Precautionary price stickiness

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Motivation

- An old question: does money matter for real allocations?
- How responsive is the *aggregate* price level to shocks?
- Far-reaching implications for how the economy behaves and for the design of suitable policies

Motivation

- Evidence: economic conditions fluctuate continuously, yet at the firm level price adjustment is intermittent
  - Bils and Klenow (2005), Klenow and Kryvstov (2008), Nakamura and Steinsson (2008), Midrigan (2008)
- Some discussion still about the typical (or relevant) frequency of price changes (a lot of heterogeneity)
- But clearly adjustment is not continuous

Motivation

- For any given frequency of micro adjustment, aggregate price stickiness depends on one's preferred model of pricing
  - e.g. Calvo (1983) vs. fixed menu cost (Golosov-Lucas, 2007)
- The most popular pricing models have unappealing features:
  - Calvo: Lucas critique, cannot study optimal rate of inflation
  - Fixed menu cost: relies on a large cost of changing price tags; ignores cognitive costs
- Both Calvo and FMC have serious difficulties matching the micro evidence on price changes

Motivation

- The search goes on for a "good" model of price stickiness
  - microfounded: not subject to the Lucas critique
  - tractable: can be simulated in general equilibrium
  - matches at least the most salient features of micro evidence
  - hopefully produces plausible IRFs to shocks

Overview of popular pricing models

Elements shared by most existing price-setting models:

- a state variable affecting period profits: $\frac{P_i/P}{A_i}$
- a control variable: P_i
- factors that shift the state away from the optimum absent control: A_i, P
- a friction that prevents continuous adjustment of the control:
  - fixed menu cost (Mankiw, Barro, Golosov-Lucas)
  - stochastic menu cost (Dotsey-King-Wolman)
    - switching between 0 and ∞ (Calvo)
  - "generalized (S,s)" (Caballero-Engel, Costain-Nakov)
  - time-dependent models (Taylor)

Overview of popular pricing models

- Useful to think of price-setting as two problems
  - a "timing" problem: is it time to change prices?
  - a "size" problem: by how much to change prices?
- In all of the above models there is a friction in the *timing* of price changes
- The decision on *size* itself is frictionless: the new price is chosen optimally given the friction in timing
- This seems arbitrary. Why consider a friction only in the timing but none in the size choice?

Idea of this paper

- Study a DSGE model in which there is a friction (only) in the size of price changes
- Price stickiness arises endogenously, as a precaution against errors in pricing
- Idea: when firms change prices, they are liable to make a mistake
- Firms are aware of this risk
  - if the current price is close to optimal, potential errors are costly, and firms choose to stick with their current price
  - if the current price is far from optimal, the expected gain from adjustment is positive, and firms change their price

Idea of this paper

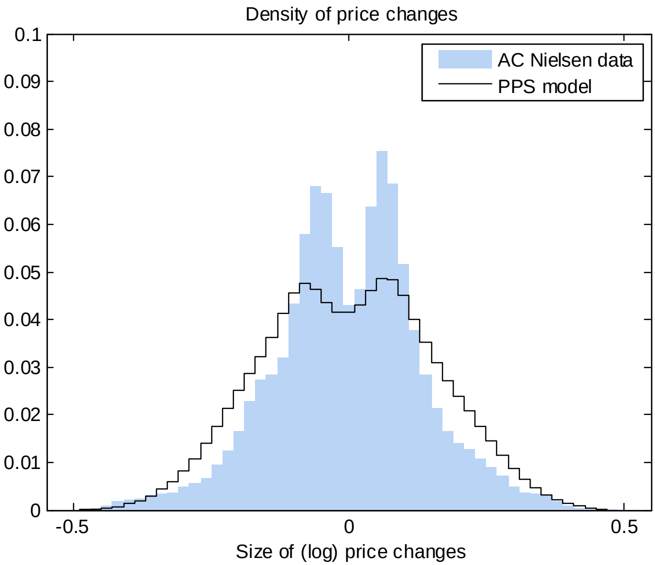
- Need discipline when talking about errors: we model mistakes as firms playing quantal (*logit*) strategies
- Quantal response equilibrium (McKelvey and Palfrey, 1995): a statistical generalization of Nash equilibrium
- Offers a disciplined deviation from REE, controlled by a single "precision" parameter
  - With infinite "precision", the model becomes the frictionless neoclassical paradigm
  - With bounded precision, prices are sticky
- Choose the precision parameter so as to replicate the median duration of regular prices in the data (10 months)

