Cost-Price Dynamics in High and Low Inflation Regimes

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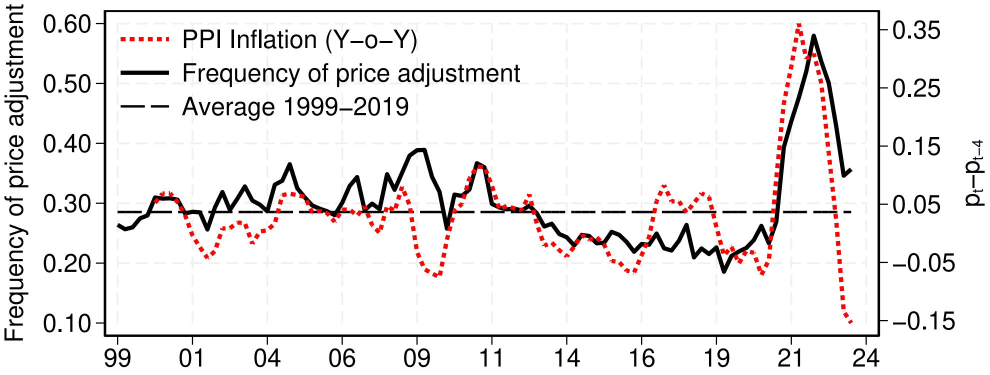
PPI Inflation vs Quarterly Price Adjustment Frequency (Belgium)



Background: GGLT (2023)

- Our previous work focuses on pre-pandemic period:
  - Addresses issue of flat output gap-based NK Phillips curve (i.e. $\kappa \approx 0$):

$$\pi_t = \kappa\,(y_t - y_t^{\star}) + \beta\,\mathbb{E}_t\{\pi_{t+1}\} + u_t$$

  - Use firm-level data to estimate marginal-cost based NK Phillips curve:

$$\pi_t = \lambda\,\widehat{mc}_t^r + \beta\,\mathbb{E}_t\{\pi_{t+1}\} + \nu_t$$

  - Estimate of λ suggests a high sensitivity of inflation to marginal cost.
  - Low slope of output-based PC due to low sensitivity of marginal cost to output gap.

$$\kappa = \lambda \cdot \frac{\partial \widehat{mc}_t^r}{\partial (y_t - y_t^{\star})}$$

This Talk: Extend Analysis to Post-Pandemic Inflation

- Allow for state-dependent pricing to capture jump in price adjustment frequency.

- Key difference from previous menu-cost studies:
  - Unique dataset: quarterly info on prices, costs, and frequency of price changes (99-23).
  - Price + Cost data allow us to:
    1. Build firm-level measure of "price gaps" (distance btw ideal reset price & current price):

       $\Rightarrow$ Determines size and frequency of price changes.

    2. Construct an aggregate marginal cost index for the manufacturing sector:

       $\Rightarrow$ Feed to quantitative model to replicate aggregate inflation dynamics.

This Talk (Cont'd)

1. Micro evidence: pricing nonlinear in gap between ideal and actual price:
   - Consistent with state-dependent pricing.
2. Model accounts for time-series and cross-section of price changes:
   - Captures (almost entirely) the recent inflation surge.
   - Marginal cost accounts for inflation as model predicts.
3. Calvo model provides good approximation in "normal times:"
   - <u>Linear</u> cost-price dynamics in normal times but <u>nonlinear</u> during the inflation surge.
4. Analytical <u>nonlinear</u> Calvo model provides good approximation for high *and* low inflation.

Literature Review

- **Menu cost models**:

  Caballero Engel (2007), Golosov Lucas (2007), Nakamura Steinsson (2010), Midrigan (2011), Alvarez Lippi Oskolkov (2022), Alvarez Lippi Souganidis (2023), Auclert Rigato Rognlie Straub (2024), Blanco Boar Jones Midrigan (2024), Morales-Jimenez Stevens (2024).

- **Evidence on state dependent pricing**:

  Zbaracki Ritson Levy Dutta Bergen (2004), Eichenbaum Jaimovich Rebelo (2011), Eichenbaum Jaimovich Rebelo Smith (2014), Karadi Schoenle Wursten (2022), Cavallo Lippi Miyahara (2024).

- **Phillips curve and pass through with micro data**:

  Amiti Itskhoki Konings (2019), McLeay Tenreyro (2020), Hazell Herreno Nakamura Steinsson (2022), Gagliardone Gertler Lenzu Tielens (2023).

Theoretical Framework

Framework

- Discrete-time menu cost model.
- Random free price adjustments
  - As in the "CalvoPlus" model of Nakamura Steinsson (2010).
- Random menu costs.
- Quadratic approximation of profit function.
- Abstract from trend inflation:
  - Good approximation for low inflation regimes. (Nakamura et al. 2018, Alvarez et al. 2019)
  - Add trend inflation in quantitative model.

The Target Price $p_t^o(i)$

- Continuum of monopolistically competitive firms indexed by $i \in [0, 1]$.
  - Each sells a differentiated product at log price $p_t(i)$.
  - Each faces CRS production function (relaxed in empirical section).
  - Strategic complementarities in price setting (Kimball variety).

- $p_t^o(i) \equiv$ optimal price absent nominal rigidities:

$$p_t^o(i) = \mu + (1 - \Omega)mc_t(i) + \Omega p_t$$

$$mc_t(i) = mc_t + a_t(i)$$

- mc_t and $a_t(i)$ obey random walks:

$$mc_t = mc_{t-1} + u_t$$

$$a_t(i) = a_{t-1}(i) + \varepsilon_t(i)$$

Price Gap $x_t(i)$ and Profit Function

- $x_t(i) \equiv$ gap between target price p_t^o and price $p_t(i)$:

$$x_t(i) \equiv p_t^o(i) - p_t(i)$$

- Quadratic approx. of period profits around flex price optimum $x_t(i) = 0$:

$$\Pi\big(x_t(i)\big) \approx -\frac{\eta(\eta-1)}{2(1-\Omega)}\big(x_t(i)\big)^2$$

- Firm must pay random fixed cost $\chi_t(i) \in [0, \overline{\chi}]$ to change price.

