Behavioral Sticky Prices

Sergio Rebelo, Miguel Santana, and Pedro Teles

September 2024

Introduction

- Consider framework widely used in cognitive psychology literature to describe decision making.
- According to this framework, people use two systems to make decisions:
  - Familiar situations - System 1: effortless decisions, but prone to systematic errors.
  - Unfamiliar situations - System 2: cognitively costly decisions but more accurate.
- In our model:
  - Households use this framework in purchasing consumption goods.
  - System 2 is triggered by changes in nominal prices of these goods.

Introduction

- Firms exploit this behavior to their advantage.
- Producers of goods with high demand relative to rational optimum want to keep their prices.
- This strategic behavior generates a new form of nominal price rigidity.

Introduction

Phenomena that are consistent with our framework:

- "Shrinkflation": Changing product size instead of prices.

  Biden discussed shrinkflation in a February 2024 Super Bowl video broadcast: '[...] Some companies are trying to pull a fast one by shrinking the products little by little and hoping you won't notice."

- Subscription services: Put consumer purchases on auto-pilot to avoid triggering System 2.

- "Convenient" prices: $9.99 creates perception that price is lower that what it is.

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 documented by Ilut, Valchev, Vincent (2020):
    - Firms that receive a high demand realization are less likely to change their prices.
3. Unlike in other cashless sticky price models, price stability is not optimal.

Literature

- System 1 vs. System 2:
  - Ilut and Valchev (2023), Stanovich and West (2000),...
- Price stickiness due to information frictions:
  - Ilut et al. (2020), Matejka (2015), Woodford (2009), Mackowiak and Wiederholt (2009), Mankiw and Reis (2002)...
- Rockets and feathers:
  - Peltzman (2000), Neumark and Sharpe (1992), Karrenbrock (1991)...
- Optimal monetary policy:
  - Woodford (2003)...

Preferences and Technology

Household Preferences:

$$U = \frac{C^{1-\sigma} - 1}{1-\sigma} - \frac{N^{1+\eta}}{1+\eta} - \int_0^1 \mathcal{I}_i di, \ \ \sigma, \eta > 0,$$

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.
$\mathcal{I}_i$ = cognitive cost of using System 2 to choose how much of good i to buy.

Production: $y_i = An_i$.

Market structure: monopolistic competition.

Household's Problem Under Full Rationality

$$\max_{c_i, N} \frac{C^{1-\sigma} - 1}{1-\sigma} - \frac{N^{1+\eta}}{1+\eta}$$

subject to

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

and

$$\int_0^1 P_i c_i di \leq WN + \int_0^1 \Pi_i di - \mathcal{T}.$$

P_i = Nominal price of good i.

W = Nominal wage.

Π_i = Nominal profits of firm i.

$\mathcal{T}$ = Nominal lump-sum taxes.

Solution to Utility Maximization Problem

The state variables of the household's problem are $\omega \equiv \left[W, \{P_i\}, \int_0^1 \Pi_i di - \mathcal{T}\right]$.

The solution to the utility maximization problem is fully characterized by

$$c_i^*(\omega) = \left(\frac{P_i}{P}\right)^{-\theta} C^*(\omega),$$

$$[C^*(\omega)]^{\sigma} [N^*(\omega)]^{\eta} = \frac{W}{P} \equiv w,$$

$$PC^*(\omega) = wN^*(\omega) + \left(\frac{\int_0^1 \Pi_i di - \mathcal{T}}{P}\right),$$

$$P \equiv \left(\int_0^1 P_i^{1-\theta} di\right)^{\frac{1}{1-\theta}}.$$

Household's Problem Under Bounded Rationality

- Bounded rationality as in Ilut and Valchev (2023).
  - Household knows ω.
  - Cannot solve for $c_i^* (\omega)$, $N^* (\omega)$ due to cognitive costs of solving optimization problems.
- Household forms beliefs about rational demand $x_i^* (\omega) \equiv \ln c_i^* (\omega)$.
- Household is only uncertain about optimal relation between c_i and P_i.
- Solution to bounded rationality problem:
  - Household choose c_i's based on costly signals about optimal demand.
  - Given c_i's, N satisfies budget constraint.

