

Lecture 19: Sticky Prices

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Recapping our business-cycle modeling

- We started with the **real business model**. Two important limitations:
 1. Frictionless consumption and investment decisions. “**Demand shocks**” as reduced-form changes in patience: want more today vs. tomorrow.
 2. **Supply shocks** generate something that looks like the cycle, while **demand shocks** are irrelevant (or move us in the wrong direction) because real rates adjust.
- We worked on relaxing 1.: in richer models of consumption & investment, demand shocks are related to **financial frictions**
- Today start working on 2. – make demand shocks matter. Approach:
 - Dig deeper into **role of r** . Connect to neutrality of money – “real-nominal dichotomy”
 - Break the dichotomy – and make demand matter – via **nominal rigidities**
Firms are sluggish to adjust prices/workers are sluggish to bargain for higher wages.

Outline

1. Demand & Monetary Neutrality

A Nominal RBC Model

Equilibrium Characterization

2. Price Setting

Background: Demand

The Firm Pricing Problem

3. Sticky Prices

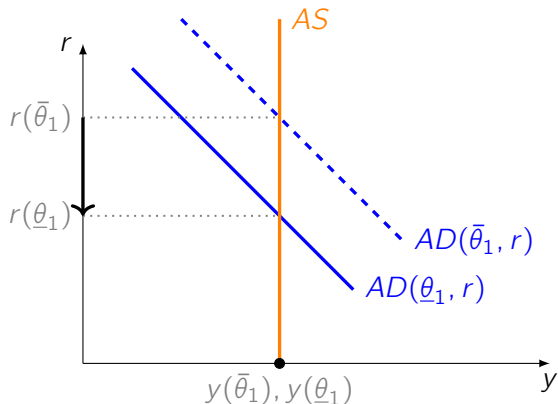
Phillips Curve

The New Keynesian Model

Demand neutrality – prices adjust

Remember our AS-AD figure from the RBC slides:

Prices (= real rates) adjust to balance demand & supply. Economy is supply-determined.



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A nominal version of the RBC model

- Let's dig a little bit deeper into how **real interest rates** are doing that adjustment, and how we could move away from this

- For this we consider a *nominal version* of our RBC model:

For simplicity we will again restrict attention to the labor-only version of the economy.

- Before we normalized the price of the final good at $t = 0$ to 1, then real interest rates gave relative prices over time
 - Now: no normalization, price in dollars denoted by p_t , nominal wage is w_t^n , nominal profits are π_t^n , households save in nominal bonds b_t^n
 - The central bank controls the rate of interest r_t^n on nominal bonds
- **Q:** what happens in this version of our RBC economy?

Households

- Preferences

$$\mathbb{E}_t \left[\sum_{s=0}^{\infty} \beta^s \theta_{t+s} U(c_{t+s}, \ell_{t+s}) \right]$$

- Constraints

- Budget:

$$p_t c_t + b_{t+1}^n = (1 + r_{t-1}^n) b_t^n + w_t^n \ell_t + \pi_t^n, \quad \forall t \geq 0$$

Note that the budget is now in nominal terms. The central bank sets r_t^n , with r_{-1}^n given.

- Feasibility: $\ell_t \geq 0$, $c_t \geq 0$, $b_{t+1}^n \geq \underline{b}$. Initial conditions: $b_0^n = 0$ given.

- The choice variables are the sequences $\{c_t, \ell_t, b_{t+1}^n\}_{t=0}^{\infty}$. Optimality:

$$\partial c_t : \theta_t U_c(c_t, \ell_t) = p_t \lambda_t^n \tag{1}$$

$$\partial \ell_t : -\theta_t U_\ell(c_t, \ell_t) = \lambda_t^n w_t^n \tag{2}$$

$$\partial b_{t+1} : \lambda_t^n = \beta(1 + r_t^n) \mathbb{E}_t [\lambda_{t+1}^n] \tag{3}$$

Households

- Combining (1) and (2):

$$-U_\ell(c_t, \ell_t) = U_c(c_t, \ell_t) \frac{w_t^n}{p_t} \quad (4)$$

- Equate marginal disutility of work to marginal return (= *real* wage), evaluated at marginal utility of consumption.

