PRICE RIGIDITY: MICROECONOMIC EVIDENCE AND MACROECONOMIC IMPLICATIONS

Emi Nakamura   Jón Steinsson

UC Berkeley

March 2019

Why Care About Price Rigidity in Macro?

Why Care About Price Rigidity in Macro?

Diverse evidence that **demand shocks** affect output:

- Monetary shocks: Friedman-Schwartz 63, Eichengreen-Sachs 85, Mussa 86, Christiano-Eichenbaum-Evans 99, Romer-Romer 04, Gertler-Karadi 15, Nakamura-Steinsson 18
- Fiscal shocks: Blanchard-Perotti 02, Ramey 11, Barro-Redlick 11, Nakamura-Steinsson 14, Guajardo-Leigh-Pescatori 14
- Household deleveraging shocks: Mian-Sufi 14

Why Care About Price Rigidity in Macro?

Diverse evidence that **demand shocks** affect output:

- Monetary shocks: Friedman-Schwartz 63, Eichengreen-Sachs 85, Mussa 86, Christiano-Eichenbaum-Evans 99, Romer-Romer 04, Gertler-Karadi 15, Nakamura-Steinsson 18
- Fiscal shocks: Blanchard-Perotti 02, Ramey 11, Barro-Redlick 11, Nakamura-Steinsson 14, Guajardo-Leigh-Pescatori 14
- Household deleveraging shocks: Mian-Sufi 14

Major challenge: How to explain this empirical finding?

Why Care About Price Rigidity in Macro?

Diverse evidence that **demand shocks** affect output:

- Monetary shocks: Friedman-Schwartz 63, Eichengreen-Sachs 85, Mussa 86, Christiano-Eichenbaum-Evans 99, Romer-Romer 04, Gertler-Karadi 15, Nakamura-Steinsson 18
- Fiscal shocks: Blanchard-Perotti 02, Ramey 11, Barro-Redlick 11, Nakamura-Steinsson 14, Guajardo-Leigh-Pescatori 14
- Household deleveraging shocks: Mian-Sufi 14

Major challenge: How to explain this empirical finding?

- In RBC type models, demand shocks have small effects on output

WHY CARE ABOUT PRICE RIGIDITY IN MACRO?

Diverse evidence that **demand shocks** affect output:

- Monetary shocks: Friedman-Schwartz 63, Eichengreen-Sachs 85, Mussa 86, Christiano-Eichenbaum-Evans 99, Romer-Romer 04, Gertler-Karadi 15, Nakamura-Steinsson 18
- Fiscal shocks: Blanchard-Perotti 02, Ramey 11, Barro-Redlick 11, Nakamura-Steinsson 14, Guajardo-Leigh-Pescatori 14
- Household deleveraging shocks: Mian-Sufi 14

Major challenge: How to explain this empirical finding?

- In RBC type models, demand shocks have small effects on output

Leading explanation: Prices adjust sluggishly to shocks

Monetary shock: Increase in money supply

- Flexible prices: Prices increase, while output and real rate unchanged
- Sticky prices: Reduction in nominal interest rate reduces real rates

Price Rigidity and the Business Cycles

Monetary shock: Increase in money supply

- Flexible prices: Prices increase, while output and real rate unchanged
- Sticky prices: Reduction in nominal interest rate reduces real rates

Fiscal shock: Increase in government spending

- Flexible prices: Real rates rise, which crowds out private spending
- Sticky prices: Real rate sluggish unless nominal rate moves, output increases more

Monetary shock: Increase in money supply

- Flexible prices: Prices increase, while output and real rate unchanged
- Sticky prices: Reduction in nominal interest rate reduces real rates

Fiscal shock: Increase in government spending

- Flexible prices: Real rates rise, which crowds out private spending
- Sticky prices: Real rate sluggish unless nominal rate moves, output increases more

Same logic implies muted response of real rates to other shocks such as: deleveraging shocks, financial panics, increased uncertainty, "animal spirits"

Could Price Rigidities Cause Major Recessions?

Could Price Rigidities Cause Major Recessions?

- Many people's first reaction is that this is not plausible

Could Price Rigidities Cause Major Recessions?

- Many people's first reaction is that this is not plausible
- But many shocks call for sharp movements in the real interest rate

Could Price Rigidities Cause Major Recessions?

- Many people's first reaction is that this is not plausible
- But many shocks call for sharp movements in the real interest rate
- Deleveraging shocks:
  (Eggertsson-Krugman 12 and Guerrieri-Lorenzoni 17)
  - Sharp increase in desire to save $\rightarrow$
    Sharp drop in "natural" rate of interest

Could Price Rigidities Cause Major Recessions?

- Many people's first reaction is that this is not plausible
- But many shocks call for sharp movements in the real interest rate
- Deleveraging shocks:
  (Eggertsson-Krugman 12 and Guerrieri-Lorenzoni 17)
  - Sharp increase in desire to save $\rightarrow$
    Sharp drop in "natural" rate of interest
  - But if prices are sticky and nominal rate constrained by ZLB ...
    Real rate stuck at too high a level, output stuck at too low a level

Could Price Rigidities Cause Major Recessions?

- Many people's first reaction is that this is not plausible
- But many shocks call for sharp movements in the real interest rate
- Deleveraging shocks:
  (Eggertsson-Krugman 12 and Guerrieri-Lorenzoni 17)
    - Sharp increase in desire to save $\rightarrow$
      Sharp drop in "natural" rate of interest
    - But if prices are sticky and nominal rate constrained by ZLB ...
      Real rate stuck at too high a level, output stuck at too low a level
- Financial disruptions and investment hang-overs have similar effects

Price Rigidity and Coordination Failure

- Nominal price stickiness not the whole story!

Price Rigidity and Coordination Failure

- Nominal price stickiness not the whole story!
- Usually combined with coordination failures among price setters
  - Staggered price setting
  - Strategic complementarity among price setters
    (firm A's optimal price increasing in firm B's price)

Price Rigidity and Coordination Failure

- Nominal price stickiness not the whole story!
- Usually combined with coordination failures among price setters
  - Staggered price setting
  - Strategic complementarity among price setters
    (firm A's optimal price increasing in firm B's price)
- These three features interact powerfully to create a lot of sluggishness

Price Rigidity and Coordination Failure

- Nominal price stickiness not the whole story!
- Usually combined with coordination failures among price setters
  - Staggered price setting
  - Strategic complementarity among price setters
    (firm A's optimal price increasing in firm B's price)
- These three features interact powerfully to create a lot of sluggishness

- Can price rigidity create long-lived effects on output?

Price Rigidity and Coordination Failure

- Nominal price stickiness not the whole story!
- Usually combined with coordination failures among price setters
  - Staggered price setting
  - Strategic complementarity among price setters
    (firm A's optimal price increasing in firm B's price)
- These three features interact powerfully to create a lot of sluggishness

- Can price rigidity create long-lived effects on output?
  - Yes! If combined with coordination failure among price setters

Micro Price Rigidity and the Business Cycles

- What matters for the business cycle is the extent to which micro price rigidity lead to a sluggish response of the aggregate price level

MICRO PRICE RIGIDITY AND THE BUSINESS CYCLES

- What matters for the business cycle is the extent to which micro price rigidity lead to a sluggish response of the aggregate price level
- This depends on the nature of the micro price rigidity

Micro Price Rigidity and the Business Cycles

- What matters for the business cycle is the extent to which micro price rigidity lead to a sluggish response of the aggregate price level
- This depends on the nature of the micro price rigidity
- Stark comparison: Calvo model vs. Caplin-Spulber model

Calvo Model

- Each firm adjusts with probability $1 - \alpha$ each period

$$p_t = (1 - \alpha) p_{it}^* + \alpha p_{t-1}$$

Calvo Model

- Each firm adjusts with probability $1-\alpha$ each period

$$p_t = (1-\alpha)p^*_{it} + \alpha p_{t-1}$$

- CES demand:

$$p^*_{it} = (1-\alpha\beta)\sum_{j=0}^{\infty}(\alpha\beta)^j E_t mc_{t+j}$$

Calvo Model

- Each firm adjusts with probability $1 - \alpha$ each period

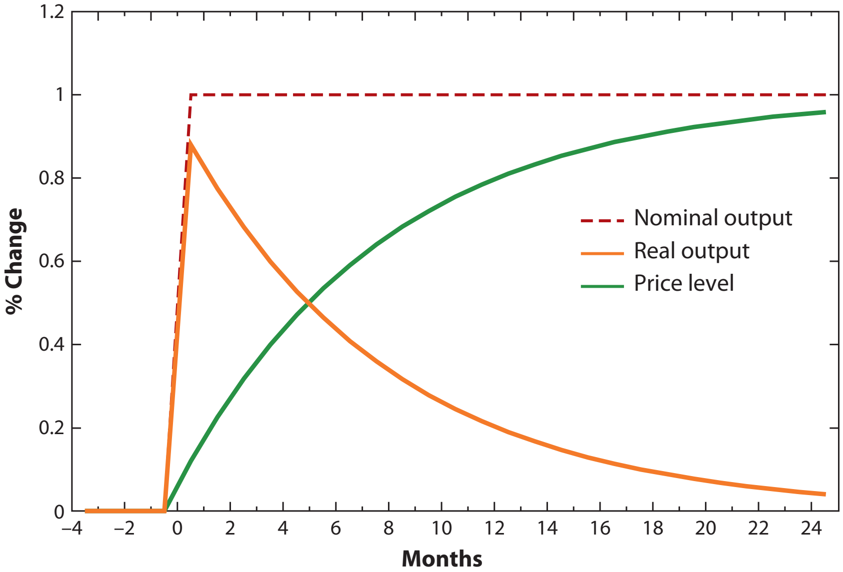
$$p_t = (1 - \alpha) p_{it}^* + \alpha p_{t-1}$$

