Behavioral Sticky Prices

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System 1 and System 2

Psychology literature: decisions made with dual-process framework (Stanovich and West (2000)).

- System 1: **Fast**, low effort decisions... but prone to biases and systematic **errors**.
- System 2: **Slow**, cognitively costly decisions... but more **accurate**.

Due to cognitive costs, System 2 only activated in **unfamiliar** situations.

Suggestive evidence that firms take advantage of this behavior.

- **Shrinkflation**: Changing product size instead of prices.
- **Subscription services:** Rare price changes put consumer purchases on auto-pilot.
- **Convenient prices:** Prices ending in 9 are the most common and the least likely to change.

Shrinkflation

- In 2016, Toblerone changed the weight of its chocolate bars in the U.K. market from 400 gr. to 360 gr. and from 170 gr. to 150 gr.
  - Packet size and price stayed the same.

- 35 percent of the products included in the U.K. consumer price index between 2012 and 2023 have suffered changes in quantity (Budianto (2024)).
  - Most of the time, product size varies but price remains the same.

Shrinkflation

President Biden discusses shrinkflation.

This paper

- Households use dual-process framework in purchasing decisions of consumption goods.
- Households can figure out optimal demand, but not always in their interest due to cognitive costs.
- Optimal information-acquisition decision depends on familiarity of state of the world.
  - If nominal prices do not change, keep historic demand function – System 1.
  - If nominal price changes, unfamiliar situation triggers reassessment – System 2.
- Firms exploit this behavior to their advantage.
- Novel price inertia: goods with irrationally high demand have sticky prices.

Model properties

1. Model is consistent with puzzling "rockets and feathers" phenomenon.
   - Prices increase rapidly when costs rise but decrease slowly when costs fall.
2. Model also consistent with "sticky winners" phenomenon: Ilut, Valchev, and Vincent (2020).
   - Firms that receive a high demand realization are less likely to change their prices.
3. Downward-sloping hazard functions within narrowly defined goods categories.
   - Klenow and Krystov (2008), Alvarez et al. (2011), Nakamura and Steinsson (2013).
4. Unlike in other cashless sticky price models, price stability is not optimal.

Related literature

- System 1 vs. System 2
  - Stanovich and West (2000), Ilut and Valchev (2023).
- Price stickiness due to information frictions
  - Mankiw and Reis (2002), Mackowiak and Wiederholt (2009), Woodford (2009), de Clippel et al. (2014), Matejka (2015), Ilut et al. (2020).
- Rockets and feathers
  - Empirical: Karrenbrock (1991), Neumark and Sharpe (1992), Borenstein, Cameron, and Gilbert (1997), Peltzman (2000).
  - Industrial Organization: Eckert (2003), Noel (2007), Tappata (2009).
  - Menu Costs: Ellingsen, Friberg, and Hassler (2006), Cavallo, Lippi, and Miyahara (2023).
- Declining hazard.
  - Nakamura and Steinsson (2013), Alvarez et al. (2011), Klenow and Krystov (2008)
- Optimal monetary policy
  - Woodford (2003), ...

Preferences and technology

Model is static, with pre-period for initial conditions.

Household preferences:

$$U = \frac{C^{1-\sigma} - 1}{1-\sigma} - \frac{N^{1+\eta}}{1+\eta} - \mathcal{I}, \ \ \sigma, \eta > 0,$$

C = composite of differentiated goods,

$$C = \left(\int_0^1 c_i^{\frac{\theta-1}{\theta}} di \right)^{\frac{\theta}{\theta-1}}, \ \ \theta > 1.$$

N = labor supply.
$\mathcal{I}$ = cognitive cost of using System 2

Production: $y_i = An_i$.
Market structure: monopolistic competition.
Policy rule: $\int P_i C_i di = M$.

Household problem with full rationality

Step 1: For a given level of consumption expenditure, E, determine the purchases of differentiated goods, C_i, that maximize

$$\mathcal{L}_e = \frac{C^{1-\sigma} - 1}{1-\sigma} + \Lambda_e \left(E - \int_0^1 P_i C_i di \right).$$

.

