Applied Macroeconomics

New Keynesian Economics: Price Adjustment

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References

- These notes are based on:
  - L. Ball, N.G. Mankiw, D. Romer (1988): "The New Keynesian Economics and the Output-Inflation Tradeoff," *Brookings Papers on Economic Activity*, 1, pp. 1-65
  - J. Galí (2008): *Monetary Policy, Inflation, and the Business Cycle. An Introduction to the New Keynesian Framework*, Princeton University Press
  - D. Romer (2018): *Advanced Macroeconomics*, 5th edition, McGraw Hill

Outline of lecture

- Introduction
- Time-dependent price adjustment
- State-dependent price adjustment: Caplin & Spulber
- State-dependent *vs*. time-dependent adjustment models
- Empirical evidence
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Introduction

- Two main ways of modelling price adjustment in a dynamic setting:

1. Time-dependent adjustment: prices are reviewed on a predetermined schedule. Examples:

   – Wages are reviewed annually.

   – Union contracts specify wages over a many-year period.

   – Companies issue catalogues with prices in effect for 6 months or a year.

2. State-dependent adjustment (prompted by developments in the economy): firms must pay a fixed (menu) cost each time they choose to change their prices.

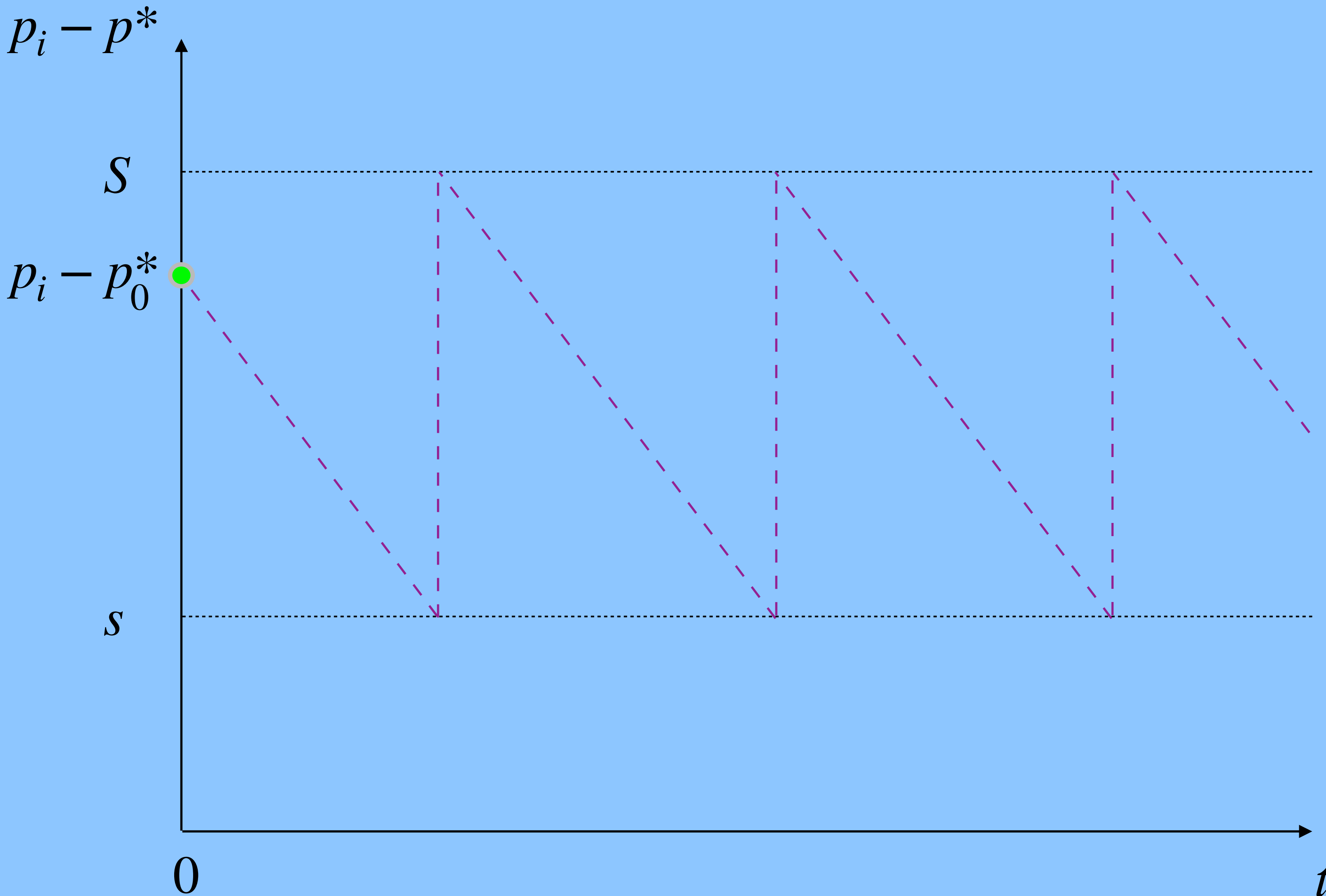
Time-dependent price adjustment

- Prices are set by multi-period contracts or commitments.
- In each period, the contracts governing some fraction of prices expire and must be renewed.
- Expiration determined by the passage of time, not economic developments.
- Central result: multi-period contracts lead to gradual adjustment of the price level to nominal disturbances. $\Rightarrow$ Persistent real effects of AD disturbances.
- Two types of time-dependent price adjustment models:
  - Predetermined (but not fixed) prices: prices are set for several periods, but can be different for each period. Example: Fischer model