Ex-Ante Price Gap $x_t'(i)$ & Price Adjustment Probability

- Ex-Ante Price Gap:

$$x_t'(i) \equiv p_t^o(i) - p_{t-1}(i)$$

$$\Rightarrow x_t'(i) = x_{t-1}(i) + (1-\Omega)(u_t + \varepsilon_t(i)) + \Omega\pi_t$$

- Price Adjustment Probability $h_t(i)$:

$$h_t(i) = (1-\theta^o) + \theta^o \cdot \Pr\left\{V_t^a - \chi_t \geq V_t\left(x_t'(i)\right)\right\}$$

$(1-\theta^o) \equiv$ free price adj. probability

$V_t^a \equiv$ value of adjusting; $V_t(x_t') \equiv$ value of not adjusting.

Pricing Policy

- Reset gap $x_t^\star \equiv p_t^\star(i) - p_t^o(i)$ solves the first-order condition:

$$V_t'(x_t^\star) = 0$$

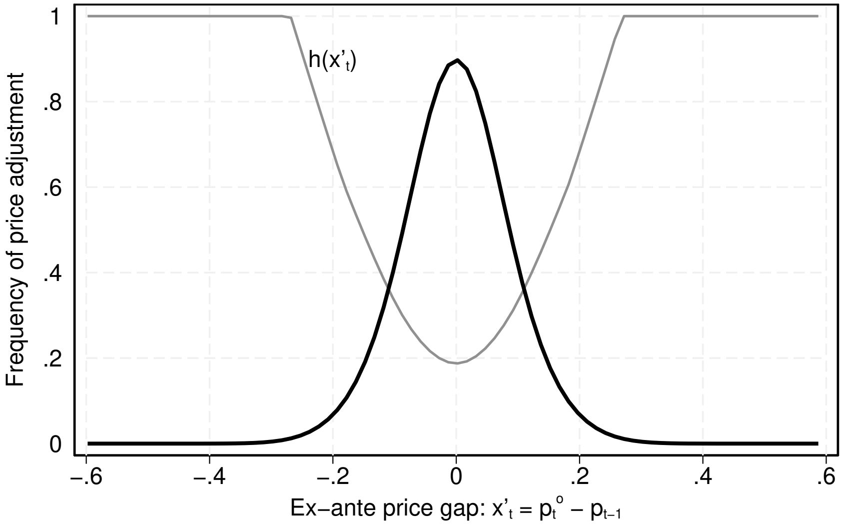
- Firm pricing policy:

$$x_t(i) = \begin{cases} x_t^\star & \text{w. p. } h_t(i) \\ x_t'(i) & \text{w. p. } 1 - h_t(i) \end{cases}$$

- Because $mc_t(i)$ obeys random walk without drift: |▷ Derivations |▷ IRFs

$$\Rightarrow p_t^\star(i) \approx p_t^o(i) = \mu + (1-\Omega) mc_t(i) + \Omega p_t \quad \Longleftrightarrow \quad x_t^\star \approx 0$$

Generalized hazard function (GHF) vs Distribution of Price Gaps



Data & Measurement

Data

- Two decades of quarterly micro-data covering Belgian manufacturing sector (1999:Q1–2023:Q4).
- Production and prices: firm-product level domestic sales and quantity sold ⇒ unit values for:
  - *domestic firms* (PRODCOM)
  - *foreign competitors* (Custom declarations)
- Costs: detailed information on total variable cost (VAT + Social Security declarations).
- Almost universal coverage: 80-90% of domestic manufacturing production + all imports.

Measurement

- Production technology (e.g. Cobb-Douglas):

$$MC_t(i) = \mathcal{C}_t \mathcal{A}_{it} Y_{it}^{\nu_i}$$

$$\Rightarrow mc_t(i) = \ln(TVC_{it}/Y_{it}) + \ln(1+\nu_i)$$

TVC_{it} := Wage bill + Intermediates costs (materials and services).

- Ex-ante price gap:

$$x_t'(i) = \left[(1-\Omega)mc_t(i) + \Omega p_t + \mu\right] - p_{t-1}(i)$$

  - Remove firm and industry-quarter fixed effects.
  - Calibration: $\Omega = 0.55$ (GGLT 2023).

▷ Summary Statistics

Micro Evidence

Micro Evidence on 4 Model Predictions: Prediction (1)

1. Adjustment probability depends on the absolute value of price gap:

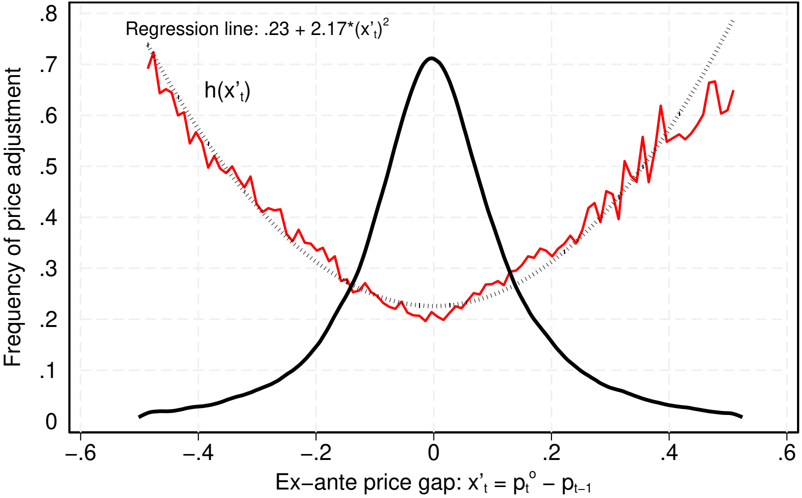
   - Quadratic functional form for generalized hazard function: (Alvarez, Lippi, Oskolkov 2022)

$$h_t(i) = (1 - \theta^o) + \phi \cdot \left(x_t'(i)\right)^2 + \mathcal{O}_t^4$$

$\Rightarrow$ Price gaps obey a bell-shaped distribution around zero with thick tails.

$\Rightarrow$ Selection: firms that adjust are those farther away from target.