Step 2: Given the solutions, C_i, to the first problem, choose the optimal levels of total consumption expenditure and hours worked:

$$\mathcal{L}_u = U\left(C, N\right) + \Lambda_u \left(WN + \Pi - T - PC\right).$$

Modeling policy function uncertainty

Behavioral bias limits ability to solve for optimal demands.

- Household can perfectly observe relevant state variables...
- ...but cannot solve for the optimal demand functions due to cognitive costs.
- Limited form of bounded rationality.
  - Households know how to adjust the consumption of each variety i to changes in the aggregate price level, or nominal wages, but not in response to shifts in prices of individual varieties.
- Behavioral errors are common to all households, so we interpret these as fads and fashions.
- Idiosyncratic behavioral erros would wash out in the aggregate so we abstract from them.

Our approach is based on Ilut and Valchev (2023) with two refinements.

- Utility-based tracking problem.
- No need to specify a residual variable that adjusts so that the budget constraint holds.

Household problem under bounded rationality

When deciding the composition of the consumption basket, household observes state variables, $\mathbf{z}$, but is uncertain about $c_i^*(\mathbf{z})$, $i \in [0,1]$. Let $x \equiv \ln\left(X/\overline{X}\right)$.

Household enters period with prior belief, $c_i^b(\mathbf{z})$, about $c_i^*(\mathbf{z})$,

$$c_i^b(\mathbf{z}) \sim \mathcal{GP}\left(\mu_i(\mathbf{z}), \gamma_i(\mathbf{z}, \tilde{\mathbf{z}})\right),$$

where $c_i^b(\mathbf{z})$ and $c_j^b(\mathbf{z})$ are orthogonal and

$$\mu_i(\mathbf{z}) = \mathbb{E}\left[c_i^b(\mathbf{z})\right], \quad \gamma_i(\mathbf{z}, \tilde{\mathbf{z}}) \equiv \mathrm{Cov}\left[c_i^b(\mathbf{z}), c_i^b(\tilde{\mathbf{z}})\right].$$

Household can obtain a noisy signal about the optimal consumption of variety i,

$$s_i(\mathbf{z}) = c_i^*(\mathbf{z}) + \gamma_\epsilon(\mathbf{z})\epsilon_i,$$

where $\epsilon_i \sim \mathcal{N}(0,1)$, and ϵ_i and ϵ_j are orthogonal for $i \neq j$.

Household problem under bounded rationality

The signal induces a posterior distribution for the optimal consumption of variety i,

$$c_i^b(\mathbf{z}) \mid s_i \sim \mathcal{GP}\left(\mu_{i|s}(\mathbf{z}), \gamma_{i|s}(\mathbf{z}, \tilde{\mathbf{z}})\right).$$

To generate a signal, the household incurs a cognitive cost that increases with the precision of the signal.

We assume that cognitive costs are proportional to the decrease in entropy (Shannon mutual information),

$$\mathcal{I} = \frac{\kappa}{2}\int_0^1 \left[\ln \gamma_i^2(\mathbf{z}) - \ln \gamma_{i|s}^2(\mathbf{z})\right] di,$$

where

$$\gamma_i^2(\mathbf{z}) \equiv \mathrm{Var}\left[c_i^b(\mathbf{z})\right], \quad \gamma_{i|s}^2 \equiv \mathrm{Var}\left[c_i^b(\mathbf{z}) \mid s_i\right].$$

Household problem under bounded rationality

Let $\hat{\mathcal{L}}_e^*$ denote the optimized Lagrangian, and define $\Delta\hat{\mathcal{L}}_e \equiv \hat{\mathcal{L}}_e - \hat{\mathcal{L}}_e^*$ as the percentage deviation of the Lagrangian evaluated at arbitrary values c_i from its optimized value. Then

$$\Delta\hat{\mathcal{L}}_e = -\frac{1}{2\theta}\left[\int_0^1 \left[c_i - c_i^*\left(\mathbf{z}\right)\right]^2 di + \left(\theta\sigma - 1\right)\left(\int_0^1 \left[c_i - c_i^*\left(\mathbf{z}\right)\right] di\right)^2\right] + \mu_e\left(c - \int_0^1 c_i di\right).$$

Under full rationality, the household chooses $\{c_i\}_{i\in[0,1]}$ and μ_e to maximize $\Delta\hat{\mathcal{L}}_e$, which yields $c_i = c_i^*\left(\mathbf{z}\right)$, $i \in [0,1]$.