  - Predetermined and fixed prices: prices are constant for several periods. Example: Calvo model (key piece of the NK DSGE model)

State-dependent price adjustment: Caplin-Spulber model

- Many similar firms, with identical optimal price $p^* = p + \phi y$. [$x \equiv \ln X$]
- Firms may have different actual prices p_i; $p = \bar{p}_i$.
- $p + y = m \;\Rightarrow p^* = (1 - \phi)p + \phi m$; assuming $\phi = 1$, $p^* = m$.
- m increases continuously; no firm-specific shocks $\Rightarrow$ p^* always increasing.
- Specific state-dependent pricing rule: "*Ss* policy" (*S*: "target"; *s*: "trigger")
  - Whenever a firm adjusts its price p_i, it sets the price so that $p_i - p^* = S$.
  - The firm then keeps its nominal price p_i fixed until money growth has raised p^* sufficiently that $p_i - p^*$ has fallen to s.
  - When $p_i - p^* = s$, regardless of how much time has passed since its last price change, the firm resets $p_i - p^* = S$, and the process begins anew.
- Such an *Ss* policy is optimal when π is steady, aggregate (real) output y is constant, and there is a fixed (menu) cost of each nominal price change.

Caplin-Spulber model: *Ss* policy for a price-setter



Caplin-Spulber model: effects of Δm

- Assume an initial uniform distribution of $p_i - p_0^*$ across firms, with density $f(p_i - p_0^*) = 1/(S - s)$ if $p_i - p_0^* \in (s, S]$, and $f(p_i - p_0^*) = 0$ otherwise.

- Consider $\Delta m < S - s$ over some time interval Δt. $\Rightarrow$ Change in each firm's p^* by the end of the time interval: $\Delta p^* = \Delta m$

- Firms change p_i if $p_i - p^* \leq s$. $\Rightarrow$ Firms change p_i over the time interval Δt we are considering if $p_i - (p_0^* + \Delta m) \leq s \Leftrightarrow p_i - p_0^* \leq s + \Delta m$.

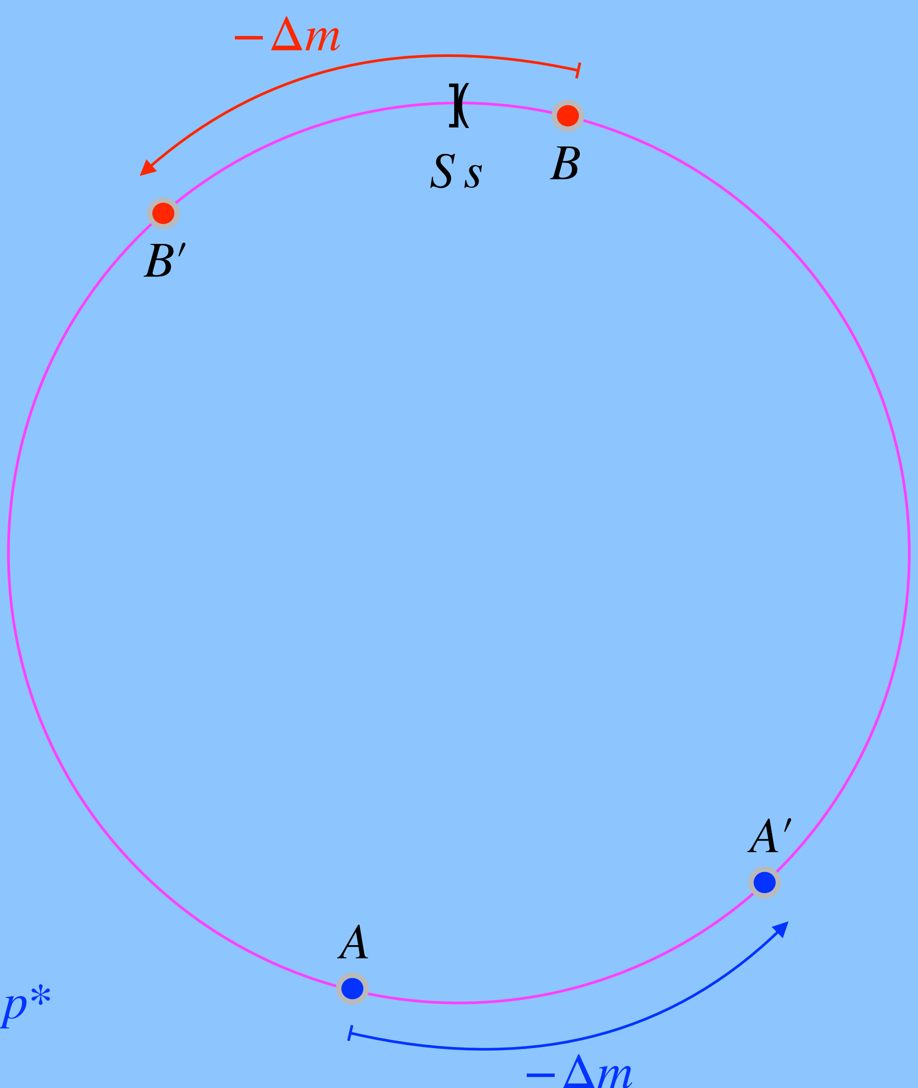
- Fraction of firms that change p_i over the time interval: $\Delta m/(S - s)$.