Empirical GHF & Distribution of Price Gaps (99:Q1-20:Q4)



Micro Evidence on 4 Model Predictions: Prediction (2)

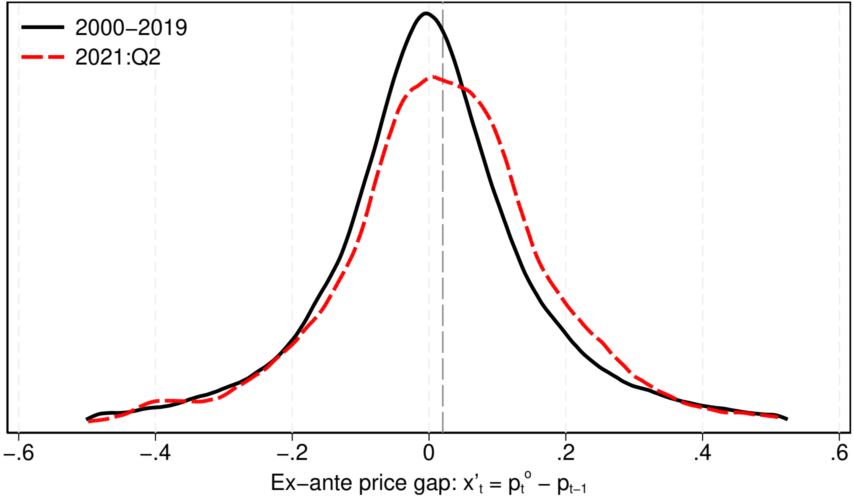
2. Macro-shocks (change in u_t) to marginal cost shift the distribution of gaps:

$$x_t'(i) = \mu + (1-\Omega) mc_t(i) + \Omega p_t - p_{t-1}(i)$$

$$= \mu + (1-\Omega)\left(mc_{t-1}(i) + u_t + \varepsilon_t(i)\right) + \Omega p_t - p_{t-1}(i)$$

- Large unexpected shocks lead to increases in the average adjustment probability.

Impact of 21:Q1 Shock to Marginal Cost on Price Gap Distribution



▷ Frequency Increase

Micro Evidence on 4 Model Predictions: Prediction (3)

3. Nonlinear relationship btw price gaps & inflation at firm level.

- Given $p_t^o \approx p_t^\star$, inflation for firms in bin b with constant gap $x_t'(b)$:

$$\pi_t(b) = \left(\int_{i \in b} h_t(i) di\right) \cdot x_t'(b) + \underbrace{Cov(h_t(i), x_t'(b))}_{=0 \text{ within bins}}$$

- Use the *quadratic* functional form for hazard function:

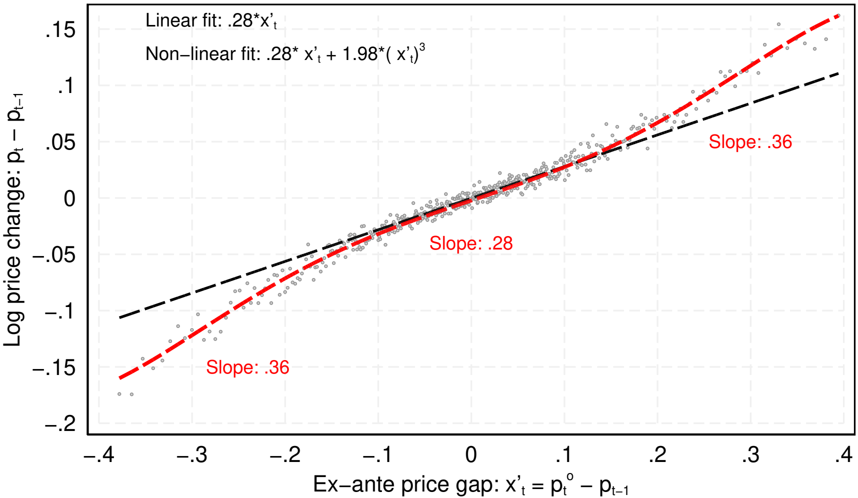
$$h_t(i) = (1 - \theta^o) + \phi \cdot (x_t'(i))^2 + \mathcal{O}_t^4$$

- $\sigma_\varepsilon^2 \equiv$ steady-state variance of gaps. Then inflation in bin b is a *cubic* function:

$$\Rightarrow \pi_t(b) = \left(1 - \theta^o + \phi \sigma_\varepsilon^2\right) \cdot x_t'(b) + \phi \cdot (x_t'(b))^3 + \mathcal{O}_t^5$$

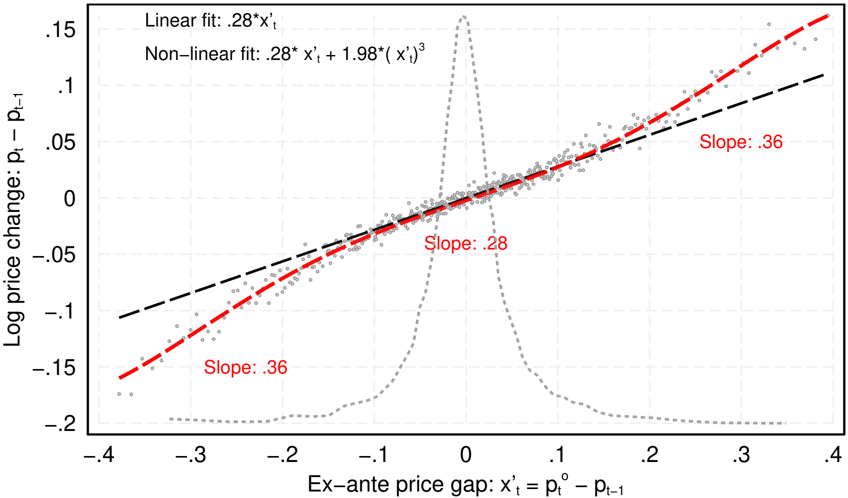
  - Coefficient of linear term corresponds to the steady-state frequency.

