Uncovering the Costs of High Inflation

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Introduction

- Sticky prices create price-cost wedges that lead to misallocation of resources
- The question: How does misallocation change with inflation?
- Study price-setting in moderate (20%) vs high (80%) inflation, Turkish data
- New sticky price model with information friction:
  $\Longrightarrow$ improved ability to explain frequency response to inflation

Introduction

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- The question: How does misallocation change with inflation?
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- New sticky price model with information friction:
  $\Longrightarrow$ improved ability to explain frequency response to inflation
- Main findings
  - Misallocation costs of inflation have steep gradient with info frictions
  - New analytic result to analyze mechanism behind effects in lumpy HA economy

Related Literature

- Models with Adjustment & Info frictions
  - Mackoviack-Wiederholt (AER09), Alvarez-Lippi-Paciello (QJE11), Morales-Jimenez and Stevens (WP)
- Use of high-inflation episodes to discipline sticky price models
  - Gagnon (QJE09), Alvarez-Beraja-Rozada-Neumeyer (QJE19), Alvarez-Neumeyer (Banco Chile)
- Misallocation costs of inflation
  - Nakamura, Steinsson, Sun and Villar (QJE18), Adam, Alexandrov, and Weber (WP), Hsieh, Klenow, Li and Miyahara (WP)

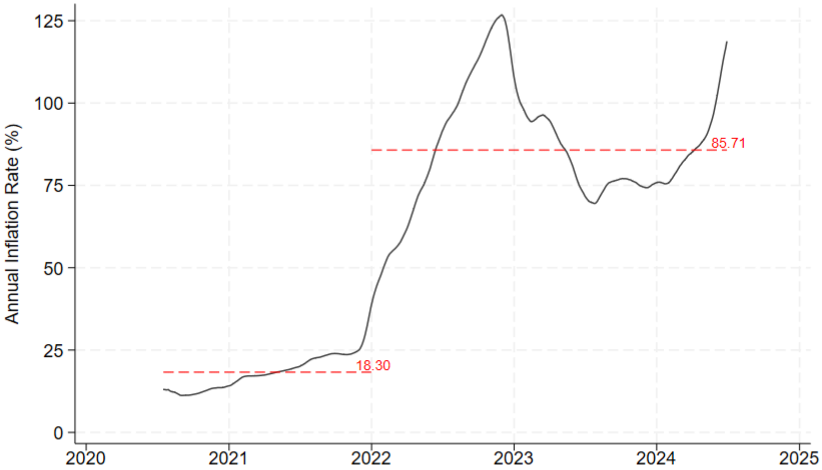
Study How Inflation Affects Behavior Using Granular Data

- Focus on Turkey going from “moderate” (20%) to “high” (80%) inflation
- Quantify “misallocation” and “price management” costs as fct. of inflation

Granular data from Turkey. Sectors: "Food and Beverages", “Electronics"

- PriceStats data, 14 largest retailers (Cavallo and Rigobon, 2016)
- Sample period between June 2019 and July 2024 , daily frequency
- Price changes, Δp, and duration of completed price spells, τ^a

Turkey: Inflation in Food and Beverages, μ (Pricestats)



CPI vs pstats

Turkey: Frequency of Price Adjustment, N_a (Pricestats)

Freq. Elasticity $\frac{\Delta \log N_a}{\Delta \log \mu} = 0.31$, Abs size of price changes

Simple setup for Demand and Production

- Monopolistic competition with CES demand $A_i c_i = \left(\frac{p_i/A_i}{P}\right)^{-\eta} C$
- Production: CRS in labor $y_i = \frac{h_i}{E_i}$ where E_i is GBM with volatility σ
- **Price gap** $z_i \equiv \log p_i - \log \underbrace{\frac{\eta}{\eta - 1}\Omega E_i}_{\equiv p_i^*}$, where Ω is aggregate wage
- Gap's law of motion: $dz = -\mu dt + \sigma dW_i$

– Simplify: steady-state (constant μ); No complementarities; $A_i = E_i$;

The Firm's Price Setting Problem

- Firm knows inflation μ but does not know gap z

  Price-setting requires costly communication with production plant

- Information about z arrives with (chosen) hazard: ω

- Price adjustment opportunities arrive with (chosen) hazard: α

- Uncontrolled evolution of expected gap $x(t) \equiv \mathbb{E}(z(t))$, for firm with t_0 info

$$x(t) = z(t_0) - \mu \cdot (t - t_0) \quad , \quad \tau(t) \equiv t - t_0 \quad , \quad z(t) \sim \mathcal{N}\left(x(t), \sigma^2 \tau(t)\right)$$

