Micro and macro cost-price dynamics during inflation surges versus normal times

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This paper

- We study micro-level cost-price dynamics with the aim of capturing aggregate inflation

- Key object: ***firm-level price gap***: $\boxed{x_t(f) \equiv p_t^{\text{Ideal}}(f) - p_{t-1}(f)}$

  Percentage difference between *today*'s ideal price (absent nominal rigidities) and the last price set.

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  Percentage difference between *today*'s ideal price (absent nominal rigidities) and the last price set.

- Size and magnitude of price gap determines frequency and size of price adjustments:

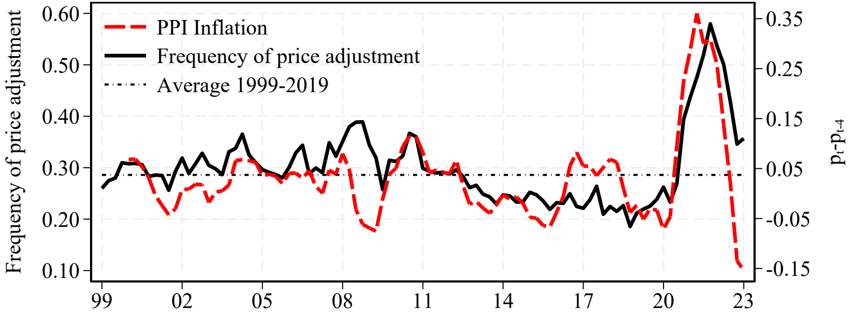
$$x_t(f) \longmapsto \mathbb{E}\Big(\Delta p_t(f) \mid x_t(f)\Big) = \mathbb{E}\Big(\underbrace{\overbrace{\text{Adjust}_t(f)}^{\text{Extensive margin}}}_{\text{Indicator for price change}} \cdot \underbrace{\overbrace{\Delta p_t^{\text{Ideal}}(f)}^{\text{Intensive margin}}}_{\text{Price change}} \mid x_t(f)\Big)$$

- **Time-dependent models** (Calvo / Taylor)
  - Price gap impacts affects only the intensive margin; Frequency of price adjustment is fixed.

- **State-dependent models** (menu-costs)
  - Price gap impacts both extensive and intensive margins;

PPI inflation and frequency of price adjustment

Quarterly, Belgian manufacturing PPI



- Frequency of price adjustment relatively stable in pre-pandemic period. (Gagliardone et al 2025)
- Sharp increase in frequency of price adjustment during inflation surge and reversal.

Cost-price dynamics in the cross-section and in the time series

- Unique micro data: quarterly info on firm-level prices, real output, and production costs.
  - Produce an empirical measure of price gaps *consistent with theory*.
  - Construct an aggregate marginal cost index for the Belgian manufacturing sector.

- Analyze data through the lens of a menu-cost model (nests Calvo as special case).

- *Passthrough in the micro-data*
  - Test predictions about mapping $x_t(f) \longmapsto \mathbb{E}\{\Delta p_t(f)|x_t(f)\}$ in the cross-section of firms.
  - Identification results using moments from joint distribution of price changes and price gaps.

- *Passthrough at macro-level*
  - Feed aggregate cost index to the model to account for aggregate inflation in the time-series.

Plan of the talk

1. Theoretical framework (simplified)

2. Data and measurement

3. *Passthrough in the cross-section*: Evidence of state-dependent pricing in the micro-data

4. *Passthrough in the time-series*: Accounting for aggregate inflation volatility

Theoretical framework

Random menu-cost model

Setup

- Continuum of firms indexed by $f \in [0, 1]$:
  - Each firm sells a differentiated product at log price $p_t(f)$;
  - Strategic complementarities in price setting (Kimball variety).
- Firm's marginal cost has an aggregate and idiosyncratic component:

$$mc_t(f) = mc_t + a_t(f)$$

- Nominal rigidities:
  - Pay random fixed cost $\chi_t(f)$ (a "menu cost") to adjust their prices (Caballero and Engle 2007)

$$\chi_t(f) \sim \text{Uniform}\ [0, \bar{\chi}]$$

  - As in "CalvoPlus", adjust for free ($\chi_t(f) = 0$) with probability $(1 - \theta^0)$. (Nakamura and Steinsson 2010)

Optimal pricing policy

- Absent nominal rigidities, **(static) optimal price** given by:

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

Ω captures strength of strategic complementarities in price setting. (Gagliardone et al 2025)

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- Given nominal rigidities (menu-costs lead to inaction), the **solution of firm's problem** has an "Ss" flavor:

$$\boxed{p_t(f) - p_{t-1}(f) = \begin{cases} p_t^\star(f) - p_{t-1}(f) & \text{w. p. } h_t \\ 0 & \text{w. p. } (1-h_t) \end{cases}}$$

  - h_t = optimal probability of price adjustment;
  - $p_t^\star(f)$ = dynamic optimal reset price, chosen upon adjustment.

Price gap and characterization of pricing policy

- Define **"ex-ante" price gap**: Log distance b/w static optimum $p_t^o(f)$ and last period price $p_{t-1}(f)$:

$$\boxed{x_t(f) \equiv p_t^o(f) - p_{t-1}(f)}$$

  with $p_t^o(f) = \mu + (1-\Omega)mc_t(f) + \Omega p_t$.

- Under standard assumptions (low trend inflation and quadratic approx of profit function)

  $x_t(f)$ serves as state variable of the firm's pricing problem.

  – measurable *before* adjustment decision, but incorporates realization of time t shocks (entering p_t^0).