Nonlinear Relation btw Price Gaps & Price Adjustments



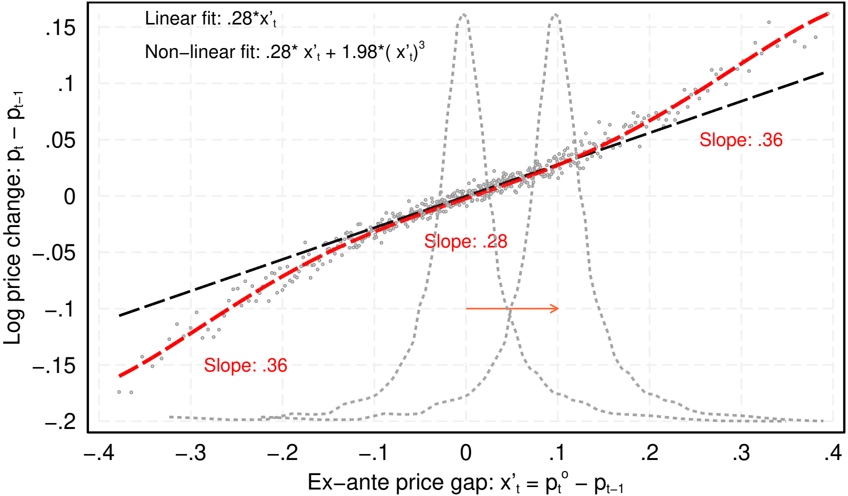
|▷ Conditional Scatterplot

Nonlinear Relation btw Price Gaps & Price Adjustments



|▷ Conditional Scatterplot

Nonlinear Relation btw Price Gaps & Price Adjustments



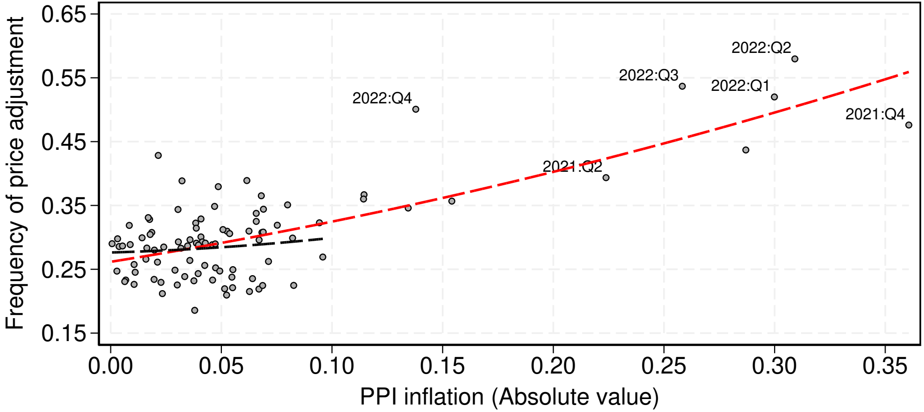
|▷ Conditional Scatterplot

Micro Evidence on 4 Model Predictions: Prediction (4)

4. Non-linear correlation btw inflation and frequency.

    - Small shock: small increase in inflation and negligible adjustment of frequency.
    - Large shock: high inflation and significant adjustment in frequency.

Price Adjustment Frequency vs Inflation



Notes. Dashed red line = quadratic fit over the entire sample.
Dashed black line = linear fit for inflation less than 10%.

Quantitative Exercises

Calibration

- 4 parameters are externally calibrated:

1. $\beta = 0.99$ Discount factor.
2. $\eta = 6$ Elasticity of substitution across goods (SS markup of 1.2).
3. $\Omega = 0.55$ Pricing complementarity (Estimation from GGLT 23).
4. $\mu_{mc} = 1.6\%$ Trend inflation (annual).

- 3 parameters are calibrated to match micro-level moments:

5. $1 - \theta^o = 0.19$ Free-price adjustment prob.

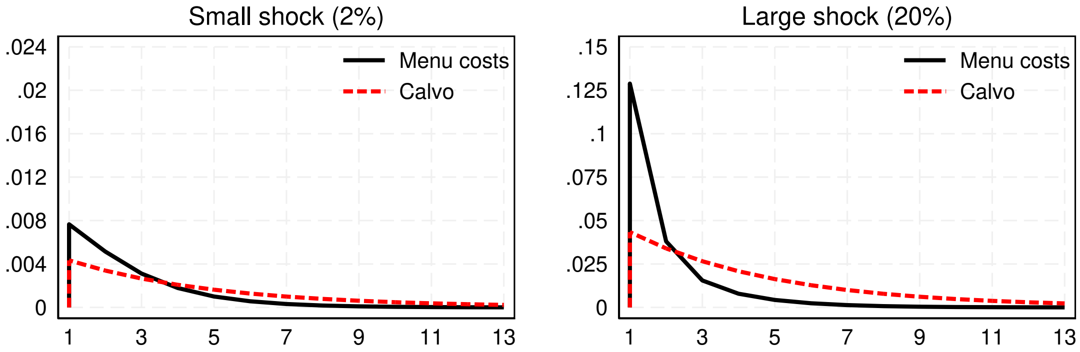
   Target: Frequency of price adjustment at zero price gap ($x = 0$).

6. $\sigma_\varepsilon = 0.06$ Standard deviation of idiosyncratic shocks.
7. $\bar{\chi} = 0.6$ Maximum menu cost.

   Joint Targets: Standard deviation of price changes &
   Steady-state frequency of price adjustments.