- Each firm that changes p_i does so at the moment when $p_i - p^* = s$. Each price increase is of amount $S - s$.

- Over Δt, $\Delta p = (S - s)\Delta m/(S - s) = \Delta m \;\Rightarrow \Delta y = 0$: money is neutral in spite of the price stickiness at the level of the individual price-setters.

Caplin-Spulber model: distribution dynamics

$p_i - p_0^* = s + k$, $k < \Delta m = k + (\Delta m - k)$ $\Rightarrow p_i - p^*$ shifts by $-k$ to s; by the time $p_i - p^* = s$, it "jumps" from s to S. $p_i - p^*$ still shifts (now from S) by $-(\Delta m - k) \Rightarrow$ Altogether, $p_i - p^*$ shifts by $-\Delta m$ in the circle.



All $p_i - p_0^*$, distributed uniformly, move by $-\Delta m$, and thus end up uniformly distributed. $\Rightarrow$ The distribution of $p_i - m$ is unchanged. Since $p = \bar{p}_i$, $p - m$ is also unchanged.

$p_i - p_0^* > s + \Delta m \Rightarrow$ No p_i change $\Rightarrow p_i - p^*$ shifts by $-\Delta m$ in the circle.

Caplin-Spulber model: distribution dynamics

- Arrange the points on segment $(s, S]$ around the circumference of a circle.
- For the firm initially at point A, $p_i - p_0^* > s + \Delta m$.
  - This firm does not raise its price p_i in response to Δm.
  - $p_i - p^*$ falls by Δm: it moves (counterclockwise) by $-\Delta m$ to A'.
- For the firm initially at point B, $p_i - p_0^* = s + k$, $k < \Delta m = k + (\Delta m - k)$.
  - By the time the increase in m reaches k, $p_i - p^*$ jumps from s to S.
  - This is an infinitesimal move around the circle (s and S are contiguous).
  - As m continues to rise, the firm does not change p_i further; $p_i - p^*$ falls by $\Delta m - k$; the total distance (from B to B') $p_i - p^*$ travels is $-\Delta m$.
- All $p_i - p^*$, initially distributed uniformly, move by $-\Delta m$. $\Rightarrow$ $p_i - m$ remains uniformly distributed. Since $p = \bar{p}_i$, $p - m$ remains unchanged.

State-dependent *vs.* time-dependent adjustment models

- Caplin-Spulber model's "frequency effect": the number of price-setters changing prices at any t is endogenous, and larger when AD increases more rapidly. ⇒ p responds fully to changes in m.

- Time-dependent adjustment models: the number of price-setters changing prices at any time is fixed. ⇒ p does not respond fully to changes in m.

- The Caplin-Spulber model's results are not robust:

  – They are based on very particular assumptions in order to illustrate the frequency effect as starkly as possible.

  – *E.g.*, non-uniform distributions of $p_i - p^*$ weaken the frequency effect.

- In any case, the effects of monetary shocks can be much smaller with state-dependent pricing than with time-dependent pricing.

- Dynamic models with fixed adjustment costs are technically challenging and difficult to integrate into DSGE models.

Empirical evidence on the output-inflation tradeoff

- Ball *et al.* (1988) estimate the effects of AD shocks on real GDP by country i: $y_t = c + \gamma t + \tau \Delta x_t + \lambda y_{t-1}$. $\Rightarrow$ Obtain "trade-off parameter" τ_i for each i.