- We can characterize

  (i) *extensive margin adjustment* $h_t(f)$

  (ii) *intensive margin adjustment* $p_t^\star(f) - p_{t-1}(f)$

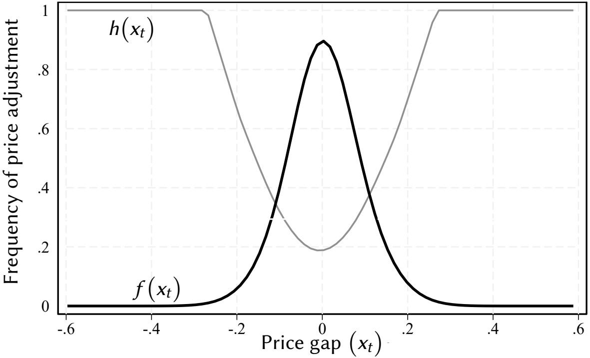
  as a function of the price gap $x_t(f)$.

Extensive margin: Optimal prob. of price adjustment $h(x_t)$

- **Price adjustment probability** approximated by a convex (quadratic) function of price gap:

$$h_t(f) \approx \phi_0 + \phi_1 \cdot \Big(x_t(f)\Big)^2$$

with $x_t(f) \equiv p_t^o(f) - p_{t-1}(f)$



Extensive margin: Optimal prob. of price adjustment $h(x_t)$

- **Price Adjustment Probability** approximated by a quadratic function of price gap.

$$h_t(f) \approx \phi_0 + \phi_1 \cdot \Big(x_t(f)\Big)^2$$

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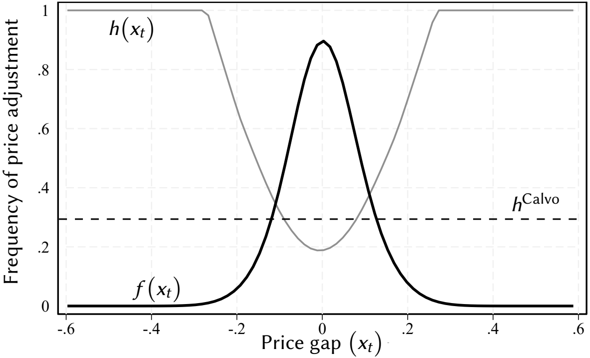

Intensive margin: Optimal price adjustment (conditional) $p_t^\star - p_{t-1}$

- Given our assumptions, up to first-order:

$$p_t^\star(f) \approx p_t^o(f)$$

Note: $p_t^\star(f) = p_t^o(f)$ absent strategic complementarities and $mc_t(f)$ approximately random walk.

- **Optimal price adjustment** (*conditional* on adjusting):

$$\Delta p_t(f)|_{\text{Adjust}_t(f)=1} \equiv p_t^\star(f) - p_{t-1}(f) \approx x_t(f)$$

with $x_t(f) \equiv p_t^o(f) - p_{t-1}(f)$

|▷ Derivations |▷ IRFs
|▷ Strategic complementarities

Data and measurement

Data

- Two decades of **quarterly** micro-data covering Belgian manufacturing sector (1999:Q1–2023:Q4).
  - *Quasi universal coverage*: 80-90% of domestic manufacturing production + all imports.
  - *2,500 firms distributed across 169 manufacturing industries.*
  - *Spans normal times and inflation surges;*

- **Output and prices**: firm-product level quantity sold and prices (unit values)
  - *domestic firms* (PRODCOM)
  - *foreign competitors* (Custom declarations)
  - *Frequency of price changes* (NBB Business Survey).

- **Production costs**: detailed information on firm-level total variable cost
  - *labor costs* (Social Security declarations)
  - *Intermediate input costs (materials and services purchased)* (VAT declarations)

Measurement of firm-level price gaps

- Construct empirical measure of firm-level price gap consistent with the theory:

$$x_{ft} = p^o_{ft} - p_{ft-1}$$
$$p^o_{ft} = \left(\mu_f + (1-\Omega)mc^n_{ft} + \Omega p_t\right)$$

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- Under general production technologies (e.g. Cobb-Douglas, CES), **log-nominal marginal cost**:

$$mc^n_{ft} \propto avc^n_{ft}$$

avc^n_{ft} := log-nominal average variable cost $\equiv \ln(TVC^n_{ft}/Y_{ft})$
TVC^n_{ft} := Firm' labor costs + intermediates costs;
Y_{ft} := Firm's real output;

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- Remove firm-level mean to account for unobserved heterogeneity in SS markups and returns to scale.
- Seasonal adjustment to account for industry-specific seasonality in costs.

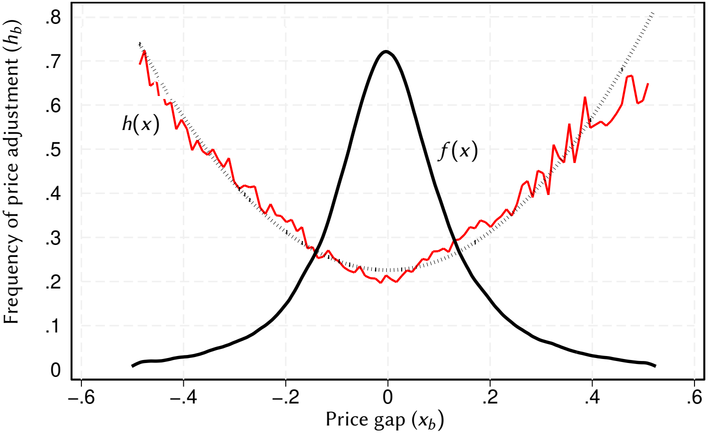
Micro evidence of state-dependent pricing

(passthrough in the cross-section)

(#1) State-dependent probability of price adjustment

Model prediction: $h_t(f) \approx a_0 + a_1 \cdot \left(x_t(f)\right)^2$

Empirical GHF & the distribution of price gaps (1999:Q1-2019:Q4)