Bounded Rationality: Timing

- Two periods, $t = 0$ (pre-period), and $t = 1$. Pre-period so System 1 is well-defined at $t = 1$.
- At $t = 0, 1$:
  - Household starts with normal prior for log demand $\mathcal{N}\left(x_{i,t-1}\left(P_i\right), \sigma_{i,t-1}\left(P_i, P_i'\right)\right)$.
  - Observes $P_{i,t}$ and chooses variance $\sigma^2_{\epsilon,i,t}$ of conditionally normal signal $s_{i,t} = x^*\left(P_{i,t}\right) + \sigma_{\epsilon,i,t}\epsilon_{i,t}$.
  - Observes $s_{i,t}$ and sets log-demand to posterior mean $x_{i,t}\left(P_{i,t}\right)$.
- Choice of $\sigma^2_{\epsilon,i,t}$ entails cognitive cost $\mathcal{I}_{i,t}$, of the standard form

$$\mathcal{I}_{i,t} = \kappa \ln\left[\frac{\sigma^2_{i,t-1}\left(P_{i,t}\right)}{\sigma^2_{i,t}\left(P_{i,t}\right)}\right], \ \ \kappa > 0,$$

  $\mathcal{I}_{i,t}$ is proportional to average reduction in entropy due to signal.

- Optimal solution: if $\sigma^2_{i,t-1}\left(P_{i,t}\right) > \kappa$, then $\sigma^2_{i,t}\left(P_{i,t}\right) = \kappa$. Otherwise, $\sigma^2_{i,t}\left(P_{i,t}\right) = \sigma^2_{i,t-1}\left(P_{i,t}\right)$.

Pre-period: Prior Variance

- Assume
$$\sigma^2_{i,-1}(P_i) = \sigma^2_c, \;\; \sigma^2_c > \kappa,$$
 and
$$\sigma_{i,-1}\left(P_i, P_i'\right) = 0 \text{ for all } P_i \neq P_i'.$$

- Initial covariance function is such that:
  1. Updating in pre-period occurs for any observed initial $P_{i,0}$, since $\sigma^2_c > \kappa$.
  2. Household believes $x_i^*(P_i)$ is uninformative about $x_i^*\left(P_i'\right)$.

- We make the independence assumption to keep System 1 simple.

Pre-period: Posterior

- In pre-period, household learns about optimal demand at observed price $P_{i,0}$.

- Posterior mean at $P_{i,0}$ is

$$x_{i,0}\left(P_{i,0}\right) = x_{i,-1}\left(P_{i,0}\right) + \alpha\left[x^{*}\left(P_{i,0}\right) + \sigma_{\epsilon}\epsilon_{i,0} - x_{i,-1}\left(P_{i,0}\right)\right],$$

where

$$\alpha \equiv 1 - \frac{\kappa}{\sigma_c^2}; \;\; \sigma_{\epsilon} \equiv \sqrt{\frac{\kappa}{\alpha}}.$$

- For other unobserved prices, $P_i \neq P_{i,0}$, the household does not learn:

$$x_{i,0}\left(P_i\right) = x_{i,-1}\left(P_i\right), \;\; P_i \neq P_{i,0}.$$

$t = 1$

- Given learning occurred in pre-period for $P_i = P_{i,0}$, prior variance function at $t = 1$ is

$$\sigma^2_{i,0}(P_i) = \begin{cases} \sigma^2_c, & \text{if } P_i \neq P_{i,0} \\ \kappa, & \text{if } P_i = P_{i,0} \end{cases}.$$

- Implies that

$$x_{i,1}(P_{i,1}) = \begin{cases} x_{i,0}(P_{i,0}), & \text{if } P_{i,1} = P_{i,0} \\ x_{i,0}(P_{i,1}) + \alpha\left[x^*(P_{i,1}) + \sigma_\epsilon \epsilon_{i,1} - x_{i,0}(P_{i,1})\right], & \text{if } P_{i,1} \neq P_{i,0} \end{cases}.$$

- If $P_{i,1} = P_{i,0}$, familiar situation. Household relies on System 1.

- If $P_{i,1} \neq P_{i,0}$, unfamiliar situation. Household activates System 2.

