Non-Linear Dynamics In Menu Cost Economies? Evidence from U.S. Data

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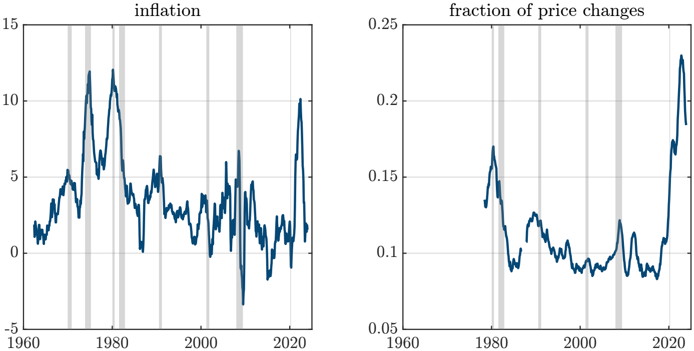
[1] The views expressed herein are those of the authors and not necessarily those of the Board of Governors of the Federal Reserve System, the Federal Reserve Bank of Atlanta or the Federal Reserve System.

Motivation

- Fraction of price changes increases with inflation



Notes: Data from Nakamura-Steinsson-Sun-Villar (2018) and Montag-Villar (2023). Inflation year-to-year changes, fraction monthly.

Motivation

- Fraction of price changes increases with inflation
- Suggests the Phillips may be non-linear
  - flat when inflation is low and steep when inflation is high
- Menu cost model → endogenously time-varying fraction of price changes
- Can menu cost model generate comovement btw inflation and frequency?
  - while simultaneously matching the microdata on price changes

This Paper

- Consider three commonly used specifications for menu cost technology
  - that increasingly allow model to reproduce distribution of price changes
- Show that none can simultaneously reproduce micro and time-series data
  - and that matters for dynamics in response to shocks
- Because idiosyncratic, rather than aggregate shocks, drive repricing
  - so fraction of price changes fluctuates little with inflation
- Offer solution that reduces relative importance of idiosyncratic shocks

Model

Model Overview

- Continuum of firms
  - produce with linear, labor-only technology
  - subject to idiosyncratic quality shocks
  - menu cost to change prices
- Monetary policy targets nominal spending (Nakamura-Steinsson, 2013)
  - only source of aggregate uncertainty
- Golosov-Lucas log-linear assumption on preferences

Model

- Consumers: log-linear preferences imply $W_t = P_t c_t$ details

- Monetary policy: $M_t \equiv P_t c_t$ and $\log \frac{M_{t+1}}{M_t} = \mu_{t+1},\ \mu_{t+1} \sim N\left(\mu, \sigma_m^2\right)$

- Technology
  - firm i produces output with technology
  $$y_{it} = z_{it} l_{it} \text{ and } \log \frac{z_{it+1}}{z_{it}} = \varepsilon_{it+1}, \varepsilon_{it+1} \sim N\left(0, \sigma_z^2\right) \Rightarrow \text{marginal cost} = \frac{W_t}{z_{it}}$$
  - final good sector competitive
  $$c_t = y_t = \left(\int \left(\frac{y_{it}}{z_{it}}\right)^{\frac{\sigma-1}{\sigma}} \mathrm{d}i\right)^{\frac{\sigma}{\sigma-1}}$$
  - demand for individual variety
  $$y_{it} = z_{it} \left(\frac{z_{it} P_{it}}{P_t}\right)^{-\sigma} y_t, \quad \text{where } P_t = \left(\int \left(z_{it} P_{it}\right)^{1-\sigma} \mathrm{d}i\right)^{\frac{1}{1-\sigma}}$$

Menu Cost Technology

- Menu cost ξ_{it} denominated in units of labor

1. Golosov-Lucas (2007) (GL)

$$\xi_{it} = \bar{\xi}$$

2. Nakamura-Steinsson (2010) (NS)

$$\xi_{it} = \begin{cases} 0, & \text{with probability } 1-\lambda \\ \bar{\xi}, & \text{with probability } \lambda \end{cases}$$

3. Blanco-Boar-Jones-Midrigan (2025a) (Uniform)

$$\xi_{it} = \begin{cases} 0, & \text{with probability } 1-\lambda \\ \sim U[0,\bar{\xi}], & \text{with probability } \lambda \end{cases}$$

Firm Objective

- Expected present value of profits

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \frac{1}{P_t c_t} \left((1+\tau) P_{it} y_{it} - W_t \frac{y_{it}}{z_{it}} - \xi_{it} W_t \mathbb{I}_{it} \right)$$

  – indicator $\mathbb{I}_{it} = 1$ if $P_{it} \neq P_{it-1}$

  – subsidy to eliminate flex-price markup distortion: $1+\tau = \frac{\sigma}{(\sigma-1)}$

