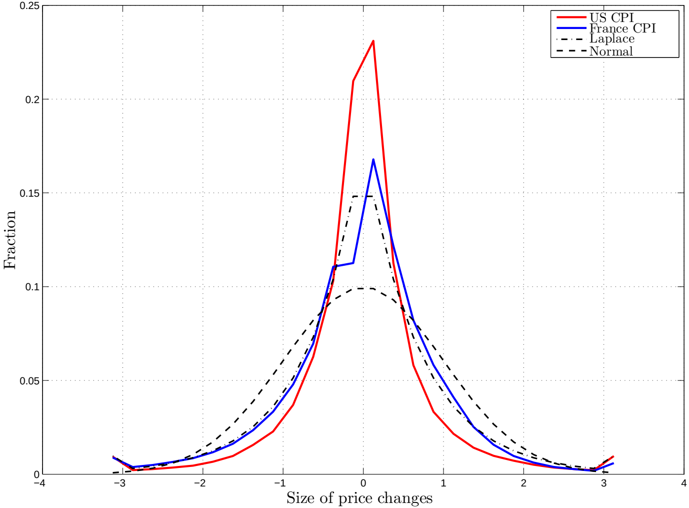
where $\mathcal{L}(\cdot; n)$.

- Fixing any $n \geq 1$, the ratio

$$\frac{\underline{\delta}}{2\, Std\,(\Delta p_i))}$$ is a strictly increasing function of ℓ

ranges from 1 to ∞ as ℓ goes from 0 to 1.

back



Pooled Standardized Δp: US (Klenow Krystov) vs France CPI

back

Measurement error: CPI vs Scraped Data (France)

- CPI very broad, but subject to measurement error:

  Eichenbaum et all: spurios small price changes in CPI and scanner data.

- Our approach:
  - Compare “error free" data for selected products with CPI.
  - Use internet scrapped data for France.
  - Match type of goods/outlet with CPI.
  - Use simple measurement error model to extrapolate to whole CPI.
- Conclusion: kurtosis is about half.

back

Measurement error: CPI vs Scraped Data (France)

Table : Matching CPI vs. the BPP by store x products

Statistic	BPP retailer 1	BPP retailer 5	CPI Hypermarkets	BPP retailer 4	CPI Large ret. electr.
duration	8.58	8.06	4.82	6.44	7.24
		Statistics for standardized price changes: z			
mean $\|z\|$	0.71	0.70	0.65	0.78	0.70
% below 0.5 mean $\|z\|$	37.85	40.93	45.48	29.17	41.69
% below 0.25 mean $\|z\|$	17.46	25.26	26.19	15.33	23.10
kurtosis of z	5.50	4.30	10.15	2.82	6.33

back

Measurement error: CPI vs Scanner data

	France		US (scanner data)		
	—	Cavallo-Rigobon	EJR	—	Midrigan
	CPI	BPP	Safe-way	IRI	Nielsen
	Statistics for standardized price changes: z				
mean of $\|z\|$	0.65	0.70	0.78	0.73	-
% below 0.50 mean $\|z\|$	45	39	33	39	29
% below 0.25 mean $\|z\|$	24	21	23	25	13
kurtosis of z:	10	5	3.0	4.3	3.5

Measurement error model: measured changes = true (u) + error (ϵ)

true u w/ pr θ and std σ_u , error ϵ w/ pr $1-\theta$ and std σ_e: $\lim_{\sigma_e \downarrow 0} kurt = \frac{kurt_u}{\theta}$

bottom-line: comparison of BPP vs CPI suggests $\theta \cong 1/2$ and $kurt \in (3,5)$

back

French CPI data 2003-2011 for Δp_i

	CPI Data		Benchmarks	
	all records	exc.sales	Normal	Laplace
Frequency of price changes	17.09	14.70		
Moments of standardized price changes: z				
Kurtosis	8.89	10.40	3	6
Moments for the absolute value of standardized price changes: $\|z\|$				
Average: $\mathbb{E}(\|z\|)$	0.70	0.69	0.80	0.70
Fraction of observations $< 0.25 \cdot \mathbb{E}(\|z\|)$	22.2	20.7	16	22
Fraction of observations $> 2 \cdot \mathbb{E}(\|z\|)$	12.9	12.5	11	13
Number of obs. with $\Delta p \neq 0$	1,544,829	1,080,183		