Household problem under bounded rationality

$$\Delta\hat{\mathcal{L}}_e^b = -\frac{1}{2\theta}\left[\int_0^1 \left[c_i - c_i^b(\mathbf{z})\right]^2 di + (\theta\sigma - 1)\left(\int_0^1 \left[c_i - c_i^b(\mathbf{z})\right] di\right)^2\right] + \mu_e\left(c - \int_0^1 c_i di\right).$$

The problem of allocating spending across differentiated goods to maximize utility for a given total consumption expenditure can be written as

$$\max_{\left(c_i, \gamma_{i|s}^2(\mathbf{z}), \mu_E\right)} \mathbb{E}\left[\Delta\hat{\mathcal{L}}_e^b\right] - \mathcal{I} \text{ s.t. } \gamma_{i|s}^2(\mathbf{z}) \leq \gamma_i^2(\mathbf{z}) \quad i \in [0,1],$$

where the constraint guarantees that cognitive costs are weakly positive.

Optimal actions

Solving for c_i:

$$c_i = \mu_{i|s}(\mathbf{z}) + c - \int_0^1 \mu_{i|s}(\mathbf{z})\, di.$$

Demand for each good equals posterior mean, adjusted by constant term $(c - \int_0^1 \mu_{i|s}(\mathbf{z})\, di)$ to ensure that the aggregate constraint, $c = \int_0^1 c_i\, di$, is satisfied.

Optimal signals

Lemma

Let $\gamma^2_{i|s}(\mathbf{z})$ be the posterior variance of demand for good i at $\mathbf{z}$, and $\gamma^2_i(\mathbf{z})$ the prior variance.

Under independence assumption, the problem of choosing the signal variance is

$$\max_{\gamma^2_{i|s}(\mathbf{z})} -\frac{1}{2\theta}\int_0^1 \gamma^2_{i|s}(\mathbf{z})\, di - \frac{\kappa}{2}\int_0^1 \left[\ln \gamma^2_i(\mathbf{z}) - \ln \gamma^2_{i|s}(\mathbf{z})\right] di \ \ s.t.\ \ \gamma^2_{i|s}(\mathbf{z}) \leq \gamma^2_i(\mathbf{z}).$$

Optimal posterior variance is

$$\gamma^2_{i|s}(\mathbf{z}) = \min\left\{\gamma^2_i(\mathbf{z})\,;\theta\kappa\right\}.$$

- Dual thinking: System 2 activated if prior uncertainty at $\mathbf{z}$ is high.
- When θ is high, lower incentive to learn: any good matters less because of greater substitutability.

Priors

Pre-period in which the household has prior mean

$$\mu_{i,0}(\mathbf{z}) = c_i^*(\mathbf{z})$$

and diagonal prior covariance $\gamma_{i,0}^2(p_i) = \gamma_c^2 > \theta\kappa$.

Assumption on prior mean from Ilut and Valchev (2023) to ensure no ex-ante biases.

Assumptions on prior covariance:

- Dependence on p_i only: household knows what to do to basket composition if aggregates change;
- Zero covariance across prices
  - Knowing demand at one price conveys no information about optimal demand for different price.
  - This independence assumption preserves simplicity that is the hallmark of System 1 reasoning.

Demands: pre-period

Since $\gamma_{i,0}^2 = \gamma_c^2 > \theta\kappa$, learning occurs in pre-period at observed price.

