Economics 742 Price Ridigity Bonus Lecture 2:

Evidence on Price Adjustment
and
Refined State-Dependent Models

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Evidence and Refined Models

- Last class we finished with Golosov and Lucas (2007).
  - State-dependent model with six times price flexibility of Calvo.
  - Add idiosyncratic shocks to match large price changes in data.
- Key feature is *selection effect*.
  - Firms that need to adjust most adjust.
  - Frequency of adjustment acyclical at low inflation as in data because idiosyncratic shocks dominate.
  - Contrasts with prior literature, which focuses on frequency.
- But is Golosov and Lucas as realistic as it seems to be?
  - Look closely at micro evidence, then present refined models.

Evidence and Refined Models

1. GL Intuition Revisited: Caballero and Engel (2007)
2. More Evidence on the Frequency and Size of Price Changes
   - Nakamura and Steinsson (2008), Klenow and Kryvtsov (2008)
3. Revised Models: Midrigan (2011)
   - Kurtosis As A Sufficient Statistic: Alvarez et al. (2016)
4. Other Issues
   - Price Setting in High Inflation Environments: Gagnon (2009), Alvarez et al. (2019)
   - Sales: Eichenbaum et al. (2011), Midrigan (2011), Keohe and Midrigan (2015)

Caballero and Engel (2007): GL Intuition Revisited

- Caballero and Engel (2007) provide a framework for thinking about Golosov and Lucas' results.
- They argue the selection effect intuition misses something.
  - Whether adjusters come from the tails or the center of the distribution actual / desired price is not critical.
- Instead, decompose effect into:
  - *Intensive Margin*: Change in desired price of firms adjusting.
  - *Extensive Margin:* Change in number of firms adjusting in direction of monetary shock.
- GL's near-neutrality comes from *strong extensive margin.*
  - Controlled by the *density of firms at the margin of adjusting*.
  - In Golosov and Lucas' calibration this is large.

Caballero and Engel (2007): Setup

- Define log values for target price p^*_{it}, actual price p_{it}, and money supply m.
- With iid shocks to each (v_{it} idiosyncratic), target price follows:

$$\Delta p^*_{it} = \Delta m_t + v_{it}$$

- Let the (negative) log price gap be

$$x_{it} \equiv p^*_{it} - p_{it}$$

- Log price gap before adjustment has PDF $f(x)$ at time t.
- Adjustment probability is distributed according to $\Lambda(x)$.
  - In GL, $\Lambda(x) = \begin{cases} 1 & \text{if } x \geq S \text{or } x \leq -S \\ 0 & \text{otherwise} \end{cases}$
  - This need not be true; e.g. with random adjustment cost (DKW 1999) or multi-product firms (Lach and Tsiddon, 2007).

CE (2007): Extensive vs. Intensive Decomposition

- Denote aggregate price response to shock as $\Delta p\left(\Delta m\right)$.
- With no money shock,

$$\Delta p\left(0\right) = \int x\Lambda\left(x\right) f\left(x\right) dx$$

- With money shock,

$$\Delta p\left(\Delta m\right) = \int \left(x + \Delta m\right) \Lambda\left(x + \Delta m\right) f\left(x\right) dx$$

- Differencing, the price level responds by an additional:

$$\Delta p = \int \left(x + \Delta m\right) \Lambda\left(x + \Delta m\right) f\left(x\right) dx - \int x\Lambda\left(x\right) f\left(x\right) dx$$

CE (2007): Extensive vs. Intensive Decomposition

$$\begin{aligned}\Delta p &= \int (x+\Delta m)\Lambda(x+\Delta m) f(x)\,dx - \int x\Lambda(x) f(x)\,dx \\ &= \int x\left[\Lambda(x+\Delta m)-\Lambda(x)\right] f(x)\,dx + \int \Delta m \Lambda(x+\Delta m) f(x)\,dx\end{aligned}$$

- Divide by Δm and take limit as $\Delta m \to 0$ to get

$$\left.\frac{dp}{dm}\right|_{dm=0} = \int \Lambda(x) f(x)\,dx + \int x\Lambda'(x) f(x)\,dx$$

1. Intensive Margin: $\int \Lambda(x) f(x)\,dx$ already adjusting by dm.
2. Extensive Margin: New adjusters who adjust by x.
   - Mass: Density $f(x)$ times change in prob of adjust $\Lambda'(x)$.
   - In other words, *mass at margin of adjusting.*

CE (2007): Extensive Margin vs. Selection Effect

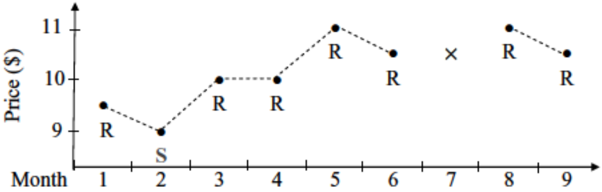
$$\left.\frac{dp}{dm}\right|_{dm=0} = \int \Lambda(x) f(x)\, dx + \int x\Lambda'(x) f(x)\, dx$$

- Calvo: only intensive margin.
- Golosov-Lucas: Extensive margin effect is selection effect.
  - Extra flexibility relative to Calvo from change in mass of adjusters in direction of monetary shock.
  - Not essential that from the extremes of the distribution of x.
  - E.g. could have $\Lambda(x)$ binary from random point in distribution and would have similar, though smaller, effect.
- Golosov Lucas have money near neutral because $f(x)$ has substantial mass at $-S$ and S.
  - Need this be the case? Turn to data.