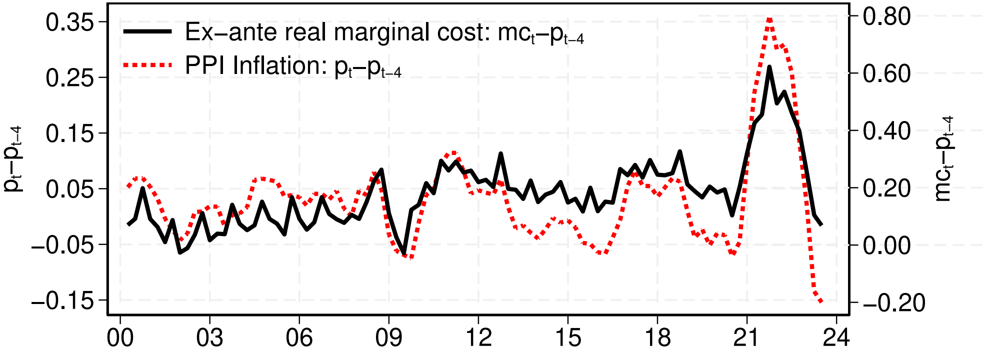
|▷ Data vs Model

Impact of Shock on Size vs Persistence of Inflation Response



|▷ p^o vs $p^\star$ |▷ IRFs Frequency

Ex-Ante Real Marginal Cost Index vs Inflation (Data)



Marginal cost index $mc_t \equiv \sum_{i \in \mathcal{I}} \bar{s}_t(i) \cdot mc_t(i)$; Revenue weight $\bar{s}_t(i) \equiv \frac{s_t(i) + s_{t-1}(i)}{2}$

|▷ Components Index

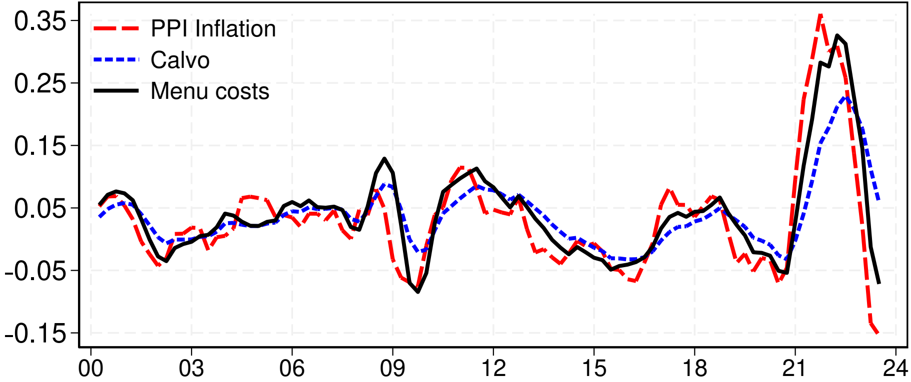
How Well Can Model Explain the Time Series?

Simulation strategy:

- Start from 1999:Q1 assuming economy is in steady state.
- Compute *sequence of impulse responses* to innovations to aggregate marginal cost.
  - Assuming all future shocks unanticipated.
- Compute responses of inflation, frequency, and price gap distribution.

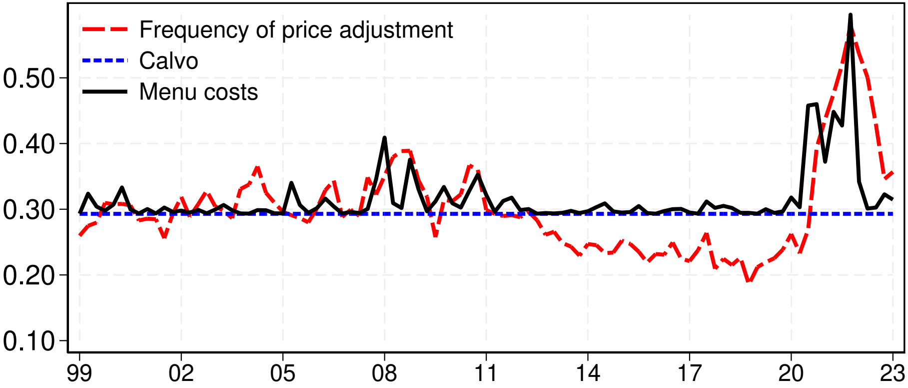
|▷ Algorithm

Inflation: Model vs Data (Y-o-Y)



▷ Quarterly ▷ Time-dependent Model

Frequency: Model vs Data



|▷ Quarterly |▷ Time-dependent Model

Nonlinear Calvo Model

Nonlinear Calvo Model

1. Quadratic hazard function:

$$h_t(i) = (1-\theta^o) + \phi\Big(p_t^o(i) - p_{t-1}(i)\Big)^2 + \mathcal{O}_t^4$$

2. Accounting for *covariance*, aggregate inflation simplifies to:

$$\pi_t = (1-\theta^o)\Big(p_t^o - p_{t-1}\Big) + \phi\int\Big(p_t^o(i) - p_{t-1}(i)\Big)^3 di + \mathcal{O}_t^5$$

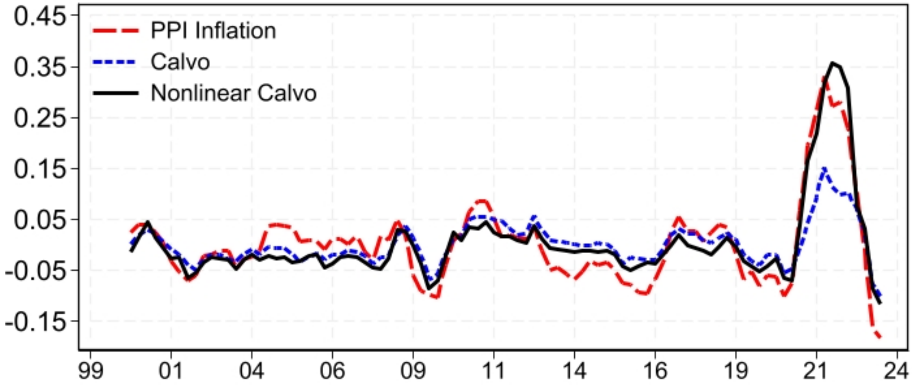
3. Pricing equation for firms resetting price (constant hazard rate θ^o):

$$p_t^o(i) = (1-\beta\theta^o)\Big((1-\Omega)mc_t(i) + \Omega p_t\Big) + \beta\theta^o\mathbb{E}_t p_{t+1}^o(i)$$

$\Rightarrow$ Guess and verify *analytical solution* for inflation:

$$\pi_t = \lambda_1(mc_t - p_{t-1}) + \lambda_3\int(mc_t(i) - p_{t-1}(i))^3 di + \mathcal{O}_t^5$$