cross-section heterogeneity $\rightarrow$ standardized price changes

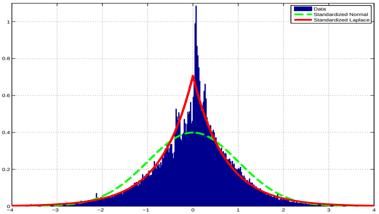
$$z_{i,j,t} = \frac{\Delta p_{i,j,t} - m_{ij}}{\sigma_{ij}}$$

i-good category (270), j-outlet type (11), t-time (120 months)

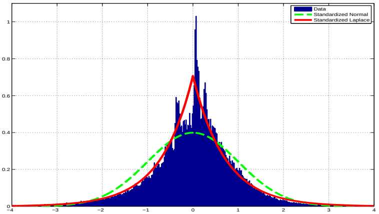
bottom-line: distribution of the standardized Δp closer to Laplace than Normal

back

All data



Excluding sales



Standardized Price Adjustments: French CPI 2003-2011

back

Table : Fraction of small price changes: US and French CPI

	Moments for the absolute value of price changes: $\lvert\Delta p\rvert$			
	France	US	Normal	Laplace
Average $\lvert\Delta p\rvert$	9.2	14.0		
Fraction of $\lvert\Delta p\rvert$ below 1%	11.8	12.5		
Fraction of $\lvert\Delta p\rvert$ below 2.5%	32.5	24.0		
Fraction of $\lvert\Delta p\rvert$ below 5%	57.1	40.6		
Fraction of $\lvert\Delta p\rvert$ below $(1/14) \cdot \mathbb{E}(\lvert\Delta p\rvert)$	2.4	12.5	4.5	6.9
Fraction of $\lvert\Delta p\rvert$ below $(2.5/14) \cdot \mathbb{E}(\lvert\Delta p\rvert)$	13.5	24.0	11.3	16.4
Fraction of $\lvert\Delta p\rvert$ below $(5/14) \cdot \mathbb{E}(\lvert\Delta p\rvert)$	28.7	40.6	22.4	30.0
Number of obs	1,542,586	1,047,547		

Data is NOT standardized

Useful simplifying assumptions for our problem

Simplification on firm problem

- unit root shocks (no mean reversion): $\rightarrow$ state summarized by gaps

Simplification on eq. structure

- Linear leisure + $\log(M/P)$ + one-time shock $\rightarrow$ wages proport. to money

back to firm-problem

Golosov-Lucas

back to IRF back to 2 useful results

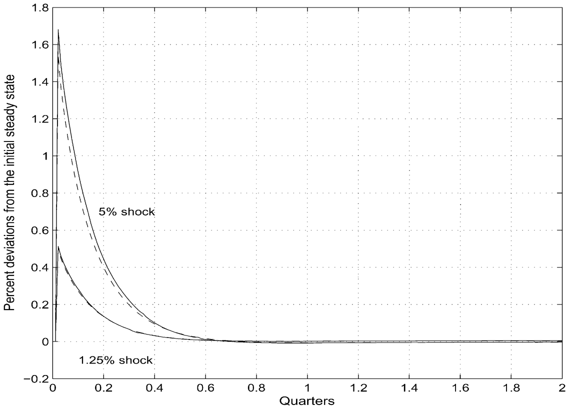
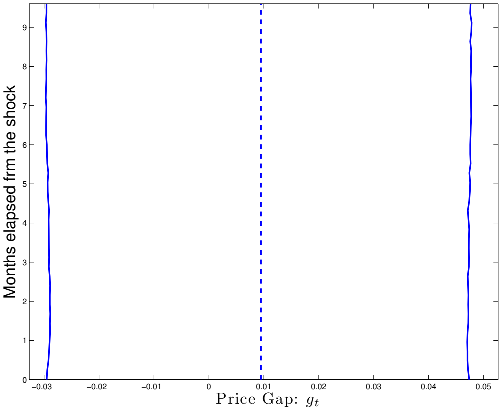


FIG. 7.—Approximate (dashed lines) and exact (solid lines) impulse-response functions: responses of output to a one-time increase (impulse) in the level of money. Initial levels are normalized to one.