Idea of this paper

- Evaluate model's ability to match the evidence on:
  - distribution of price changes by size
    - Data: large and small price changes coexist even within narrowly defined product categories
    - Calvo: too many small changes; FMC: either all large, or all small
  - adjustment hazard rate over time
    - Data: first downward sloping, then flat
    - Calvo: flat; FMC: upward sloping
  - size of price changes as a function of time elapsed since last adjustment
    - Data: flat
    - Calvo & FMC: upward sloping
- Study macro behavior of the model economy: IRFs to (money) shocks

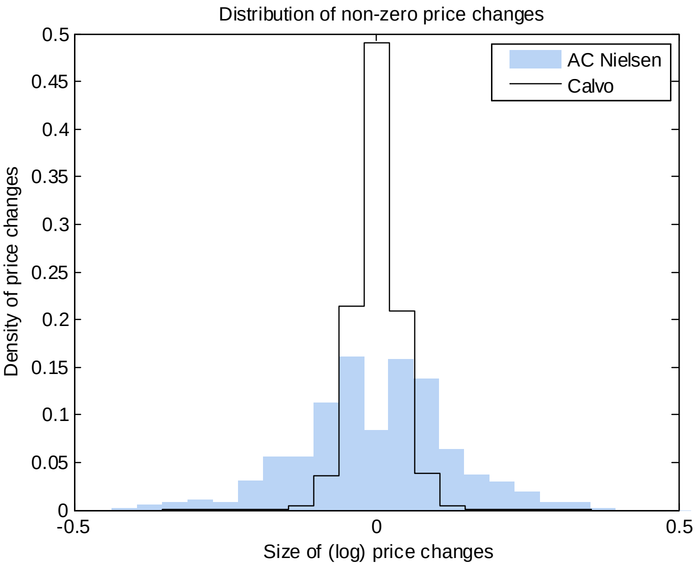
Preview of the results

Size distribution of price changes



Preview of the results

Size distribution of price changes



Preview of the results

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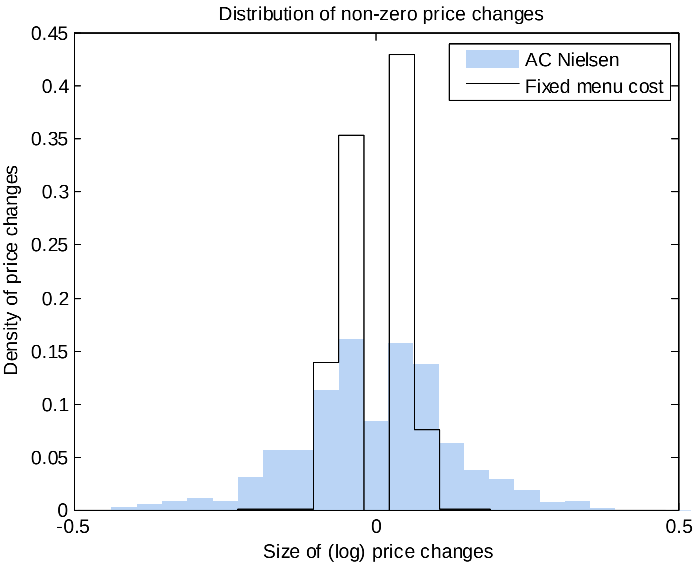
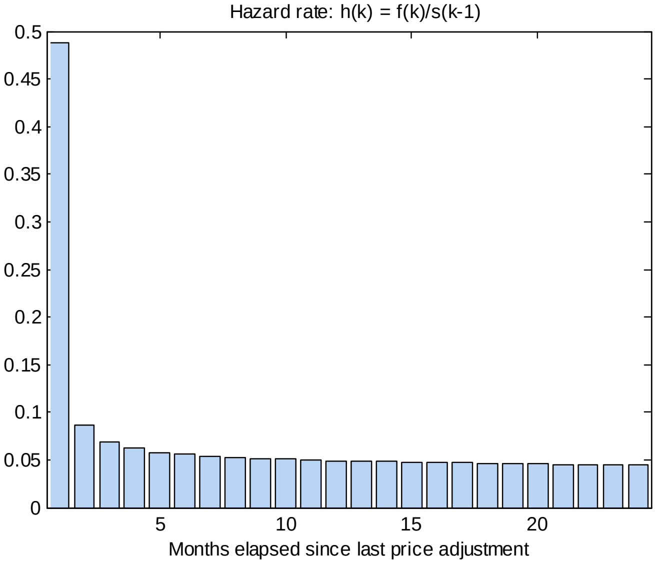