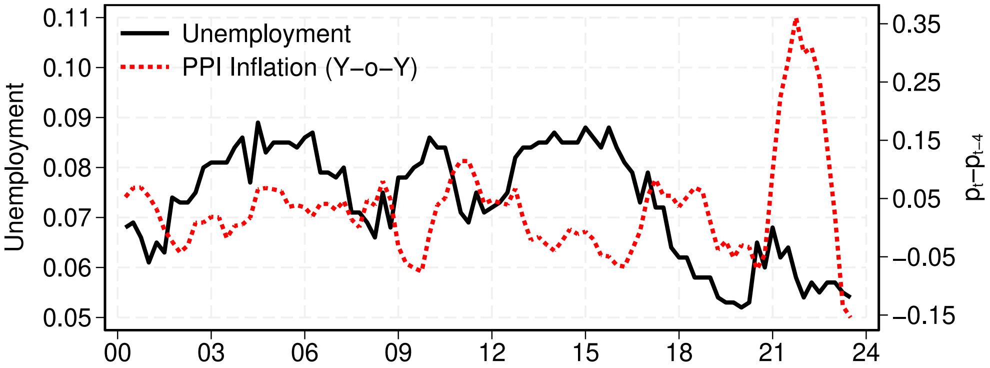
Inflation: Analytical Model vs Data (Y-o-Y)

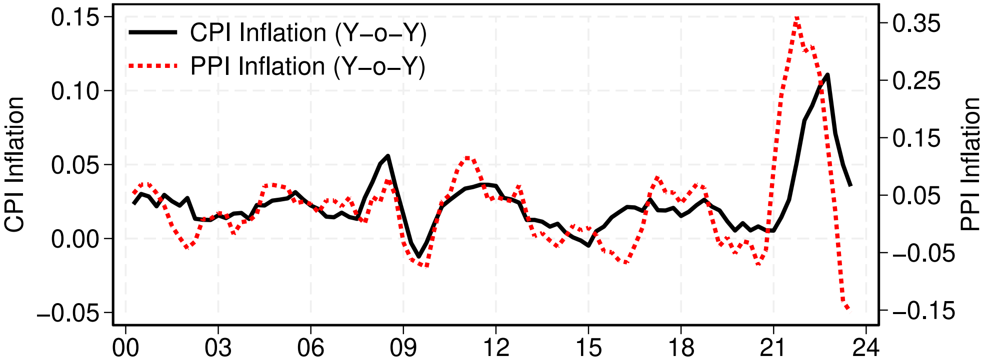


Conclusions

- For "normal" low inflation times $\Rightarrow$ Cost price dynamics $\approx$ linear (Calvo).
- For the inflation surge $\Rightarrow$ Cost price dynamics $\approx$ nonlinear (state dependency).
- In either case, variation in marginal cost accounts for variation in inflation.
- To-do list: Modeling cost dynamics in both normal and abnormal times.
  - Improve modeling of marginal cost in DSGE models:
    - DSGE typically feature marginal cost-based PC but labor is only variable input.
  - Allow for intermediate inputs, energy, and supply chains.

Extra Slides


Unemployment
PPI Inflation (Y−o−Y)
Unemployment
$p_t - p_{t-4}$
0.11
0.10
0.09
0.08
0.07
0.06
0.05
0.35
0.25
0.15
0.05
−0.05
−0.15
00
03
06
09
12
15
18
21
24


CPI Inflation (Y–o–Y)
PPI Inflation (Y–o–Y)
CPI Inflation
PPI Inflation
0.15
0.10
0.05
0.00
–0.05
0.35
0.25
0.15
0.05
–0.05
–0.15
00
03
06
09
12
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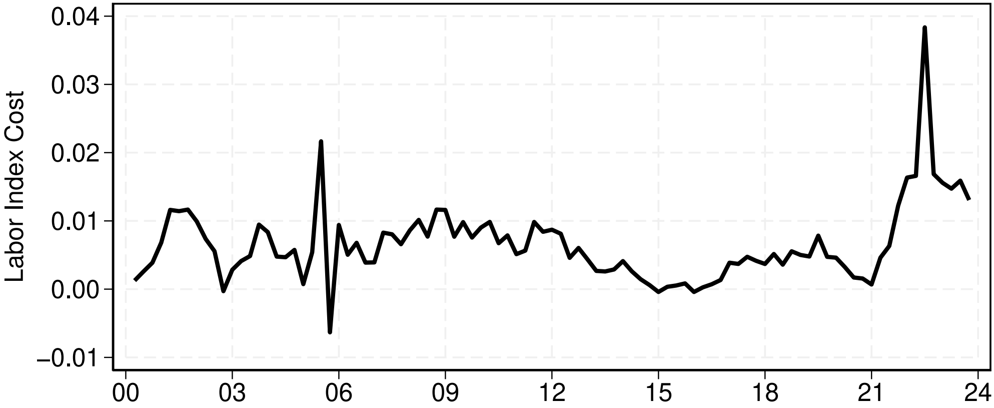
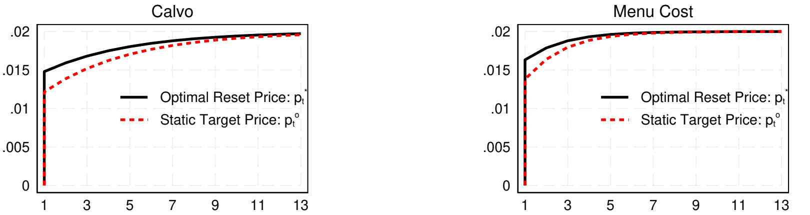
21
24


Labor Index Cost
0.04
0.03
0.02
0.01
0.00
−0.01
00
03
06
09
12
15
18
21
24

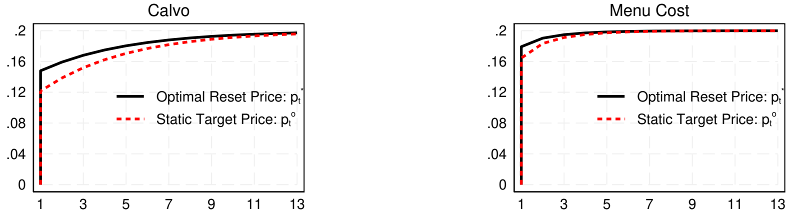
Static vs Dynamic Price Targets

▷ Back to Model ▷ Back to IRFs

Small shock (2%)



Large shock (20%)



Optimal Reset Gap ($x_t^\star \equiv p_t^\star(i) - p_t^o(i)$)

- Value of not adjusting:

$$V_t(x) = -\frac{\sigma(\sigma-1)}{2(1-\Omega)} \cdot x^2 + \beta \mathbb{E}_t \left\{ h_{t+1}(x') V_{t+1}^a + [1 - h_{t+1}(x')] V_{t+1}(x') \right\}$$

with $x' = x + (1-\Omega)(g' + \varepsilon') + \Omega \pi'$.