BLS Data: Structure and Measurement Issues

- BLS collects thousands of prices of individual goods and services each month (or two) to create CPI.
  - 70% of consumer expenditures (most ex housing).
- Panel of prices for particular product at store.
  - So Quart of 2% Hood Milk sold at Stop and Shop.
  - Also sales flag.
  - Determine which goods to include based on Consumer Expenditures Survey. Then sample to get panel.
- Group products into "Entry Level Items" (like NAICS for CPI).
- Some issues with substitutions, out of season, out of stock, etc. See papers.

BLS Data: Structure and Measurement Issues



	1	2	3	4	5	6	7	8	9
Price change indicator	×	1	1	0	1	1	×	1	1
Size of price change (%)	×	–5	+10	×	+10	–5	×	+5	–5
Duration clock	×	1	1	1	1	1	×	2	1
Regular price change indicator	×	×	1	0	1	1	×	1	1
Size of regular price change (%)	×	×	+5	×	+10	–5	×	+5	–5
Duration clock	×	×	2	1	1	1	×	2	1

Source: Klenow and Kryvtsov (2008)

Klenow and Kryvtsov (2008): Is World Calvo?

1. Frequency of adjustment:
   - Mean Duration: 3.7 with sales, 7-9 without sales.
   - Median: 4-7 months without sales.
2. Price changes large in absolute value.
   - Weighted average 14.0%, median of 11.5%.
   - 11.3% and 9.7% excluding sales.
3. Yet many price changes are small.
   - 40% under 5%.
   - Eichenbaum et al. (2015) argue measurement error.
4. Durations are variable, even for given item.
5. Hazard rates are flat for a given item.
6. Size of change unrelated to time since previous change.
7. Intensive margin dominates variance of inflation.
   - However, increases become more prevalent with inflation.

Nakamura and Steinsson (2008): Five Facts to Re-Evaluate Menu Cost Models

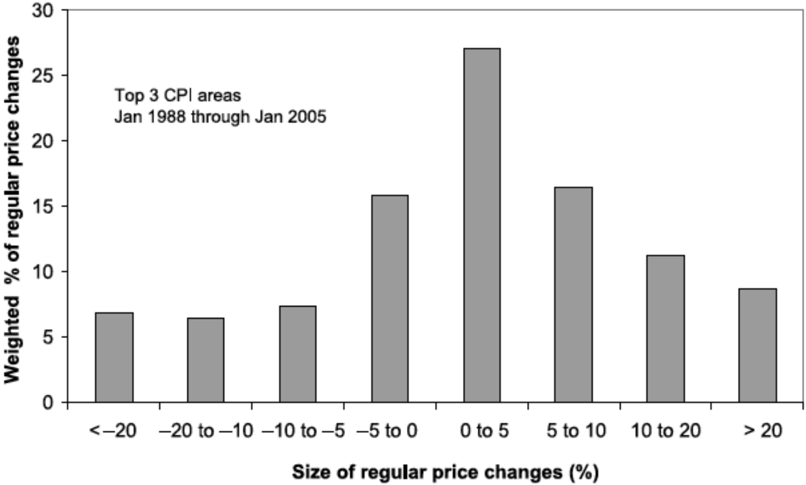
1. Frequency 8-11 months without substitutions, 7-9 with (price change or product disappears).
    - Double what it is including sales.
    - Median frequency for finished good producer prices comparable to no sales.
    - Substantial heterogeneity across sectors.
2. One third of non-sale price changes are decreases.
3. Frequency of increases varies with inflation, frequency of decreases and size of price changes does not.
4. Frequency highly seasonal (in first quarter).
5. Flat or downward sloping hazard rates.

Frequency of Price Change (From NS 2013)

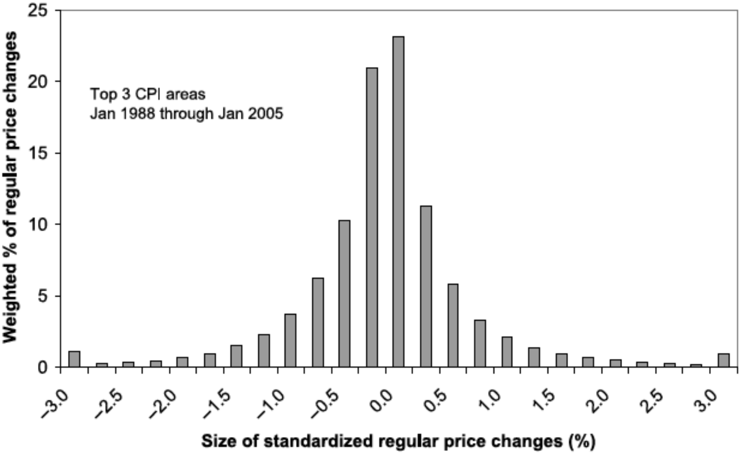
- Report frequency rather than duration due to censored spells.
- Constant hazard λ implies frequency $f = 1 - e^{-\lambda} \Rightarrow d = 1/\lambda = -1/\log(1-f)$ is implied duration