- Combining (1) and (3):

$$\theta_t U_c(c_t, \ell_t) = \beta \mathbb{E}_t \left[\theta_{t+1} \frac{1 + r_t^n}{1 + \pi_{t+1}} U_c(c_{t+1}, \ell_{t+1}) \right] \quad (5)$$

- Here $1 + \pi_{t+1} = \frac{p_{t+1}}{p_t}$ denotes inflation. Note that

$$1 + r_{t+1} = \frac{1 + r_t^n}{1 + \pi_{t+1}}$$

is the *real* rate of return.

- The nominal firm problem is now

$$\pi_t^n \equiv \max_{k_t^f, \ell_t^f} [p_t A_t F(\ell_t^f) - w_t^n \ell_t^f]$$

- Optimal behavior is thus characterized by the relation

$$w_t^n = p_t A_t F_\ell(\ell_t^f)$$

or equivalently

$$\frac{w_t^n}{p_t} = A_t F_\ell(\ell_t^f)$$

and so again *real* wages equal *real* marginal products

Equilibrium

- We now have an eq'm definition for our nominal model:

Definition

Given stochastic processes for $\{\theta_t, A_t\}_{t=0}^{\infty}$, nominal interest rate policy $\{r_t^n\}_{t=0}^{\infty}$, and an initial nominal price level p_{-1} , an equilibrium is stochastic paths of prices $\{\pi_t, w_t^n\}_{t=0}^{\infty}$, household choice variables $\{c_t, \ell_t, b_t^n\}_{t=0}^{\infty}$, and firm choice variables $\{y_t, \ell_t^f, \pi_t^n\}_{t=0}^{\infty}$, such that:

- (i) Given demand, prices, and firm profits, household choices are optimal. Similarly, given supply and prices, firm choices are optimal.
- (ii) All markets clear. That is:

$$c_t = A_t F(\ell_t), \quad \ell_t = \ell_t^f, \quad b_t^n = 0, \quad \forall t$$

- What can we say about this eq'm?

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Equilibrium characterization

- Straightforward to see: exactly the same as in the real model!
- The *real* side of the economy is characterized by the same four equations as before:

$$\theta_t U_c(c_t, \ell_t) = \beta \mathbb{E}_t [\theta_{t+1} (1 + r_{t+1}) U_c(c_{t+1}, \ell_{t+1})] \quad (6)$$

$$-U_\ell(c_t, \ell_t) = U_c(c_t, \ell_t) w_t \quad (7)$$

$$w_t = A_t F_\ell(\ell_t^f) \quad (8)$$

$$c_t = A_t F(\ell_t) \quad (9)$$

where I use real wages $w_t = \frac{w_t^n}{p_t}$ and real interest rates $1 + r_{t+1} = \frac{1 + r_t^n}{1 + \pi_{t+1}}$. Same four equations in four unknowns as before, so same solution.

- The central bank instead just determines the nominal side—it sets nominal rates r^n , and then prices adjust to deliver the required eq'm real rate:

$$1 + \pi_t = \frac{1 + r_{t-1}^n}{1 + r_t}$$

Real-nominal dichotomy. Real side as before, nominal side determined by central bank.

More on the equilibrium

- Now return to the interest rate relation, known as the **Fisher equation**:

$$1 + \pi_t = \frac{1 + r_{t-1}^n}{1 + r_t}$$

- Note: higher nominal rates here lead to *higher* inflation! Known as the Fisher effect.
- This is not what you'd see in standard policy discourse—view there is that higher rates *lower* inflation.
- Suggests that something important is missing—it's again that demand doesn't matter here! We will revisit this soon ...
Preview: here r_t is unaffected by central bank behavior. We will break that.
- Aside: central bank here sets nominal rates, as is modern practice. Would get the same **real-nominal dichotomy** if instead it set the money supply.