Using formula for normal,

$$\mu_i\left(p_{i,0}\right) = c_i^*\left(p_{i,0}\right) + \alpha\gamma_\epsilon\epsilon_{i,0}$$

$$\gamma_i^2\left(p_{i,0}\right) = \theta\kappa$$

where

$$\alpha = 1 - \left(\theta\kappa/\gamma_c^2\right) \text{ and } \gamma_\epsilon = \sqrt{\theta\kappa/\alpha}.$$

At $p_i \neq p_{i,0}$, no extrapolation due to zero covariance:

$$\mu_i\left(p_i\right) = c_i^*\left(p_i\right);\ \ \gamma_i^2\left(p_i\right) = \gamma_c^2 > \theta\kappa.$$

Demands: period 1

Signal redrawn if situation is unfamiliar ($p_i \neq p_{i,0}$):

$$c_i = \text{constant} + c - \theta\left(p_i - p\right) + \alpha\gamma_\epsilon \begin{cases} \epsilon_{i,0}, & \text{if } p_i = p_{i,0} \\ \epsilon_{i,1} \sim \mathcal{N}\left(0,1\right), & \text{if } p_i \neq p_{i,0} \end{cases}.$$

The constant ensures that the constraint $c = \int_0^1 c_i \, di$ is satisfied.

Firms' problem

Firms are fully rational: $\epsilon_{i,0}$ is known.

Price change triggers System 2: $\epsilon_{i,1}$ is unknown.

The firm has two decisions to make:

1. Whether to change its price;
2. Conditional on changing its price, by how much.

Solution to firm's problem

- Optimal reset price p^* sets markup over marginal costs.
  - Optimal price depends only on the demand elasticity not on the level of demand.
- Firm weighs benefit of setting $MR = MC$ with cost of forsaking $\epsilon_{i,0}$.
- There is a threshold $\overline{\epsilon}$ such that if $\epsilon_{i,0} \geq \overline{\epsilon}$, the firm does not change the price.
- The firm only triggers System 2 if demand is too low.
- Sticky prices arise endogenously for goods with high demand.

Key asymmetry: high inflation

Profits at system 1 demand:

$$e^{\alpha \gamma_\epsilon \epsilon_{i,0}} \left[\left(\frac{P_0}{P} \right) - MC\left(\pi, ...\right) \right] \left(\frac{P_0}{P} \right)^{-\theta}$$

For **high inflation** levels, **all firms reset** their price.

- As π increases, profit margin becomes small, eventually negative;
- Regardless of how high past demand was, prices optimally change.

Key asymmetry: low inflation

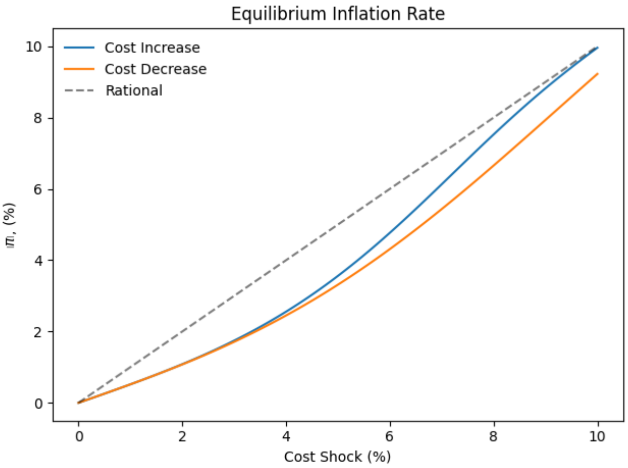
Profits at system 1 demand:

$$e^{\alpha\gamma_\epsilon\epsilon_{i,0}}\left[\left(\frac{P_0}{P}\right)-MC\left(\pi,...\right)\right]\left(\frac{P_0}{P}\right)^{-\theta}$$

For **low inflation** levels, **not all firms reset** their price.

- As π decreases, profit margins become unprofitably high.
- There is a sufficiently high past demand such that the firm does not want to reset prices.

Rockets and feathers



Price stability is not optimal

- Price stability minimizes cognitive costs.
- But there is consumption dispersion at zero inflation.
- Dispersion is mitigated with deflation.
    - Deflation raises the relative price of (high-demand) sticky firms.