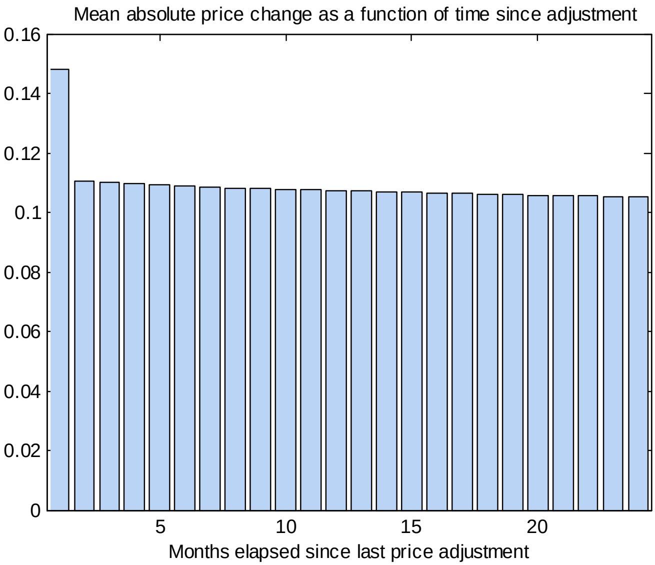
Preview of the results

Probability of price change over time



Preview of the results

Size of price changes over time



Related literature

On state-dependent pricing

- In partial equilibrium
  - Barro (1972), Sheshinski and Weiss (1977), Mankiw (1985), Caplin and Spulber (1987), Caballero-Engel (1993,..., 2007), Woodford (2008)
- In general equilibrium
  - Dotsey-King-Wolman (1999) (stochastic menu costs; aggr. shock only)
  - Golosov-Lucas (2007) (fixed menu cost; aggr. + idiosync. shocks)
  - Gertler-Leahy (2008) (simplify for analytic results)
  - Midrigan (2006) (multi-product firms, leptokurtic shocks)
  - Costain-Nakov (2008) (generalized (S,s); aggr. + idiosync.)

Related literature

On quantal response equilibrium

- McKelvey and Palfrey (1995)
  - A generalization of Nash equilibrium that allows for noisy optimizing behavior while maintaining the internal consistency of rational expectations
- Very successful in matching observed behavior in experiments
  - Fey, McKelvey, and Palfrey (1996): centepede game
  - Anderson, Goeree, Holt (1998): all-pay auctions
  - Goeree, Holt, and Palfrey (2000): coordination games
  - Goeree, Holt, and Palfrey (2002): first-price auctions

Related literature

On quantal response equilibrium

- Camerer, Ho, Chong (2004):
  - "Quantal response equilibrium, a statistical generalization of Nash, almost always explains the direction of deviations from Nash, and should replace Nash as the static benchmark to which other models are routinely compared"
- Haile, Horacsu, Kosenok (AER, 2008):
  - Need additional maintained assumptions to be able to test the model empirically, e.g. logit choice