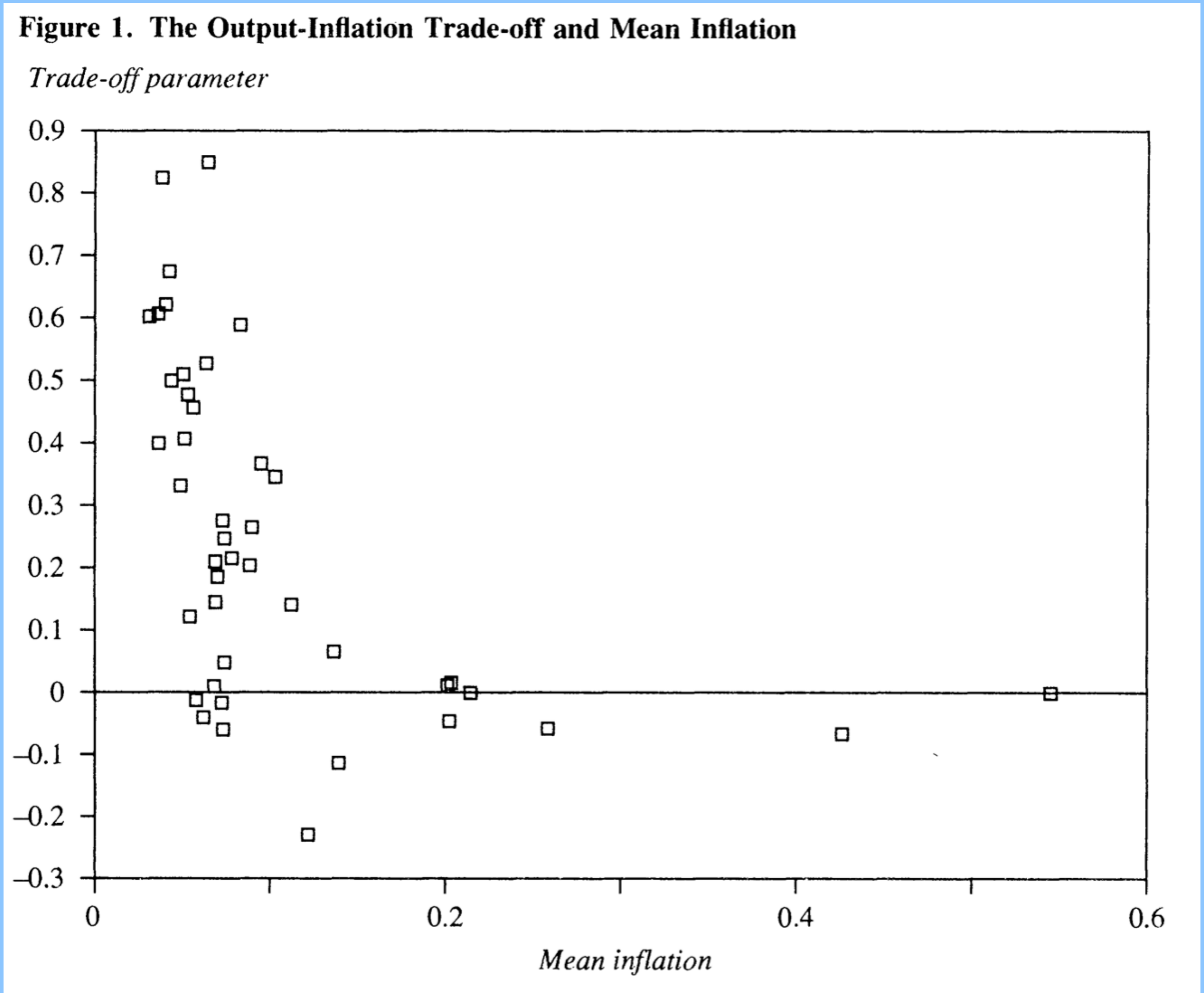
- y: log real GDP; Δx: change in log nominal GDP, which proxies for AD shocks.

- They then estimate the following cross-country regression equation: $\tau_i = \alpha + \beta_1 \bar{\pi}_i + \beta_2 \bar{\pi}_i^2 + \beta_3 \sigma_{\Delta x,i} + \beta_4 \sigma_{\Delta x,i}^2$.

- $\bar{\pi}$: average inflation; $\sigma_{\Delta x,i}$: standard deviation of the change in log nominal GDP

- Estimated coefficients: $\hat{\beta}_1 = -5.73$ (standard error:1.97); $\hat{\beta}_2 = 8.41$ (3.85); $\hat{\beta}_3 = 1.24$ (2.47); $\hat{\beta}_4 = -2.38$ (7.06)

Empirical evidence on the output-inflation tradeoff



Source: L. Ball, N.G. Mankiw, D. Romer (1988): "The New Keynesian Economics and the Output-Inflation Tradeoff," *Brookings Papers on Economic Activity*, 1, pp. 1-65

Empirical evidence on the output-inflation tradeoff

- $\hat{\beta}_1 = -5.73$: when $\bar{\pi}$ is higher, firms
  - adjust their prices more often to keep up with the price level.
  - pass AD disturbances into prices more quickly, and the real effects of AD shocks are smaller.
- The null hypothesis that the coefficients on $\sigma_{\Delta x,i}$ and $\sigma^2_{\Delta x,i}$ are zero cannot be rejected. This result questions the empirical validity of
  - the Lucas model: once $\bar{\pi}_i$ is included as a regressor, the effect of $\sigma_{\Delta x,i}$ on τ_i ceases to be statistically significant.
  - NK models: an increase in $\sigma_{\Delta x,i}$ should make firms change their prices more often, and should therefore reduce the real impact of AD shocks.