- Define

  – firm price gap $x_{it} \equiv \frac{z_{it} P_{it}}{M_t}$

  – aggregate price gap $X_t \equiv \left(\int x_{it}^{1-\sigma} \mathrm{d}i \right)^{\frac{1}{1-\sigma}} = \frac{P_t}{M_t}$

- If price are flexible, then $x_{it} = X_t = 1$

Firm Objective

- Can express firm objective as function of x_{it} and X_t

$$\max_{x_{it}} \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left(X_t^{\sigma-1} \left((1+\tau)\, x_{it}^{1-\sigma} - x_{it}^{-\sigma} \right) - \xi_{it} \mathbb{I}_{it} \right)$$

- Choice of own price gap x_{it} only depends on aggregate price gap X_t
  - so all firms that adjust have the same reset price gap x_t^*
- Firm must forecast X_t, which depends on the distribution of price gaps
- Solve with Krusell-Smith type algorithm

details

Adjustment Probability

- Adjustment probability depends on assumptions about menu cost

$$h_t(s) = \begin{cases} \mathbb{I}\left(v_t^a - \bar{\xi} > v_t^n(s)\right), & \text{in GL} \\ 1 - \lambda + \lambda \mathbb{I}\left(v_t^a - \bar{\xi} > v_t^n(s)\right), & \text{in NS} \\ 1 - \lambda + \lambda \min\left\{\frac{v_t^a - v_t^n(s)}{\bar{\xi}}, 1\right\}, & \text{in Uniform.} \end{cases}$$

- Has implications for the model implied distribution of price changes
  - which is observable, so can be used to discriminate between models

Parameterization

- Assigned parameters: period 1 month
  - discount factor $\beta = 0.96$ (annualized) and elasticity of substitution $\sigma = 3$
  - probability of free price changes $1 - \lambda = 0.75$ (Nakamura-Steinsson, 2010)

- Calibrated parameters
  - mean and volatility of nominal spending growth μ and σ_m
  - volatility of idiosyncratic shocks σ_z and menu cost parameter $\bar{\xi}$

- Calibration targets
  - mean and standard deviation of inflation
  - mean fraction of price changes and median size of price changes

Calibration Results

A. Moments

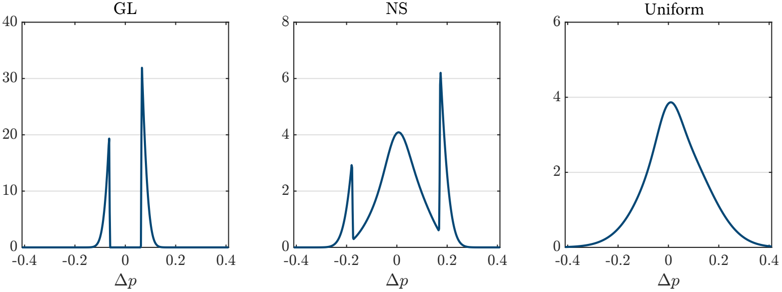
	Data	GL	NS	Uniform
fraction Δp	0.105	0.105	0.105	0.105
median $\|\Delta p\|$	0.075	0.075	0.075	0.075
mean inflation	0.034	0.034	0.034	0.034
std dev. inflation	0.026	0.026	0.026	0.026

B. Calibrated Parameter Values

		GL	NS	Uniform
μ	mean money growth rate	0.034	0.034	0.034
σ_m	s.d. monetary shocks	0.008	0.009	0.010
σ_z	s.d. idios. shocks	0.024	0.037	0.037
$\bar{\xi}$	menu cost	0.015	0.246	2.818

Note: Moments are calculated for the period 1979-2014. The money growth rate is annualized and the menu cost parameter $\bar{\xi}$ is expressed relative to total revenue.