- CES demand:

$$p_{it}^* = (1 - \alpha\beta) \sum_{j=0}^{\infty} (\alpha\beta)^j E_t mc_{t+j}$$

- MP targets nominal output: $m_t = y_t + p_t$
- Simple utility and production function: $mc_t = m_t$
- Random walk nominal output (no drift): $E_t mc_{t+j} = m_t$

$$p_t = (1 - \alpha) m_t + \alpha p_{t-1}$$



% Change
Months
Nominal output
Real output
Price level
1.2
1
0.8
0.6
0.4
0.2
0
–4
–2
0
2
4
6
8
10
12
14
16
18
20
22
24

Caplin-Spulber Model

- MP targets nominal output: $m_t = y_t + p_t$
- m_t is increasing (i.e., high inflation)
- $p_t^* \propto m_t$

Caplin-Spulber Model

- MP targets nominal output: $m_t = y_t + p_t$
- m_t is increasing (i.e., high inflation)
- $p_t^* \propto m_t$
- Fixed cost of changing prices
- When real price falls to s, firms raise it to S
- Initial distribution of real prices uniform on (s, S)

Caplin-Spulber Model

- Say infinitesimal Δm occurs

Caplin-Spulber Model

- Say infinitesimal Δm occurs
- $p_{it} - p_t^*$ falls by Δm for all firms
- Firms with initial real price below $s + \Delta m$ fall below s
  and raise their price to S (think of this occurring in continuous time)

Caplin-Spulber Model

- Say infinitesimal Δm occurs
- $p_{it} - p_t^*$ falls by Δm for all firms
- Firms with initial real price below $s + \Delta m$ fall below s
  and raise their price to S (think of this occurring in continuous time)
- Fraction of firms that change their price?

Caplin-Spulber Model

- Say infinitesimal Δm occurs
- $p_{it} - p_t^*$ falls by Δm for all firms
- Firms with initial real price below $s + \Delta m$ fall below s
  and raise their price to S (think of this occurring in continuous time)
- Fraction of firms that change their price?

$$\frac{\Delta m}{S - s}$$

Caplin-Spulber Model

- Say infinitesimal Δm occurs
- $p_{it} - p_t^*$ falls by Δm for all firms
- Firms with initial real price below $s + \Delta m$ fall below s
  and raise their price to S (think of this occurring in continuous time)
- Fraction of firms that change their price?

$$\frac{\Delta m}{S - s}$$

- How much do they change their price by?

Caplin-Spulber Model

- Say infinitesimal Δm occurs
- $p_{it} - p_t^*$ falls by Δm for all firms
- Firms with initial real price below $s + \Delta m$ fall below s
  and raise their price to S (think of this occurring in continuous time)
- Fraction of firms that change their price?

$$\frac{\Delta m}{S - s}$$

- How much do they change their price by?

$$S - s$$

CAPLIN-SPULBER MODEL

- How much does the price level and output respond?

Caplin-Spulber Model

- How much does the price level and output respond?

$$\Delta p = \frac{\Delta m}{S - s}(S - s) = \Delta m$$

Caplin-Spulber Model

- How much does the price level and output respond?

$$\Delta p = \frac{\Delta m}{S - s}(S - s) = \Delta m$$

$$\Delta y = \Delta m - \Delta p = 0$$

Caplin-Spulber Model

- How much does the price level and output respond?

$$\Delta p = \frac{\Delta m}{S - s}(S - s) = \Delta m$$
$$\Delta y = \Delta m - \Delta p = 0$$

- Conclusion: Money is neutral no matter how sticky prices are!!

Caplin-Spulber vs. Calvo

Calvo model:

- Timing of price changes random
- Random assortment of firms that change prices
- Some don't really need to change
- Aggregate price level responds modestly

Caplin-Spulber vs. Calvo

Calvo model:

- Timing of price changes random
- Random assortment of firms that change prices
- Some don't really need to change
- Aggregate price level responds modestly

Caplin-Spulber model:

- Timing of price changes chosen optimally
- Firms with biggest "pent-up" desire to change price do
- Aggregate price level responds a great deal
- Golosov-Lucas call this "selection effect"

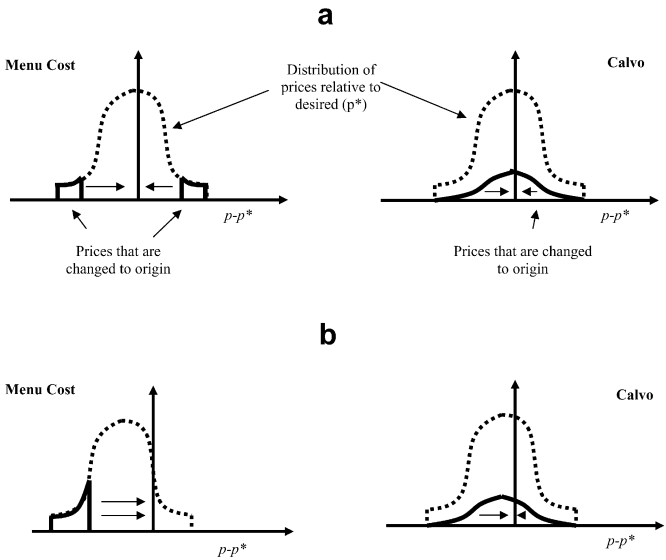


FIG. 6.—Price adjustment in menu cost and Calvo models. *a*, Price adjustment before aggregate shock. *b*, Price adjustment after aggregate shock.

Source: Golosov and Lucas (2007)

Caplin-Spulber vs. Calvo

Both models extreme cases

- Calvo: Aggregate conditions have no effect on which firms or how many firms change prices
- Caplin-Spulber model: Aggregate shocks only determinant of which firms and how many firms change prices
  (+ other special assumption that matter for result)

Caplin-Spulber vs. Calvo

Both models extreme cases

- Calvo: Aggregate conditions have no effect on which firms or how many firms change prices
- Caplin-Spulber model: Aggregate shocks only determinant of which firms and how many firms change prices (+ other special assumption that matter for result)

Subsequent literature explores intermediate cases and uses empirical evidence on characteristics of micro price adjustment to choose between models

Literature Gets Revitalized

- Ss literature had gotten a bit stale in late 90's
  - Only so much you can do analytically
    (computers not yet good enough to simulate realistic models)
  - Lack of data to discipline models

Literature Gets Revitalized

- Ss literature had gotten a bit stale in late 90's
  - Only so much you can do analytically
    (computers not yet good enough to simulate realistic models)
  - Lack of data to discipline models
- Both things changed after 2000:
  - Computers became powerful enough to simulate realistic models
  - Bils and Klenow (2004) introduced massive new source of data

Basic Facts: How Often Do Prices Change?

- Conventional wisdom in late 90's: Prices change once a year
  - Cecchetti (1986), Carlton (1986), Kashyap (1995), Blinder et al. (1998)

Basic Facts: How Often Do Prices Change?

- Conventional wisdom in late 90's: Prices change once a year
  - Cecchetti (1986), Carlton (1986), Kashyap (1995), Blinder et al. (1998)
- Bils and Klenow (2004) used BLS micro data from 95-97:
  - Prices change every 4-5 months
- Spawned a large subsequent literature

Additional Facts about Prices

- BLS micro data allowed researchers to document additional facts about price adjustment
- Klenow and Kryvtsov (05,08):
  - Average absolute size of price changes large: about 10%
- Golosov-Lucas 07:
  - 2.5% annual inflation
  - 20% of prices changing every month
  - Average absolute size of price change 10%
  - How can this be?

Additional Facts about Prices

- BLS micro data allowed researchers to document additional facts about price adjustment
- Klenow and Kryvtsov (05,08):
  - Average absolute size of price changes large: about 10%
- Golosov-Lucas 07:
  - 2.5% annual inflation
  - 20% of prices changing every month
  - Average absolute size of price change 10%
  - How can this be?
  - Evidence for large, transitory idiosyncratic shocks that drive price adjustment
  - Quantitatively assess monetary non-neutrality in menu cost model in light of these facts

Households maximize:

$$E_0 \sum_{t=0}^{\infty} \beta^t \left[\log C_t - \omega L_t\right]$$

where

$$C_t = \left[\int_0^1 c_t(z)^{\frac{\theta-1}{\theta}} dz\right]^{\frac{\theta}{\theta-1}}$$

subject to:

$$P_t C_t + Q_{t,t+1} B_{t+1} \leq B_t + W_t L_t + \int_0^1 \Pi_t(z) dz$$

and natural borrowing limits

Household Optimization

Cost minimization implies

$$c_t(z) = C_t \left(\frac{p_t(z)}{P_t} \right)^{-\theta}$$

Household Optimization

Cost minimization implies

$$c_t(z) = C_t \left(\frac{p_t(z)}{P_t} \right)^{-\theta}$$

Labor-leisure optimization yields:

$$W_t = \omega P_t C_t$$

So, nominal wages are proportional to nominal output

Define nominal aggregate demand as:

$$S_t = P_t C_t$$

Suppose central banks varies interest rate / money supply in such a way that log nominal aggregate demand follows a random walk:

$$\log S_t = \mu \log S_{t-1} + \eta_t$$

where $\eta_t \sim \mathrm{N}(0, \sigma_\eta^2)$.
This is aggregate source of uncertainty in the model

Firm's Problem

Linear production function

$$y_t(z) = A_t(z)L_t(z)$$

This implies that marginal cost of production is $W_t/A_t(z)$

Firm's Problem

Linear production function

$$y_t(z) = A_t(z)L_t(z)$$

This implies that marginal cost of production is $W_t/A_t(z)$

Idiosyncratic productivity follows an AR(1) in logs:

