Macroeconomics
Lecture 10 – Monetary economies: Classical, New Keynesian

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Price flexibility & monetary neutrality

- So far, all quantities were real, i.e. measured in units of consumption good (even prices: w, r)
- **Does money matter?**
  - In a **flexible price** economy, nominal variables (price level, inflation, nominal interest) have no real effect: **monetary neutrality**
  - We will see it in a simplified verison of RBC without capital – a classical monetary economy
  - Then, we will start building the New Keynesian model with **nominal rigidities (sticky prices)**

Outline

Outline

Household budget with nominal variables

In a monetary economy, the flow budget constraint of a household is

$$P_t C_t + B_{t+1}^n = (1 + i_{t-1}) B_t^n + W_t^n N_t + \Pi_t^n$$

with:

- P_t price level of period t
- $W_t^{\mathbf{n}}$ **n**ominal (i.e. in units of currency) wage
- i_t the nominal interest rate
- $B_t^{\mathbf{n}}$ **n**ominal value of bonds held at beginning of t
- $\Pi_t^{\mathbf{n}}$ **n**ominal profits

Households' optimization

We will solve the model with particular functions:

$$u(C_t) - \nu(N_t) = \frac{C_t^{1-\sigma}}{1-\sigma} - \frac{N_t^{1+\eta}}{1+\eta}$$

FOCs can be computed as in RBC:

$$N_t^{\eta} C_t^{\sigma} = \frac{W_t^n}{P_t} \quad (= W_t, \text{the real wage})$$

$$C_t^{-\sigma} = \beta E_t \left[C_{t+1}^{-\sigma} \frac{P_t}{P_{t+1}} (1+i_t) \right] = E_t \left[C_{t+1}^{-\sigma} \underbrace{\frac{1+i_t}{1+\pi_{t+1}}}_{1+r_t} \right]$$

These equations are easy to linearize by simply taking logs.
Lowercase letters for logs: $c_t = \ln C_t, n_t = \ln N_t, \pi_{t+1} = p_{t+1} - p_t$:

$$\eta n_t + \sigma c_t = w_t^n - p_t \qquad \rightarrow \text{consumption-labor}$$

$$c_t = E_t[c_{t+1}] - \frac{1}{\sigma}(i_t - E_t[\pi_{t+1}] - \rho) \quad \rightarrow \text{Euler}$$

with $\rho = -\ln \beta$ the discount **rate** (used in continuous time models)

$$p_{t+1} - p_t = \ln P_{t+1} - \ln P_t$$
$$= \ln\left(\frac{P_{t+1}}{P_t}\right) = \ln(1+\pi_{t+1})$$
$$\approx \pi_{t+1}$$

$$\mathcal{L}_t = \beta^t\left(\frac{C_t^{1-\sigma}}{1-\sigma} - \frac{N_t^{1+\eta}}{1+\eta} + \lambda_t\left(W_t^n N_t + (1+i_{t-1})B_t^n + \Pi_t^n - P_t C_t - B_{t+1}^n\right)\right)$$

$$+ \beta^{t+1}\mathbb{E}_t\left(\frac{C_{t+1}^{1-\sigma}}{1-\sigma} - \frac{N_{t+1}^{1+\eta}}{1+\eta} + \lambda_{t+1}\left(W_{t+1}^n N_{t+1} + (1+i_t)B_{t+1}^n + \Pi_{t+1}^n - P_{t+1}C_{t+1} - B_{t+2}^n\right)\right)$$

$$+ \beta^{t+2}\mathbb{E}_t \ldots$$

$$\frac{\partial \mathcal{L}}{\partial C_t} = \beta^t\left(C_t^{-\sigma} - \lambda_t P_t\right) = 0 \Leftrightarrow C_t^{-\sigma} = \lambda_t P_t \Leftrightarrow \lambda_t = \frac{C_t^{-\sigma}}{P_t}$$

$$\frac{\partial \mathcal{L}}{\partial B_{t+1}^n} = \beta^t(-\lambda_t) + \beta^{t+1}\mathbb{E}_t\lambda_{t+1}(1+i_t) = 0 \Leftrightarrow \lambda_t = \beta\mathbb{E}_t\lambda_{t+1}(1+i_t)$$

$$\frac{\partial \mathcal{L}}{\partial N_t} = \beta^t\left(-N_t^\eta + \lambda_t W_t^n\right) = 0 \Leftrightarrow N_t^\eta = \lambda_t W_t^n$$