- The firm's state is $\{x, \tau\}$, i.e., *predicted gap* and the *information age*

The Firm's Problem (HJB)

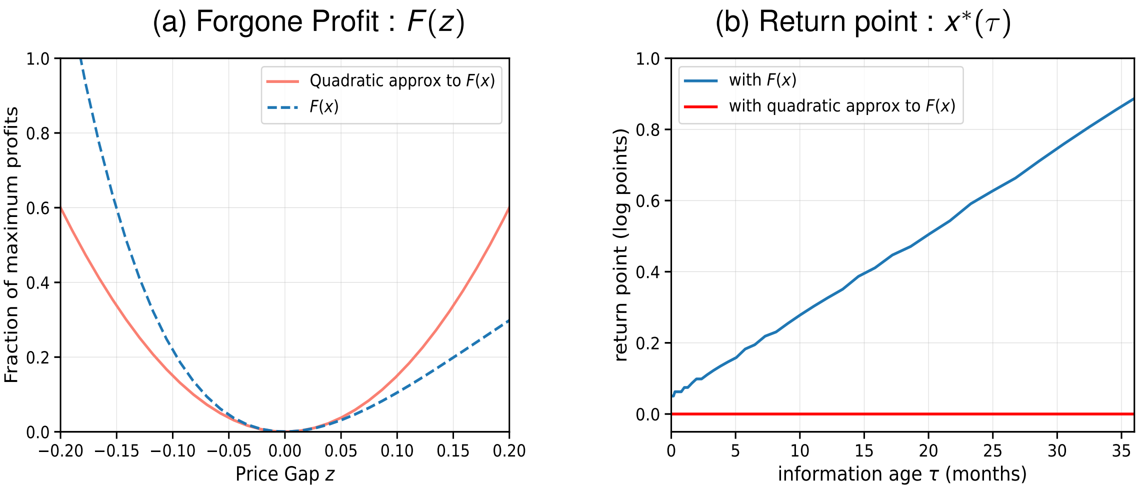
- Flow cost $F(z)$: forgone profits due to $z \neq 0$ with CES demand

- Consider $\mathbb{E}$ w.r.t. $z \sim \mathcal{N}(x, \sigma^2 \tau)$. The firm's value function v solves HJB

$$\begin{aligned}
\rho\, v(x,\tau) = {} & \mathbb{E}\left[F(z) | x, \tau\right] - \mu \partial_x v(x,\tau) + \partial_\tau v(x,\tau) \\
& + \min_{\alpha \geq 0,\, x^*} \{\alpha \cdot (v(x^*,\tau) - v(x,\tau)) + \frac{\kappa_a}{2} \alpha^2\} \\
& + \min_{\omega \geq 0} \{\omega \cdot (\mathbb{E}\left[v(z,0) | x, \tau\right] - v(x,\tau)) + \frac{\kappa_r}{2} \omega^2\}
\end{aligned}$$

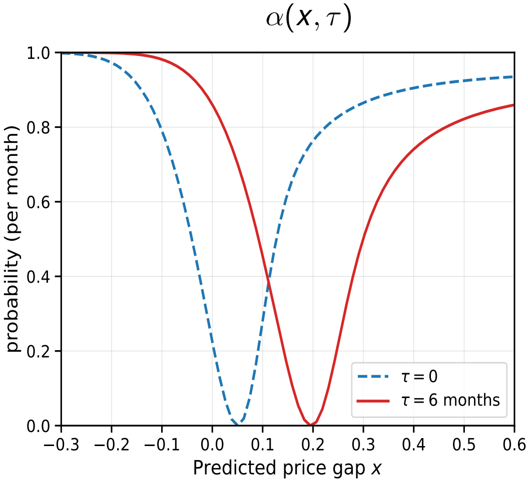
$\implies$ Policy functions: Hazards $\alpha(x,\tau)$, $\omega(x,\tau)$ and return point $x^*(\tau)$