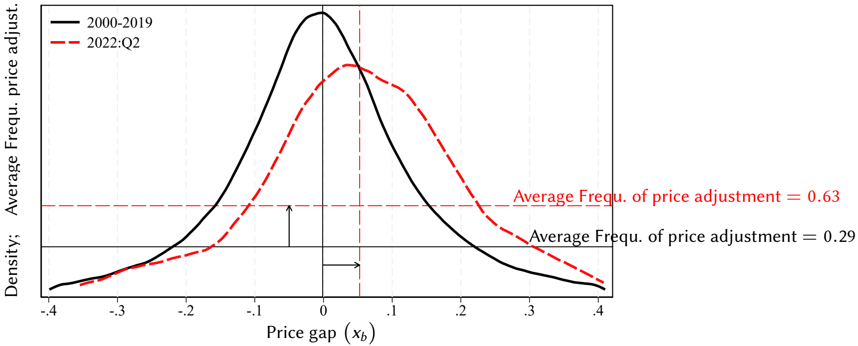
|▷ Asymmetric

(#1) The impact of large cost shocks

$$x_t(f) = p_t^o - p_{t-1}(f)$$

$$p_t^o = \mu + (1-\Omega)(mc_{t-1} + \text{aggregate shock} + a_t(f)) + \Omega p_t$$

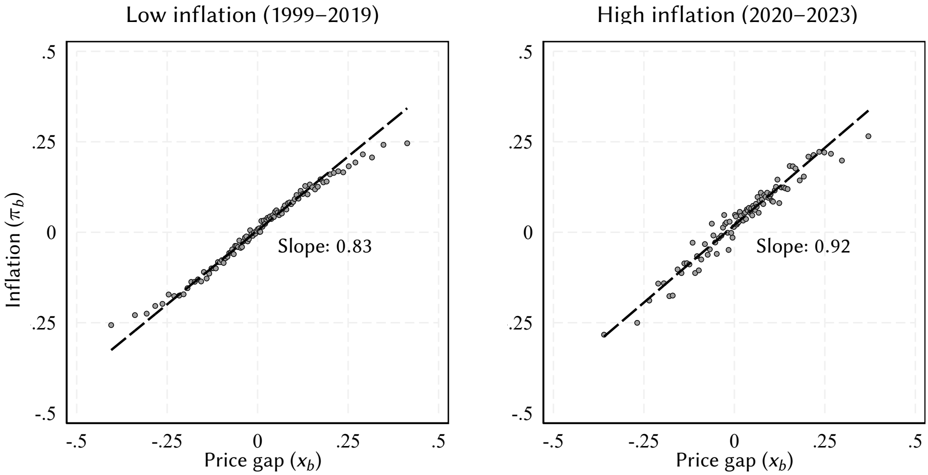
Pre-pandemic vs pandemic price gap distribution



- Macro-shocks to marginal cost shift the entire distribution of price gaps;
- Consequently, the frequency of price adjustment (extensive margin) increases.

(#2) Price changes and price gaps, conditional on adjusting

Model prediction: $\Delta p_t(f)|_{\text{Adjust}_t(f)=1} \approx x_t(f)$



(#3) Nonlinear price dynamics along price gap distribution

- Sort firms into narrowly defined *bins* based on quantiles of distribution of price gaps.

- Inflation within a bin b: $\pi_b \equiv \int_{f \in b} \Delta p_t(f)\, df = \int_{f \in b} \underbrace{h_t(f)}_{\text{Extensive}} \cdot \underbrace{x_t(f)}_{\text{Intensive}}\, df$

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- Average price gap for firms in bin b: $$x_b = \int_{f \in b} x_t(f)$$

- Using quadratic approximation, frequency of price adjustment for firms in bin b:

$$h_b \approx \tilde{\phi}_0 + \phi_1 \cdot \left(x_b\right)^2$$

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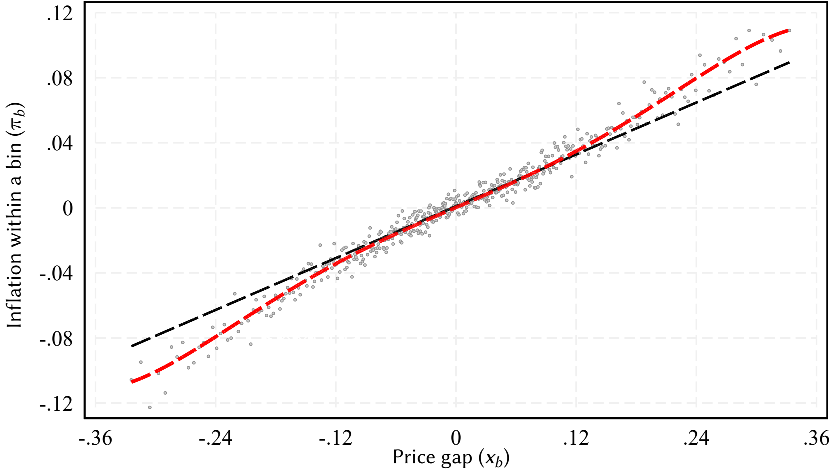
- Inflation within bin b is a nonlinear function (cubic polynomial) in the average price gap:

$$\boxed{\pi_b \approx b_0 \cdot \left(x_b\right) + b_1 \cdot \left(x_b\right)^3}$$

  – Calvo is a special case (linear function) $\Rightarrow \pi_b = \phi^{Calvo} \cdot x_b$