Distribution of Price Changes



little dispersion
no small changes
no large changes
kurtosis = 1.5

more dispersion
small changes
jumps
kurtosis = 2.4

more dispersion
small changes
no jumps
kurtosis = 3.3

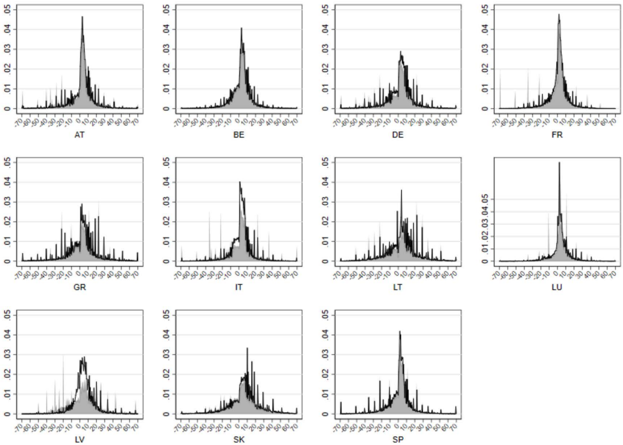
Empirical Distribution of Price Changes

- Evidence most consistent with the uniform specification

- Evidence of small price changes
  - U.S. (Klenow-Kryvtsov, 2008): 25% of price changes below 2.5%
  - France (Alvarez-Le Bihan-Lippi, 2016)
  - U.K. (Blanco-Boar-Jones-Midrigan, 2025a)
  - 11 other European countries (Gautier and many co-authors, 2024)
  - specific sectors (Midrigan, 2011)

- Evidence of large dispersion
  - U.S. (Morales-Jimenez-Stevens, 2024): std. dev. $\Delta p = 0.129$
  - U.K. (Blanco-Boar-Jones-Midrigan, 2025a): std. dev. $\Delta p = 0.188$

Empirical Distribution of Price Changes



Source: Gautier, Conflitti, Faber, Fabo, Fadejeva, Jouvanceau, Menz, Messner, Petroulas, Roldan-Blanco, Rumler, Santoro, Wieland, Zimmer (2024).
Grey shaded histogram includes sales. Black line excludes sales.

Aggregate Dynamics

Aggregate Dynamics

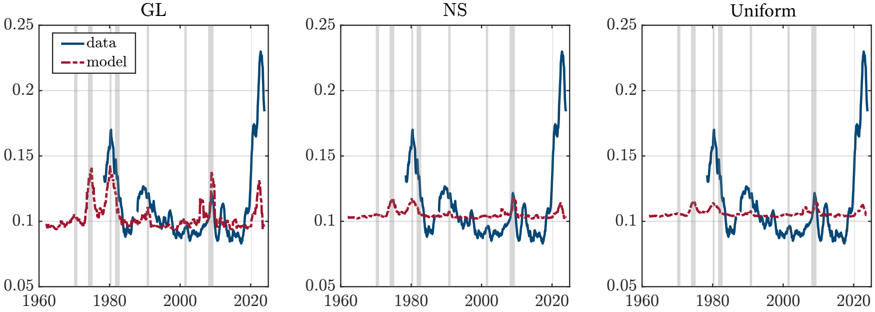
1. How does the fraction of price changes fluctuate in the time-series?

   – recall in the data fraction of price changes is high when inflation is high

2. What are the real effects of aggregate shocks in these economies?

Inflation and The Fraction of Price Changes

- Back out shocks μ_t to match inflation series
- Compare model-implied fraction of price changes with data



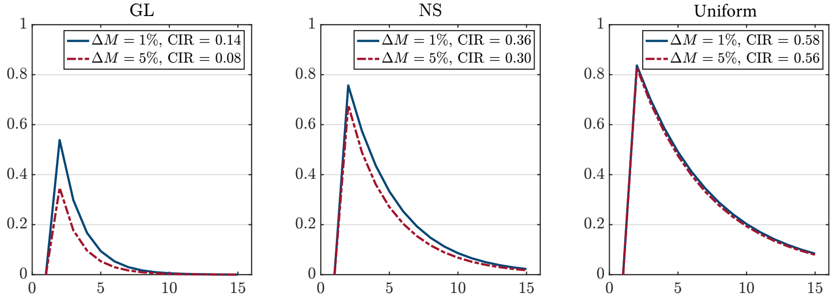
Intuition

- NS and Uniform can best match the distribution of price changes
- Idiosyncratic rather than aggregate shocks drive repricing decisions
  - recall larger σ_z in calibration, as well as randomness in menu cost
- So fraction of price changes $\approx$ invariant to shocks that drive inflation
- Need larger aggregate shocks to generate more fluctuations in frequency
  - but implies inflation more volatile than observed

Real Effects of Monetary Shocks

- Initialize economy at stochastic steady state
- Consider 1% and 5% monetary shock
  - recall $M_t = W_t$, so this increases firms' marginal cost
- Trace out impulse response of output
  - depends on how prices adjust because $M_t = P_t y_t$

Output Response to Monetary Shocks



Note: IRFs scaled by shock size. CIR relative to Calvo model with frequency equal to average frequency in menu cost model.

money ≈ neutral non-linear effects	larger real effects less non-linearity	even larger real effects ≈ no non-linearity

A Solution

Model Overview

- A multi-product menu cost model (Midrigan, 2011; Alvarez-Lippi, 2014)
  - firms sell continuum of products subject to product quality shocks z_{ikt}
  - economies of scope: menu cost $\xi_{it} \sim U\left[0, \bar{\xi}\right]$ to change all prices