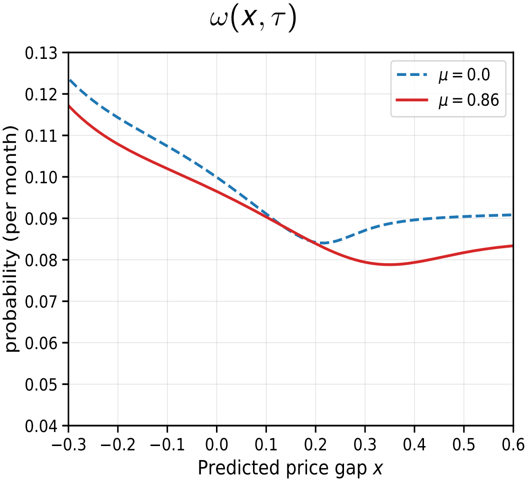
Optimal Return Point: $x^*(\tau)$



– *hedging motive* as information ages (high τ)

Adjustment Hazard $\alpha(x,\tau)$ and Research Hazard: $\omega(x,\tau)$





Cross-section Aggregation of Firms

- Aggregation: density $m(x, \tau)$ solves KFE equation (omit arguments)

$$(\alpha + \omega)\, m = \mu\, \partial_x\, m - \partial_\tau m \quad , \quad \text{for all } x \neq x^*(\tau)$$

  – Note: $m(x, \tau)$ not differentiable at the reinjection points $x^*(\tau)$

Mapping model to data

- Frequency of price adjustment and research

$$N_a = \int_0^\infty \int_{-\infty}^\infty \alpha(x, \tau) \cdot m(x, \tau)\, dx\, d\tau$$
$$N_r = \int_0^\infty \int_{-\infty}^\infty \omega(x, \tau) \cdot m(x, \tau)\, dx\, d\tau$$

Bounding σ^2 from Micro Price Data (Proposition 1)

With full-info many models (Taylor, Reis, SW, Calvo, GL, NS, ...) satisfy the identity

$$\underbrace{N_a \, \tilde{\mathbb{E}} \left(\Delta p - \mu \tau^a \right)^2}_{\text{data}} = \sigma^2$$

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Information frictions add a wedge to the identity:

$$\underbrace{N_a \, \tilde{\mathbb{E}} \left(\Delta p - \mu \tau^a\right)^2}_{\text{data}} = \sigma^2 + N_a \underbrace{\widetilde{\text{Var}}\Big(x^*(\tau) - x^*(\tau_0)\Big)}_{\text{return point dispersion}}$$

- Without full-info, the standard models overstate σ^2.

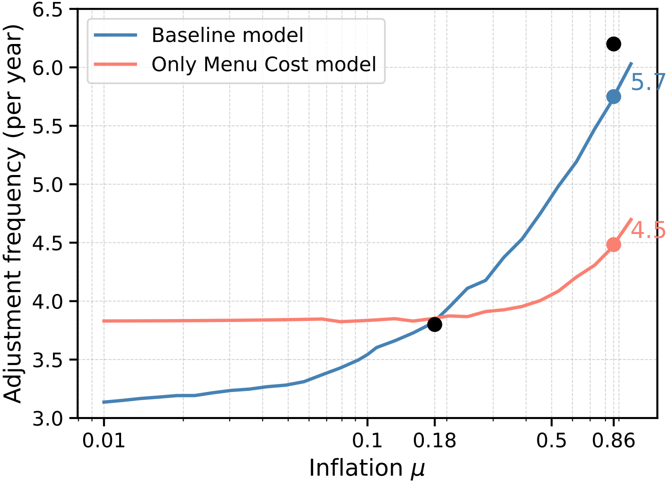
Calibration for Food & Beverages, 2019-2021 (inflation $\mu = 0.18$)

- Select four parameters: $\{\mu,\ \sigma^2,\ \kappa_a,\ \kappa_r\}$
- To match four moments: $\{\tilde{\mathbb{E}}\,(\Delta\,p)\ ,\ N_a\,,\ \tilde{\mathbb{E}}\,(\Delta\,p - \mu\tau^a)^2\ ,\ \frac{\Delta \log N_a}{\Delta \log \mu}\}$

	Targeted moments				Parameters				Others
	N_a	$\tilde{\mathbb{E}}[\Delta p]$	$N_a\,\tilde{\mathbb{E}}\left[(\Delta p - \mu\tau^a)^2\right]$	Freq. Elasticity	σ^2	κ_a	κ_r	μ	N_r
Data	3.8	0.05	0.15	0.31	–	–	–	–	–
Baseline model	3.8	0.05	0.15	0.26	0.05	0.0014	0.1458	0.18	1.05
w/o info frictions	3.8	0.05	0.15	0.11	0.15	0.0034	–	0.18	–

Model with info frictions requires smaller $\sigma \implies$ yields larger Freq Elasticity