(#3) Nonlinear price dynamics along price gap distribution

Model prediction: $\pi_b \approx b_0 \cdot (x_b) + b_1 \cdot (x_b)^3$



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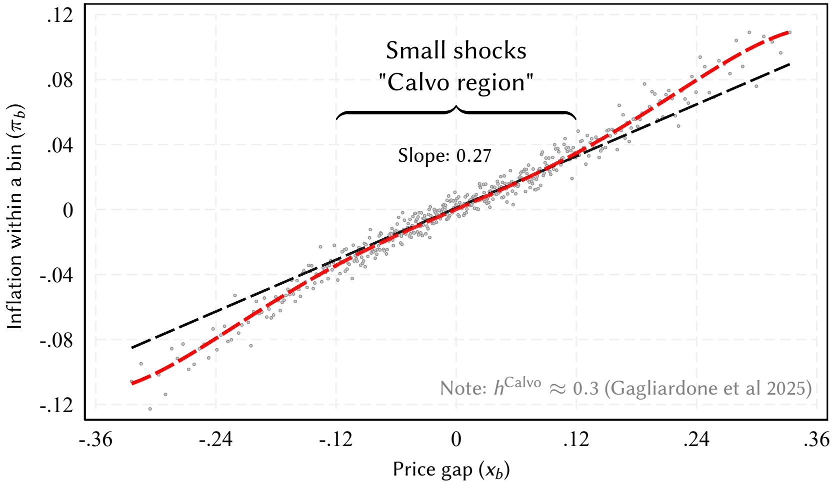

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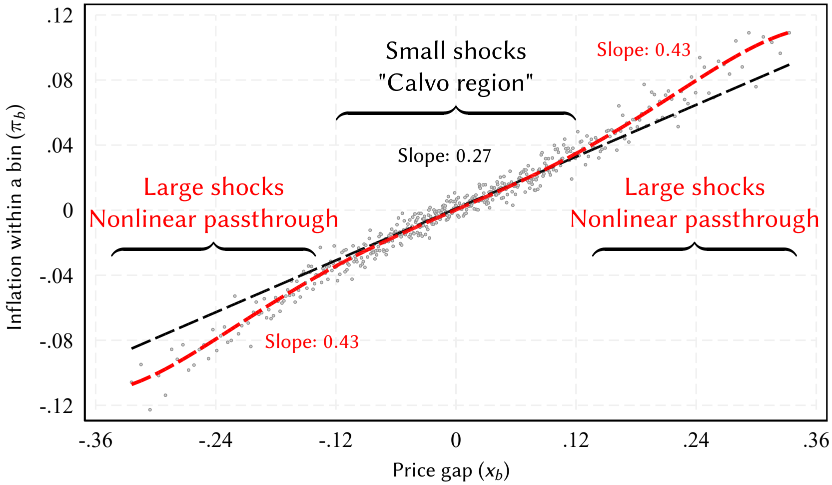
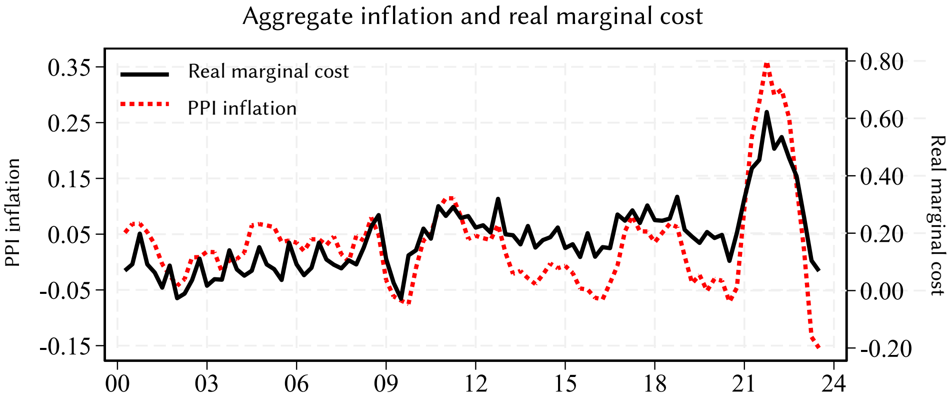


Aggregate cost-price dynamics

Accounting for inflation volatility

(passthrough in the time-series)

Aggregate real marginal cost index vs PPI inflation (manufacturing)



Y-o-Y PPI Inflation: $\pi_t \equiv \sum_{f \in \mathcal{I}} \bar{s}_{ft} \cdot \left(p_{ft} - p_{ft-4}\right);$

Real Marginal Cost: $\widetilde{mc}_t \equiv \sum_{f \in \mathcal{I}} \bar{s}_{ft} \cdot \left(mc^n_{ft} - p_{ft-4}\right);$

▷More ▷Aggregate markup ▷Decomposition mc^n_t

How well can the menu-cost model explain the time series of inflation?

- Calibrate model parameters exploiting moments from the join distribution of price changes and price gaps.

- Feed-in and simulation:

  1. Start from 1999:Q1 assuming economy is in steady state.

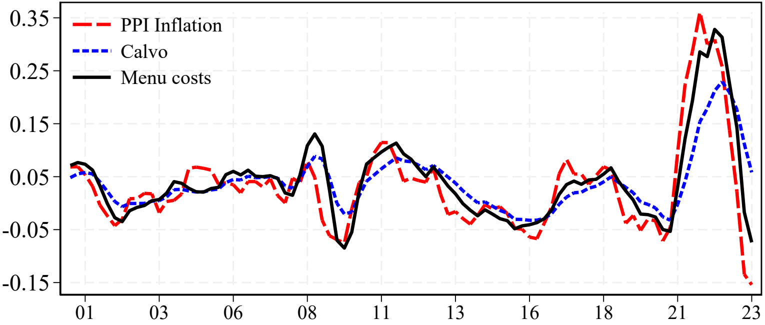
  2. Feed aggregate nominal *mc* shocks recovered from the data to the model and compute inflation response:
     - Assuming all future shocks unanticipated (as in an impulse response function).