Outline of the talk

1. Introduction ✓
2. Model
3. Calibration
4. Results
5. Conclusions

Model: main features

- Firm output: $Y = A_{(i)}N$
- Profits: $U = PY - WN$
- Firm value: $V(P, A, ...) = U + E(QV(P', A', ...))$
- Optimal price choice (neoclassical):
  $P^*(A) = \arg\max_P V(P, A)$
- Instead, we assume *noisy optimization:*
  - firms' price is drawn from a (*logit*) distribution over possible prices, with probabilities proportional to the payoff associated with each price, adjusted by precision parameter $\xi \in [0, \infty)$:

$$\pi(P|A) = \frac{\exp(\xi V(P, A))}{\sum_P \exp(\xi V(P, A))}$$

Model: main features

$$\pi(P|A) = \frac{\exp(\xi V(P,A))}{\sum_P \exp(\xi V(P,A))}$$

- Parameter $\xi \in [0, \infty)$ controls the "degree of rationality":
  - When precision is infinite ($\xi = \infty$), firms choose the optimal price P^* with probability $\pi(P^*|A) = 1$ (neoclassical)
  - When precision is zero ($\xi = 0$), firms choose a uniform distribution over possible prices (myopic firms)
- When precision is positive but bounded ($0 < \xi < \infty$), the probability of choosing the optimal price $0 < \pi(P^*|A) < 1$
- The optimal price has the highest probability of being chosen
- And the probability of choosing a "good" price is (much) higher than choosing a "bad" price

Model: main features

- Firm's expected value if it decides to change its price

$$E(V(A)) = \sum_P \pi(P|A)V(P,A)$$

Weighted average over all possible prices, including some which are *worse* than the current price, so

- *Expected gain from adjustment*, $G = E(V(A)) - V(P,A) \gtrless 0$
- Adjustment (timing) decision:
  - change price if $G > 0$
  - stay with old price if $G < 0$

Model: main features

- Changing the price itself is costless (zero “menu” cost), the friction comes from the possibility of errors in pricing
- Errors occur only in the size of price changes, not in the timing (later we relax this)

Model: main features

- Whether $G \gtrless 0$ depends on the proximity of the current price to the optimum "(S,s)-type model"
  - If the current price is far from the optimal (there was a big fundamental shock), then $G > 0$
    - the firm resets its price
  - If the current price is close to optimal (there was a small shock), then $G < 0$
    - the firm chooses to stick with its old price
  - Price stickiness is "precautionary"

Model: the rest is standard

- Household utility: $\frac{C^{1-\gamma}}{1-\gamma} - \chi N + \nu \log(M/P)$ with discount factor β
- Period budget constraint:
  $P_t C_t + M_t + R_t^{-1} B_t = W_t N_t + M_{t-1} + T_t + B_{t-1} + \Pi_t$
- Consumption bundle: $C_t = \left[\int_0^1 C_{it}^{\frac{\epsilon-1}{\epsilon}} di \right]^{\frac{\epsilon}{\epsilon-1}}$ with price index
  $P_t \equiv \left[\int_0^1 P_{it}^{1-\epsilon} di \right]^{\frac{1}{1-\epsilon}}$
- Money supply: $M_t = \mu_t M_{t-1}$ where $\mu_t = \mu \exp(z_t)$, and
  $z_t = \phi_z z_{t-1} + \epsilon_t^z$

Solution method

- Challenge: firms are ex-ante identical, but not ex-post, so the entire distribution of firms on (P, A) is a state variable
- Solution: Reiter's (*JEDC*, 2009) method of "projection and perturbation"
- Typically idiosyncratic shocks are much bigger than aggregate shocks
- Combines
  - Nonlinear solution of the aggregate steady-state on a grid (projection)
  - Linearization around the steady-state wrt aggregate shocks (perturbation)

Solution method: steady state (projection)