Adjustment Frequency N_a vs inflation, μ



– menu cost flat because σ^2/μ large; info friction make model more SW like

– research activity flat w.r.t. inflation

Costs of Inflation: “Misallocation” and “Price management”

- Misallocation, χ, due to price gaps

$$\text{Misall. Cost}_\mu = \frac{\eta}{2}\,\text{Var}_\mu\,(z)$$

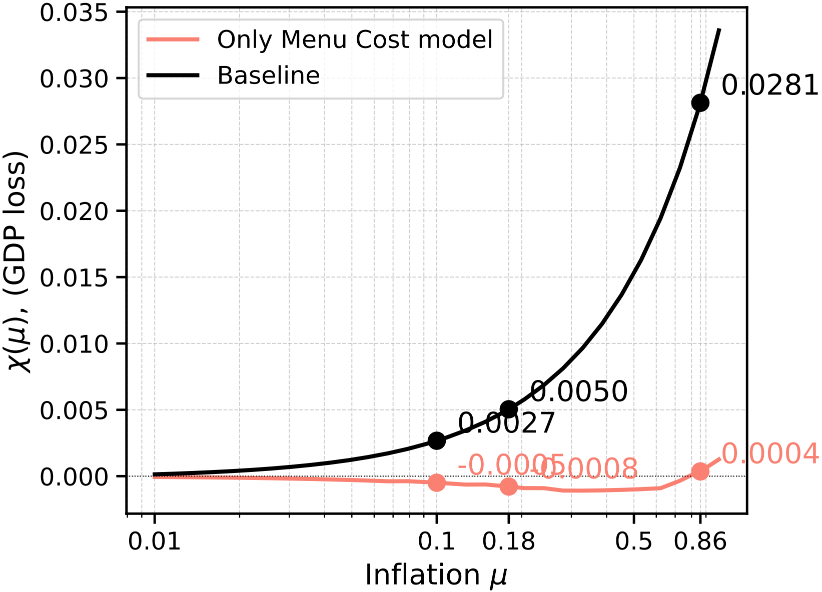
- Price management, ϕ, of adjustment and research

$$\text{Mgmt. Cost}_\mu = \frac{1}{\eta}\mathbb{E}\,[\frac{\kappa_a}{2}\alpha(x,\tau)^2 + \frac{\kappa_r}{2}\omega(x,\tau)^2]$$

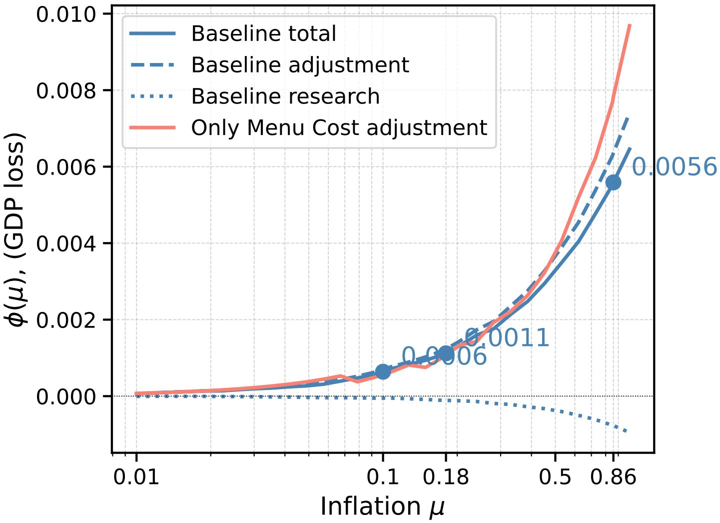
– Costs defined in excess of level at $\mu = 0$

$$\chi(\mu) \equiv \text{Misall. Cost}_\mu - \text{Misall. Cost}_0, \qquad \phi(\mu) \equiv \text{Mgmt. Cost}_\mu - \text{Mgmt. Cost}_0$$

Misallocation Costs vs Inflation (baseline calibration)



Management Costs vs Inflation (baseline calibration)



Inspecting the misallocation mechanism: $\dot{\chi}(\mu) \equiv \frac{d}{d\mu}\chi(\mu)$

- What are the economic forces behind an increase in misallocation?