Demands

- As in Ilut and Valchev (2023), assume $x_{i,-1}(P_i) = x^*(P_i)$.
- This assumption ensures results are not driven by *ex-ante* biases.
- Substituting period 1's prior mean, $x_{i,0}$, in period 1's posterior mean, $x_{i,1}$, we get

$$x_{i,1}(P_{i,1}) = \begin{cases} x^*(P_{i,0}) + \alpha\sigma_\epsilon\epsilon_{i,0}, & \text{if } P_{i,1} = P_{i,0} \\ x^*(P_{i,1}) + \alpha\sigma_\epsilon\epsilon_{i,1}, & \text{if } P_{i,1} \neq P_{i,0} \end{cases}.$$

- Letting $\gamma \equiv \alpha\sigma_\epsilon$ and $p_i \equiv \frac{P_i}{P}$, demand for good i is

$$c_i = e^{\gamma\epsilon_i} c_i^*(\omega) = e^{\gamma\epsilon_i} p_i^{-\theta} C^*(\omega),$$

so

$$c_i \equiv \begin{cases} e^{\gamma\epsilon_{i,0}} p_{i,0}^{-\theta} C^*(\omega), & \text{if } P_{i,1} = P_{i,0} \\ e^{\gamma\epsilon_{i,1}} p_{i,1}^{-\theta} C^*(\omega), & \text{if } P_{i,1} \neq P_{i,0} \end{cases}.$$

Firms' Problem

Firms are fully rational and observe past demand shock $\epsilon_{i,0}$.

A new demand shock $\epsilon_{i,1}$ is only generated if the firm changes its price.

If a firm changes its price, expected profit is

$$\mathbb{E}\left[e^{\gamma\epsilon_{i,1}}\right]\left[p_{i,1} - (1-\tau_n)\frac{w}{A}\right] p_{i,1}^{-\theta} C^*(\omega),$$

where τ_n is labor subsidy.

Assume $P_{i,0} = P_0$ for all i. If a firm does not change its price, profit is

$$e^{\gamma\epsilon_{i,0}}\left[\left(\frac{P_0}{P}\right) - (1-\tau_n)\frac{w}{A}\right]\left(\frac{P_0}{P}\right)^{-\theta} C^*(\omega).$$

Firms' Pricing Policy

Optimal relative reset price is

$$p^* = \left(\frac{\theta}{\theta - 1}\right)(1 - \tau_n)\frac{w}{A}$$

There is a demand shock, ℓ, such that whenever $\epsilon_{i,0} \geq \ell$ the firm chooses to keep its price constant.

Pricing policy is

$$p_{i,1} = \begin{cases} p^*, & \text{if } \epsilon_{i,0} < \ell \\ \frac{P_0}{P} \equiv \frac{1}{\pi}, & \text{if } \epsilon_{i,0} \geq \ell \end{cases}.$$

If System 1 demand is high, firm prefers relative price $\frac{1}{\pi}$ to p^* to avoid triggering System 2.

Equilibrium Reset Price

Fraction χ sets real price $\frac{1}{\pi}$, fraction $1-\chi$ sets real price p^*. Can define $p^*(\pi)$ from

$$1 = \chi(\pi)\left(\frac{1}{\pi}\right)^{1-\theta} + [1-\chi(\pi)]\,[p^*(\pi)]^{1-\theta}.$$

Different from Calvo pricing because probability of price change $\chi(\pi)$ is endogenous.

Key asymmetry:

- For high inflation levels, all firms reset their price.
  - If π is high, nominal marginal costs are high.
  - By keeping old price, firms get negative profit margin.
  - No $\epsilon_{i,0}$ makes them want to keep price.
- For deflation, a share of firms with high demands want to keep their prices.

Labor Market Clearing, Government

Market clearing conditions for labor and for good i imply

$$\Delta_n(\pi)\, C^*(\omega) = AN.$$

$\Delta_n(\pi) = \int_0^1 e^{\gamma \tilde{\epsilon}_i} p_i^{-\theta} di$ is a production distortion caused by deviations from rationality.

Government:

- Finances τ_n with lump-sum taxes.
- Controls growth of $P \times C^*(\omega)$:

$$\mu = \pi \frac{C^*(\omega)}{C_0},$$

where C_0 is normalized to 1. Target is not $\int_0^1 P_i c_i di$ for technical reasons. Details

Equilibrium Conditions

Demands can be written as $c_i = e^{\gamma \tilde{\epsilon}_i} p_i^{-\theta} C^* \left(\omega\right)$.