- Value of adjusting:

$$V_t^a = \max_x V_t(x)$$

- Reset gap $x_t^\star$ obtained from FONC:

$$V_t'(x^\star) = 0$$

|▷ Back

Optimal Reset Gap ($x_t^\star \equiv p_t^\star(i) - p_t^o(i)$)

- To a first-order:

$$x_t^\star = \Psi_t \equiv \Omega \frac{\mathbb{E}_t\{\sum_{i=1}^{\infty}(p_{t+i} - p_t)\beta^i \prod_{\tau=1}^{i}(1 - h_{t+\tau})\}}{\mathbb{E}_t\{\sum_{i=0}^{\infty} \beta^i \prod_{\tau=0}^{i}(1 - h_{t+\tau})\}}$$

$$\Rightarrow p_t^\star(i) = \mu + (1 - \Omega)mc_t(i) + \Omega p_t + \Psi_t$$

- With low trend inflation or absent complementarities ($\Omega = 0$):

$$\Psi_t \approx 0 \Rightarrow p_t^\star(i) \approx p_t^o(i)$$

- When $1 - h_t = \theta \; \forall t$ (Calvo):

$$\Rightarrow \Psi_t = (1 - \beta\theta) \sum_{i=1}^{\infty} (\beta\theta)^i \Omega(p_{t+i} - p_t)$$

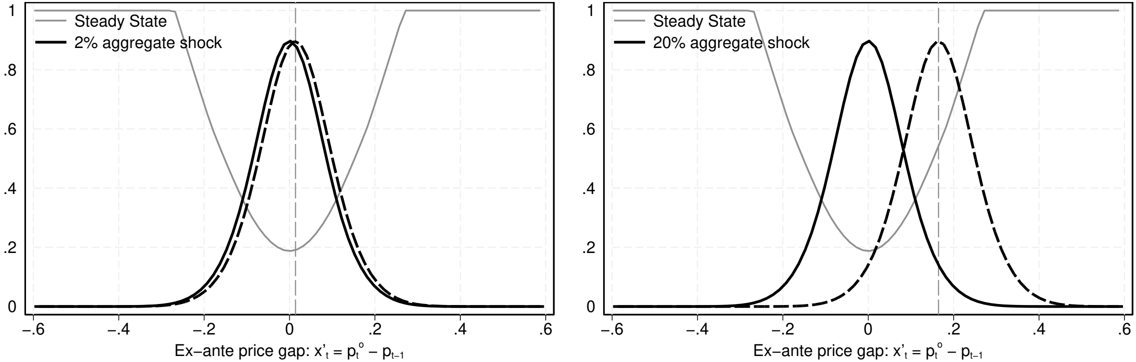
▷ Back

Summary Statistics

▷ Back

Price change $[p_t(i) - p_{t-1}(i)]$				Inverse price gap $[p_t^o(i) - p_{t-1}(i)]$		
Panel a: Time period 2000-2020						
Mean	Std	Kurtosis	Freq. Adjust.	Mean	Std	Kurtosis
0.004	0.11	3.23	0.29	0.005	0.14	4.14
Panel b: Time period 2021-2023						
Mean	Std	Kurtosis	Freq. Adjust.	Mean	Std	Kurtosis
0.019	0.12	4.46	0.38	0.024	0.16	3.64
Number of observations:			133,401			
Number of firm-industry pairs:			5,348			
Number of firms:			4,811			