$$\frac{C_t^{-\sigma}}{P_t} = \beta\mathbb{E}_t\frac{C_{t+1}^{-\sigma}}{P_{t+1}}(1+i_t)$$

$$\frac{N_t^\eta}{C_t^{-\sigma}} = \frac{W^n}{P_t} \Leftrightarrow \boxed{C_t^\sigma N_t^\eta = \frac{W^n}{P_t}}$$

$$\frac{P_{t+1}}{P_t} = 1 + \frac{P_{t+1} - P_t}{P_t}$$

$$= 1 + \pi_{t+1}$$

$$\frac{C_t^{-\sigma}}{P_t} = \beta \mathbb{E}_t \frac{C_{t+1}^{-\sigma}}{P_{t+1}} (1+i_t) \quad \Big| \times P_t$$

$$C_t^{-\sigma} = \beta \mathbb{E}_t \left[C_{t+1}^{-\sigma} \cdot \underbrace{\frac{P_t}{P_{t+1}} (1+i_t)} \right]$$

$$= \mathbb{E}_t \frac{1}{1+\pi_{t+1}} (1+i_t)$$

$$= \mathbb{E}_t \boxed{\frac{1+i_t}{1+\pi_{t+1}} = 1 + r_t}$$

$$\ln(1+x) \xrightarrow[x \to 0]{} x$$

$$\ln(1+i_t) - \mathbb{E}_t \ln(1+\pi_{t+1}) = \ln(1+r_t)$$

$$i_t - \mathbb{E}_t \pi_{t+1} = r_t$$

Firm optimization

Firms only use labor: $Y_t = A_t N_t^{1-\alpha}$ $\to$ $\ln Y_t = \ln A_t + (1-\alpha) \ln N_t$

$y_t = a_t + (1-\alpha) n_t$

Maximize discounted profits:

$$\max_{\{N_t\}_{t=0}^{\infty}} \sum_{t=0}^{\infty} M_t (P_t Y_t - W_t^n N_t)$$

with M_t the stochastic discount factor: $M_t = E_0 \beta^t \left[\frac{C_t^{-\sigma}}{C_0^{-\sigma}} \frac{P_0}{P_t} \right]$

Static problem again; solution: $(1-\alpha) A_t N_t^{-\alpha} = \frac{W_t^n}{P_t}$ $(= W_t)$

Or, in log form, $a_t - \alpha n_t + \ln(1-\alpha) = w_t^n - p_t$

Classical equilibrium: monetary neutrality

The following system is sufficient to find equilibrium in period t:

$$\begin{aligned} \sigma c_t + \eta n_t &= w_t^n - p_t \; (= w_t) \\ a_t - \alpha n_t + \ln(1-\alpha) &= w_t^n - p_t (= w_t) \\ y_t &= c_t \\ y_t &= a_t + (1-\alpha) n_t, \end{aligned}$$

where the last equation is the production function in logs.

We have 4 equations, 4 unknowns y_t, c_t, n_t, w_t, $\Rightarrow$ static solution each period that only depends on a_t:

$$y_t = \frac{(1+\eta)a_t + (1-\alpha)\ln(1-\alpha)}{(1-\alpha)\sigma + \eta + \alpha}$$

As in RBC, no real quantities depends on nominal ones P_t, W_t^n, i_t in equilibrium

Euler equation defines the real interest rate

Real interest rate is a real quantity that can also be obtained in equilibrium using the log Euler equation:

$$c_t = E_t[c_{t+1}] - \frac{1}{\sigma}(i_t - E_t\pi_{t+1} - \rho)$$

Then, recall the approximate Fischer formula for real interest rate:

$$r_t = i_t - E_t\pi_{t+1}$$

combine the two equations and $y_t = c_t$ to obtain

$$\begin{aligned} r_t &= \rho + \sigma(E_t c_{t+1} - c_t) = \rho + \sigma(E_t y_{t+1} - y_t) \\ &= \rho + \sigma\frac{1+\eta}{\sigma(1-\alpha)+\eta+\alpha}(E_t a_{t+1} - a_t), \quad \text{(using equilibrium } y_t\text{)} \end{aligned}$$

In a steady state, TFP constant, so $r_{ss} = \rho$

Central Bank in a monetary neutrality economy

We still have the price level in the economy (although neutral), so let's consider a central bank