$C^* \left(\omega\right)$ is aggregate consumption that a rational household would choose in this economy.

Using

- conditions of utility-maximization problem,
- equilibrium value of profits and taxes,

we obtain

$$C^* \left(\omega\right) = C^* \left(\pi\right) = \left\{ \frac{\left[\left(\frac{\theta - 1}{\theta} \right) \frac{1}{1 - \tau_n} p^* \left(\pi\right) A \right]^{1+\eta}}{\left[\vartheta \left(\pi\right) \right]^{\eta}} \right\}^{\frac{1}{\sigma + \eta}},$$

where $\vartheta \left(\pi\right)$ is a function that summarizes the effect of profits and taxes.

Equilibrium Conditions

C determined by aggregator

$$C = \left(\int_0^1 c_i^{\frac{\theta-1}{\theta}} di \right)^{\frac{\theta}{\theta-1}} = \Delta_u (\pi) \, C^* (\omega) \, ,$$

where

$$\Delta_u (\pi) \equiv \left(\int_0^1 e^{\left(\frac{\theta-1}{\theta} \right) \gamma \tilde{\epsilon}_i} p_i^{1-\theta} di \right)^{\frac{\theta}{\theta-1}}$$

is a utility distortion due to deviations from rationality.

N determined by labor market clearing,

$$\frac{\Delta_n (\pi)}{\Delta_u (\pi)} C = AN,$$

Equilibrium Conditions Summarized

Can combine above equations and policy rule, $\pi C^*(\omega) = \mu$, to obtain two equations in C and π:

$$C(\pi) = \Delta_u(\pi) \left\{ \frac{\left[\left(\frac{\theta-1}{\theta}\right) \frac{1}{1-\tau_n} p^*(\pi) A\right]^{1+\eta}}{\left[\vartheta(\pi)\right]^{\eta}} \right\}^{\frac{1}{\sigma+\eta}}$$

$$\pi C(\pi) = \Delta_u(\pi) \mu$$

For now, set $1 - \tau_n = \frac{\theta-1}{\theta}$ and $\mu = 1$.

Rockets and Feathers

We study the equilibria associated with productivity levels $A_L = \frac{1}{1+\upsilon}$ and $A_H = (1+\upsilon)$, $\upsilon > 0$.

In the frictionless version of our model, inflation π^f satisfies $\left|\ln \pi_H^f\right| = \left|\ln \pi_L^f\right|$.

In our model, we have $|\ln \pi_L| > |\ln \pi_H|$ for large shocks.

Prices rise more than they decline in response to a shock of the same amount.

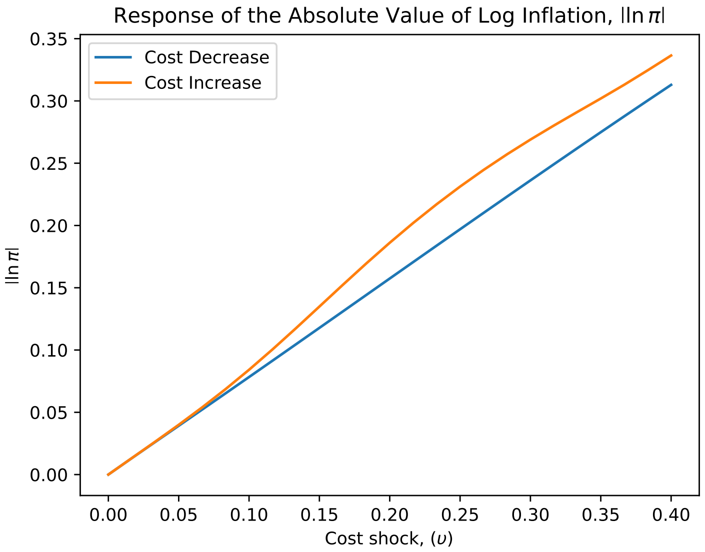
For now, able to show for particular parameters. But numerically seems always true.