The way forward

- This analysis suggests what to do: **prevent prices** from adjusting instantaneously to re-equilibrate the market [= hit the eq'm r]. Will have the following effects:
 - Monetary policy will start to matter for real quantities. Moving r^n moves r if prices and thus π is sluggish, and moving r affects household & firm behavior
 - Demand in general will start to matter. Prices not flexibly adjusting means supply curve can be non-vertical, i.e. upward-sloping, or even horizontal.
- Challenge: firms in our model are price-takers, they don't set prices. Need them to set prices to get sluggishness in how prices adjust. Thus now:
 1. We first change the firm side to give firms **market power**, so that firms set prices. Will see: if there are no impediments to price changes, then the model is (essentially) unchanged.
 2. Then make **price adjustments costly**. This delivers the desired constraint on π .
Real-world interpretation: costs to re-optimizing/figuring out where exactly to set prices. No instantaneous equilibration via prices adjusting.

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Overview

- So far: perfect competition among firms, take prices—both for the good you're selling, and for the factors you're hiring—as given

- Now: give firms market power, allow them to *set* the price of their good

Note: could also have market power for factors, e.g., a single firm being dominant for workers in a particular profession. But not today.

- Will proceed in two steps:

1. **Demand**: make goods imperfectly substitutable. This gives market power.

So far we considered infinitely elastic demand – all firms sell the same good. Now instead they sell different goods, so price increases don't drop demand to zero. E.g., Apple has pricing power for the iPhone—higher price means less sales, not zero sales.

2. **Firm decisions**: given demand, what price should be set?

- Afterwards: add frictions to the firm price-setting problem

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Consumption of multiple goods

- So far: single homogeneous final good, produced by all firms
- Now suppose instead that the goods of all firms are slightly different. Index goods by $j \in [0, 1]$. Write total household consumption as

$$c = \left(\int_0^1 c(j)^{\frac{\varepsilon-1}{\varepsilon}} dj \right)^{\frac{\varepsilon}{\varepsilon-1}} \quad (10)$$

- $\varepsilon \rightarrow \infty$ is what we've had so far: all goods j are perfectly substitutable, if price slightly higher than competition you lose all demand
 - Now instead $\varepsilon \ll \infty$: goods are imperfectly substitutable
- Next: work out the effect of preferences like (10) for the demand that firm j will face

Consumer demand

- Consumers will maximize consumption,

$$c = \left(\int_0^1 c(j)^{\frac{\varepsilon-1}{\varepsilon}} dj \right)^{\frac{\varepsilon}{\varepsilon-1}}$$

subject to the budget constraint

$$\int_0^1 p(j)c(j)dj = y$$

where y is income

- Taking the first-order condition, we get

$$c^{\frac{1}{\varepsilon}} c(j)^{-\frac{1}{\varepsilon}} = p(j) \cdot \lambda$$

where λ is the Lagrange multiplier

Consumer demand

- Now raise all terms in the equation to $1 - \varepsilon$:

$$c^{\frac{1-\varepsilon}{\varepsilon}} c(j)^{-\frac{1-\varepsilon}{\varepsilon}} = p(j)^{1-\varepsilon} \cdot \lambda^{1-\varepsilon}$$

- Integrate across j :

$$c^{\frac{1-\varepsilon}{\varepsilon}} \int_0^1 c(j)^{\frac{\varepsilon-1}{\varepsilon}} dj = \int_0^1 p(j)^{1-\varepsilon} dj \cdot \lambda^{1-\varepsilon}$$

- Raise to $\frac{1}{1-\varepsilon}$:

$$c^{\frac{1}{\varepsilon}} \underbrace{\left(\int_0^1 c(j)^{\frac{\varepsilon-1}{\varepsilon}} dj \right)^{\frac{1}{1-\varepsilon}}}_{=c^{-\frac{1}{\varepsilon}}} = \left(\int_0^1 p(j)^{1-\varepsilon} dj \right)^{\frac{1}{1-\varepsilon}} \cdot \lambda$$

Consumer demand

- Since the consumption terms cancel we can write

$$\frac{1}{\lambda} = \left(\int_0^1 p(j)^{1-\varepsilon} dj \right)^{\frac{1}{1-\varepsilon}} \equiv p$$

- Why call this p ?
 - p is an av'g price that accounts for partial substitutability between goods.
 $\lambda = 1/p$: value of 1 addt'l dollar is $\frac{1}{p}$, because it yields p addt'l units of consumption.
 - Can then equivalently view the problem as one where there is an aggregate consumption good that costs p