- Guess: w
- Labor FOC: $C = (\chi/w)^{1/\gamma}$
- Payoffs in different (p, a) grid points:
  $u_{ij} = (p_i - w/a_j)\, C(p_i)^{-\epsilon}$
- Solve Bellman equation: $\mathbf{V} = \mathbf{U} + \beta \mathbf{R}' \left(\mathbf{V} + \mathbf{G}^{\xi}\right) \mathbf{S}$
- Calculate distributions:
  - $\tilde{\boldsymbol{\Psi}} = \mathbf{R}\boldsymbol{\Psi}\mathbf{S}'$
  - $\boldsymbol{\Psi} = (1 - \boldsymbol{\Lambda}) .* \tilde{\boldsymbol{\Psi}} + \boldsymbol{\Pi} .* \left(\mathbf{1} * (\boldsymbol{\Lambda} .* \tilde{\boldsymbol{\Psi}})\right)$
- Check if $1 = \left[\sum_{ij} \psi_{ij} (p_j)^{1-\epsilon}\right]^{\frac{1}{1-\epsilon}}$ and adjust w until it is satisfied

Solution method: dynamics (perturbation)

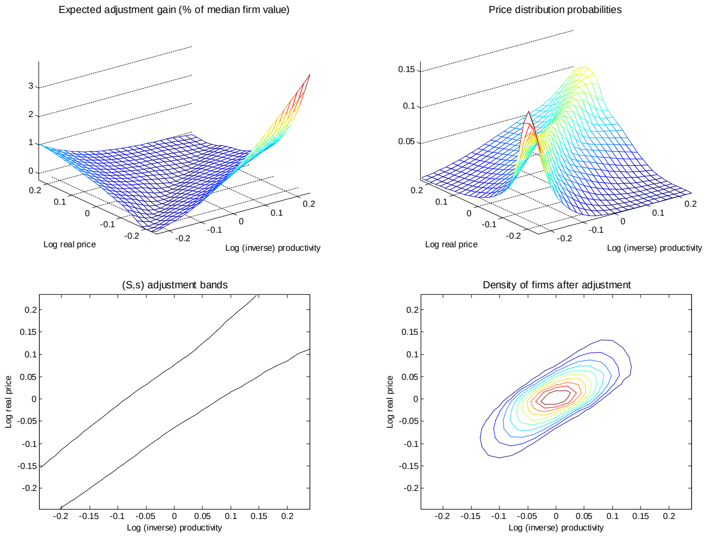
- Dynamic Bellman equation:
  $\mathbf{V}_t = \mathbf{U}_t + \beta E_t \left[\frac{u'(C_{t+1})}{u'(C_t)} \mathbf{R}'_{t+1} \left(\mathbf{V}_{t+1} + \mathbf{G}^{\xi}_{t+1} \right) \mathbf{S} \right]$
- Distribution dynamics:
  - $\tilde{\mathbf{\Psi}}_t = \mathbf{R}_t \; \mathbf{\Psi}_{t-1} \mathbf{S}'$
  - $\mathbf{\Psi}_t = (1 - \mathbf{\Lambda}_t) \,.*\, \tilde{\mathbf{\Psi}}_t + \mathbf{\Pi}_t \,.*\, (\mathbf{1} * (\mathbf{\Lambda}_t .* \tilde{\mathbf{\Psi}}_t))$
- Collect variables in vector:
  $X_t = (vec(\mathbf{V}_t)', C_t, p_t, vec(\mathbf{\Psi}_{t-1})')$
- Model: $E_t \mathcal{F}\left(X_{t+1}, X_t, z_{t+1}, z_t\right) = 0$
- Linearization: $E_t \mathcal{A} \Delta X_{t+1} + \mathcal{B} \Delta X_t + E_t \mathcal{C} z_{t+1} + \mathcal{D} z_t = 0$
- Solve with Klein's QZ method for linear models