Suppose a central bank follows a Taylor Rule:

$\phi_\pi > 0$

$$i_t = \rho + \phi_\pi \pi_t, \quad \textit{with } \rho = -\ln \beta, \text{ the discount } \text{~~factor~~ rate}$$

Then, we can combine it with the Fischer equation $r_t = i_t - E_t \pi_{t+1}$

$$\phi_\pi \pi_t = E_t \pi_{t+1} + r_t - \rho$$

$$\pi_t = \mathbb{E}_t \frac{1}{\phi_\pi} \pi_{t+1} + \underbrace{\frac{1}{\phi_\pi}(r_t - \rho)}$$

$$\pi_{t+1} = \mathbb{E}_t \frac{1}{\phi_\pi} \pi_{t+2} + \frac{1}{\phi_\pi}(r_{t+1} - \rho)$$

$$\rightarrow \pi_t = \mathbb{E}_t\left[\left(\frac{1}{\phi_\pi}\right)^2 \pi_{t+2} + \left(\frac{1}{\phi_\pi}\right)^2 (r_{t+1} - \rho)\right] + \frac{1}{\phi_\pi}(r_t - \rho)$$

Inflation determinacy needs active Taylor Rule

$$\phi_\pi \pi_t = E_t \pi_{t+1} + r_t - \rho$$

$\pi_{t+1} - \xi_{t+1}$

$\mathbb{E}_t \xi_{t+1} = 0$

If $\phi_\pi > 1$ (active Taylor Rule), the level of inflation can be determined as a discounted sum of expected $r_t - \rho$:

$$\pi_t = \sum_{s=0}^{\infty} \left(\frac{1}{\phi_\pi} \right)^{s+1} E_t[r_{t+s} - \rho]$$

If $\phi_\pi < 1$ (passive Taylor Rule), inflation follows an AR(1) process:

$$\pi_{t+1} = \phi_\pi \pi_t - r_t + \rho + \xi_{t+1}$$

Where ξ_{t+1} is a random variable with $E_t \xi_{t+1} = 0$ and no economic meaning. This is a **sunspot shock** – a random factor affecting economic outcomes such as inflation, but with no economic explanation. **Inflation is not determined in equilibrium**

Outline

The New Keynesian model: structure

Households

- ▷ consume a bundle of differentiated goods
- ▷ supply labour, receive nominal wage
- ▷ save by holding nominal bonds

Firms

- ▷ each (small) firm produces a one differentiated good
- ▷ using only labor (model can be extended to have capital)
- ▷ pricing the good
  - ▷ under monopolistic competition
  - ▷ given **nominal rigidities (sticky prices)**

Before looking at sticky prices, we solve a flexible price model today

Outline

1. Classical monetary economy
2. New Keynesian model
   - Differentiated goods and the agregator
   - Firms
   - Flexible price equilibrium
   - Sticky prices

Differentiated goods

We need firms to be **price setters** in the model to have a Phillips Curve/ AS type of relationship between GDP and inflation

Solution: multiple goods in the model, 1 firm produces 1 good

Goods are differentiated $\Rightarrow$ **imperfect substitution**

Each firm has some **market power** (monopolistic competition)

Differentiated goods: a 2-good example

Consider a consumer choice with 2 goods, C_A (apples) and C_B (bananas)

Consider an **aggregator function** for the two goods:

$$C = \left(C_A^{\frac{\varepsilon-1}{\varepsilon}} + C_B^{\frac{\varepsilon-1}{\varepsilon}} \right)^{\frac{\varepsilon}{\varepsilon-1}}$$

Let's maximize the utility $U = C$ subject to a constraint $P_A C_A + P_B C_B = Z$

This maximization results in a **price index** $P = \left(P_A^{1-\varepsilon} + P_B^{1-\varepsilon} \right)^{\frac{1}{1-\varepsilon}}$ that allows to write $P_A C_A + P_B C_B = P \cdot C$