- Inflation affects pricing behavior (α, ω, x^*) and markups dynamics (μ)

Analytical decomposition: Preliminaries

- Recall $\chi(\mu) \propto Var(z) = \int (x^2 + \sigma^2\tau) m(dx, d\tau) - (\mathbb{E}x)^2$

- $\dot{\chi}(\mu) \equiv \frac{d}{d\mu}\chi(\mu) = \int g(x,\tau)\dot{m}(dx, d\tau)$ where $g(x,\tau) = x^2 - 2x\mathbb{E}x + \sigma^2\tau$

- Average of g with respect to derivative of distribution, $\dot{m}$, (complicated object!)
  rmk: (i) $\dot{m}$ has kinks at x^*; (ii) no clear econ insight embedded in $\dot{m}$

Analytical Decomposition of $\dot{\chi}(\mu)$.

Let $\mathcal{A}$ be the generator of the Markov process for a test function $f(x,\tau)$

$$\mathcal{A}f = -\mu\partial_x f + \partial_\tau f + \alpha \cdot (f(x^*,\tau) - f) + \omega \cdot (\mathbb{E}[f(z,0)] - f).$$

Proposition 2: Let m be the stationary distribution solving the KFE. Then

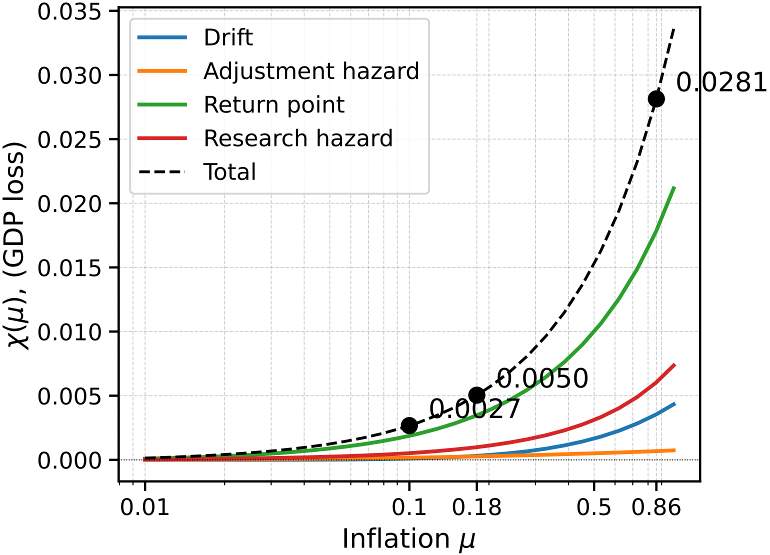
$$\dot{\chi}(\mu) = \langle g, \dot{m}\rangle = \langle \dot{\mathcal{A}}f, m\rangle = \underbrace{\langle -\partial_x f, m\rangle}_{\text{drift effect}} + \underbrace{\langle \dot{\alpha}\left(f(x^*,\tau) - f\right), m\rangle}_{\text{adjustment freq. response}}$$

$$+ \underbrace{\langle \alpha\partial_x f\left(x^*,\tau\right) \cdot \dot{x}^*, m\rangle}_{\text{return point response}} + \underbrace{\langle \dot{\omega}\left(\mathbb{E}\left[f(z,0)|x,\tau\right] - f\right), m\rangle}_{\text{research response}}$$

where f is the “ergodic value function” solving: $-\mathcal{A}f = g - \langle g, m\rangle$

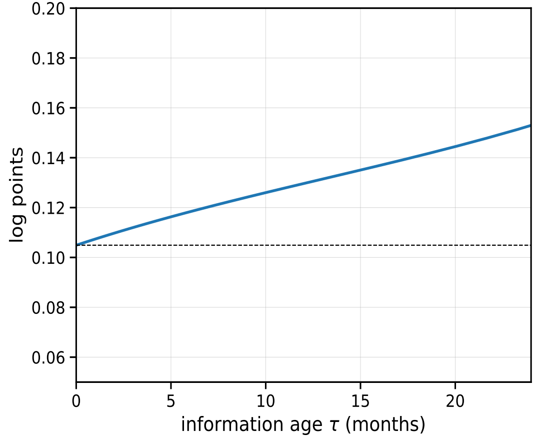
See Golosov, Krasikov, and Miyahara (2026) for an adjacent result in a single drift control setting