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

where $\epsilon_t(z) \sim \mathrm{N}(0, \sigma_\epsilon^2)$

Firm's Problem

Firm maximizes value of expected profits

$$E_t \sum_{\tau=0}^{\infty} D_{t,t+\tau} \Pi_{t+\tau}(z)$$

where profits are

$$\Pi_t(z) = p_t(z) y_t(z) - W_t L_t(z) - \chi_j W_t I_t(z) - P_t U$$

- Firm must hire χ_j units of labor to change price
- U fixed cost of operation
  (helpful to reconcile large markups with small profits)
- $D_{t,t+\tau}$ is household's stochastic discount factor

How to Solve Firm's Problem

- "Perturbation methods" won't work due to fixed cost

How to Solve Firm's Problem

- "Perturbation methods" won't work due to fixed cost
- Alternative: Dynamic programming, i.e., set up a Bellman equation

$$V(Z_t) = max_{p_t}[\Pi_t^R(z) + E[D_{t,t+1}^R V(Z_{t+1})]$$

$$\Pi_t^R(z) = C_t \left(\frac{p_t(z)}{P_t}\right)^{-\theta} \left(\frac{p_t(z)}{P_t} - \frac{1}{A_t(z)}\frac{W_t}{P_t}\right) - \chi_j \frac{W_t}{P_t} I_t(z) - U$$

- Z_t denotes vector of state variables

How to Solve Firm's Problem

- "Perturbation methods" won't work due to fixed cost
- Alternative: Dynamic programming, i.e., set up a Bellman equation

$$V(Z_t) = max_{p_t}[\Pi_t^R(z) + E[D_{t,t+1}^R V(Z_{t+1})]$$

$$\Pi_t^R(z) = C_t \left(\frac{p_t(z)}{P_t}\right)^{-\theta} \left(\frac{p_t(z)}{P_t} - \frac{1}{A_t(z)} \frac{W_t}{P_t}\right) - \chi_j \frac{W_t}{P_t} I_t(z) - U$$

- Z_t denotes vector of state variables
- Key question: What is the state?
  - Generic answer: All variables that affect firm's value

How to Solve Firm's Problem

- "Perturbation methods" won't work due to fixed cost
- Alternative: Dynamic programming, i.e., set up a Bellman equation

$$V(Z_t) = max_{p_t}[\Pi_t^R(z) + E[D_{t,t+1}^R V(Z_{t+1})]$$

$$\Pi_t^R(z) = C_t \left(\frac{p_t(z)}{P_t}\right)^{-\theta} \left(\frac{p_t(z)}{P_t} - \frac{1}{A_t(z)}\frac{W_t}{P_t}\right) - \chi_j \frac{W_t}{P_t} I_t(z) - U$$

- Z_t denotes vector of state variables
- Key question: What is the state?
  - Generic answer: All variables that affect firm's value
  - $A_t(z)$, $p_{t-1}(z)/P_t$, C_t

How to Solve Firm's Problem

- "Perturbation methods" won't work due to fixed cost
- Alternative: Dynamic programming, i.e., set up a Bellman equation

$$V(Z_t) = max_{p_t}[\Pi_t^R(z) + E[D_{t,t+1}^R V(Z_{t+1})]$$

$$\Pi_t^R(z) = C_t \left(\frac{p_t(z)}{P_t}\right)^{-\theta} \left(\frac{p_t(z)}{P_t} - \frac{1}{A_t(z)} \frac{W_t}{P_t}\right) - \chi_j \frac{W_t}{P_t} I_t(z) - U$$

- Z_t denotes vector of state variables
- Key question: What is the state?
  - Generic answer: All variables that affect firm's value
  - $A_t(z)$, $p_{t-1}(z)/P_t$, C_t
  - Any variable that is needed to forecast Z_{t+1} (e.g., C_{t+1} and P_{t+1})

How to Solve Firm's Problem

- "Perturbation methods" won't work due to fixed cost
- Alternative: Dynamic programming, i.e., set up a Bellman equation

$$V(Z_t) = max_{p_t}[\Pi_t^R(z) + E[D_{t,t+1}^R V(Z_{t+1})]$$

$$\Pi_t^R(z) = C_t \left(\frac{p_t(z)}{P_t}\right)^{-\theta} \left(\frac{p_t(z)}{P_t} - \frac{1}{A_t(z)}\frac{W_t}{P_t}\right) - \chi_j \frac{W_t}{P_t} I_t(z) - U$$

- Z_t denotes vector of state variables
- Key question: What is the state?
  - Generic answer: All variables that affect firm's value
  - $A_t(z)$, $p_{t-1}(z)/P_t$, C_t
  - Any variable that is needed to forecast Z_{t+1} (e.g., C_{t+1} and P_{t+1})
  - Entire joint distribution of $(p_{t-1}(z)/P_t, A_t(z))$

How to Solve Firm's Problem

- Krusell-Smith (1998):
  - Assume firms are slightly boundedly rational
  - Firms perceive price level as being a function of a small number of moments of the joint distribution of $(p_t(z)/P_t, A_t(z))$

How to Solve Firm's Problem

- Krusell-Smith (1998):
  - Assume firms are slightly boundedly rational
  - Firms perceive price level as being a function of a small number of moments of the joint distribution of $(p_t(z)/P_t, A_t(z))$
- Response to single unexpected shock
  - Conjecture path for endogenous aggregates
  - Solve household problem conditional on this by backward induction
  - Simulate and update conjecture

How to Solve Firm's Problem

- Krusell-Smith (1998):
  - Assume firms are slightly boundedly rational
  - Firms perceive price level as being a function of a small number of moments of the joint distribution of $(p_t(z)/P_t, A_t(z))$
- Response to single unexpected shock
  - Conjecture path for endogenous aggregates
  - Solve household problem conditional on this by backward induction
  - Simulate and update conjecture
- Reiter (2009) method
- Continuous time methods (Ahn-Kaplan-Moll-Winberry-Wolf 17)

  More generally, see Ben Moll's website and Alisdair McKay's website.

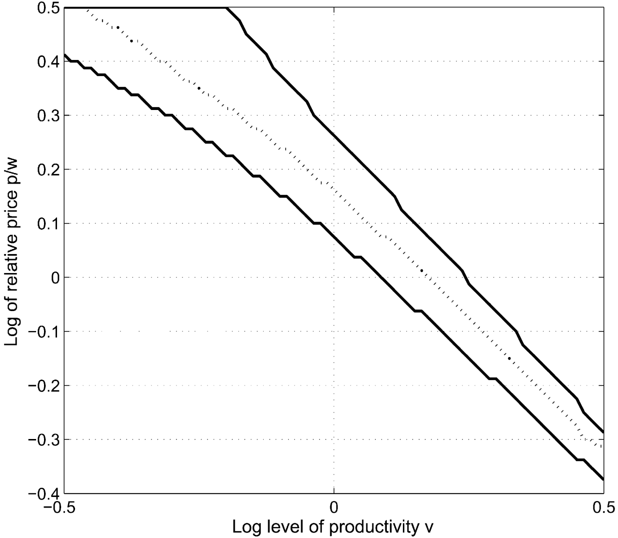
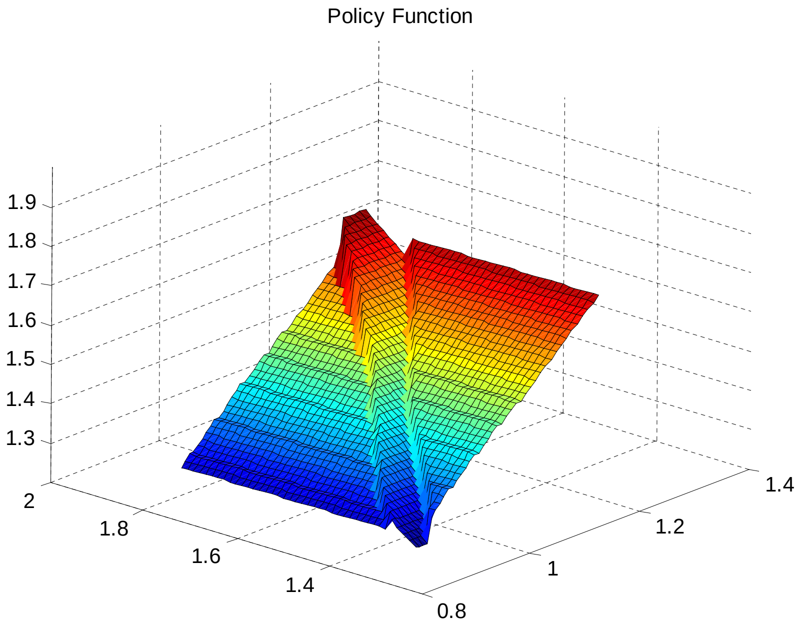


FIG. 1.—Pricing bounds for 0.64 percent quarterly inflation. Solid lines: upper and lower bounds $U(v)$ and $L(v)$. Dotted line: $g(v)$.

Source: Golosov and Lucas (2007)



Left axis: Prior price. Right axis: Marginal cost. Vertical axis: New price.