Proposition (Rockets and Feathers)

Suppose $\sigma = 1$ and $\eta = 0$. There is $\overline{\upsilon}$ such that if $\upsilon > \overline{\upsilon}$,

$$|\ln \pi_L| > |\ln \pi_H|.$$

Rockets and Feathers



Rockets and Feathers

- For infinitesimal shocks, response of inflation is symmetric.
- For large shocks, inflation responds more to cost increases than declines.
- If costs rise significantly, all firms increase prices to avoid losses.
  - Prices and costs eventually rise one-to-one.
- If costs decline, there are always firms willing to keep their price to benefit from favorable demand.
  - Prices decline by less than costs.
- Proposition holds for Taylor rule in dynamic version of the model. Details

Optimal Policy

Planner has two instruments: τ_n and π. Welfare function is

$$\mathcal{W}\left(\tau_n, \pi\right) = \frac{\left[C\left(\tau_n, \pi\right)\right]^{1-\sigma} - 1}{1-\sigma} - \frac{\left[N\left(\tau_n, \pi\right)\right]^{1+\eta}}{1+\eta} - \kappa\left[1-\chi\left(\pi\right)\right]\ln\left(\frac{\sigma_c^2}{\kappa}\right).$$

Welfare depends negatively on fraction of flexible firms $1-\chi\left(\pi\right)$.

The higher σ_c^2, the more effort the household needs to put into thinking about good i.

Optimal Policy

Solve problem in two steps:

1. Choose τ_n optimally given π.
2. Choose π.

Moreover, recast choice of τ_n as choice of C and N subject to equilibrium conditions.

The condition

$$C(\tau_n, \pi) = \Delta_u(\pi) \left\{ \frac{\left[\left(\frac{\theta - 1}{\theta} \right) \frac{1}{1 - \tau_n} p^*(\pi) A \right]^{1+\eta}}{\left[\vartheta(\pi) \right]^{\eta}} \right\}^{\frac{1}{\sigma + \eta}}$$

does not constrain the problem because τ_n can be chosen to set any C.

Optimal Policy

The condition

$$C = \frac{\Delta_u(\pi)}{\Delta_n(\pi)} AN$$

is needed because τ_n cannot affect $\Delta_u(\pi)$ or $\Delta_n(\pi)$.

Lemma: $\Delta_u(\pi) < \Delta_n(\pi)$ by concavity.

Due to distortions in c_i's, can never implement first-best, since it involves $C = AN$.

Given π, problem of choosing C and N is

$$\max \frac{C^{1-\sigma} - 1}{1-\sigma} - \frac{N^{1+\eta}}{1+\eta} \text{ s.t. } C = \frac{\Delta_u(\pi)}{\Delta_n(\pi)} AN.$$

Optimal Fiscal Policy

Solution is similar to first-best, but with modified productivity:

$$C_{\text{opt}}(\pi) = \left[\frac{\Delta_u(\pi)}{\Delta_n(\pi)} A\right]^{\frac{1+\eta}{\sigma+\eta}} ; \quad N_{\text{opt}}(\pi) = \left[\frac{\Delta_u(\pi)}{\Delta_n(\pi)} A\right]^{\frac{1-\sigma}{\sigma+\eta}}$$

τ_n is then set to satisfy

$$\underbrace{\Delta_u(\pi) \left\{ \frac{\left[\left(\frac{\theta-1}{\theta}\right) \frac{1}{1-\tau_n} p^*(\pi) A\right]^{1+\eta}}{[\vartheta(\pi)]^{\eta}} \right\}^{\frac{1}{\sigma+\eta}}}_{C(\pi)} = \underbrace{\left[\frac{\Delta_u(\pi)}{\Delta_n(\pi)} A\right]^{\frac{1+\eta}{\sigma+\eta}}}_{C_{\text{opt}}(\pi)}.$$

Fiscal policy cannot undo distortions in aggregate production, but can set $MRS_{C,N} = MRT_{C,N}$.

Optimal Monetary Policy

There is threshold $\overline{\pi}$ such that if $\pi \geq \overline{\pi}$, all firms change price.

Prices are flexible in equilibrium, so allocations do not depend on inflation.

So $\mathcal{W}(\pi) = \mathcal{W}_s$ for all $\pi \geq \overline{\pi}$.

Proposition (If cognitive costs are high, price stability is better than inflation)

There is $\overline{\sigma}_c^2$ such that $\sigma_c^2 \geq \overline{\sigma}_c^2$ implies $\mathcal{W}(1) \geq \mathcal{W}_s$.

When $\pi = 1$, the pre-period's price is already at optimal reset price.

The fraction of firms with sticky prices is maximized. Cognitive costs are minimized.