	Median		Mean	
	Frequency	Implied duration	Frequency	Implied duration
Nakamura & Steinsson (2008)				
Regular prices (excluding substitutions 1988–1997)	11.9	7.9	18.9	10.8
Regular prices (excluding substitutions 1998–2005)	9.9	9.6	21.5	11.7
Regular prices (including substitutions 1988–1997)	13.0	7.2	20.7	9.0
Regular prices (including substitutions 1998–2005)	11.8	8.0	23.1	9.3
Posted prices (including substitutions 1998–2005)	20.5	4.4	27.7	7.7
Klenow & Kryvtsov (2008)				
Regular prices (including substitutions 1988–2005)	13.9	7.2	29.9	8.6
Posted prices (including substitutions 1988–2005)	27.3	3.7	36.2	6.8

Klenow and Kryvtsov (2008): Size of Reg Price Changes

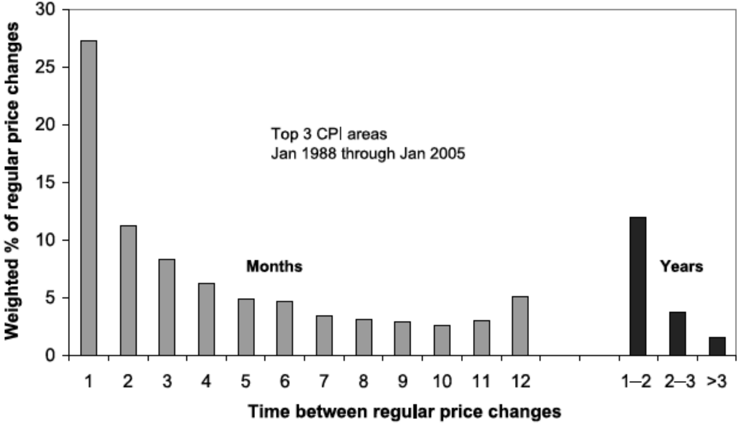


Klenow and Kryvtsov (2008): Fat Tailed Distribution



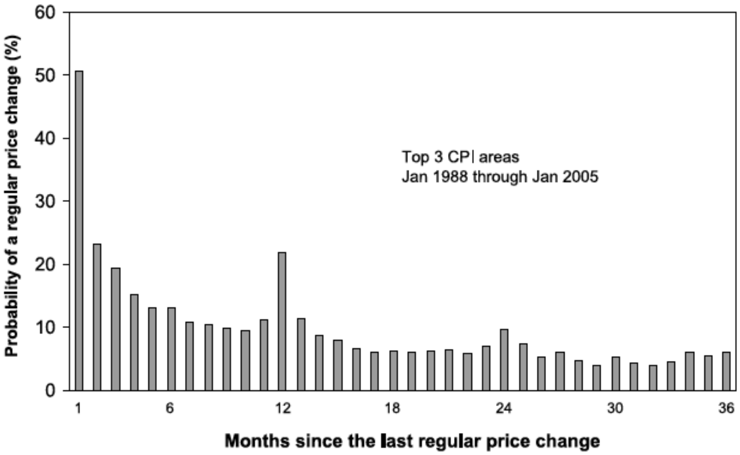
- Standardize using ELI z-score

Klenow and Kryvtsov (2008): Duration of Spells



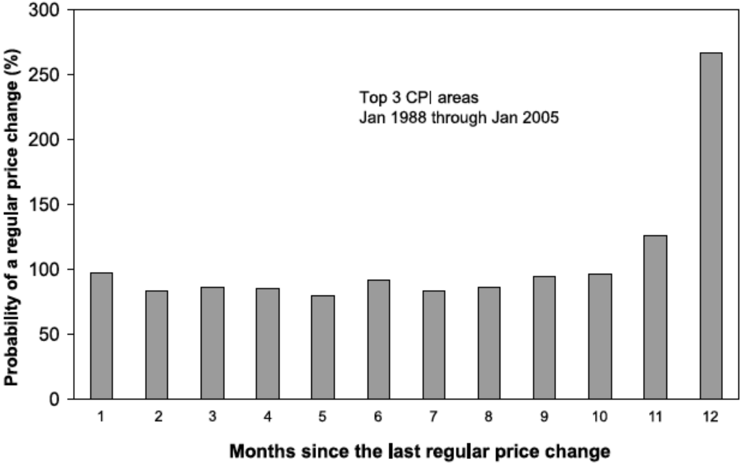
- Standard Deviation within a single product-store is 4.3 months with sales, 5.2 months without.