- Solid line: fixed point on path of aggregate consumption.
- Dashed line: keeps aggregate consumption at steady state.

Policy rules in non-linear GE model ($n = 1, \mu = 0.02$)

Figure : Threshold rules



Source: Alvarez-Lippi-Paciello (2012)

back to IRF
back to 2 useful results

Selection on size and time

Compare the average price change of firms that adjust t periods after shock

- Golosov-Lucas: early on almost all adjustments upwards. graph
- Selection on size decreases with ℓ and n.
  - Calvo: adjustments are independent of price gaps.
  - Taylor: adjustments are independent of each price gaps.
  - Any case with $n = \infty$ avg. price change δ every horizon t
  - Difference due to distribution of times to adjust $\{\tau\}$.

    In general, when there is no selection in size,

$$\mathcal{M}(\delta) = \frac{\delta}{\epsilon}\left[\frac{1 + CV(\tau)}{2\, N\,(\Delta p_i)}\right]$$

  - So higher *variability* of times to adjustments $\{\tau\}$ increases area under IRF.

back

Interpretation as menu cost

- Firms observes profit from n products, which are proportional to $||p||^2$.
- Firms don't know profits of each product line separately.
- If they pay ψ disentangle profits from each product, and can change prices accordingly.
- In this case ψ covers other activities than setting new prices.

back

Results for Impulse Responses : scaling

$\mathcal{P}_{n,\ell}(\delta, t)$: aggregate price level t periods after the monetary shock δ

- Scaling and Stretching:

  IRF $\mathcal{P}$ of economy with $(Std[\Delta p], N(\Delta p_i))$ at (δ, t) is

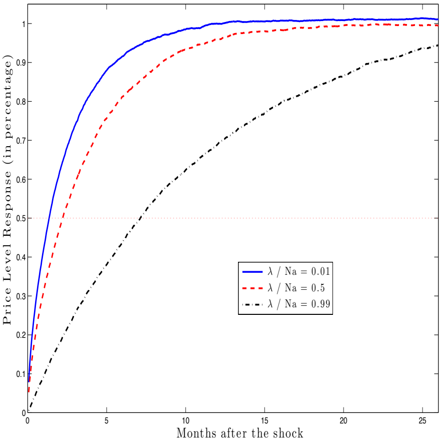
  a *scaled* version of one for $\delta / Std[\Delta p]$ and *stretched horizon* $N(\Delta p_i)\ t$:

$$\mathcal{P}_{n,\ell}(\delta,\ t;\ N(\Delta p_i)\ ,\ Std[\Delta p]\ ) = Std[\Delta p]\ \mathcal{P}_{n,\ell}\left(\frac{\delta}{Std[\Delta p]},\ N(\Delta p_i)\ t\ ;\ 1,\ 1\right)$$

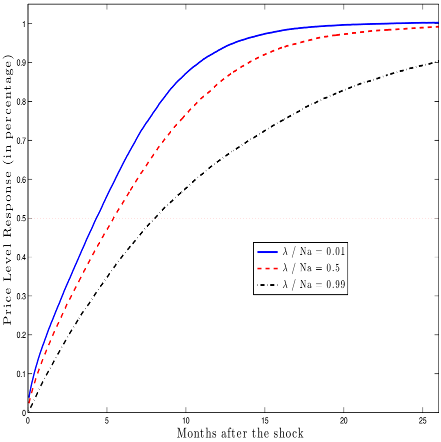
back

$\mathcal{P}_{n,\ell}(\delta, t)$: Response of CPI to shock $\delta = 1\%$

Economy with $n = 1$



Economy with $n = 10$



Scales depend on $N(\Delta p_i) = 2$, $Std(\Delta p) = 0.15$; Shape on n, ℓ