Misallocation Costs of Inflation: Decomposition

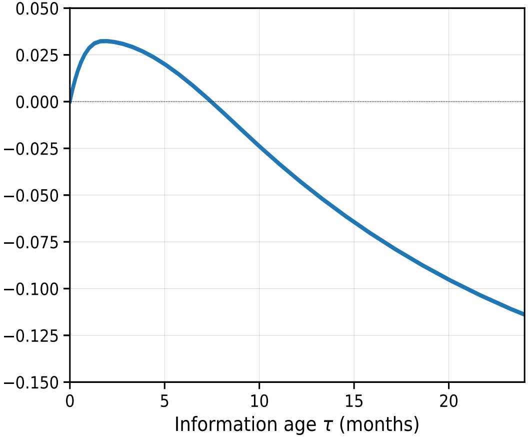


Higher inflation induces “more hedging” and staler information

Return point response $\dot{x}^*(\tau)$



Research hazard response $\mathbb{E}\left[\dot{\omega} \mid x\right]$



– This change in behavior makes markups more dispersed

Summary

- Today: add an information friction to a standard sticky price model
  - firms engage in info-collection (research) and price-adjustment activities
- Our model is able to match the elasticity of frequency to inflation in data
- Firms choose more dispersed markups and operate with more stale info
  $\Longrightarrow$ new channels for price dispersion
- Non negligible inflation costs, steep gradient
  - The misallocation cost of 10% inflation are 27 bp of GDP in cons. equiv.
  - The misallocation cost of 86% inflation are 280 bp of GDP in cons. equiv.

Thank you!

Appendix

- How to compute joint moments of price adjustments and time between adjustments $\{\Delta p, \tau^a\}$
- Define generator of the uncontrolled state + discovery process
- From an initial condition, propagate that process forward removing mass upon adjustments
- The removed density is the joint distribution of price changes, information ages (measured at adjustment dates) and time between adjustments
- Continue in next slide...

Appendix cont'd

- Let $\mathcal{A}$ be the generator of the uncontrolled + observation process
- Let $F(x, \tau, t)$ be a time-varying measure on (x, τ) that keeps track of the states that have not adjusted and Q for the measure of states that have
- Let $P(\Delta p, \tilde{\tau}, \tau^a)$ be the distribution of price changes, information age (measured at times of adjustments) and time between adjustments

Appendix cont'd

- Let $F(x, \tau, 0)$ be a density integrating to 1 of states right after an adjustment e.g. a Dirac density on $(x^*(\tau), \tau)$
- $F(x, \tau, t)$ solves the following PDE

$$\partial_t F = \mathcal{A}F - \alpha \cdot F$$

- Then the distributions Q and P are

$$P(x^*(\tau) - x, \tilde{\tau}, \tau^a) = Q(x, \tilde{\tau}, \tau^a) = \alpha(x, \tau) \cdot F(x, \tilde{\tau}, \tau^a)$$

Analytical Decomposition of $\dot{\chi}(\mu)$: Preliminaries

- Define the *generator* $\mathcal{A}$ of the Markov process (x, τ)

$$\begin{aligned}\mathcal{A}v(x,\tau) = & -\mu\partial_x v(x,\tau) + \partial_\tau v(x,\tau) + \alpha(x,\tau)\left(v(x^*(\tau),\tau) - v(x,\tau)\right) \\ & + \omega(x,\tau)\left(\mathbb{E}\left[v(z,0)|x,\tau\right] - v(x,\tau)\right).\end{aligned}$$

where $\mathcal{A}v_t = \lim_{\Delta\downarrow 0}\mathbb{E}_t(v_{t+\Delta} - v_t)/\Delta$.

- Given $\mathcal{A}$ and v, $\dot{v}$ solves a linear PDE

$$\rho\dot{v}(x,\tau) = -\partial_x v(x,\tau) + \mathcal{A}\dot{v}(x,\tau),$$

and price-setting behavior responses are given by

$$\dot{\alpha} = \frac{\dot{v}(x,\tau) - \dot{v}(x^*(\tau),\tau)}{\kappa_a}, \quad \dot{\omega} = \frac{\dot{v}(x,\tau) - \mathbb{E}\left[\dot{v}(z,0)|x,\tau\right]}{\kappa_r}, \quad \dot{x}^* = -\frac{\partial_x\dot{v}(x^*(\tau),\tau)}{\partial_{xx}v(x^*(\tau),\tau)}$$

$\dot{v}, \dot{\alpha}, \dot{\omega}, \dot{x}^*$ only use equilibrium objects!