Klenow and Kryvtsov (2008): Months Since Last Change

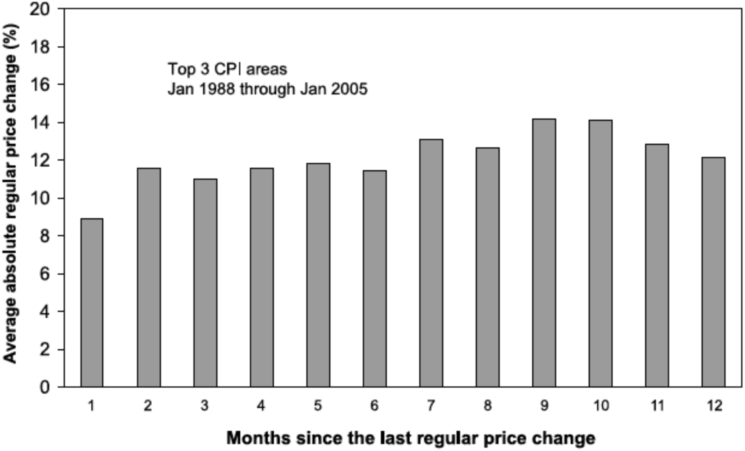


- Could be composition

Klenow and Kryvtsov (2008): Hazard Taking Out Fixed Effects For Decile of Price Change Frequency

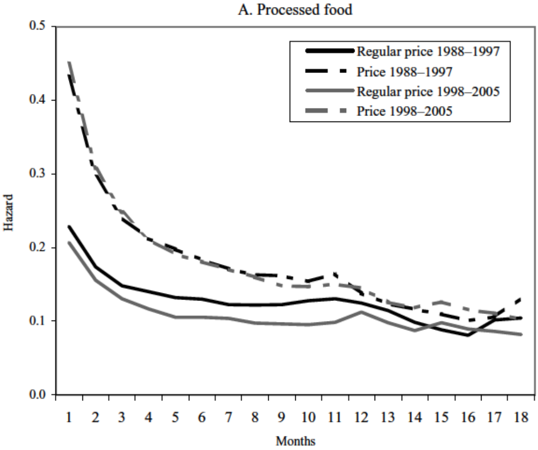


Klenow and Kryvtsov (2008): Size of Price Change By Age Taking Out Fixed Effects For Decile of Price Change Freq



Nakamura and Steinsson (2008): Hazard Functions

- Rather than fixed effects, use semi-parametric proportional hazards model to account for unobserved Heterogeneity



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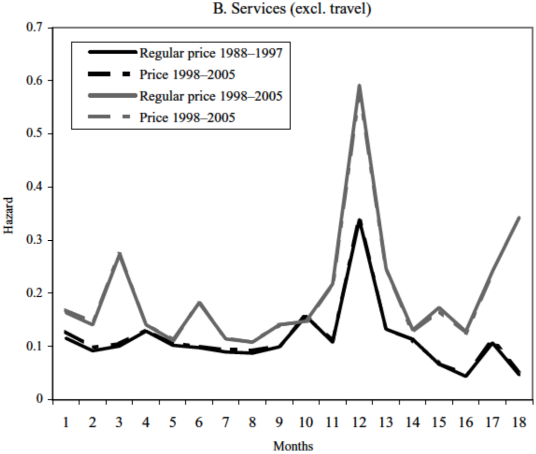
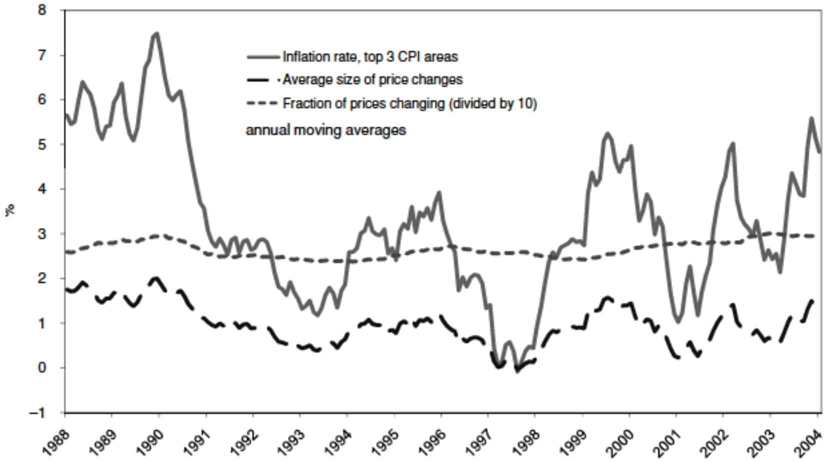
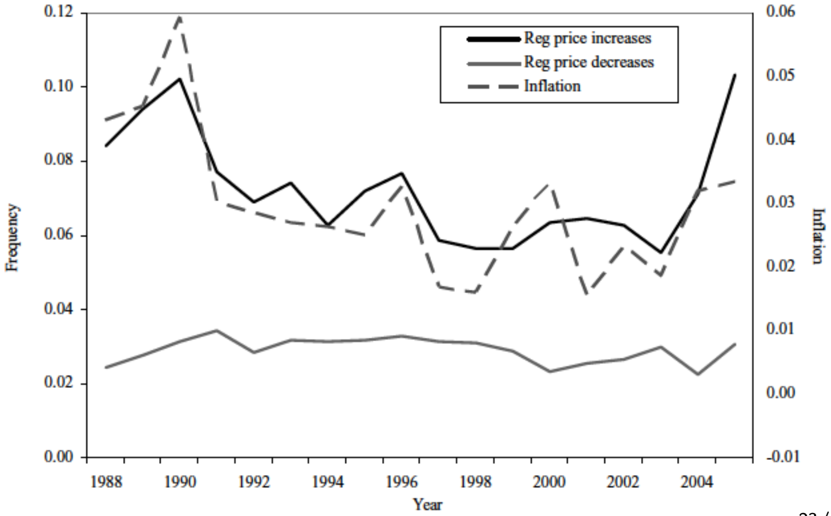