Consumer demand

- Returning to the original first-order condition, we find that

$$c(j) = \left(\frac{p(j)}{p} \right)^{-\varepsilon} \cdot c \quad (11)$$

- We see three key properties of this consumer demand function:
 1. If overall consumption is bigger (c), then each component of consumption gets demanded more
 2. If all goods have the same price, then $c(j) = c$ for all goods. Spend your money equally on all goods.
 3. Fixing c , demand for good j is declining in the relative price of good j . If $\varepsilon \rightarrow \infty$, then either zero or infinite demand if $p(j) \neq p$
- Now: given demand (11), how do firms set prices?

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The firm problem

- Given demand, firms now *set* prices to maximize profits
- For simplicity consider a production function that only uses labor. We can write the problem of firm j as

$$\max \pi^n(j) = p(j)y(j) - C^n(y(j))$$

where the nominal cost function is given as

$$C^n(y(j)) = w^n \ell(j)$$

and output satisfies

$$y(j) = AF(\ell(j)) = \left(\frac{p(j)}{p} \right)^{-\varepsilon} \cdot y$$

- Note that, if $F(\ell(j)) = \ell(j)$, then

$$C^n(y(j)) = \frac{w^n}{A} y(j)$$

Optimality

- The first-order condition for the firm is

$$(1 - \varepsilon)p(j)^{-\varepsilon}p^\varepsilon y + \varepsilon p(j)^{-\varepsilon-1}p^\varepsilon y \mathcal{MC}^n(y(j)) = 0$$

where $\mathcal{MC}^n(\bullet)$ denotes nominal marginal costs

- But this becomes

$$p(j) = \frac{\varepsilon}{\varepsilon - 1} \mathcal{MC}^n(y(j))$$

- Note that marginal costs in general are given as

$$\mathcal{MC}^n(y(j)) = w^n \cdot \frac{1}{AF_\ell(\ell(j))}$$

- And with a constant returns to scale production function this becomes

$$p(j) = \frac{\varepsilon}{\varepsilon - 1} \frac{w^n}{A}$$

- Interpretation: nominal prices are set as a constant mark-up over nominal marginal costs. Firms exploit their market power. [If $\varepsilon \rightarrow \infty$, then prices are just equal to marginal costs.]

Aggregation & general equilibrium

- All firms j are identical, so in eq'm they will set the same price $p(j) = p$. This gives

$$p(j) = p = \frac{\varepsilon}{\varepsilon - 1} \cdot w^n \cdot \frac{1}{AF_\ell(\ell)}$$

and so real wages are given as

$$w = \frac{w^n}{p} = \frac{\varepsilon - 1}{\varepsilon} \cdot AF_\ell(\ell)$$

I.e., real wages are a *markdown* on the worker real marginal product.

- Now return to equations (6) - (9) characterizing equilibrium in our RBC economy. The only change is to replace (8) by the adjusted wage relation

$$w_t = \frac{\varepsilon - 1}{\varepsilon} \cdot A_t F_\ell(\ell_t) \tag{12}$$

Aggregation & general equilibrium

- We conclude that adding imperfect competition only has a moderate effect—depress wages because firms extract surplus from market power.

A pure *level* effect. Make sure you see that demand/supply shocks will still propagate exactly as before.

- Aside: note how the mark-up leads to higher firm profits
 - Using the firm profit equation:

$$\pi_t = y_t - w_t \ell_t = A_t F(\ell_t) - w_t \ell_t$$

- So with constant returns to scale we have

$$\pi_t = (A_t - w_t) \ell_t = \frac{1}{\varepsilon} A_t \ell_t = \frac{1}{\varepsilon} y_t > 0$$

- We thus now have pure profits related to firm market power. As $\varepsilon \rightarrow \infty$, those profits vanish, and we return to the baseline model.