Theory and applications: Miyahara (robust control); Golosov, Krasikov and Miyahara (Aiyagari model)

New information at price adjustment dates

- New information (mg cost shocks) at adjustment dates has three components
- τ_0: information age at start of price spell
- τ^a: information that transpired during the price spell
- τ: information age at end of price spell
- $\implies$ new info has variance $\tau_0 + \tau^a - \tau$ Return

Sequential problem

- Firm with state (x, τ) at $t = 0$ solves

$$v(x,\tau) = \min_{\alpha,\omega,x^*} \mathbb{E}\left[\int_0^\infty e^{-\rho t} F[z(t)]dt \mid z(0) \sim \mathcal{N}(x, \sigma^2 \tau)\right]$$

$dx = -\mu\, dt$ and $d\tau = dt$.

- For illustration assume α, ω fixed.
- Developing the RHS for the flow and the non-jump term

$$v(x,\tau) = \min_{x^*} \mathbb{E}_0 \left[F[z(0)]\Delta + o(\Delta) + e^{-(\rho+\alpha+\omega)\Delta} \int_\Delta^\infty e^{-\rho(t-\Delta)} F[z(t)]dt + \dots\right]$$

$$v(x,\tau) = \min_{x^*} \mathbb{E}_0 \left[F[z(0)]\Delta + o(\Delta) + e^{-(\rho+\alpha+\omega)\Delta} v[x(\Delta), \tau(\Delta)] + \dots\right]$$

$$v(x,\tau) = \min_{x^*} \mathbb{E}_0 \left[F[z(0)]\Delta + o(\Delta) + e^{-(\rho+\alpha+\omega)\Delta} \{v(x,\tau) + \partial_x v \cdot (-\mu\Delta) + \partial_\tau v \cdot (\Delta)\} + \dots\right]$$

$$(\rho+\alpha+\omega)\Delta\, v(x,\tau) = \min_{x^*} \mathbb{E}_0 \left[F[z(0)]\Delta + o(\Delta) + e^{-(\rho+\alpha+\omega)\Delta} \{\partial_x v \cdot (-\mu\Delta) + \partial_\tau v \cdot (\Delta)\} + \dots\right]$$

Denote the conditional expectation by $\mathbb{E}_0$

Sequential problem (cont'd)

- Developing the jump terms

$$\ldots = \min_{x^*} \mathbb{E}_0 \left[\ldots + e^{-\rho\Delta} \left[(1 - e^{-\alpha\Delta}) v(x^*, \tau(\Delta)) + (1 - e^{-\omega\Delta}) v(z(\Delta), 0) \right] \right]$$

$$\ldots = \min_{x^*} \mathbb{E}_0 \left[\ldots + e^{-\rho\Delta} \left[(1 - e^{-\alpha\Delta}) \left[v(x^*, \tau) + \partial_\tau v \cdot \Delta \right] + (1 - e^{-\omega\Delta}) v(z(\Delta), 0) \right] \right]$$

$$\ldots = \min_{x^*} \mathbb{E}_0 \left[\ldots + e^{-\rho\Delta} \left[\alpha\Delta v(x^*, \tau) + o(\Delta) + \omega\Delta v(z(0), 0) \right] \right]$$

  2nd to 3rd line: drift and diffusion terms times hazards are order Δ^2

- Putting the terms together, dividing by Δ and taking the limit as $\Delta \to 0$

$$(\rho + \alpha + \omega)\, v(x, \tau) = \min_{x^*} \mathbb{E}_0 \left[F[z(0)] + \partial_x v \cdot (-\mu) + \partial_\tau v + \alpha v(x^*, \tau) + \omega v(z(0), 0) \right]$$

$$(\rho + \alpha + \omega)\, v(x, \tau) = \mathbb{E}_0 F[z(0)] + \partial_x v \cdot (-\mu) + \partial_\tau v + \alpha \min_{x^*} v(x^*, \tau) + \omega \mathbb{E}_0 v(z(0), 0)$$

  Q.E.D. Return

Mapping Observables to Model Parameters: No Info Friction

- LHS: moments in the data $\{\Delta p, \tau^a\}$
- Operators $\tilde{\mathrm{E}}, \widetilde{\mathrm{Var}}$ integrate w.r.t. density of $\{\Delta p, \tau^a\}$

$$\frac{1}{\tilde{\mathrm{E}}\,\tau^a} = N_a, \tag{1}$$

$$N_a \tilde{\mathrm{E}}\,\Delta p = \mu, \tag{2}$$

$$N_a \tilde{\mathrm{E}}\,(\Delta p - \mu\tau^a)^2 = \sigma^2, \tag{3}$$

$$N_a \tilde{\mathrm{E}}\tau^a \left(\Delta p - \frac{\mu}{2}\tau^a\right) = x^* - \tilde{\mathrm{E}}x \tag{4}$$