Klenow and Kryvtsov (2008): Intensive Margin Dominates



NS (2008): Due to Changing Prob of Price Increase

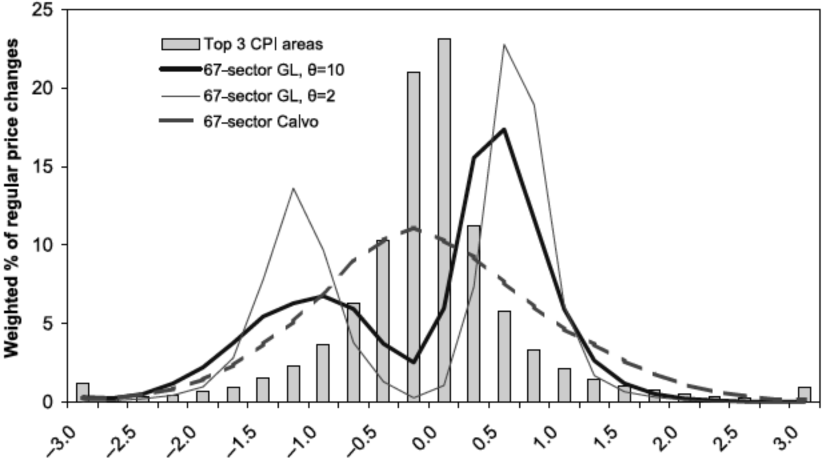


What Do Facts Mean For Golosov and Lucas?

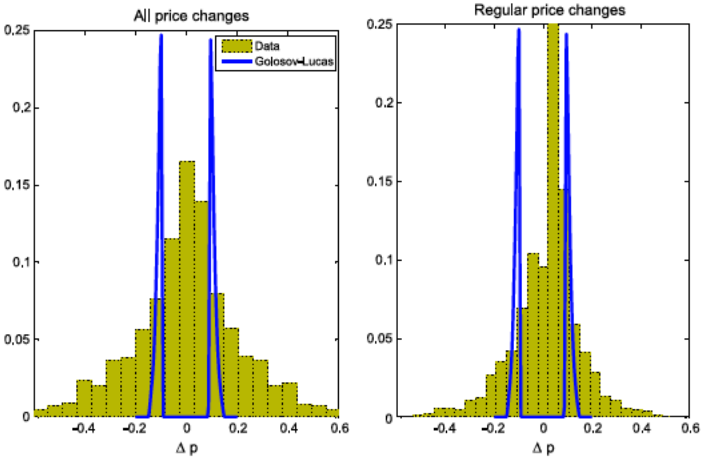
- Golosov and Lucas add idiosyncratic shocks to match many large price changes, large frequency of price decreases.
  - How do they do?
- Match some key facts, but miss others:

1. KK: Large number of both very small and very large price changes.
   - GL has single large fixed cost to change price, get lots of mass at (S,s) bands, little in tails or middle.
2. NS: Hazard rising in first few months in most menu cost models (if adjust, at optimum and need multiple small shocks to get to tails) but flat or decreasing in data if account for unobserved heterogeneity.
3. NS: Seasonality of price changes.

KK (2008): Price Change Sizes: GL vs. Data



Midrigan (2011): Price Change Sizes: GL vs. Data



Midrigan (2011): Modifications to Golosov-Lucas

- Midrigan updates Golosov-Lucas to match hazard rate and distribution of size of price changes with 3 changes:

1. Leptokurtic ("Fat Tailed") Shocks

$$\begin{aligned} \log A_t(z) &= \rho \log A_{t-1}(z) + \varepsilon_t(z) \\ \varepsilon_t(z) &\sim \begin{cases} 0 & \text{with } Pr\left[1 - p^a\right] \\ N\left(0, \sigma_A^2\right) & \text{with } Pr\left[p^a\right] \end{cases} \end{aligned}$$

   - Helps get thick tails of price change dist.

2. Economies of Scope in Price Adjustment
   - Adj cost to change all N goods sold (multi-product firm).
   - Helps get many small price changes. Some evidence in paper from synchronization of price changes (see section 5).
3. Sales (as in Kehoe and Midrigan):
   - Gets many temp changes. Put off to end of lecture

Midrigan (2011): Calibration

- Exogenous: elasticities of substitution, money process.
- Assumes $N = 2$ products per firm.
  - Alvarez and Lippi (2014) consider how stickiness changes with N in analytic framework. Find non-neutrality doubles when N goes from 1 to 10.
  - Can also get small price changes from DKW (1999) stochastic menu costs. He does this because some evidence for it in data.
- Other parameters based on micro data.
  - GL calibrate to large mean size of price changes.
  - Midrigan add to this quantiles of the distribution of size of price changes (plus some on sales).