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Adding price adjustment costs

- So far: firms can freely set prices. That makes the problem static: set prices to maximize profits period-by-period, which delivers

$$\mathcal{MC}(y_t) = \frac{\varepsilon - 1}{\varepsilon}, \quad \text{or} \quad w_t = \frac{\varepsilon - 1}{\varepsilon} \cdot A_t F_\ell(\ell_t)$$

I.e., exact mark-up over real marginal costs. The more inelastic demand, the bigger the mark-up.

- Now instead: cost to **changing prices**. Costless to keep prices where they are, but costly to move them away from the current level.

Interpretation: costs of figuring out what new price to set. “Menu costs” less relevant.

- Note that this makes the problem *dynamic*: the price you set today also matters for tomorrow, because you will be reluctant to change it over time.
- Firms’ per-period nominal profits are now

$$\pi_t(j) = p_t(j)y_t(j) - \mathcal{C}^n(y_t(j)) - \underbrace{\frac{\phi}{2} \left(\frac{p_t(j)}{p_{t-1}(j)} - 1 \right)^2 y_t p_t}_{\text{cost of price change}}$$

The extended firm problem

- Firms now choose the *sequence* of prices to maximize profits. As usual they discount at market interest rates. So the problem now is

$$\max \mathbb{E}_0 \left[\sum_{t=0}^{\infty} \left(\prod_{s=0}^t \frac{1}{1+r_s^n} \right) \pi_t^n(j) \right]$$

where nominal profits are given as

$$\pi_t^n(j) = p_t(j)y_t(j) - C^n(y_t(j)) - \frac{\phi}{2} \left(\frac{p_t(j)}{p_{t-1}(j)} - 1 \right)^2 y_t p_t,$$

and with nominal costs and output

$$C^n(y_t(j)) = w_t^n \ell_t(j), \quad y_t(j) = A_t F(\ell_t(j)) = \left(\frac{p_t(j)}{p_t} \right)^{-\varepsilon} \cdot y_t$$

- I will look at a special case of the problem where the firm sits at date t , $\phi > 0$ at that date t , but then ϕ becomes zero after, i.e., no more adjustment costs after t .

Optimal price-setting

- Evaluating the firm's first-order condition at date t with $\phi = 0$ after date $t + 1$, we find

$$\underbrace{(1 - \varepsilon)p_t(j)^{-\varepsilon}p_t^\varepsilon y_t + \varepsilon \mathcal{MC}_t^n(y_t(j))p_t(j)^{-\varepsilon-1}p_t^\varepsilon y_t}_{\text{same as before}} - \underbrace{\phi \left(\frac{p_t(j)}{p_{t-1}(j)} - 1 \right) y_t \frac{p_t}{p_{t-1}(j)}}_{\text{new adj. cost term}} = 0$$

- Proceed as before: since all firms are identical we in eq'm have $p_t(j) = p_t$, so we get

$$(1 - \varepsilon) + \varepsilon \mathcal{MC}_t(y_t) - \phi(1 + \pi_t)\pi_t = 0$$

and so

$$\mathcal{MC}_t(y_t) = \frac{\varepsilon - 1}{\varepsilon} + \frac{\phi}{\varepsilon}(1 + \pi_t)\pi_t = \frac{w_t}{A_t F_\ell(\ell_t)}$$

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Marginal costs and inflation

- Repeat the key relation that we just derived:

$$\frac{w_t}{A_t F_\ell(\ell_t)} = \frac{\varepsilon - 1}{\varepsilon} + \frac{\phi}{\varepsilon}(1 + \pi_t)\pi_t \quad (13)$$

This replaces (8), which I re-state here for convenience & comparison:

$$w_t = A_t F_\ell(\ell_t) \quad (8)$$

- Imperfect competition—i.e., $\varepsilon < \infty$ just adds a mark-up
- Key is price stickiness, $\phi > 0$: now positive relation between inflation and marginal costs
 - Intuition: if real wages are high then firm mark-ups are low, so firms would like to increase prices. But this is slow because of price stickiness.
 - So now we ask: *when* are wages high? And what does this imply for the relationship between inflation and economic activity?
- Next slide: combine (13) with household labor supply to get the “**Phillips Curve**”