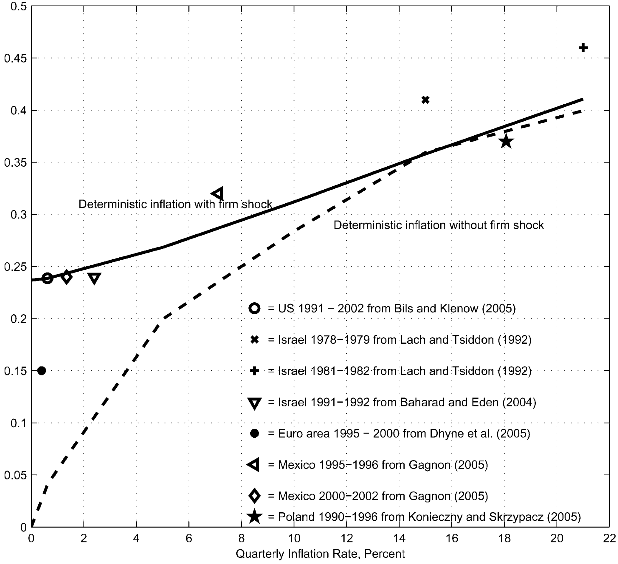
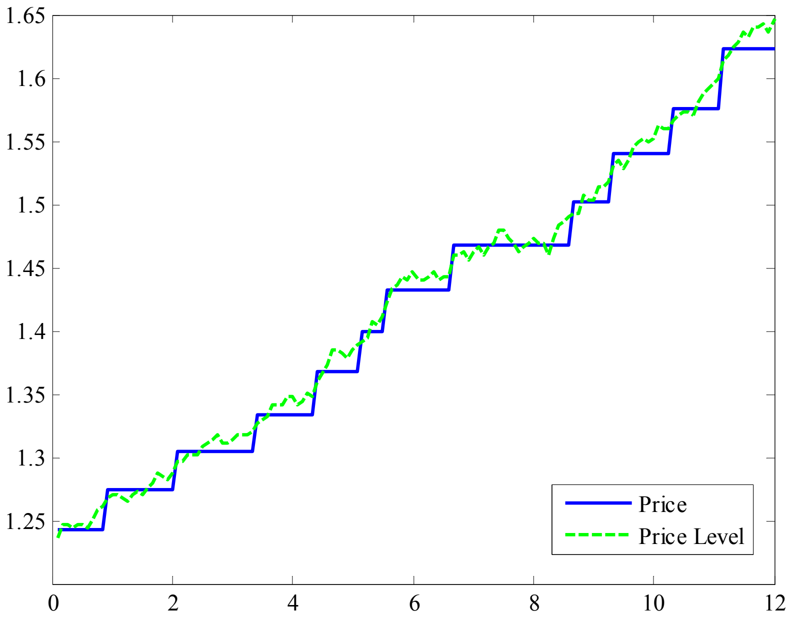
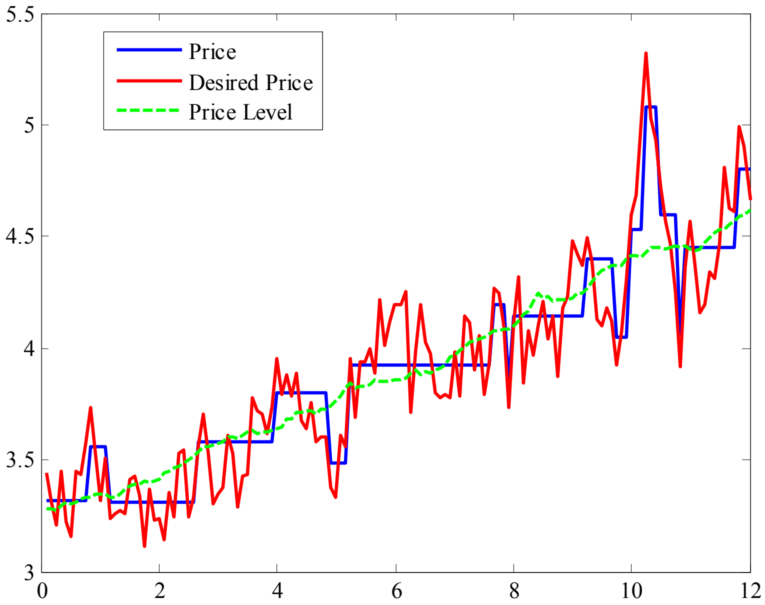


Fig. 3.—Fraction of prices changed each month

Source: Golosov and Lucas (2007)



Sample path without idiosyncratic shocks. Small price changes. No price decreases.



Sample path with idiosyncratic shocks.

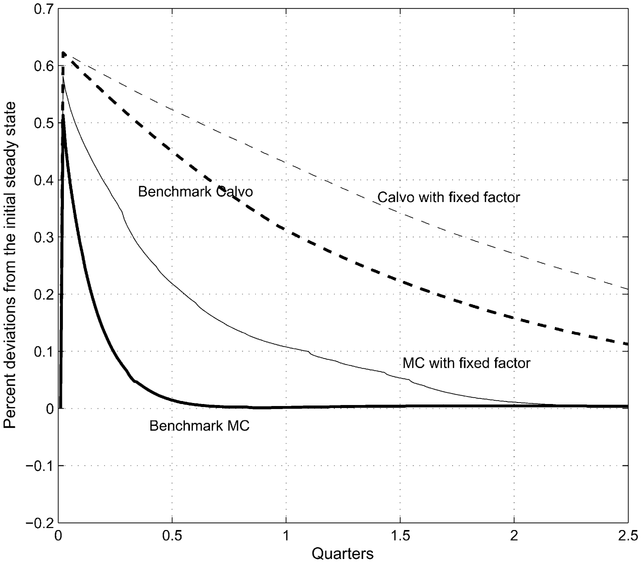


Fig. 5.—Output responses in menu cost and Calvo models

Source: Golosov and Lucas (2007)

Golosov and Lucas 07

- Very strong selection effect
- 6 times less monetary non-neutrality than in Calvo model

Golosov and Lucas 07

- Very strong selection effect
- 6 times less monetary non-neutrality than in Calvo model
- Bottom line: Realistic menu cost model yields monetary non-neutrality that is “small and transient”

Bils and Klenow (2004)

- Prices change every 4-5 months

Golosov and Lucas (2007)

- Monetary non-neutrality is “ small and transient”

Keynesian Economics Fights Back

Perhaps Golosov-Lucas model not sufficiently realistic to yield credible policy conclusions

Keynesian Economics Fights Back

Perhaps Golosov-Lucas model not sufficiently realistic to yield credible policy conclusions

Empirical Issues:

- How should we treat temporary sales?

Keynesian Economics Fights Back

Perhaps Golosov-Lucas model not sufficiently realistic to yield credible policy conclusions

Empirical Issues:

- How should we treat temporary sales?
- How does heterogeneity in price rigidity matter?

Keynesian Economics Fights Back

Perhaps Golosov-Lucas model not sufficiently realistic to yield credible policy conclusions

Empirical Issues:

- How should we treat temporary sales?
- How does heterogeneity in price rigidity matter?
- Are all price changes selected?

Keynesian Economics Fights Back

Perhaps Golosov-Lucas model not sufficiently realistic to yield credible policy conclusions

Empirical Issues:

- How should we treat temporary sales?
- How does heterogeneity in price rigidity matter?
- Are all price changes selected?
- What is a realistic distribution of idiosyncratic shocks?

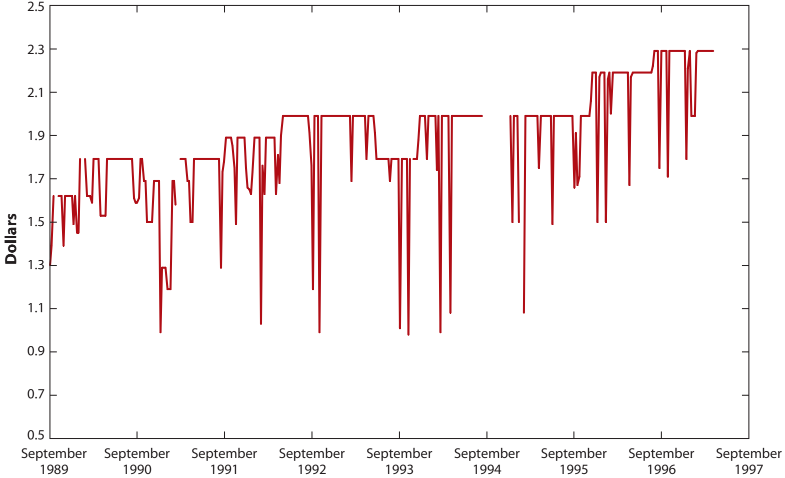


Figure 2

Price series of Nabisco Premium Saltines (16 oz) at a Dominick's Finer Foods store in Chicago.

Source: Nakamura and Steinsson (2013)

Two features stand out:

1. Change in “regular” price is infrequent and “lumpy”
    - Only 9 “regular price” changes in a 7 year period

Price Rigidity

Two features stand out:

1. Change in “regular” price is infrequent and “lumpy”
    - Only 9 “regular price” changes in a 7 year period
2. Frequent temporary discounts (sales)
    - 117 price changes in 365 weeks

Price Rigidity

Two features stand out:

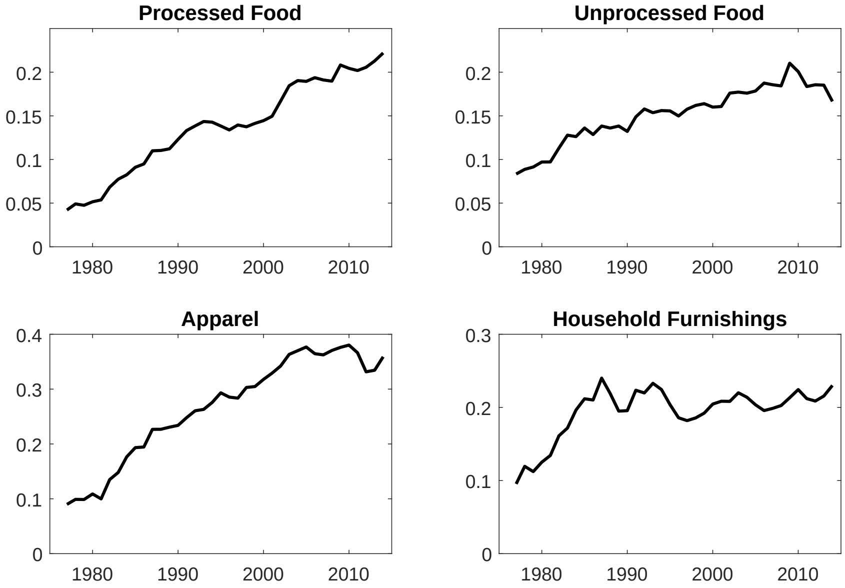
1. Change in “regular” price is infrequent and “lumpy”
   - Only 9 “regular price” changes in a 7 year period
2. Frequent temporary discounts (sales)
   - 117 price changes in 365 weeks

- Does this product have essentially flexible prices?
- Or is it’s price highly rigid?