Midrigan (2011): Calibration

Moments	Data	Benchmark	No Temp. Changes	Golosov–Lucas
Used in calibration				
10. Mean size of price changes	0.20	0.20	0.11	0.11
11. Mean size of regular price changes	0.11	0.10	0.11	0.11
12. 10th percentile size regular price changes	0.03	0.03	0.03	0.10
13. 25th percentile size regular price changes	0.05	0.05	0.05	0.10
14. 50th percentile size regular price changes	0.09	0.09	0.09	0.11
15. 75th percentile size regular price changes	0.13	0.14	0.15	0.11
16. 90th percentile size regular price changes	0.21	0.20	0.22	0.12
Additional moments				
21. Std. dev. size of price changes	0.18	0.15	0.08	0.01
22. Kurtosis price changes	3.15	1.65	2.97	1.06
23. Fraction changes $<1/2$ mean	0.36	0.36	0.28	0.00
24. Fraction changes $<1/4$ mean	0.19	0.34	0.07	0.00

- Standardize using z-score to avoid bias from good-specific heterogeneity.

Midrigan (2011): Parameters

$$\log A_t(z) = \rho \log A_{t-1}(z) + \varepsilon_t(z)$$

$$\varepsilon_t(z) \sim \begin{cases} 0 & \text{with } Pr[1-p^a] \\ N(0,\sigma_A^2) & \text{with } Pr[p^a] \end{cases}$$

- Golosov-Lucas: $p^a = 1$

	Benchmark	No Temp. Changes	Golosov–Lucas	BLS Calibration
Calibrated				
σ_a	0.080	0.100	0.023	0.112
ϕ^R, relative to SS revenue	0.022	0.018	0.038	0.012
χ	0.845	0.999	–	0.466
p^a	0.030	0.040	–	0.079
α	0.126	–	–	
ρ	0.524	–	–	
e	0.741	–	–	
κ, relative to SS revenue	0.012	–	–	

Midrigan (2011): Findings

- Non-neutrality is nearly as large as Calvo.
- Looks like Calvo not Golosov and Lucas on a number of important dimensions:

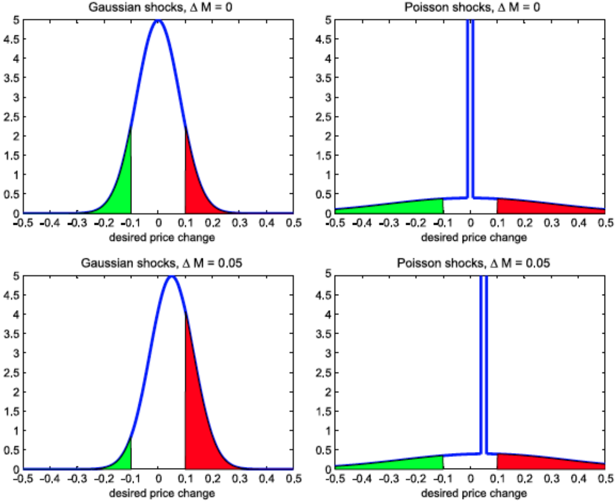
	Calvo	Benchmark	No Temp. Changes	Golosov–Lucas
Business cycle statistics[a]				
$\sigma(C)$ (%)	0.35	0.29	0.31	0.07
Serial correlation C	0.93	0.93	0.92	0.84
Inflation dynamics				
var(π) intensive margin	1.00	0.90	0.96	0.99
correlation (π, fractionally adjusted)	–	0.65	0.40	0.16
Law of motion P[b]				
$P(t-1)$	0.946	0.947	0.932	0.816
$g(t)$	–0.668	–0.544	–0.652	–0.270
R^2	1	0.9997	0.9998	0.9808

Midrigan (2011): Intuition

$$\left.\frac{dp}{dm}\right|_{dm=0} = \int \Lambda(x) f(x)\, dx + \int x\Lambda'(x) f(x)\, dx$$

- With leptokurtic shocks, less density at margin of adjustment.
  - Weakens extensive margin effect: fewer people induced to change price in direction of shock.
    - Adjusting downward to not adjusting or not adjusting to adjusting upward.
  - Similar intuition to extensive margin of labor supply (dist of reservation wages at margin matters), except upper and lower adjustment bounds so need to think about both.
- Looks like Calvo because dominant component of shock is Poisson, not Gaussian.

Midrigan (2011): Intuition



Gertler and Leahy (2008): (S,s)-Based Phillips Curve

- Gertler and Leahy (2008) are able to get a log-linear approx to an (S,s) micro-founded Phillips curve analytically.
- Key Tricks:
  - Leptokurtic Shocks: uniform idiosyncratic shock with prob $1 - \alpha$, no shock prob α.
  - Non-Convexities from (S,s) rule: Small decision cost to contemplating price adjustment. If agg shocks small relative to idiosyncratic, only consider adjusting with idiosyncratic.
- With tricks, (S,s) collapses to Calvo-like model.
  - Slope-coefficient on output gap is related to idiosyncratic shock process.
  - Get inflation more sensitive to movements in output gap due to selection effect. Depends on things like α.
  - Midrigan calibration suggests close to Calvo.