  3. Update price-gap distribution, compute new shock, feed in new *mc* shock.

  4. Repeat until 2023:Q4.

|▷ Calibration |▷ Moments: Model vs Data |▷ Impulse-response

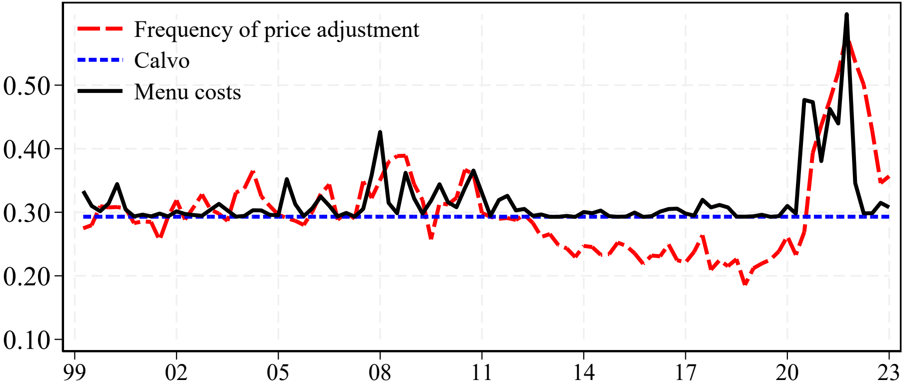
Inflation: Model vs Data (Y-o-Y)



1. Time- and state-dependent models very close in normal times (Gertler and Leahy 2008; Auclert et al 2024).
2. Menu-cost model captures inflation dynamics in both normal times and during inflation surges;
3. In Calvo, inflation reacts too little and for too long.

▷ Quarterly

Frequency: Model vs Data



|▷ Selection: Time-varying Calvo

Final thoughts

- Microdata shows strong evidence of state-dependent pricing.
- State-dependent framework + price-cost data goes a long way:
  - explaining both passthrough in the *cross-section* and *time-series* of inflation;
  - both in normal times and during inflation surges.

Path forward: Embed features of state-dependent models in existing macro frameworks:

- Calvo: Highly tractable but linear passthrough;
- Menu-cost: Flexible (linear & nonlinear passthrough, depending on shock's magnitude)

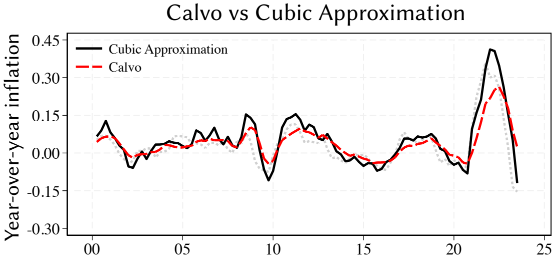
  ... but no general analytical solutions and computationally intensive.

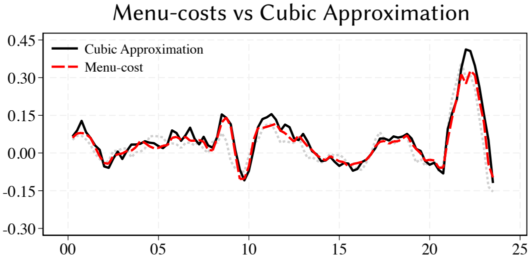
An *odd approximation* of inflation for state dependent pricing models

- Up to third-order, approximate inflation as a **cubic (odd) polynomial** in the average price gap:

$$\boxed{\pi_t \approx \kappa_0 \cdot x_t + \kappa_1 \cdot x_t^3}$$

- Calvo is a special case: $\pi_t = \kappa^{Calvo} \cdot x_t$





Appendix

Related literature

- **Menu cost models**:
  Caballero and Engel (1993, 2007), Dias et al. (2007), Golosov and Lucas (2007), Gertler and Leahy (2008), Nakamura-Steinsson (2010), Midrigan (2011), Alvarez et al. (2016), Alvarez et al. (2017), Alvarez et al. (2022), Alvarez et al. (2023), Auclert et al (2024), Blanco et al. (2024), Morales-Jimenez and Stevens (2024).

- **Evidence on state-dependent pricing**:
  Zbaracki et al (2004), Eichenbaum et al (2011), Gagnon et al (2012), Campbell and Eden (2014), Karadi and Reiff (2019), Karadi et al. (2021), Cavallo et al. (2024), Blanco et al. (2024a, 2024b).

- **Pass-through with micro-data**:
  Amiti et al. (2019), McLeay and Tenreyro (2020), Hazell et al. (2022), Gagliardone et al. (2025).