Then, the demand for each good i ($i = A$ or $i = B$) is

$$C_i = \left(\frac{P_i}{P} \right)^{-\varepsilon} C$$

$$\max C \qquad C = \left(C_A^{\frac{\varepsilon-1}{\varepsilon}} + C_B^{\frac{\varepsilon-1}{\varepsilon}} \right)^{\frac{\varepsilon}{\varepsilon-1}}$$

$$\text{s.t. } P_A C_A + P_B C_B = Z$$

$$\mathcal{L} = \left(C_A^{\frac{\varepsilon-1}{\varepsilon}} + C_B^{\frac{\varepsilon-1}{\varepsilon}} \right)^{\frac{\varepsilon}{\varepsilon-1}} + \lambda (Z - P_A C_A - P_B C_B)$$

$$\frac{\partial \mathcal{L}}{\partial C_A} = \cancel{\frac{\varepsilon}{\varepsilon-1}} \left(C_A^{\frac{\varepsilon-1}{\varepsilon}} + C_B^{\frac{\varepsilon-1}{\varepsilon}} \right)^{\frac{1}{\varepsilon-1}} \cdot \cancel{\frac{\varepsilon-1}{\varepsilon}} \cdot C_A^{-\frac{1}{\varepsilon}} - \lambda P_A = 0$$

$$\frac{\varepsilon}{\varepsilon-1} - 1 = \frac{\varepsilon}{\varepsilon-1} - \frac{\varepsilon-1}{\varepsilon-1} = \frac{\varepsilon - \varepsilon + 1}{\varepsilon - 1} = \frac{1}{\varepsilon-1}$$

$$\frac{\varepsilon-1}{\varepsilon} - 1 = \frac{\varepsilon-1}{\varepsilon} - \frac{\varepsilon}{\varepsilon} = -\frac{1}{\varepsilon}$$

$$\frac{\partial \mathcal{L}}{\partial C_B}: \quad \begin{cases} \left(C_A^{\frac{\varepsilon-1}{\varepsilon}} + C_B^{\frac{\varepsilon-1}{\varepsilon}} \right)^{\frac{1}{\varepsilon-1}} C_A^{-1/\varepsilon} = \lambda P_A \\ \left(C_A^{\frac{\varepsilon-1}{\varepsilon}} + C_B^{\frac{\varepsilon-1}{\varepsilon}} \right)^{\frac{1}{\varepsilon-1}} C_B^{-1/\varepsilon} = \lambda P_B \end{cases}$$

$$\frac{C_A^{-1/\varepsilon}}{C_B^{-1/\varepsilon}} = \frac{P_A}{P_B} \Leftrightarrow \frac{C_A}{C_B} = \left(\frac{P_A}{P_B}\right)^{-\varepsilon} \Leftrightarrow \boxed{C_A = \left(\frac{P_A}{P_B}\right)^{-\varepsilon} C_B}$$

$$Z = P_A C_A + P_B C_B = P_A \left(\frac{P_A}{P_B}\right)^{-\varepsilon} C_B + P_B C_B = P_A^{1-\varepsilon} P_B^{\varepsilon} C_B + P_B C_B$$

$$\boxed{C_B = \frac{Z}{P_A^{1-\varepsilon} P_B^{\varepsilon} + P_B}} \Leftarrow Z = \left(P_A^{1-\varepsilon} P_B^{\varepsilon} + P_B\right) C_B$$

$$C_B = \frac{Z}{P_A^{1-\varepsilon} P_B^{\varepsilon} + P_B} = \frac{Z}{P_A^{1-\varepsilon} + P_B^{1-\varepsilon}} P_B^{-\varepsilon}$$

$$C_A = \frac{Z}{P_B^{1-\varepsilon} P_A^{\varepsilon} + P_A} = \frac{Z}{P_A^{1-\varepsilon} + P_B^{1-\varepsilon}} P_A^{-\varepsilon} \qquad (*)$$

$$C = \left(C_A^{\frac{\varepsilon-1}{\varepsilon}} + C_B^{\frac{\varepsilon-1}{\varepsilon}}\right)^{\frac{\varepsilon}{\varepsilon-1}} = \left(\left(\frac{Z}{P_A^{1-\varepsilon} + P_B^{1-\varepsilon}}\right)^{\frac{\varepsilon-1}{\varepsilon}} \left(P_A^{-\varepsilon\cdot\frac{\varepsilon-1}{\varepsilon}} + P_B^{-\varepsilon\cdot\frac{\varepsilon-1}{\varepsilon}}\right)\right)^{\frac{\varepsilon}{\varepsilon-1}}$$

$$C = \frac{Z}{P_A^{1-\varepsilon} + P_B^{1-\varepsilon}} \cdot \left(P_A^{1-\varepsilon} + P_B^{1-\varepsilon}\right)^{\frac{\varepsilon}{\varepsilon-1}}$$