Alvarez et al. (2016): Kurtosis As A Sufficient Statistic

- Alvarez, Le Bihan, and Lippi (2016) unify the literature by providing an analytical sufficient statistic for the output response to a monetary shock.
- Assumptions
  - Continuous time *n*-product firm model.
  - iid normal cost shocks.
  - Low inflation.
  - No strategic complementarity (next lecture).
- Let:
  - $\mathcal{M}$ be the area under the output impulse response function
  - δ be a small monetary shock.
  - The labor supply elasticity is $1/\varepsilon - 1$
  - $N(\Delta p_i)$ be the number of price changes per year
  - $Kur(\Delta p_i)$ be the kurtosis of the size dist of price changes.
- Then

$$\mathcal{M} = \frac{\delta}{6\epsilon} \frac{Kur(\Delta p_i)}{N(\Delta p_i)}$$

Alvarez et al. (2016): Kurtosis As A Sufficient Statistic

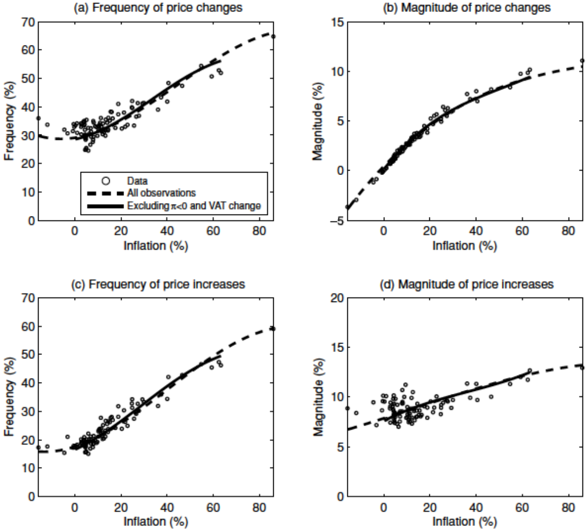
$$\mathcal{M} = \frac{\delta}{6\epsilon} \frac{Kur\left(\Delta p_i\right)}{N\left(\Delta p_i\right)}$$

- Kurtosis is scale-free statistic for "peakedness."
- Kurstosis summarizes strength of the selection effect.
  - If Kurtosis is high, many price changes are interior to adjustment thresholds (multi-product or Calvo-plus). Shift in thresholds does not induce many price changes.
  - In Golosov-Lucas, all changers at thresholds, price changes are concentrated, and Kurtosis is near 1.
  - In Calvo, random selection of firms changes prices, large cross-section of price change sizes, and Kurtosis is near 6.
- Alvarez et al. estimate Kurtosis to be around 4.
  - 4x larger output response than Golosov-Lucas
  - But 30% smaller than Calvo.

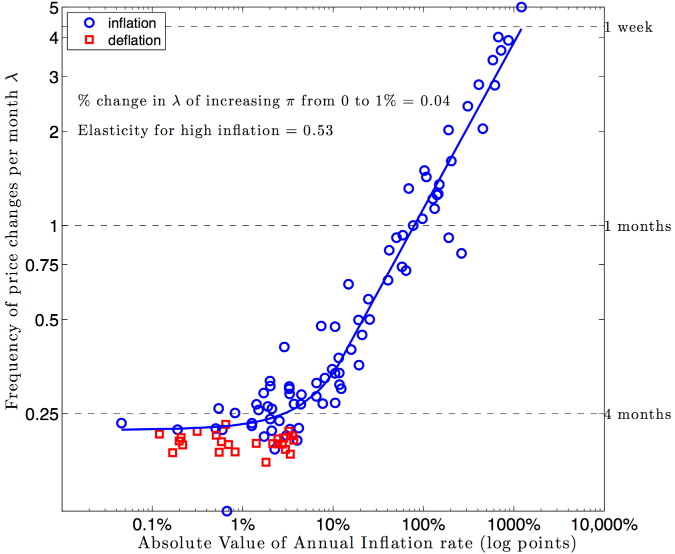
Some Additional Topics

1. High-inflation environments
   - What are facts?
   - Does frequency of price adjustment start to matter (so Calvo is bad assumption)?
   - If so does it look like a menu cost model?
2. Cyclical importance of sales, and other measurement issues.
   - Do we use frequency of price changes including or excluding sales in calibrating a Calvo model?