Aggregate inflation and nonlinear dynamics

Recall: $x_t(f) \equiv p^o_t(f) - p_{t-1}(f)$

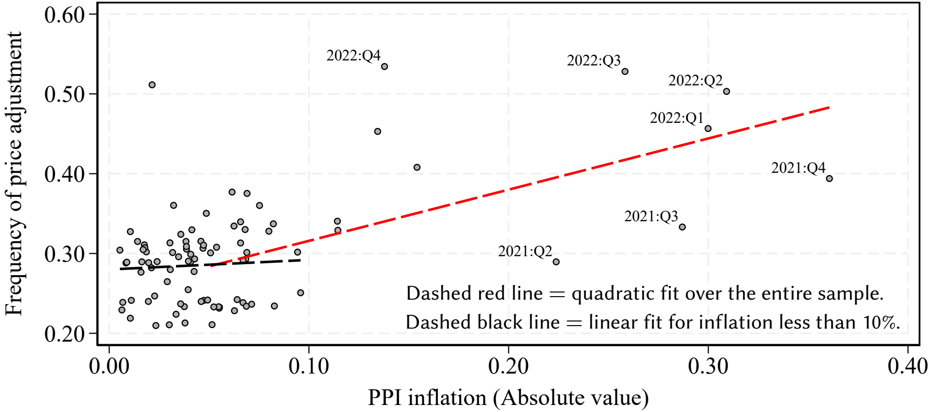
$h_t(f) \equiv h_t\big(x_t(f)\big)$

$$\pi_t = \int \Delta p_t(f)\, df \approx \int h_t(f) \cdot x_t(f)\, df$$

$$= \underbrace{\int h_t(f)\, df}_{\text{Extensive margin}} \cdot \underbrace{\int x_t(f)\, df}_{\text{Intensive margin}} + \underbrace{\mathbb{C}\text{ov}\Big(h_t(f)\,, x_t(f)\Big)}_{\text{Selection effect}}$$

- **Calvo pricing**
  - $h_t(f)$ is constant: Inflation dynamics *linear* in average price gap.
- **State-dependent pricing**
  - *Large* correlated shocks to $x_t(f)$: *Nonlinear* inflation dynamics; $h_t(f)$ moves significantly;
  - *Small* correlated shocks to $x_t(f)$: Approx. *linear* inflation dynamics; $h_t(f)$ approx. constant.

Frequency of price adjustment and inflation



- Small shock: small increase in inflation and negligible adjustment of frequency (as in Calvo model).
- Large shock: high inflation and significant adjustment in frequency.

Aggregate inflation and marginal cost index

- Aggregate PPI inflation and price index:

$$\pi_t = \sum_{f \in \mathcal{F}} \bar{s}_{ft} \cdot \Delta p_{ft} \qquad \text{Törnqvist weight } \bar{s}_{ft} \equiv \tfrac{1}{2}\left(s_{ft} + s_{ft-1}\right).$$

$$p_t = p_{1999:Q1} \cdot \sum_{t=1999:Q2}^{2023:Q4} \pi_t$$

- Aggregate nominal marginal cost index:

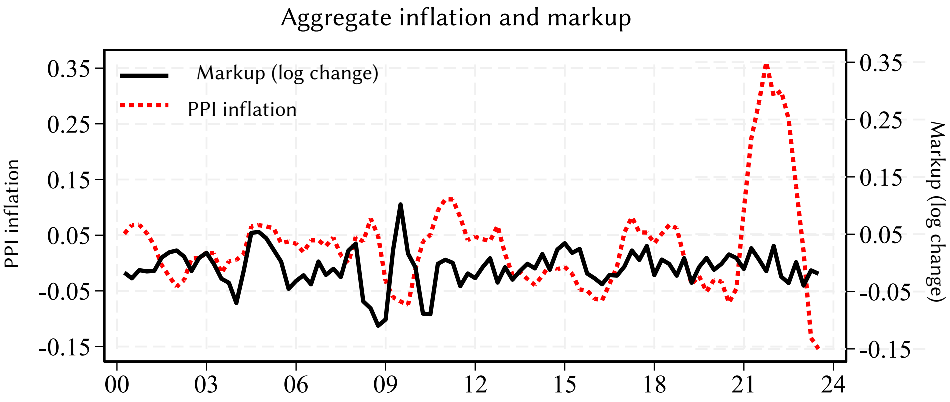
$$\Delta mc_t^n = \sum_{f \in \mathcal{F}} \bar{s}_{ft} \cdot \Delta mc_{ft}^n$$

$$mc_t^n = mc_{1999:Q1} \cdot \sum_{t=1999:Q2}^{2023:Q4} \Delta mc_t^n$$

normalization $p_{1999:Q1} = mc_{1999:Q1} = 1$.

▷Back

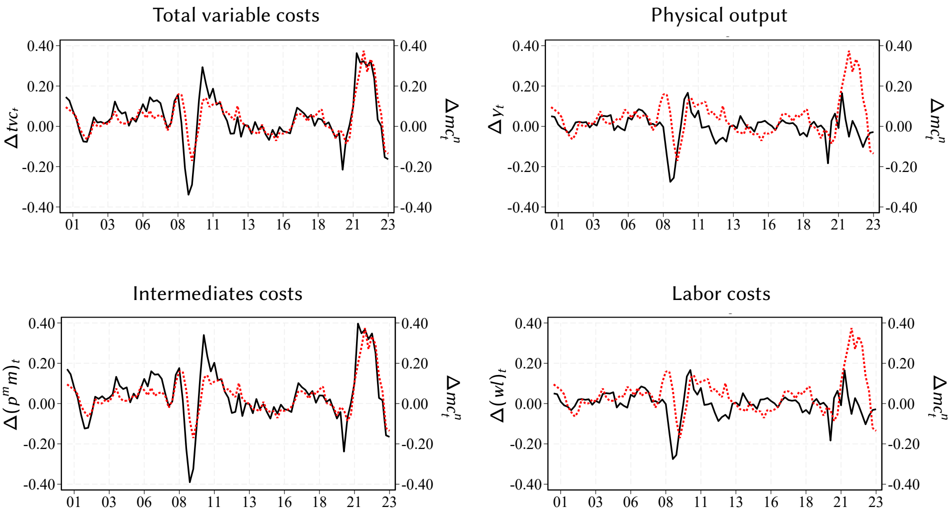
Aggregate markup vs manufacturing PPI inflation



Log-change in Aggregate markup: $\Delta \ln(\text{Markup}) \equiv \pi_t - \Delta mc_t^n$;

|▷Back

Decomposition of aggregate marginal cost index



|▷Back

Quantitative exercises

Calibration of menu cost model

- 4 parameters are externally calibrated:
  1. $\beta = 0.99$ Discount factor.
  2. $\sigma = 6$ Elasticity of substitution across goods (SS markup of 1.2).
  3. $\Omega = 0.5$ Estimation from Gagliardone et al (2023).
  4. $\mu_g = 0.5\%$ (1.6% year-over-year) Trend inflation.