Empirical evidence on price adjustment

- Average interval between price changes for
  - intermediate goods: about a year.
  - final goods and services: about 4 months.
- Price adjustment does not follow any simple pattern.
  - Temporary "sale" prices are common: prices often fall sharply and are then quickly raised again, often to their previous levels.
  - Sales occur at irregular intervals and are of irregular lengths; the sizes of the reductions during sales vary.
  - Intervals between adjustments of the "regular" price are heterogeneous.
  - The regular price sometimes rises and sometimes falls; and the sizes of the changes in the regular price vary.

Empirical evidence on price adjustment

- Other findings:
  - large heterogeneity across products in the frequency of adjustment;
  - tendency for some prices to be adjusted at fairly regular intervals, most often once a year;
  - substantial fraction of price decreases (of both regular and sale prices), even in environments of moderately high inflation.
- Time-dependent models contradicted by the overwhelming presence of irregular intervals between price adjustments.
- State-dependent models contradicted by the tendencies for prices to be in effect for exactly one year, and to revert to their original level after a sale.
- The costs of changing prices at supermarkets (costs of putting on new price tags on shelves, etc.) are high, between 0.5 and 1 percent of revenue.

Calvo model

- There is a continuum of differentiated goods, indexed by $i \in [0,1]$. A representative household spends given amount $P_t C_t$ across all of them.

- $\max\limits_{C_t(i)} C_t = \left[\int_0^1 C_t(i)^{\frac{\varepsilon-1}{\varepsilon}} di \right]^{\frac{\varepsilon}{\varepsilon-1}}$, $\varepsilon > 1$, s.t. $\int_0^\infty P_t(i) C_t(i) di = P_t C_t$ yields:

$$C_t(i) = [P_t(i)/P_t]^{-\varepsilon} C_t, \quad P_t = \left[\int_0^1 P_t(i)^{1-\varepsilon} di \right]^{\frac{1}{1-\varepsilon}}$$

- Each good is produced by a monopolist with $Y_t(i) = A_t L_t(i)$.

- Perfectly competitive labour market. Aggregate labour supply L_t is given.

- Firms face $C_t(i) = [P_t(i)/P_t]^{-\varepsilon} C_t$; they take P_t, C_t, and the wage W_t as given.

- [$P_t C_t$, W_t, L_t, and discount factor $Q_{t,t+k}$ (introduced below) are given for the moment; they will be determined within the NK DSGE model.]

Calvo model

- Each firm may reset its price only with probability $1-\theta$ in any period, independently of the time elapsed since the last adjustment.
- Thus, each period a fraction (or mass) $1-\theta$ of firms reset their prices, and a mass θ keep their prices unchanged: "staggered price setting".
- We can think of θ as an index of price stickiness: the average duration of a price is given by $1/(1-\theta)$.
- [The fact that the timing of individual firms' price changes is not "history-dependent" makes the model relatively tractable.]
- $\Pi_t \equiv P_t/P_{t-1}$: gross inflation rate between $t-1$ and t
- [Notation: $x \equiv \ln X$. *E.g.*, $\pi_t \equiv \ln \Pi_t = \ln(P_t/P_{t-1}) = p_t - p_{t-1}$.]
- P_t^*: price set in t by firms re-optimising their price in that period (all firms will choose the same price because they face an identical problem).

Expected price duration

Calvo model: aggregate-price dynamics

- The distribution of prices among firms not adjusting in t corresponds to the distribution of effective prices in $t-1$, though with total mass reduced to θ.

- $P_t = [\theta P_{t-1}^{1-\varepsilon} + (1-\theta)(P_t^*)^{1-\varepsilon}]^{1/(1-\varepsilon)} \Leftrightarrow \Pi_t^{1-\varepsilon} = \theta + (1-\theta)(P_t^*/P_{t-1})^{1-\varepsilon}$

  – Inflation results from the fact that firms re-optimising in any t choose $P_t^* \neq P_{t-1}$.

  – In a steady state with $\pi_t = 0\ \forall t$, $\Pi_t = 1$ and $P_t^* = P_{t-1} = P_t\ \forall t$.

  – A log-linear approximation of $\Pi_t^{1-\varepsilon} = \theta + (1-\theta)(P_t^*/P_{t-1})^{1-\varepsilon}$ around a zero-inflation steady state yields $\pi_t \approx (1-\theta)(p_t^* - p_{t-1})$.

  – In order to understand the evolution of π_t over time, we need to analyse the firms' price-setting decisions.