- Add two ingredients that make price dispersion less costly inside the firm
  - low elasticity of substitution between products of a firm

$$y_{it} = \left(\int \left(\frac{y_{ikt}}{z_{ikt}} \right)^{\frac{\gamma-1}{\gamma}} \mathrm{d}k \right)^{\frac{\gamma}{\gamma-1}}$$

  - specific factor (e.g. managerial input) mobile across products within firm

$$y_{ikt} = z_{ikt} \left(m_{ikt} \right)^{1-\eta} \left(l_{ikt} \right)^{\eta}, \quad \text{where} \quad \int m_{ikt} \mathrm{d}k = 1$$

Intuition

- Firm-level aggregation

$$y_{it} = \phi_{it} l_{it}^{\eta}, \quad \eta < 1 : \quad \text{strategic complementarities at firm level}$$

- Losses from misallocation from price dispersion

$$\phi_{it} = \exp\left(-d\gamma\frac{\sigma_z^2}{2}\right)$$

  - increasing in γ and σ_z, given duration d

- Price dispersion less costly than in standard model, given d and σ_z

  - so lower importance of idiosyncratic rel to aggregate shocks in repricing

Calibration

- Assigned parameters: $\gamma = 1$, $\sigma = 6$ and $\eta = 2/3$

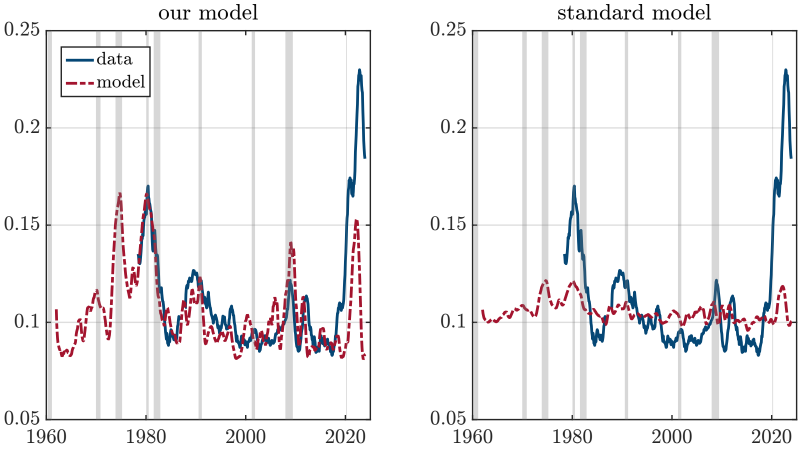
A. Moments

	data	our model	standard
fraction Δp	0.105	0.105	0.105
median $\lvert\Delta p\rvert$	0.075	0.075	0.075
mean inflation	0.034	0.034	0.034
std dev. inflation	0.026	0.026	0.026

B. Calibrated Parameter Values

		our model	standard
μ	mean money growth rate	0.034	0.034
σ_m	s.d. monetary shocks	0.010	0.010
σ_z	s.d. idios. shocks	0.039	0.038
$\bar{\xi}$	upper bound menu cost	0.632	10.59

Inflation and the Fraction of Price Changes



Conclusion

- Commonly used variants of menu cost model cannot reproduce both
  - distribution of micro-price changes
  - time-series comovement between inflation and fraction of price changes
- Matters for the size and non-linearity of the effect of aggregate shocks
  - and ultimately the tradeoff faced by monetary policy
- Challenge for the literature to develop models that are consistent w both

Consumers

- Life-time utility

$$\mathbb{E}_t \sum_{t=0}^{\infty} \beta^t \left(\log c_t - h_t\right)$$

- Budget constraint

$$P_t c_t + \frac{1}{1+i_t} B_{t+1} = W_t h_t + B_t + D_t$$

- Optimal labor supply implies

$$W_t = P_t c_t$$

back

Recursive Formulation

- Idiosyncratic state: price gap absent a price change

$$s_{it} = \frac{z_{it} P_{it-1}}{M_t}$$

- Adjustment decision

$$x_{it} = \begin{cases} s_{it}, & \text{if do not adjust} \\ x_t^*, & \text{if adjust} \end{cases} \quad \rightarrow \quad \text{adjust with probability } h_t(s)$$

- Aggregate price gap X_t depends on distribution $F_t\left(s\right) \rightarrow$ aggregate state

$$X_t = \left(\int \left[h_t\left(s\right) \left(x_t^*\right)^{1-\sigma} + \left(1 - h_t\left(s\right)\right) s^{1-\sigma} \right] \mathrm{d}F_t\left(s\right) \right)^{\frac{1}{1-\sigma}}$$

- Solve with Krusell-Smith type algorithm: $X_t = \mathcal{X}\left(S_t\right)$

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