- 3 parameters are calibrated to match 3 micro-level moments:
  5. $1 - \theta^0 = 0.188$ Probability of a free-price adjustment.

     $\Rightarrow$ Use $(1 - \theta^0) \approx$ average of empirical GHF $h(x_t)$ around $x_t = 0$
  6. $\sigma_\varepsilon^2 = 0.0036$ Standard deviation of idiosyncratic shocks.

     $\Rightarrow$ Use SS identity (Alvarez et al. 2016): $\sigma_\varepsilon^2 = \bar{h}_{ss} \cdot \text{Var}_{ss}(\Delta p_{ft})$
  7. $\bar{\chi} = 0.61$ Maximum menu cost.

     $\Rightarrow$ Given $(1 - \theta^0)$ and σ_ε, match the SS frequency of price changes ($\bar{h}_{ss}$).

▷ Back

Moments: Data vs model (steady state)

	Price change ($p_{ft} - p_{ft-1}$)				Share MC
	Mean	Std	Freq. Adj.	Kurt	Mean (%)
Data	0.00	0.12	0.29	3.26	1.22
Menu cost	0.00	0.12	0.29	2.62	1.70
Calvo	0.00	0.12	0.29	5.21	

- Menu costs amount to 1.7 percent of firm revenues, on average.

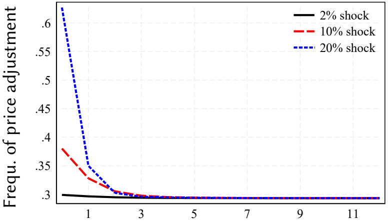
  Consistent w/ empirical evidence of small menu costs (Levy et al. 1997 & Zbaracki et al. 2004).

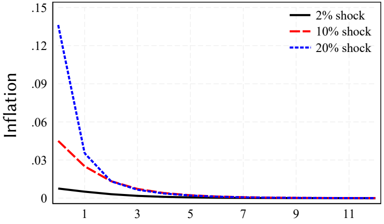
|▷ Back

Impact of shocks to aggregate marginal cost

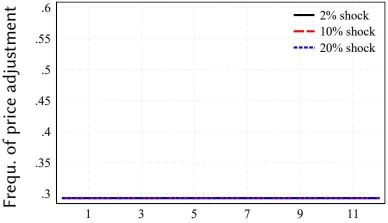
|▷ p^o vs $p^\star$

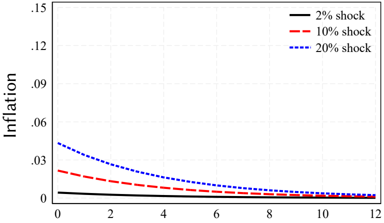
Panel a: State-dependent pricing (Menu costs)





Panel b: Time-dependent pricing (Calvo)





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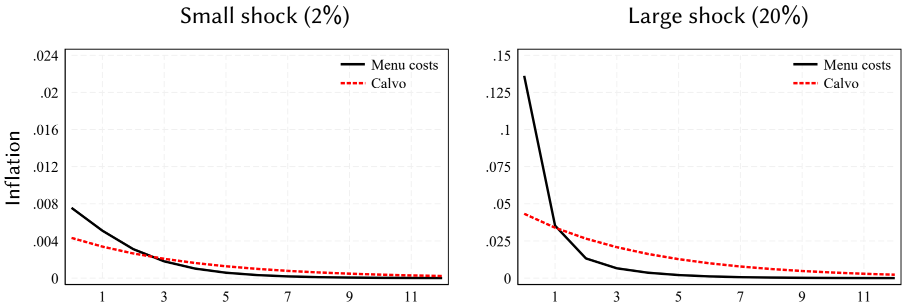
Impact of shock on size vs persistence of inflation response



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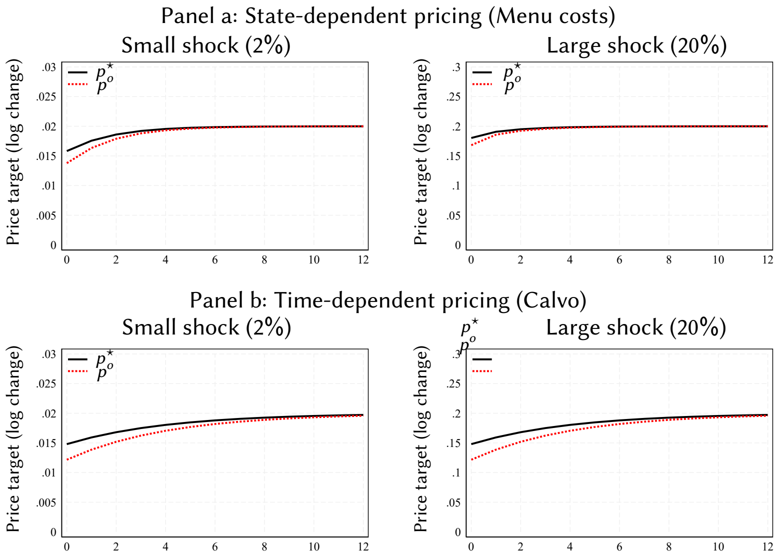
Static vs Dynamic Price Targets