Log-linearisation of aggregate price index

Calvo model: optimal price-setting rule

- Under $\theta = 0$, the firm maximises $(P_t - W_t/A_t)Y_t$ each period. $\Rightarrow$ The optimal (flexible) price is a markup over (nominal) marginal cost: $P_t^* = \mathscr{M}(W_t/A_t)$.

- $\mathscr{M} \equiv \varepsilon/(\varepsilon - 1)$: desired markup in the absence of constraints on the frequency of price adjustment.

- For $\theta \in (0,1)$, a firm re-optimising in t chooses the price P_t^* that maximises the expected present value of the profits earned while P_t^* remains effective.

- $\max\limits_{P_t^*} \sum\limits_{k=0}^{\infty} \theta^k \mathbb{E}_t[Q_{t,t+k}(P_t^* - W_{t+k}/A_{t+k})Y_{t+k|t}]$, $Y_{t+k|t} = (P_t^*/P_{t+k})^{-\varepsilon} C_{t+k} \equiv Y_{t+k|t}^d$

- $Y_{t+k|t}$: output in $t+k$ by a firm that last reset its price in t; $Q_{t,t+k}$: firm's discount factor; $Q_{t,t} = 1$, $Q_{t,t+k} = \prod\limits_{j=1}^{k} Q_{t+j}$ for $\forall k \geq 1$.

- F.O.C.: $\sum\limits_{k=0}^{\infty} \theta^k \mathbb{E}_t[Q_{t,t+k} Y_{t+k|t}^d (P_t^* - \mathscr{M} W_{t+k}/A_{t+k})] = 0$

Calvo model: optimal price-setting rule

- F.O.C.: $\sum_{k=0}^{\infty} \theta^k \mathbb{E}_t [Q_{t,t+k} Y^d_{t+k|t} (P^*_t - \mathscr{M} W_{t+k}/A_{t+k})] = 0.$

- $P^*_t = \mathscr{M} \sum_{k=0}^{\infty} \mathbb{E}_t [\omega_{t,t+k} W_{t+k}/A_{t+k}], \quad \omega_{t,t+k} \equiv \dfrac{\theta^k Q_{t,t+k} Y^d_{t+k|t}}{\sum_{h=0}^{\infty} \theta^h \mathbb{E}_t [Q_{t,t+h} Y^d_{t+h|t}]}$

  - Firms resetting their prices choose one that corresponds to $\mathscr{M}$ over a weighted average of their current and expected future W_{t+k}/A_{t+k}.

  - W_{t+k}/A_{t+k} of earlier periods (with a higher θ^k), or of periods with larger expected present values of demand $\mathbb{E}_t[Q_{t,t+k} Y^d_{t+k|t}]$, carry larger weights.

- In order to understand the implications of this price-setting rule for π we simplify the F.O.C. by linearising it around the zero-inflation steady state.

Calvo model: zero-inflation steady state

- Dividing the F.O.C. by P_{t-1}, and defining $\Pi_{t,t+k} \equiv P_{t+k}/P_t$, $MC_t \equiv W_t/(A_t P_t)$,
$$\sum_{k=0}^{\infty} \theta^k \mathbb{E}_t[Q_{t,t+k} Y_{t+k|t}[P_t^*/P_{t-1} - \mathscr{M} MC_{t+k} \Pi_{t-1,t+k}]] = 0.$$
- All variables above have well-defined values in the $\pi = 0$ steady state:
  - $\Pi_{t-1,t+k} = \Pi = 1 \Rightarrow P_t^* = P_{t-1} = P_{t+k} = P_{t+k}^* \ \forall k$; $P_t^*/P_{t-1} = P^*/P = 1$
  - $P_t^* = P_{t+k}^* = P_{t+k} \Rightarrow Y_{t+k|k} = Y_{t+k} \ \forall k$: all firms produce equal amounts.
  - Assume no long-run growth: $A_{t+k} = A_t = A$ and $Y_{t+k} = Y_t = Y \ \forall k$.
  - $MC_{t+k} = W_{t+k}/(A_{t+k} P_{t+k}) = W_t/(A_t P_t) = W/(AP) \equiv MC \ \forall k$
  - Without long-run growth, $Q_{t,t+k} = \beta^k$; $\beta \in (0,1)$. [We will discuss this within the NK DSGE model.]
  - $Y(P^*/P - \mathscr{M} MC \Pi) \sum_{k=0}^{\infty} (\beta\theta)^k = 0 \ \Rightarrow MC = 1/\mathscr{M} \ \forall k$

[First-order Taylor expansion of F.O.C.]