Table: Frequency of Price Change by Major Group 1998-2005

Major Group	Weight	Reg. Price Freq.	Price Freq.	Frac. Price Ch. Sales
Processed Food	8.2	10.5	25.9	57.9
Unprocessed Food	5.9	25.0	37.3	37.9
Household Furnishing	5.0	6.0	19.4	66.8
Apparel	6.5	3.6	31.0	87.1
Transportation Goods	8.3	31.3	31.3	8.0
Recreation Goods	3.6	6.0	11.9	49.1
Other Goods	5.4	15.0	15.5	32.6
Utilities	5.3	38.1	38.1	0.0
Vehicle Fuel	5.1	87.6	87.6	0.0
Travel	5.5	41.7	42.8	1.5
Services (excl. Travel)	38.5	6.1	6.6	3.1

Source: Nakamura and Steinsson (2008)



Source: Nakamura-Steinsson-Sun-Villar (2018)

Table 1 Frequency of price change in consumer prices

	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

Source: Nakamura and Steinsson (2013)

Is a Price Change Just a Price Change?

- Temporary sales have very special empirical characteristics
  - They are highly transient
  - They very often return to the original price
  - Strongly suggests that firms are not reoptimizing
- How do these empirical characteristics affect degree to which temporary sales enhance the flexibility of the aggregate price level?

Table 2 Transience of temporary sales

	Fraction return after one-period sales	Frequency of regular price change	Frequency of price change during one-period sales	Average duration of sales
Processed food	78.5	10.5	11.4	2.0
Unprocessed food	60.0	25.0	22.5	1.8
Household furnishings	78.2	6.0	11.6	2.3
Apparel	86.3	3.6	7.1	2.1

The sample period is 1998–2005. The first data column gives the median fraction of prices that return to their original level after one-period sales. The second is the median frequency of price changes excluding sales. The third lists the median monthly frequency of regular price change during sales that past one month. The monthly frequency is calculated as $1-(1-f)^{0.5}$, where f is the fraction of prices that return to their original levels after one-period sales. The fourth data column gives the weighted average duration of sale periods in months. Data taken from Nakamura & Steinsson (2008).

Source: Nakamura and Steinsson (2013)

Is a Price Change Just a Price Change?

- Temporary sales have very special empirical characteristics
  - They are highly transient
  - They very often return to the original price
  - Strongly suggests that firms are not reoptimizing

- How do these empirical characteristics affect degree to which temporary sales enhance the flexibility of the aggregate price level?

KEHOE AND MIDRIGAN (2015)

- Menu cost model (also consider Calvo model)
- Firms can change prices for one period at lower cost
  - Change regular price permanently ("buy" a new price)
  - Temporary sale ("rent" a new price)

Kehoe and Midrigan (2015)

- Menu cost model (also consider Calvo model)
- Firms can change prices for one period at lower cost
  - Change regular price permanently ("buy" a new price)
  - Temporary sale ("rent" a new price)
- Timing of sales chosen optimally and responds to macro shocks

Kehoe and Midrigan (2015)

- Menu cost model (also consider Calvo model)
- Firms can change prices for one period at lower cost
  - Change regular price permanently (“buy” a new price)
  - Temporary sale (“rent” a new price)
- Timing of sales chosen optimally and responds to macro shocks
- Nevertheless, sales generate very little aggregate price flexibility
- Results on monetary non-neutrality close to those if sales had been excluded

Sales Orthogonal to Macro Shocks?

- Two Views of Sales:
  - Intertemporal price discrimination (e.g., Varian, 1980)
  - Inventory Management (e.g., Lazear, 1986)
    - Due to unpredictable shifts in taste (fashion)?

Empirical Issues

- How should we treat temporary sales?
- How does heterogeneity in price rigidity matter?
- Are all price changes selected?
- What is a realistic distribution of idiosyncratic shocks?

Table 1 Frequency of price change in consumer prices

	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

Source: Nakamura and Steinsson (2013)

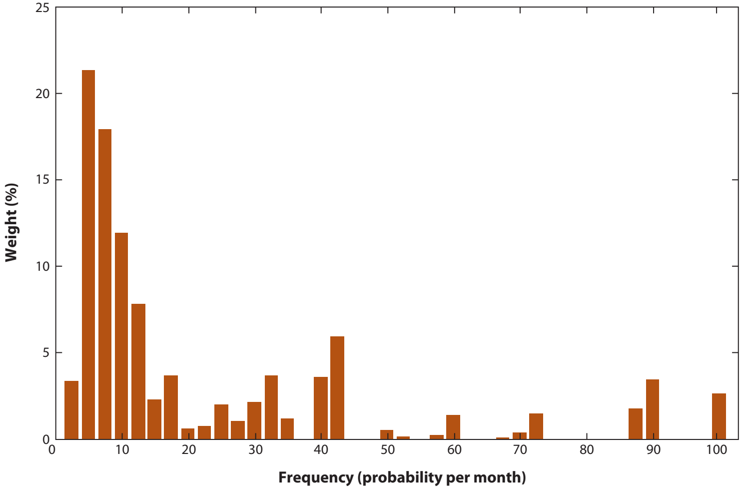


Figure 3

The expenditure weighted distribution of the frequency of regular price change (percent per month) across product categories (entry-level items) in the US Consumer Price Index (CPI) for the period 1998–2005. Data taken from Nakamura & Steinsson (2008).

Source: Nakamura and Steinsson (2013)

Heterogeneity in Price Rigidity

- Distribution is skewed: long right tail
  - Many products with low frequency
  - Some products with very high frequency
- Different summary statistics give impressions:
  - Excl. sales: Mean freq: 23%, median freq: 11%
- Questions:
  - Does this heterogeneity matter for aggregate monetary non-neutrality?
  - What statistic should single sector models be calibrated to?

Heterogeneity and Monetary Non-Neutrality

- Heterogeneity matters a lot!
- No model free answer for calibrating a single sector model

Heterogeneity and Monetary Non-Neutrality

- Heterogeneity matters a lot!
- No model free answer for calibrating a single sector model
- In Taylor model: Bils-Klenow (2002) use median frequency

- Heterogeneity matters a lot!
- No model free answer for calibrating a single sector model
- In Taylor model: Bils-Klenow (2002) use median frequency
- In Calvo model: Carvalho (2007) use mean implied duration (NOT = inverse of mean frequency)

Heterogeneity and Monetary Non-Neutrality

- Heterogeneity matters a lot!
- No model free answer for calibrating a single sector model
- In Taylor model: Bils-Klenow (2002) use median frequency
- In Calvo model: Carvalho (2007) use mean implied duration (NOT = inverse of mean frequency)
- In menu cost model: Nakamura and Steinsson (2010) say use median frequency for US data (no general theorem)
- Intuition: Extra price change not as useful in high frequency sector since everyone has already changed

Empirical Issues

- How should we treat temporary sales?
- How does heterogeneity in price rigidity matter?
- Are all price changes selected?
- What is a realistic distribution of idiosyncratic shocks?

Figure: Seasonality in Product Substitution

Source: Nakamura and Steinsson (2008)

SUBSTITUTIONS NOT SELECTED

Nakamura and Steinsson 10:

- Consider version of model in which substitutions are not selected (i.e., substitutions are like Calvo price changes, while other price changes are selected)
- Non-selected price changes matter very little

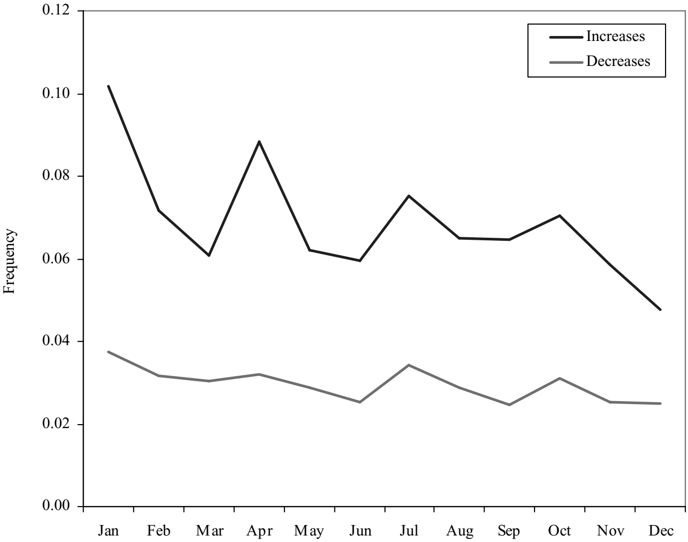
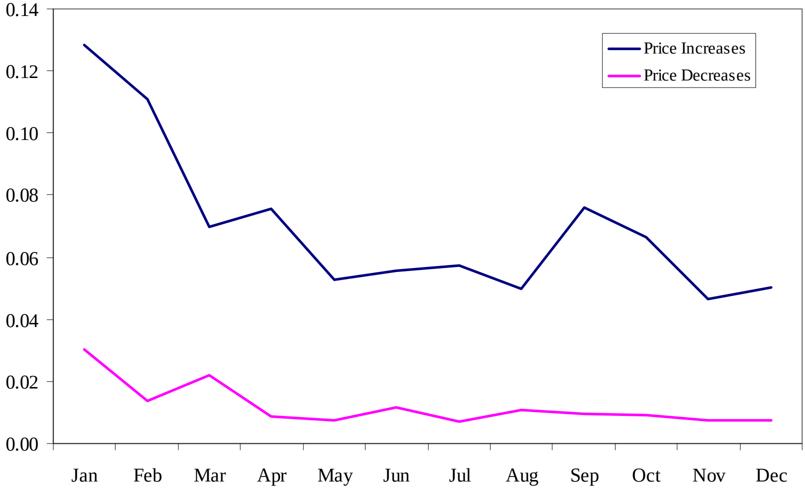


FIGURE V
Frequency of Regular Price Increases and Decreases by Month for Consumer Prices

Source: Nakamura and Steinsson (2008)

Figure 19: Frequency of Regular Price Increases and Decreases by Month for Finished Producer Goods



The figure plots the weighted median frequency of price increase and decrease by month.