▷ Back to Model ▷ Back to IRFs

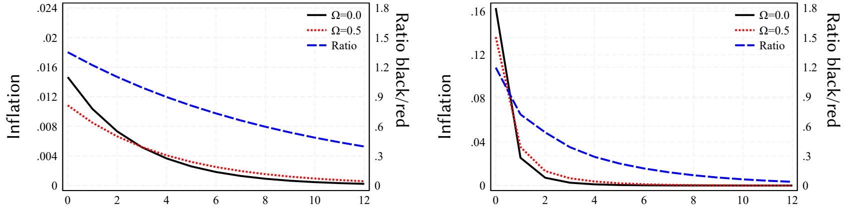


Strategic complementarities

⊳ Back to Model

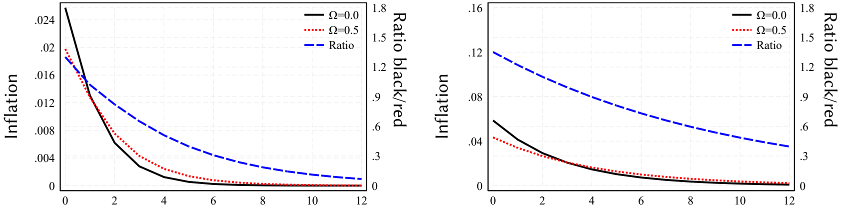
Panel a: State-dependent pricing (Menu costs)

Small shock (2%) | Large shock (20%)



Panel b: Time-dependent pricing (Calvo)

Small shock (2%) | Large shock (20%)



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

- 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 $x' = p^0 - p - (1-\Omega)(g' + \varepsilon') - \Omega(p' - p)$.

- Value of adjusting:

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

- Reset gap $x_t^\star \equiv p_t^\star - p_t^0$ obtained from FONC:

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

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

- To a first-order:

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

$$\boxed{\Rightarrow p_t^\star(f) = \mu + (1 - \Omega)mc_t(f) + \Omega p_t + \Psi_t}$$

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

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

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

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

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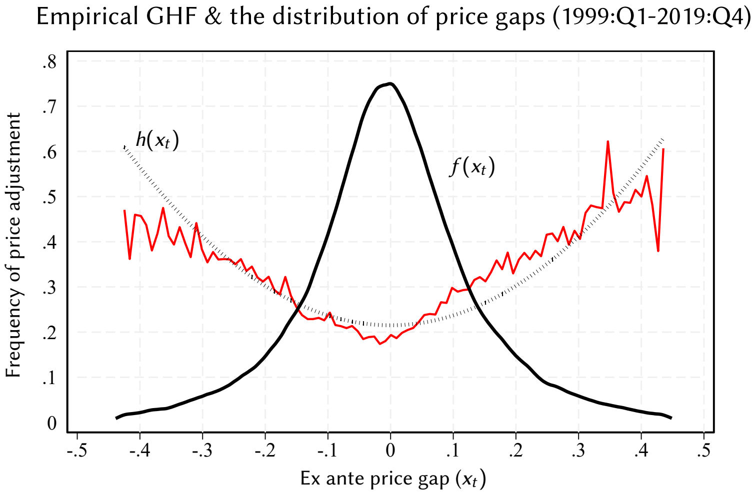
(#1) State-dependent probability of price adjustment



Quadratic fit: $\hat{h}_t = \hat{a}_0 + \hat{a}_1 \cdot \Big(x_t(f)\Big)^2$

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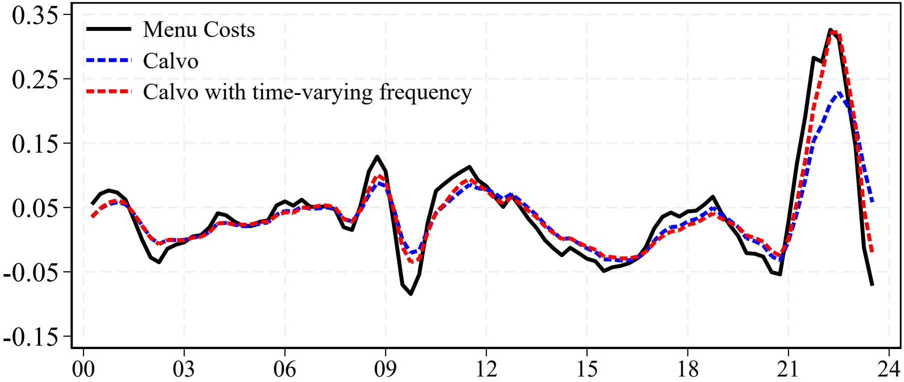
Menu costs vs Calvo with Time-varying Frequency



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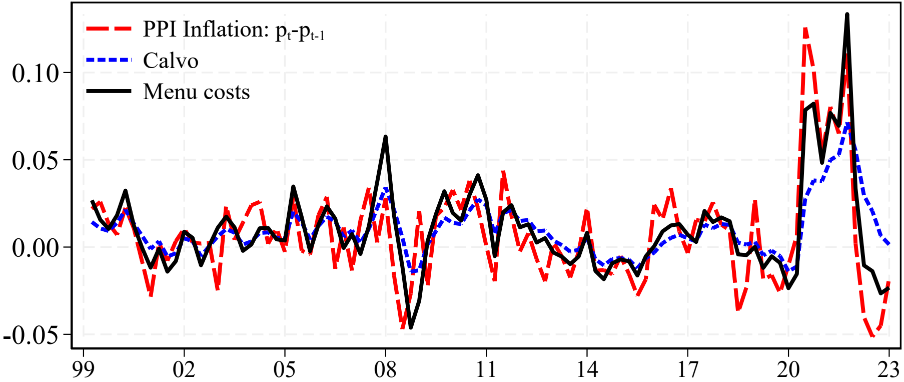
Inflation: Model vs Data (Quarterly)



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