Calvo model: inflation dynamics

- The appendix shows $\pi_t = \beta \mathbb{E}_t[\pi_{t+1}] + \lambda(mc_t - mc)$; $\lambda > 0$ constant
- Assume $\lim_{T\to\infty} \beta^T \mathbb{E}_t[\pi_{t+T}] = 0$. [This will hold in the NK DSGE model.]
- Solve $\pi_t = \beta \mathbb{E}_t[\pi_{t+1}] + \lambda(mc_t - mc)$ forward: $\pi_t = \lambda \sum_{k=0}^{\infty} \beta^k \mathbb{E}_t[mc_{t+k} - mc]$.
- π_t: discounted sum of current and expected future log-deviations of real marginal costs $MC_{t+k} \equiv W_{t+k}/(A_{t+k}P_{t+k})$ from steady state.
- Define $\mu_t \equiv -mc_t$, $\mu \equiv \ln \mathscr{M} = -mc$: $\pi_t = \lambda \sum_{k=0}^{\infty} \beta^k \mathbb{E}_t[\mu - \mu_{t+k}]$:
  - π_t is high when firms expect average markups below their desired μ.
  - In that case, firms resetting prices choose a price above the economy's average price level in order to realign their markup closer to μ.

First-order Taylor expansion of F.O.C.

Calvo model: equilibrium

- Goods market clearing: $Y_t(i) = C_t(i)$ for all $i \in [0,1]$ and all t.
- Defining aggregate output as $Y_t = \left[\int_0^1 Y_t(i)^{\frac{\varepsilon-1}{\varepsilon}} di\right]^{\frac{\varepsilon}{\varepsilon-1}}$, $Y_t = C_t$ for all t.
- Labour market clearing: $L_t = \int_0^1 L_t(i)di = \int_0^1 \frac{Y_t(i)}{A_t} di = \frac{Y_t}{A_t}\int_0^1 \left[\frac{P_t(i)}{P_t}\right]^{-\varepsilon} di.$
- Taking logs, $l_t = y_t - a_t + d_t$; $d_t \equiv \ln\left[\int_0^1 \left[\frac{P_t(i)}{P_t}\right]^{-\varepsilon} di\right].$
- d_t: measure of price (and therefore output) dispersion across firms.
- In a neighbourhood of the zero-inflation steady state, $d_t \approx 0$. [For a proof, see the appendix to chapter 3 in Galí (2008).] $\Rightarrow a_t + l_t \approx y_t = c_t$
- Close to a zero-inflation steady state, firms that have the chance to reset prices keep them aligned with the prices of firms that cannot reset them.

Mathematical appendix: Expected price duration

- Consider a firm that adjusts its price in period 0.
- Probability of the firm's adjusting its price in period t: $\theta^{t-1} \times (1-\theta)$
- This is the probability of the firm not getting to adjust in periods 1 through $t-1$, θ^{t-1}, times the probability of adjusting in period t, $1-\theta$.
- Expected duration of a price: $(1-\theta)\sum_{t=1}^{\infty}\theta^{t-1}t$.
- $\sum_{t=1}^{\infty}\theta^{t-1}t = 1 + 2\theta + 3\theta^2 + 4\theta^3 + \ldots$
- $\theta\sum_{t=1}^{\infty}\theta^{t-1}t = \theta + 2\theta^2 + 3\theta^3 + \ldots$
- $(1-\theta)\sum_{t=1}^{\infty}\theta^{t-1}t = 1 + \theta + \theta^2 + \theta^3 + \ldots = 1/(1-\theta)$

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Mathematical appendix: Log-linearisation of $\Pi_t^{1-\varepsilon}$

- Expression $1 = [\theta + (1-\theta)(P_t^*/P_{t-1})^{1-\varepsilon}]/\Pi_t^{1-\varepsilon}$ can be rewritten as follows: $1 = \exp\{\ln[\theta + (1-\theta)(P_t^*/P_{t-1})^{1-\varepsilon}] - (1-\varepsilon)\ln \Pi_t\}$.

- Replacing the RHS with a first-order Taylor expansion around $\Pi = 1$ and $P^*/P = 1$ yields:

$$1 \approx \exp\{\ln[\theta + (1-\theta)(P^*/P)^{1-\varepsilon}] - (1-\varepsilon)\ln \Pi\} \times$$

$$\times \left[1 + \frac{(1-\varepsilon)(1-\theta)(P^*/P)^{-\varepsilon}}{\theta + (1-\theta)(P^*/P)^{1-\varepsilon}}\left(\frac{P_t^*}{P_{t-1}} - \frac{P^*}{P}\right) - \frac{(1-\varepsilon)}{\Pi}(\Pi_t - \Pi)\right] =$$

$$= 1 + (1-\varepsilon)(1-\theta)(P_t^*/P_{t-1} - 1) - (1-\varepsilon)(\Pi_t - 1)$$

$$\Leftrightarrow \Pi_t - 1 = (1-\theta)(P_t^*/P_{t-1} - 1) \Leftrightarrow \pi_t = (1-\theta)(p_t^* - p_{t-1})$$

- $\ln(P_t^*/P_{t-1}) \approx P_t^*/P_{t-1} - 1$, $\pi_t = \ln(P_t/P_{t-1}) \approx \Pi_t - 1$

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Mathematical appendix: First-order Taylor expansion of F.O.C.