Source: Nakamura and Steinsson (2008 Supplement)

Empirical Issues

- How should re treat temporary sales?
- How does heterogeneity in price rigidity matter?
- Are all price changes selected?
- What is a realistic distribution of idiosyncratic shocks?

Midrigan (2011)

- Strength of selection effect highly sensitive to assumptions about distribution of idiosyncratic shocks

Midrigan (2011)

- Strength of selection effect highly sensitive to assumptions about distribution of idiosyncratic shocks
- Golosov-Lucas 07 assume normal shocks
- Suppose we instead assume shocks are either tiny or huge i.e., that they have huge kurtosis

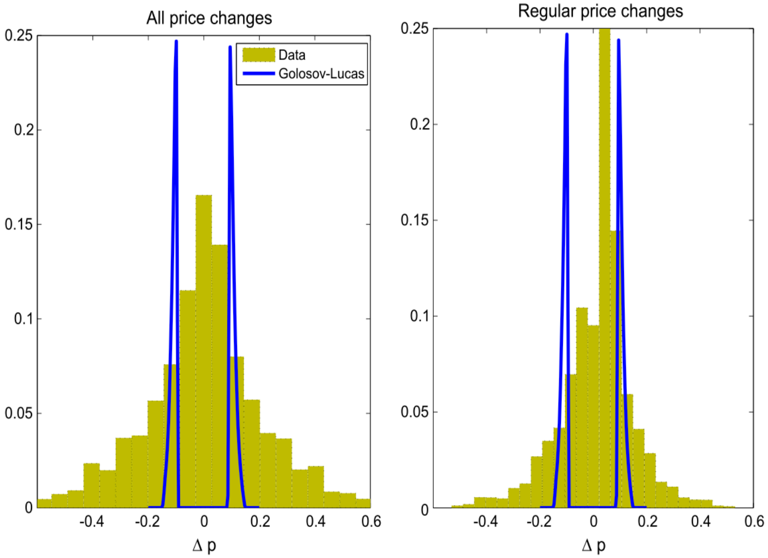
MIDRIGAN (2011)

- Strength of selection effect highly sensitive to assumptions about distribution of idiosyncratic shocks
- Golosov-Lucas 07 assume normal shocks
- Suppose we instead assume shocks are either tiny or huge i.e., that they have huge kurtosis
- In the limit, model becomes much like Calvo

Midrigan (2011)

- Strength of selection effect highly sensitive to assumptions about distribution of idiosyncratic shocks
- Golosov-Lucas 07 assume normal shocks
- Suppose we instead assume shocks are either tiny or huge i.e., that they have huge kurtosis
- In the limit, model becomes much like Calvo
- Midrigan evidence:
  - Size of price changes dispersed
  - Many small price changes
  - Coordination of timing of price changes within category

Distribution of p changes: Data vs. GL model



Source: Midrigan (2011)

Midrigan (2011)

Two changes to Golosov-Lucas model:

- Leptokurtic distribution of idiosyncratic shocks
- Returns to scale in price adjustment

Midrigan (2011)

Two changes to Golosov-Lucas model:

- Leptokurtic distribution of idiosyncratic shocks
- Returns to scale in price adjustment

- Selection effect much smaller.
- Model yields similar conclusions as Calvo model

Sufficient Statistic for Real Effects

Alvarez-Le Bihan-Lippi 15:

- In a wide class of models ...

  (Calvo, Taylor, Golosov-Lucas, Reis, Midrigan, etc.)
- Cumulative output effect of money shock:

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

  - δ size of monetary shock
  - $1/\epsilon - 1$ Frisch elasticity of labor supply
  - $\text{Kur}(\Delta p_i)$ kurtosis of size distribution of price changes
  - $\text{N}(\Delta p_i)$ frequency of price change

Alvarez-Le Bihan-Lippi 15:

- In a wide class of models ...
  (Calvo, Taylor, Golosov-Lucas, Reis, Midrigan, etc.)
- Cumulative output effect of money shock:

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

  - δ size of monetary shock
  - $1/\epsilon - 1$ Frisch elasticity of labor supply
  - $\text{Kur}(\Delta p_i)$ kurtosis of size distribution of price changes
  - $\text{N}(\Delta p_i)$ frequency of price change
- Obviously, there are some simplifying assumptions
  (e.g., unit root shock, no inflation, no strategic complementarity, etc.)

Kurtosis is Key

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

- Kurtosis in Calvo model is 6
- Kurtosis in Golosov-Lucas model is 1

Measuring Kurtosis

Kurtosis is hard to measure!!

- Heterogeneity:
  - Mixture of distributions with different variances but same kurtosis will have higher kurtosis
  - Authors divide by standard deviation at category level
- Measurement errors:
  - Standard to drop large observations. Kurtosis very sensitive to this!!
  - Authors drop largest 1% of price changes
  - Spurious small price changes also a problem (product not held constant, coupons)
  - Authors drop price changes that are smaller than 1 cent or 0.1%

Calvo versus Menu Costs

Distinction between time-dependent and state-dependent pricing models important for key questions:

- Degree of monetary non-neutrality
- Costs of inflation

Calvo versus Menu Costs

Distinction between time-dependent and state-dependent pricing models important for key questions:

- Degree of monetary non-neutrality
- Costs of inflation

Which class of models does the evidence favor?

Calvo versus Menu Costs

- Calvo model implies that frequency of price change doesn't change as inflation changes
- Menu cost model implies that frequency increases

Calvo versus Menu Costs

- Calvo model implies that frequency of price change doesn't change as inflation changes
- Menu cost model implies that frequency increases

- Empirical Strategy: Measure how frequency changes as inflation changes

Calvo versus Menu Costs

- Calvo model implies that frequency of price change doesn't change as inflation changes
- Menu cost model implies that frequency increases

- Empirical Strategy: Measure how frequency changes as inflation changes
  - Gagnon 09: Mexico 1994-2002 (Tequila crisis)
  - Nakamura-Steinsson-Sun-Villar 18: U.S. 1978-2014 (Great Inflation/Volcker disinflation)
  - Alvarez-Baraja-Gonzalez-Rozada-Neumeyer 19: Argentina 1988-1997 (Hyperinflation /Stabalization)

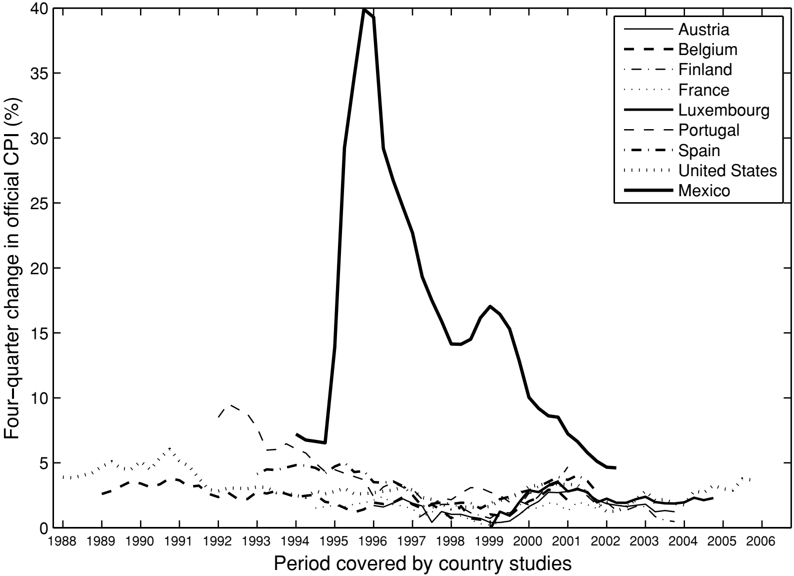
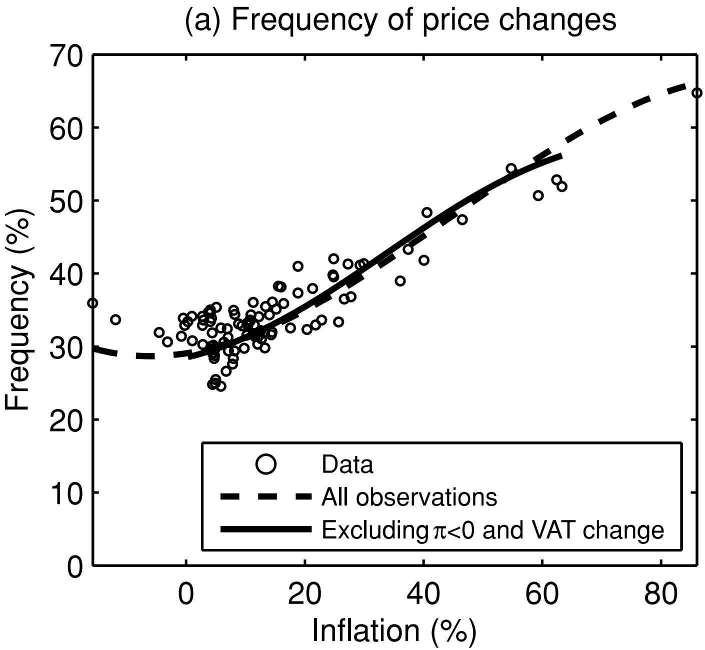