Calibration

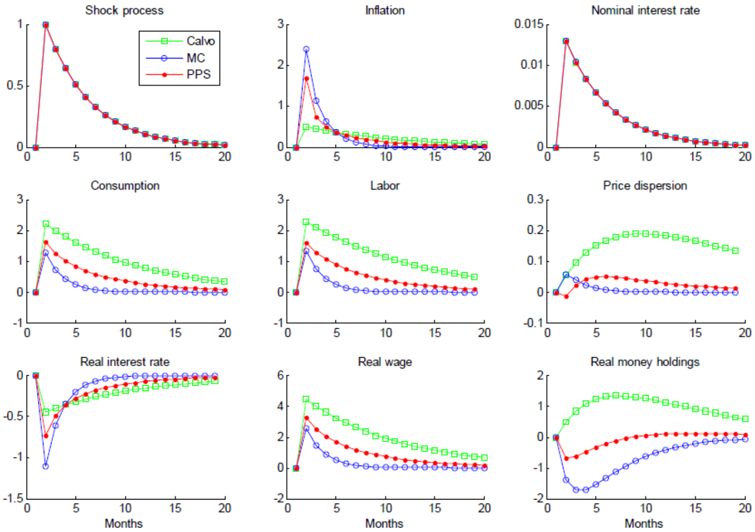
Discount factor	$\beta = 1.04^{-1/12}$	Golosov-Lucas (2007)
CRRA	$\gamma = 2$	Ibid.
Labor supply	$\chi = 6$	Ibid.
MIUF coeff.	$\nu = 1$	Ibid.
Elast. subst.	$\epsilon = 7$	Ibid.
Money growth	$\mu = 1$	AC Nielsen dataset: zero inflation
Persistence	$\rho = 0.95$	Blundell-Bond (2000)
Std. dev. prod.	$\sigma = 0.06$	Eichenbaum et. al. (2009)
Precision	$\xi = 16.67$	Nakamura-Steinsson (2008): 10m

- Note: noise $=$ 1/precision $=$ 0.06; even less noise than is typically estimated in applied GT experiments

Some steady-state objects



Responses to a correlated money growth shock

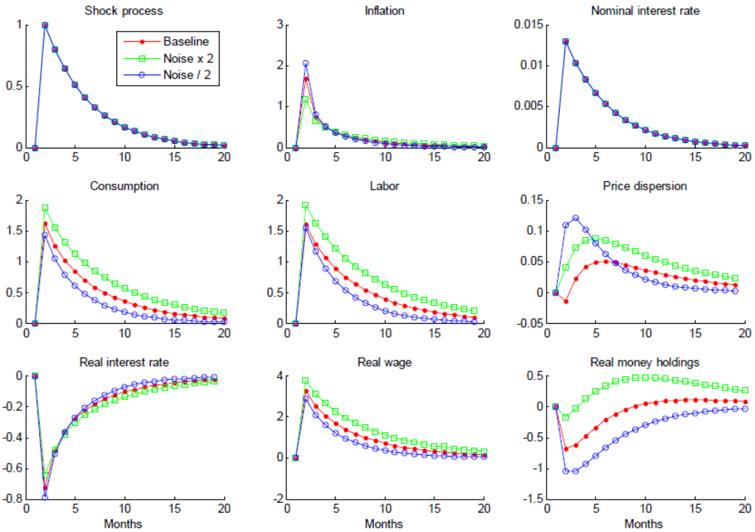


Phillips curves

	Calvo	FMC	PPS	Data
Monthly frequency (%)	10	10	10	10
Std. dev. money shock (%)	0.33	0.12	0.18	
Std. dev. quart. inflation (%)	0.25	0.25	0.25	0.25
Std. dev. quart. output (%)	1.08	0.19	0.40	0.51
Slope β_2 of Phillips curve	1.10	0.15	0.37	

$c_t = \beta_1 + \beta_2 \hat{\pi}_t + \varepsilon_t$, where $\hat{\pi}_t$ is instrumented by the money supply

Sensitivity to noise



Summary

- We propose a disciplined approach for studying near-rational price setting in DSGE models based on logit equilibrium
- Logit choice generates price stickiness even if firms are free to change their price costlessly in each period
- When prices are close to optimal, firms prefer to leave them unchanged
- The model matches several "puzzles" from micro data on pricing which existing models are unable to match
- Money shocks have real effects inbetween the fixed menu cost and the Calvo model

Extensions

- The model can easily accommodate errors in both the size and timing of price changes. "Nested logit":
  - decide whether to adjust
  - decide by how much to adjust
- The solution method can easily be applied to a larger scale (Smets-Wouters type) DSGE
  - Straightforward to model monetary policy with a Taylor rule, to study other aggregate shocks, add frictions etc.
- The framework can be applied to other situations where action is intermittent