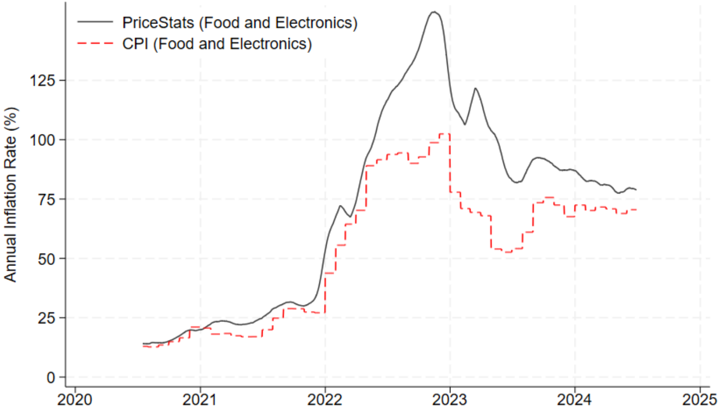
$$\frac{1}{3}\frac{N_a}{\mu}\tilde{\mathrm{E}}\,(\Delta p)^3 - (x^* - \tilde{\mathrm{E}}x)\left(\frac{\sigma^2}{\mu} + x^* - \tilde{\mathrm{E}}x\right) = \mathrm{Var}(z) \tag{5}$$

Return

Relative Entropy (skip)

- How the distribution of gaps changes with higher inflation?
- One measure is relative entropy between two densities m_1 and m_0 e.g. m_1 corresponds to 0.6 inflation and m_0 to 0.3 inflation
- Relative entropy measures $\int_{-\infty}^{\infty} \log[n(x)] n(x)\, m_0(x) dx$ where $n(x) \equiv m_1(x)/m_0(x)$
- Next figure displays $\log[n(x)] n(x)\, m_0(x) dx$ as a share of relative entropy to understand important contributors

Pricestats vs CPI data: Turkey



Return

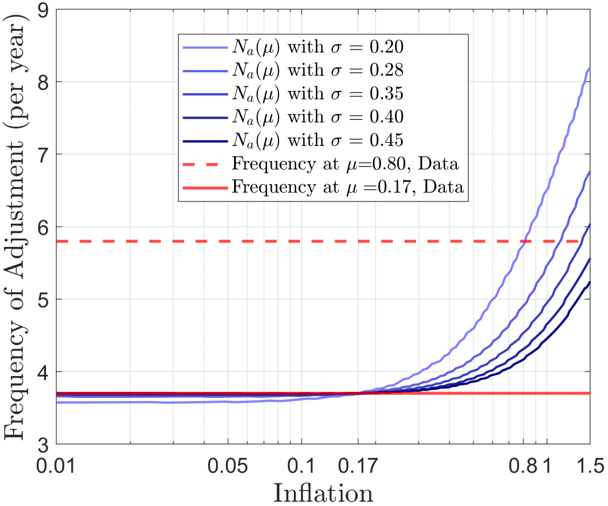
Turkey: Absolute Size of Price Changes

return

Adjustment Frequency and Inflation in Menu Cost Model

For different σ parameters back

OLD PARAMETRIZATION, NEEDS UPDATING



Substitutability between Price Setting Activities with Higher Inflation

- **Producer theory lens**: state-by-state, the firm "maximizes profits"

$$\max_{\alpha \geq 0, \omega \geq 0} \underbrace{\alpha p_a(v) + \omega p_r(v)}_{\text{benefits}} - \left(\underbrace{\frac{\kappa_a}{2}\alpha^2 + \frac{\kappa_r}{2}\omega^2}_{\text{costs}} \right), \quad \text{where}$$

$$p_a(v)(x,\tau) := \; v(x,\tau) - v(x^*(\tau),\tau), \qquad p_r(v) := \; v(x,\tau) - \mathbb{E}\left[v(z,0)|x,\tau\right]$$

- The response in the cost share of adjustment activities s_a is:

$$\dot{s}_a = 2\, s_a(1 - s_a) \left(\frac{p_a(\dot{v})}{p_a(v)} - \frac{p_r(\dot{v})}{p_r(v)} \right), \qquad \text{where } s_a := \frac{\kappa_a \alpha^2}{\kappa_a \alpha^2 + \kappa_r \omega^2}$$

- Inflation induces substitution toward whichever activity becomes *relatively* more valuable — the pattern varies across the state space (x, τ)