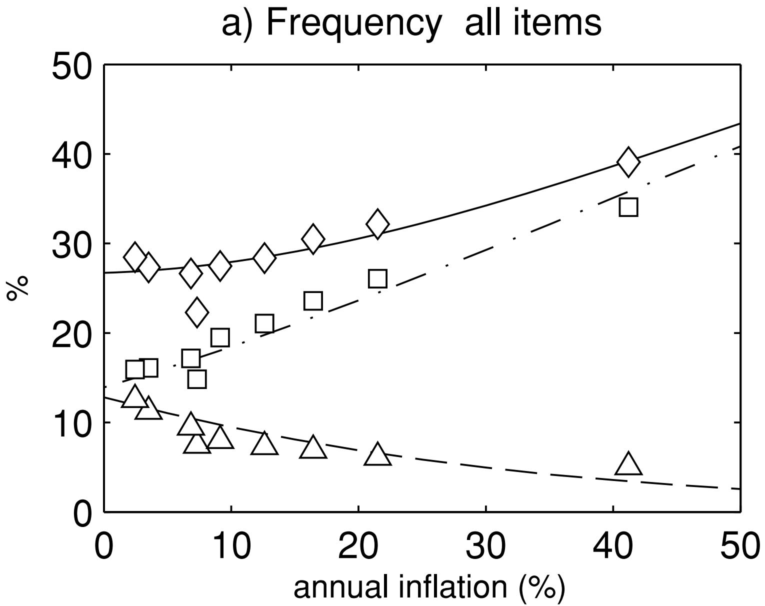
FIGURE I

Inflation and Time Coverage of U.S., Euro-Area, and Mexican CPI Studies

Source: Gagnon (2009)



Source: Gagnon (2009)



Source: Gagnon (2009). Diamonds: data on changes. Boxes: data on increases. Triangles: data on decreases. Lines: corresponding statistics from model.

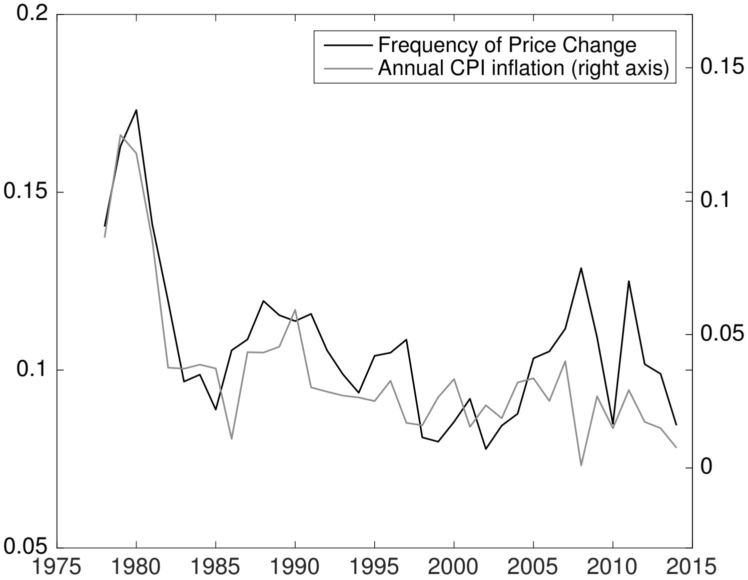


Figure 12: Frequency of Price Changes in U.S. Data

Source: Nakamura-Steinsson-Sun-Villar (2018)

Alvarez et al. (2019): Theoretical Results

At zero inflation:

- Derivative of frequency = 0
- Derivative of price dispersion = 0
- Inflation 9/10th due to "extensive margin"

$$\pi = \lambda^+ \Delta^+ - \lambda^- \Delta^-$$

Alvarez et al. (2019): Theoretical Results

At zero inflation:

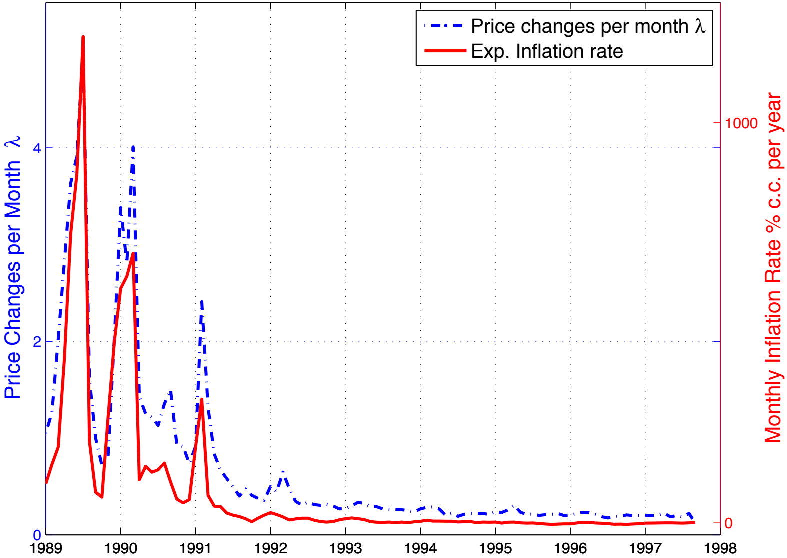
- Derivative of frequency = 0
- Derivative of price dispersion = 0
- Inflation 9/10th due to “extensive margin”

$$\pi = \lambda^+ \Delta^+ - \lambda^- \Delta^-$$

At high inflation:

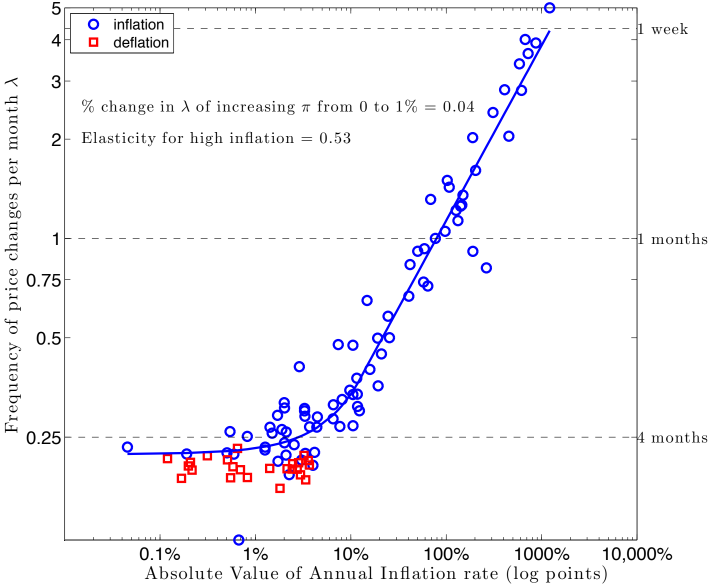
- Elasticity of frequency with inflation equal to 2/3
- Elasticity of dispersion with inflation equal to 1/3

Figure 5: Estimated Frequency of Price Changes λ and Expected Inflation



Source: Alverez-Beraja-Gonzalez-Rozada-Neumeyer (2019)

Figure 6: The Frequency of Price Changes (λ) and Expected Inflation.



Source: Alverez-Beraja-Gonzalez-Rozada-Neumeyer (2019)

Have Prices Become More Flexible?

- Large changes in technology over past 40 years
- Perhaps costs of changing prices have fallen?
- This would make price changes more frequent

Have Prices Become More Flexible?

- Large changes in technology over past 40 years
- Perhaps costs of changing prices have fallen?
- This would make price changes more frequent

- However, evolution of frequency of price (excluding sales) change can be explained by menu cost model with a constant menu cost over entire sample period
- Regular prices have not becomes more flexible

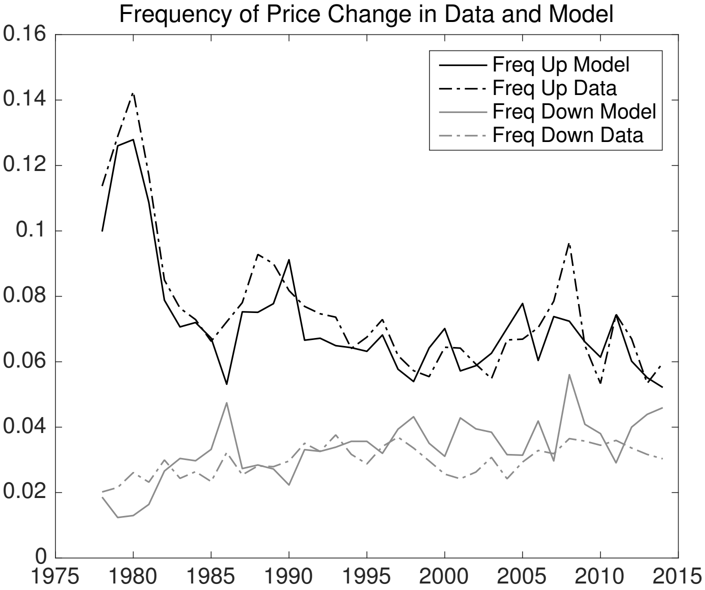


Figure 14: Predicted and Actual Frequency of Price Changes

Source: Nakamura-Steinsson-Sun-Villar (2018)

Optimal Level of Inflation

What level of inflation should central banks target?

- Pre-crisis policy consensus to target roughly 2% inflation per year
- Academic studies argued for still lower rates
  (Schmitt-Grohe and Uribe, 2011; Coibion et al., 2012)

Optimal Level of Inflation

What level of inflation should central banks target?