$$C = Z \cdot \left(P_A^{1-\varepsilon} + P_B^{1-\varepsilon}\right)^{-1} \left(P_A^{1-\varepsilon} + P_B^{1-\varepsilon}\right)^{\frac{\varepsilon}{\varepsilon-1}}$$

$$C = Z\left(P_A^{1-\varepsilon} + P_B^{1-\varepsilon}\right)^{\frac{1}{\varepsilon-1}} \quad \Big| \times \left(P_A^{1-\varepsilon} + P_B^{1-\varepsilon}\right)^{\frac{-1}{\varepsilon-1}}$$

$$P \searrow \boxed{\left(P_A^{1-\varepsilon} + P_B^{1-\varepsilon}\right)^{\frac{1}{1-\varepsilon}}} \cdot C = Z$$

$$P \cdot C = Z$$

$$P = \left(P_A^{1-\varepsilon} + P_B^{1-\varepsilon}\right)^{\frac{1}{1-\varepsilon}}$$

$$(*):\ C_A = \frac{Z}{P_A^{1-\varepsilon} + P_B^{1-\varepsilon}} P_A^{-\varepsilon} = \frac{P \cdot C}{P_A^{1-\varepsilon} + P_B^{1-\varepsilon}} P_A^{-\varepsilon}$$

$$= \frac{P \cdot C}{\left(P_A^{1-\varepsilon} + P_B^{1-\varepsilon}\right)^{\frac{1}{1-\varepsilon} \cdot (1-\varepsilon)}} P_A^{-\varepsilon}$$

$$= \frac{P \cdot C}{P^{1-\varepsilon}} P_A^{-\varepsilon} = \frac{C}{P^{-\varepsilon}} \cdot P_A^{-\varepsilon} = \left(\frac{P_A}{P}\right)^{-\varepsilon} \cdot C$$

$$C_A = \left(\frac{P_A}{P}\right)^{-\varepsilon} \cdot C$$

Differentiated goods: a continuum case

- The New Keynesian model has an infinity (continuum) of goods and firms indexed by $i \in [0,1]$. The aggregator becomes:

$$C_t \equiv \left(\int_0^1 C_t(i)^{\frac{\varepsilon-1}{\varepsilon}} di \right)^{\frac{\varepsilon}{\varepsilon-1}}$$

- ε is the **elasticity of substitution** between any pair of differentiated goods. Higher $\varepsilon \Rightarrow$ goods ~~more~~ less unique
- Solution analogous to two-good case:
  - price index

$$P_t = \left(\int_0^1 P_t(i)^{1-\varepsilon} di \right)^{\frac{1}{1-\varepsilon}} \quad \Rightarrow \int_0^t P_t(i) C_t(i) di = P_t \cdot C_t$$

  - demand $C_t(i) = \left(\frac{P_t(i)}{P_t} \right)^{-\varepsilon} C_t$

Household choices... same as in classical

$$\frac{C_t^{1-\sigma}}{1-\sigma} - \frac{N_t^{1+\eta}}{1+\eta}$$

The household budget constraint is

$$\int_0^1 P_t(i)C_t(i)di + B^n_{t+1} = (1+i_{t-1})B^n_t + W^n_t N_t + \Pi^n_t$$

or, using the consumption aggregator and the price aggregator:

$$P_t C_t + B^n_{t+1} = (1+i_{t-1})B^n_t + W^n_t N_t + \Pi^n_t$$

identical to classical monetary economy
$\Rightarrow$ the New Keynesian model has **the same consumption-leisure optimality and Euler equation as the classical monetary** model, despite many goods!

Outline

Firms

- Continuum of firms indexed by $i \in [0,1]$ (1 firm – 1 good)
- $Y_t(i) = A_t N_t(i)^{1-\alpha} \Rightarrow$ one can define labor as a function of output: $N_t(i) = \left(\frac{Y_t(i)}{A_t}\right)^{\frac{1}{1-\alpha}}$
- Then, define nominal cost function:

$$TC^n(Y_t(i)) = W_t^n N_t(i) = W_t^n \left(\frac{Y_t(i)}{A_t}\right)^{\frac{1}{1-\alpha}}$$