Dynamic model: setup

- Partial equilibrium problem, a single firm.
- Incomplete memory: households only recalls one System 2 price.
- The logarithm of marginal cost, ξ, follows jump-diffusion process.

$$\xi' = \xi + \upsilon'$$

$$\upsilon' = \begin{cases} 0, & \text{with probability } 1-\rho \\ \sim \mathcal{N}\left(0, \gamma_\upsilon^2\right), & \text{with probability. } \rho \end{cases}.$$

- We use second-order approximation to firm problem (p is the log of price.)

$$-\frac{\theta\left(\theta-1\right)}{2}\left(p-\xi\right)^2 + \begin{cases} \alpha\gamma_\epsilon\epsilon_{t-1}, & \text{if } p_t = p_{t-1} \\ \frac{1}{2}\left(\alpha\gamma_\epsilon\right)^2, & \text{if } p_t \neq p_{t-1} \end{cases}.$$

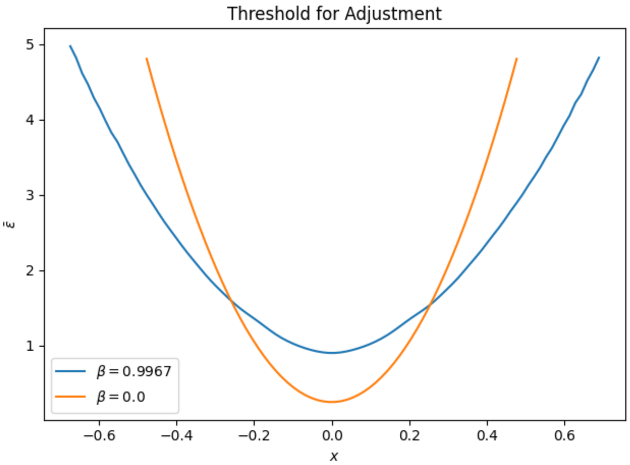
- ρ and γ_υ^2 are calibrated to match moments of cost shocks estimated in Eichenbaum, Jaimovich, and Rebelo (2011).

Dynamic vs static

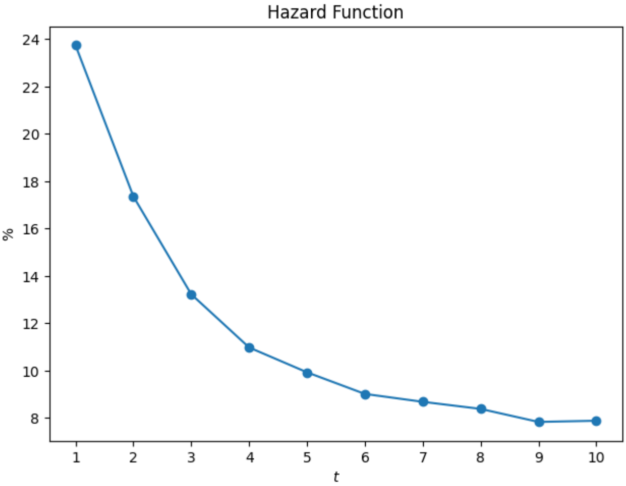
In dynamic model, there is an option value.

- Even if ϵ is positve, it might be worthwhile to change price to try to obtain a better demand shock.
- If ϵ is very high, it might be worthwhile to endure a large price gap (x) relative to marginal cost, to preserve the high demand shock for the future.

Option value



Hazard function



$\alpha\gamma_\epsilon$ calibrated to match average price spell duration in weeks.

Firms with favorable demand shocks tend to keep their prices constant for longer periods.

Decreasing hazard

With a standard menu cost model, hazard is increasing.

- The longer the price spell, the more likely the price gap is to leave (S, s) bands.

In this model, not the case because (S, s) bands are ϵ-dependent.

Consistent with Ilut et al. (2020): “sticky winners”.

- Firms with high demand realization are less likely to change prices.

Decreasing hazard driven by demand heterogeneity, not by permanent differences in hazards.

Conclusion

- We explore a framework where a dual process mechanism drives household choices.
- Framework gives rise to new kind of price rigidity due to strategic behavior by firms.
- Firms with high demands select into rigid prices ("sticky winners").
- Model generates "rockets and feathers" and decreasing hazard function.