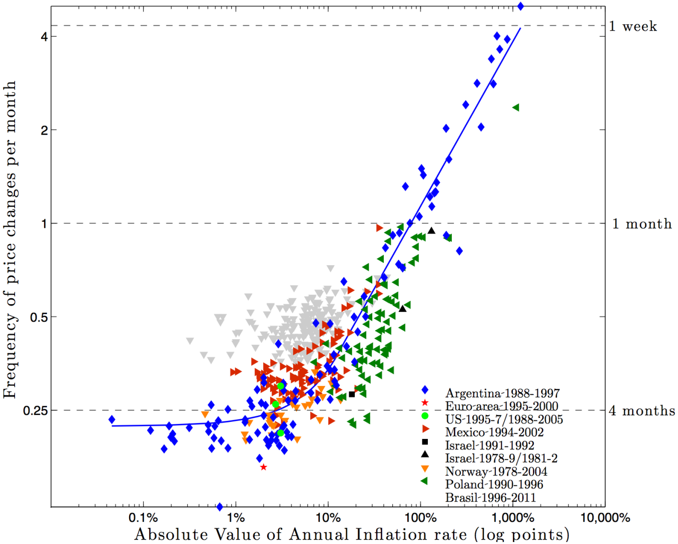
Gagnon (2009): Mexico (Inflation 4%-42%)



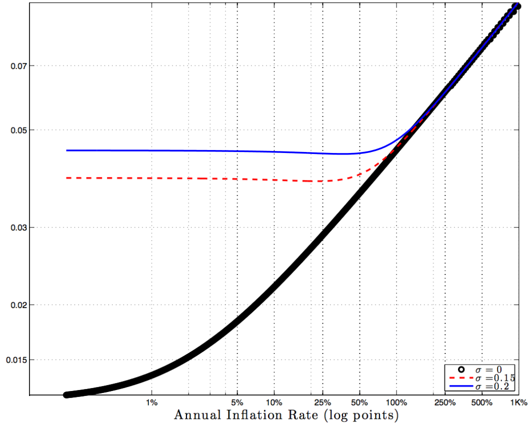
Alvarez et al. (2019): Argentina (Inflation 0%-5000%)



Alvarez et al. (2019): Combining Many Countries

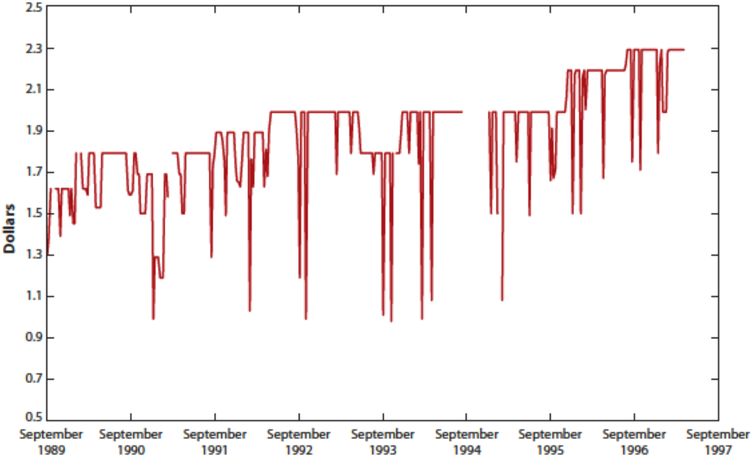


High Inflation Evidence Consistent With Menu Costs



- σ is variance of idiosyncratic shock in Golosov-Lucas model.

Sales Frequent and Brief: Saltines at Dominick's (NS AR)



Sales and Temporary Price Changes

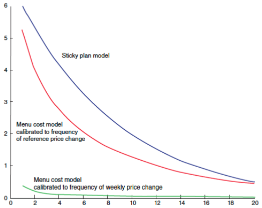
- Are sales relevant macroeconomically?
  - Do they depend on the state of the economy?
  - If so are they important for aggregate flexibility and monetary non-neutrality?
  - When calibrating a (Calvo) model can we filter them out?
- How to handle sales?
  - Technical and less interesting, but crucial for measurement.
  - See papers on reading list.
- Similar issues for substitutions (when product is pulled off shelves and replaced with newer, presumably better product).

Sales: Kehoe and Midrigan (2015) and Midrigan (2011)

- Two menu costs: high to adjust "regular" price, low to create temp sale which reverts to exact previous price.
  - Choose cost for one period sale because prices frequently return to previous price to the cent.
- Result: Sales barely diminish real effects of monetary shock.
- Intuition: Persistence of price level is key to determining non-neutrality, determined by regular price adjustments.
  - True even if 40% of goods sold during sales, as in data.

Sales: Eichenbaum, Jaimovich, and Rebelo (2011)

- Inertia is in “reference prices” and “reference costs.”
    - Define as most quoted price (or cost).
    - Last a year rather than 3 weeks in supermarket they study.
    - Low frequency stickiness, high-frequency flexibility.
- Model: Firms face menu cost for changing “price plan” – set of prices can change between costlessly.
- Even more inertia than just looking at sales because change plans *very* infrequently (so high adj cost) and KM intuition.



Conclusion

- Where is this literature?
  - Fairly settled.
  - The world is not Calvo.
  - But does that matter?
  - A bit but not much. Calvo is probably a fine approximation.
  - Except in high-inflation environments $> 10\%$ annually.
- But evidence implies price stickiness lasts 7-10 months.
  - NK models need price stickiness to last much longer!
  - Turn to this in bonus lecture.