- Then, define nominal marginal cost function:

$$MC^n(Y_t(i)) = \frac{dTC^n(Y_t(i))}{dY_t(i)} = \frac{1}{1-\alpha} W_t^n A_t^{\frac{1}{\alpha-1}} Y_t(i)^{\frac{\alpha}{1-\alpha}}$$

We will look at firm optimization and model equilibrium under **flexible prices** before looking at **sticky prices**

Firm optimization – flexible prices

Maximize profits:

$$\max_{\substack{\{\cancel{Y_t(i)}\}_{t=0}^{\infty} \\ P_t(i)}} \sum_{i=0}^{\infty} M_t(P_t(i)Y_t(i) - TC^n(Y_t(i)))$$

Where:

- $Y_t(i)$ related to $P_t(i)$ via demand: $Y_t(i) = \left(\frac{P_t(i)}{P_t}\right)^{-\varepsilon} Y_t$ (because $C_t(i) = Y_t(i)$)
- continuum of goods $\Rightarrow$ firm i doesn't influence Y_t, C_t, P_t

Typical micro problem of monopolistic pricing. Solution:

$$P_t(i) = \underbrace{\frac{\varepsilon}{\varepsilon - 1}}_{\textbf{markup}} MC^n(Y_t(i))$$

$$\frac{\varepsilon}{\varepsilon - 1} = 1 + \frac{1}{\varepsilon - 1}$$

The higher the elasticity of substitution, the less the good is unique $\Rightarrow$ less market power $\Rightarrow$ smaller markup

Outline

Flexible price equilibrium: monetary neutrality again

Symmetry of goods $\Rightarrow C_t(i) = C_t, N_t(i) = N_t$ etc. and:

$$
\begin{aligned}
\sigma c_t + \eta n_t &= w_t^n - p_t \\
p_t &= \mu - \ln(1-\alpha) + w_t^n + \frac{1}{\alpha - 1} a_t + \frac{\alpha}{1-\alpha} y_t \\
y_t &= c_t \\
y_t &= a_t + (1-\alpha) n_t,
\end{aligned}
$$

with $\mu = \ln(\varepsilon/(\varepsilon - 1))$ log of markup. Static solution with 4 equations and 4 unknowns again; Euler equation used to obtain r_t. Denote the flex-price equilibrium variables with superscript f:

$$
\begin{aligned}
y_t^f &= \frac{1-\alpha}{(1-\alpha)\sigma + \eta + \alpha}\left(-\mu + \ln(1-\alpha) + \frac{\eta - 1}{1-\alpha} a_t\right) \\
r_t^f &= \rho + \sigma \frac{1+\eta}{\sigma(1-\alpha) + \eta + \alpha}(E_t a_{t+1} - a_t)
\end{aligned}
$$

Monetary neutrality obtained as in the classical, 1-good model

Outline

Nominal rigidities, a.k.a. sticky prices

- How often do prices change?
- Empirical work $\rightarrow$ average duration of a price spell is **4-5 quarters** in the EU
- How to build this in the New Keynesian model?

$\rightarrow$ Common sticky price mechanisms:

1. **Calvo pricing**: constant probability that firm **can** change price at a given period
2. *Rotemberg pricing*: firm can change price every period, but s.t. a quadratic 'menu cost'
3. *Taylor contracts*: firm can change price every T periods

Will study Calvo pricing – most common and convenient

Calvo pricing

- ▷ Every period, each firm may change price with probability $1 - \theta$

$\Rightarrow$ at a given period, fraction θ of firms keeps price unchanged

$\Rightarrow$ fraction $1 - \theta$ can set new price

- ▷ average duration of a price $1/(1 - \theta)$ periods
  - ▷ can set θ to match a target duration, e.g. 5 quarters

Aggregate price dynamics

$$\underbrace{(\frac{P_t}{P_{t-1}})}_{1+\pi_t}{}^{1-\varepsilon} = \theta + (1-\theta)(\frac{P_t^*}{P_{t-1}})^{1-\varepsilon}$$

with P_t^* the optimal price set in period t by firms that can change price. Firms identical $\Rightarrow$ P_t^* same for all.
Linearized using Taylor series around steady state with $P_t/P_{t-1} = 1$ and $P_t^*/P_{t-1} = 1$:

$$\pi_t = (1-\theta)(p_t^* - p_{t-1}) \tag{1}$$

- How are optimal prices P_t^* chosen in a sticky price model? $\rightarrow$ coming up next