- Pre-crisis policy consensus to target roughly 2% inflation per year
- Academic studies argued for still lower rates
  (Schmitt-Grohe and Uribe, 2011; Coibion et al., 2012)

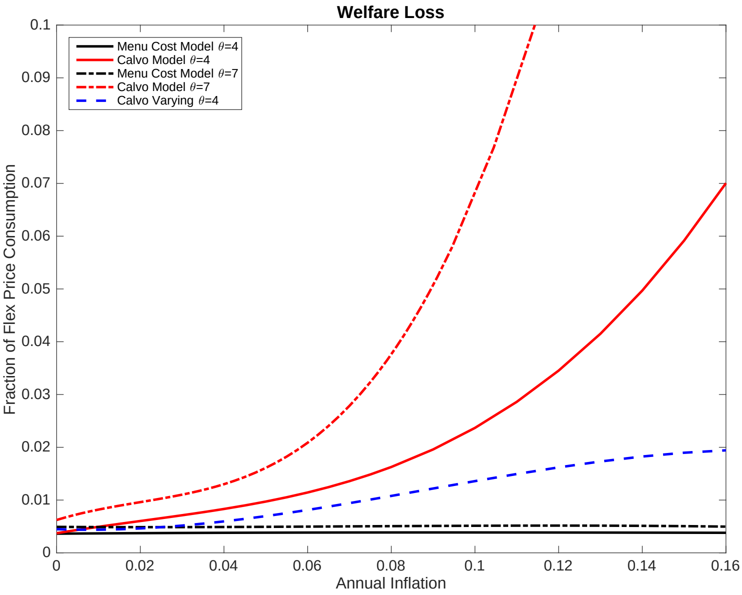
- Great Recession has lead to increasing calls for higher inflation targets
  - Blanchard, Dell'Ariccia, Mauro (2010), Ball (2014), Krugman (2014)
  - Blanco (2015)

Price Dispersion and the Costs of Inflation

- Higher inflation will lead to higher price dispersion
  - Prices will drift further from optimum between times of adjustment
  - Distorts allocative role of the price system

Price Dispersion and the Costs of Inflation

- Higher inflation will lead to higher price dispersion
  - Prices will drift further from optimum between times of adjustment
  - Distorts allocative role of the price system
- In standard New Keynesian models, these costs are very large
  - Going from 0% to 12% inflation per year yields a 10% loss of welfare
- Much more costly than business cycle fluctuations in output in these same models



Welfare Loss
Menu Cost Model θ=4
Calvo Model θ=4
Menu Cost Model θ=7
Calvo Model θ=7
Calvo Varying θ=4
Fraction of Flex Price Consumption
Annual Inflation
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16

Nakamura-Steinsson-Sun-Villar 18

- Measure sensitivity of inefficient price dispersion to changes in inflation

Nakamura-Steinsson-Sun-Villar 18

- Measure sensitivity of inefficient price dispersion to changes in inflation

Challenges:

1. Very limited variation in inflation over last 30 years!

Nakamura-Steinsson-Sun-Villar 18

- Measure sensitivity of inefficient price dispersion to changes in inflation

Challenges:

1. Very limited variation in inflation over last 30 years!
    - Extend BLS micro-data on consumer prices back to 1977
    - Covers "Great Inflation" and Volcker disinflation

Nakamura-Steinsson-Sun-Villar 18

- Measure sensitivity of inefficient price dispersion to changes in inflation

Challenges:

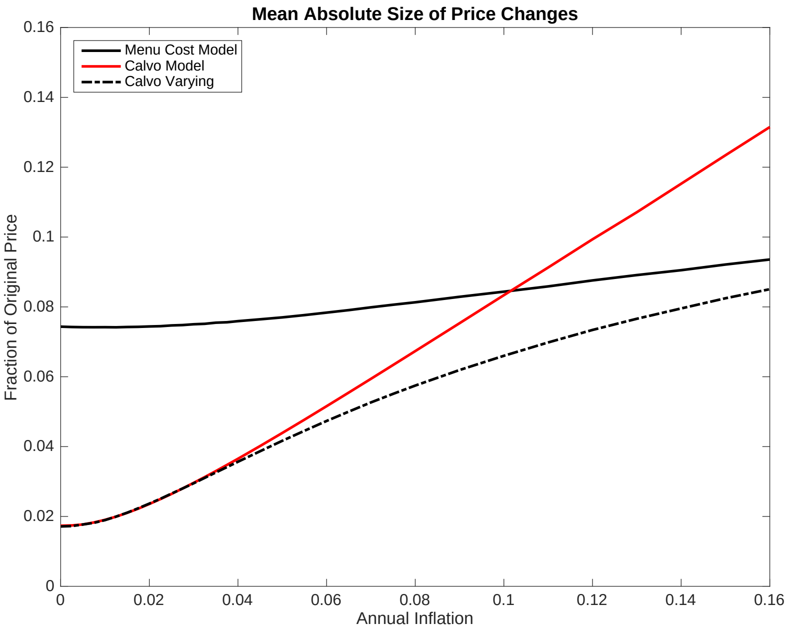
1. Very limited variation in inflation over last 30 years!
   - Extend BLS micro-data on consumer prices back to 1977
   - Covers "Great Inflation" and Volcker disinflation
2. Difficulty in interpreting raw price dispersion

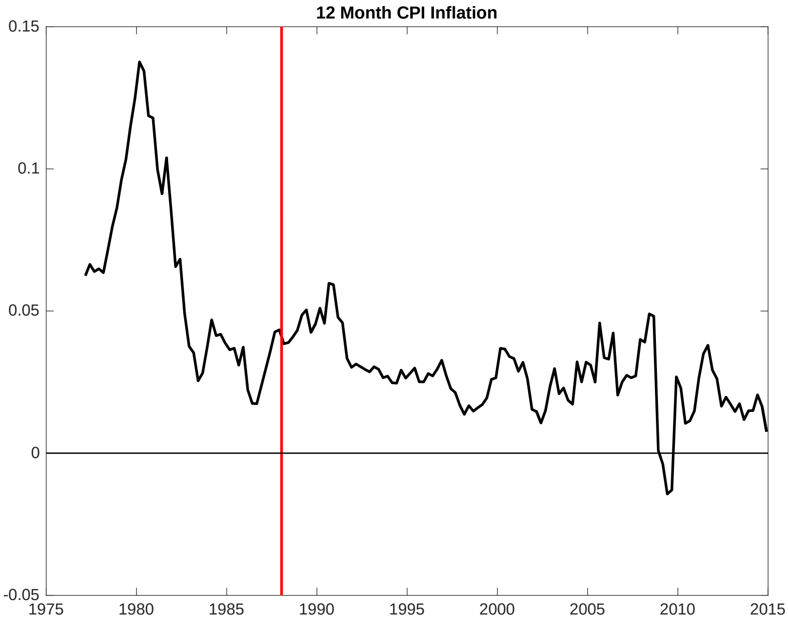
Nakamura-Steinsson-Sun-Villar 18

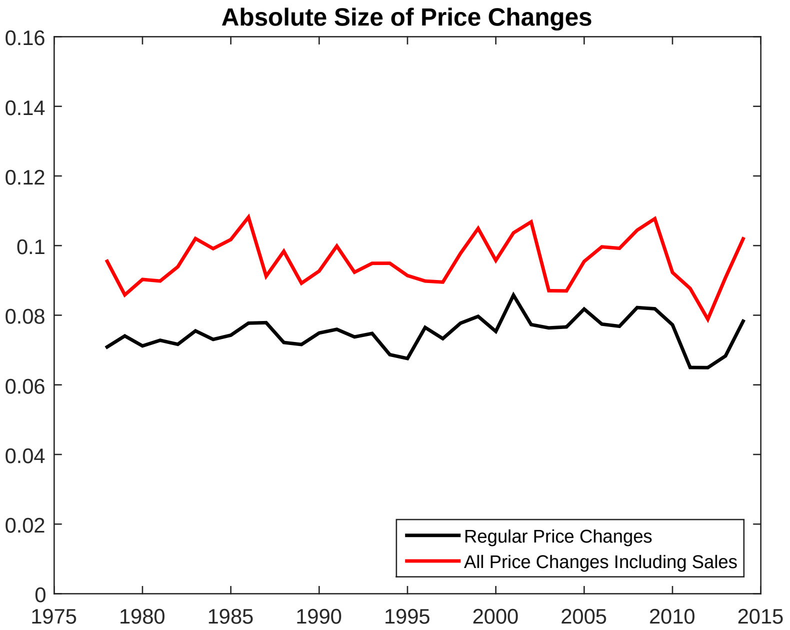
- Measure sensitivity of inefficient price dispersion to changes in inflation

Challenges:

1. Very limited variation in inflation over last 30 years!
   - Extend BLS micro-data on consumer prices back to 1977
   - Covers "Great Inflation" and Volcker disinflation
2. Difficulty in interpreting raw price dispersion
   - Heterogeneity in size and quality of products
   - Absolute size of price changes informative about inefficient price dispersion


Mean Absolute Size of Price Changes
Menu Cost Model
Calvo Model
Calvo Varying
Fraction of Original Price
Annual Inflation
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16


12 Month CPI Inflation
0.15
0.1
0.05
0
-0.05
1975
1980
1985
1990
1995
2000
2005
2010
2015


Absolute Size of Price Changes
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
1975
1980
1985
1990
1995
2000
2005
2010
2015
Regular Price Changes
All Price Changes Including Sales

Nakamura-Steinsson-Sun-Villar 18

- No evidence that absolute size of price changes rose during Great Inflation
- Suggests inefficient price dispersion not any higher during Great Inflation
- Costs of inflation emphasized in New Keynesian models elusive