- First-order Taylor expansion of F.O.C. around the $\pi = 0$ steady-state:

$$Y\left(\frac{P^*}{P} - \mathscr{M}MC\Pi\right)\sum_{k=0}^{\infty}(\beta\theta)^k + Y\left(\frac{P^*}{P} - \mathscr{M}MC\Pi\right)\sum_{k=0}^{\infty}\theta^k \mathbb{E}_t[Q_{t,t+k} - Q^k] +$$

$$+\left(\frac{P^*}{P} - \mathscr{M}MC\Pi\right)\sum_{k=0}^{\infty}(\beta\theta)^k \mathbb{E}_t[Y_{t|t+k} - Y] + \left(\frac{P_t^*}{P_{t-1}} - \frac{P^*}{P}\right)Y\sum_{k=0}^{\infty}(\beta\theta)^k +$$

$$-\mathscr{M}Y\Pi\sum_{k=0}^{\infty}(\beta\theta)^k \mathbb{E}_t\left[MC_{t+k} - MC\right] - \mathscr{M}YMC\sum_{k=0}^{\infty}(\beta\theta)^k \mathbb{E}_t[\Pi_{t-1,t+k} - \Pi] \approx 0$$

- The first three terms are zero. The rest of the expression can be rewritten as

$$\frac{1}{1-\beta\theta}\left(\frac{P_t^*}{P_{t-1}} - 1\right) = \sum_{k=0}^{\infty}(\beta\theta)^k \mathbb{E}_t\left[\frac{MC_{t+k}}{MC} - 1\right] + \sum_{k=0}^{\infty}(\beta\theta)^k \mathbb{E}_t\left[\frac{P_{t+k}}{P_{t-1}} - 1\right]$$

$$\Leftrightarrow p_t^* - p_{t-1} = (1-\beta\theta)\sum_{k=0}^{\infty}(\beta\theta)^k \mathbb{E}_t[mc_{t+k} - mc + p_{t+k} - p_{t-1}]$$

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Mathematical appendix: Inflation dynamics

- $(1-\beta\theta)\sum_{k=0}^{\infty}(\beta\theta)^k\mathbb{E}_t[p_{t+k}-p_{t-1}]=\sum_{k=0}^{\infty}(\beta\theta)^k\mathbb{E}_t[\pi_{t+k}]$ (see next slide)

- This enables us to rewrite the linearised F.O.C. as

$$p_t^*-p_{t-1}=(1-\beta\theta)\sum_{k=0}^{\infty}(\beta\theta)^k\mathbb{E}_t[mc_{t+k}-mc]+\sum_{k=0}^{\infty}(\beta\theta)^k\mathbb{E}_t[\pi_{t+k}]$$

- The above expression can be derived from, and is therefore equivalent to, $p_t^*-p_{t-1}=\beta\theta\mathbb{E}_t[p_{t+1}^*-p_t]+(1-\beta\theta)(mc_t-mc)+\pi_t$.

- Plugging $\pi_t=(1-\theta)(p_t^*-p_{t-1})$, $\pi_t=\beta\mathbb{E}_t[\pi_{t+1}]+\lambda(mc_t-mc)$.

- $\lambda\equiv(1-\theta)(1-\beta\theta)/\theta$ is decreasing in θ.

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Mathematical appendix: Inflation dynamics

$$(1-\beta\theta)\sum_{k=0}^{\infty}(\beta\theta)^k\mathbb{E}_t[p_{t+k}-p_{t-1}] =$$

$$= (1-\beta\theta)\sum_{k=0}^{\infty}(\beta\theta)^k\mathbb{E}_t[p_{t+k}] - (1-\beta\theta)p_{t-1}\sum_{k=0}^{\infty}(\beta\theta)^k =$$

$$= \sum_{k=0}^{\infty}(\beta\theta)^k\mathbb{E}_t[p_{t+k}] - \sum_{k=0}^{\infty}(\beta\theta)^{k+1}\mathbb{E}_t[p_{t+k}] - p_{t-1} =$$

$$= \sum_{k=1}^{\infty}(\beta\theta)^k\mathbb{E}_t[p_{t+k}] - \sum_{k=1}^{\infty}(\beta\theta)^k\mathbb{E}_t[p_{t+k-1}] + p_t - p_{t-1} =$$

$$= \sum_{k=1}^{\infty}(\beta\theta)^k\mathbb{E}_t[p_{t+k}-p_{t+k-1}] + p_t - p_{t-1} = \sum_{k=0}^{\infty}(\beta\theta)^k\mathbb{E}_t[\pi_{t+k}]$$

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Food for thought (beyond this course)

- F. Alvarez, M. Beraja, M. González-Rozada & P.A. Neumeyer (2019): "From Hyperinflation to Stable Prices: Argentina's Evidence on Menu Cost Models," *Quarterly Journal of Economics*, pp. 451-505
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