Price stability is better than high inflation if cognitive costs are high enough.

Optimal Monetary Policy

Proposition (Some deflation is always better than price stability)

There is $\pi < 1$ *such that* $\mathcal{W}(\pi) > \mathcal{W}(1)$.

If the probability of keeping the price were the same for all firms, price stability would be optimal.

That is the case with Calvo pricing.

Here there is selection: firms with sticky prices are the ones with relatively high demands.

Present even at $\pi = 1$, since at $\pi = 1$ firms with low $\epsilon_{i,0}$ still change price infinitesimally.

Mitigating Selection Distortion

At π, average demand for firms that do not change their price is

$$\mathbb{E}_I\left[e^{\gamma\epsilon_{i,0}} \mid \epsilon_{i,0} \geq \ell(\pi)\right] c^*\left(\frac{1}{\pi}\right)$$

and average demand for firms that change their price is

$$\mathbb{E}_I\left[e^{\gamma\epsilon_{i,1}}\right] c^*\left[p^*(\pi)\right].$$

At $\pi = 1$:

1. $p^*(1) = 1$, so no price dispersion.
2. But $\mathbb{E}_I\left[e^{\gamma\epsilon_{i,0}} \mid \epsilon_{i,0} \geq \ell(\pi)\right] > \mathbb{E}_I\left[e^{\gamma\epsilon_{i,1}}\right]$, so there is selection.

By deflating, planner reduces consumption of sticky firms goods through $c^*\left(\frac{1}{\pi}\right)$.

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.
- There is range of cost shocks for which some producers do not change prices.
- Model is consistent with "rockets and feathers" phenomenon.
- Unlike in other cashless economies with sticky prices, price stability is not optimal.

Policy Rule

In principle, could set

$$\mu = \int_0^1 P_i c_i di.$$

But

$$\int_0^1 P_i c_i di = \Delta_p(\pi) PC^*(\pi),$$

where $\Delta_p(\pi) \equiv \int_0^1 e^{\gamma\tilde{\varepsilon}_i} p_i^{1-\theta} di$ is an expenditure distortion arising from bounded rationality.

$\Delta_p(\pi)$ is non-monotonic, so economy becomes vulnerable to multiplicity of equilibria. Back

Taylor Rule

Suppose the household is infinitely-lived, and time is indexed by $t = 1, 2, \dots$.

Production structure is the same in each period.

Aggregate productivity is $A_t = 1$, for $t \geq 2$.

The household is fully rational from $t \geq 2$ onwards.

The central bank sets the gross nominal interest rate, R_t, to

$$R_t = \frac{1}{\beta} \pi_t^{\phi}, \;\; \phi > 1.$$

From period 2 onwards, $C_t = \pi_t = 1$ is the (locally) unique equilibrium.

Taylor Rule

In period 1, solution to utility maximization problem implies

$$\frac{1}{\beta}\left[\frac{1}{C^*(\omega)}\right]^{\sigma} = R_1.$$

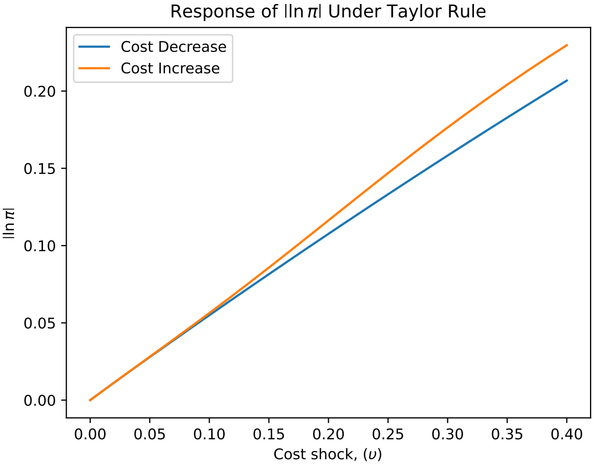
Combining with the Taylor rule,

$$C^*(\omega) = \pi_1^{-\frac{\phi}{\sigma}}.$$

Negative relation between output and inflation like with $\mu = \pi C^*(\omega)$.

When $\sigma = 1$, $\eta = 0$, our main proposition holds as long as $\phi > 1$.

Rockets and Feathers With a Taylor Rule



Back