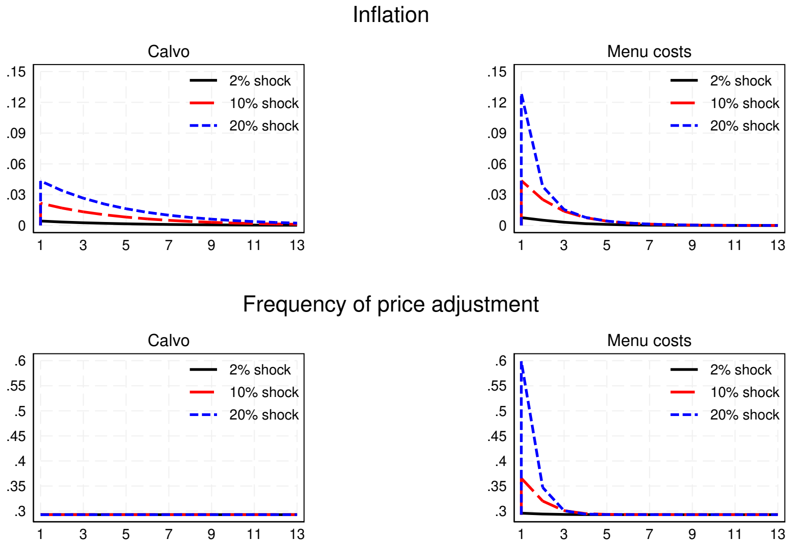
Small vs Large Shocks to Marginal Cost



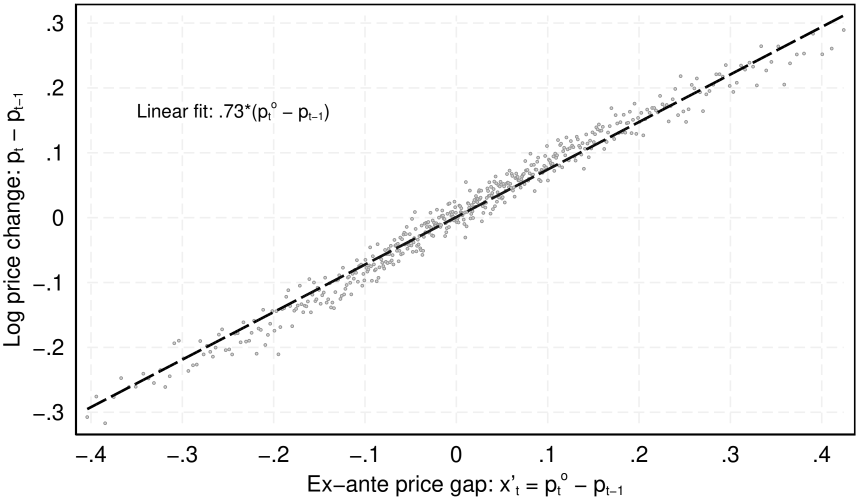
▷ Back

Impact of Shocks to Aggregate Marginal Cost

▷ p^o vs $p^\star$ ▷ Back



Scatterplot Conditional on Adjustment



▷ Back

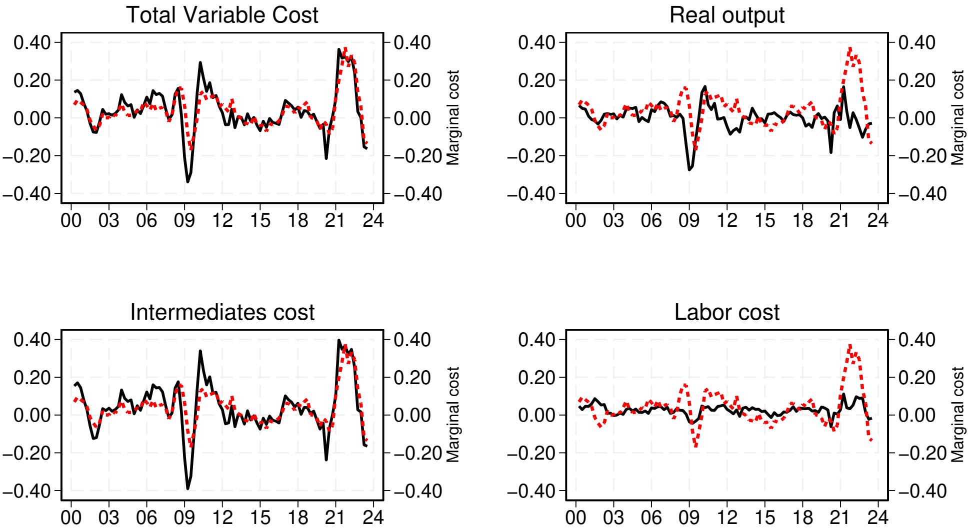
Data vs Model (Steady State)

Price change $[p_t(i) - p_{t-1}(i)]$				Inverse price gap $[p_t^o(i) - p_{t-1}(i)]$			Menu Cost
Panel a: Data							
Mean	Std	Kurtosis	Freq. Adjust.	Mean	Std	Kurtosis	Share of revenues
0.004	0.11	3.23	0.29	0.005	0.14	4.14	1.22% (Zbaracki et al. 04)
Panel a: Model							
Mean	Std	Kurtosis	Freq. Adjust.	Mean	Std	Kurtosis	Share of revenues
0.004	0.11	2.26	0.29	0.005	0.09	3.31	1.67%

▷ Back

Decomposition of Y-o-Y MC Index

▷ Back



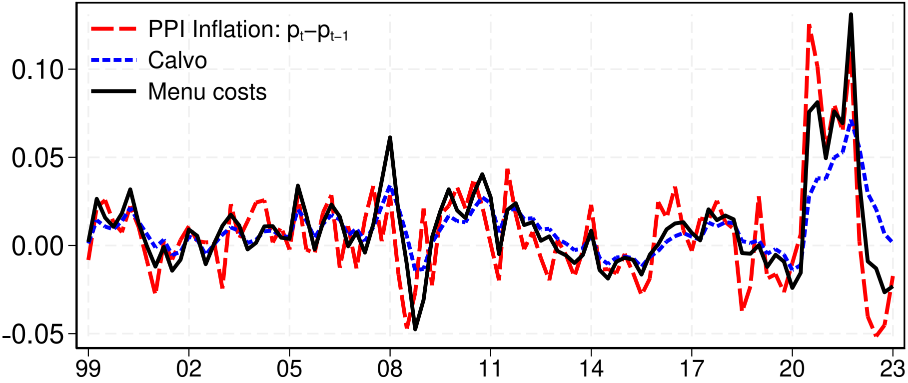
Algorithm

Simulation strategy: sequence of impulse responses to marginal cost innovations

1. Start from 1999:Q1 assuming economy is in steady state.
2. Given mc_t follows RW with drift, construct shock for Q2 using realization from data.
3. Feed shock into model and compute inflation and price gap distribution response:
   - Assuming all future shocks unanticipated (as in an impulse response function).
4. Update starting distribution, compute new shock, feed in.
5. Repeat until 2023:Q4.

|▷ Back

Inflation: Model vs Data (Quarterly)



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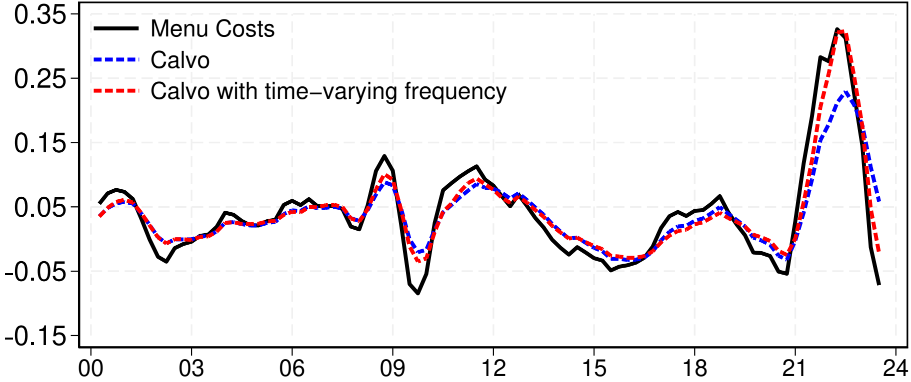
Menu costs vs Calvo with Time-varying Frequency



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