Economic activity and inflation

- To make our lives easy let us suppose that production is constant returns to scale and preferences take the usual separable form. We then have

$$\frac{w_t}{A_t} = \frac{\varepsilon - 1}{\varepsilon} + \frac{\phi}{\varepsilon}(1 + \pi_t)\pi_t$$

as the firm pricing relation, as well as

$$\ell_t^{\frac{1}{\phi}} = w_t c_t^{-\gamma}$$

as the household labor supply relation

- Using $c_t = y_t = A_t \ell_t$ this becomes, with some re-arranging,

$$y_t = A_t^{\frac{\frac{1}{\phi}+1}{\frac{1}{\phi}+\gamma}} \cdot \left[\frac{\varepsilon - 1}{\varepsilon} + \frac{\phi}{\varepsilon}(1 + \pi_t)\pi_t \right]^{\frac{1}{\frac{1}{\phi}+\gamma}}$$

- If $\varepsilon < \infty$ and $\phi > 0$, then positive link from inflation to output – upward-sloping “supply”
- Intuition: high production requires high real wages, which given sticky prices we can have if mark-ups are low and inflation is high in order to catch up

The Phillips Curve

- Theory has given us a positive relationship between economic activity and inflation, referred to as the **New Keynesian Phillips Curve**
If adjustment costs ϕ also remain tomorrow, then this relation also features future *expected* inflation. Nothing else changes.
- Name comes from an *empirical* regularity first documented in 1958 by A.W. Phillips: negative relation between **wage inflation and unemployment**.
- For us this relation will be key to get demand & monetary policy to finally matter. What is its modern empirical support?
 - Recall Lecture 13: no clear *unconditional*, average relation between prices and activity
 - But will see next time: *conditional* on a change in demand [e.g., because the central bank cut interest rates], we do see prices and activity co-moving
 - Also there is micro evidence: in the data firms don't change their prices all that frequently

The Phillips Curve

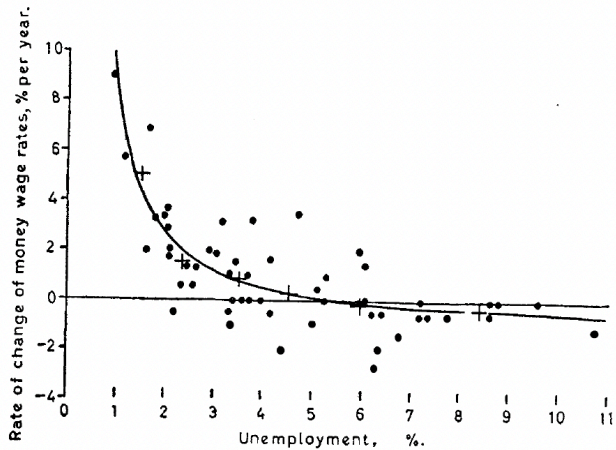


Fig.1. 1861 - 1913

Aside: further comments on nominal rigidities

1. I here did everything via **sticky prices**. Could do **sticky wages** instead.
 - We just need something that slows equilibrating role of prices, so quantities adjust instead
 - In our theory: prices adjust sluggishly, so price mark-ups are not at target – i.e., firms are off their ideal supply curve. Could instead have workers being off their ideal labor supply curve – “sticky wages”. Broadly similar predictions.
2. The trade-off between **activity** and **inflation** is *transitory*, not *permanent*
 - Reflects prices slowly catching up to changes in demand, moving mark-ups back to target. This is inherently *transitory*.
 - Dynamic version of the theory (which we did not cover) makes clear that there is no permanent trade-off – in the long run the economy is described by RBC model equations.
 - History of thought: Friedman (1968) and Phelps (1968) argue that the *long-run* Phillips Curve is again vertical at the RBC level of output

What we are developing here – the New Keynesian model – is a *short-run* model.

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The New Keynesian model

- The New Keynesian model is the RBC model with two twists:

1. The firm wage equation

$$w_t = A_t F_\ell(\ell_t)$$

is replaced by its sticky-price analogue

$$\frac{w_t}{A_t F_\ell(\ell_t)} = \frac{\varepsilon - 1}{\varepsilon} + \frac{\phi}{\varepsilon} (1 + \pi_t) \pi_t$$

2. The central bank sets nominal interest rates r_t^n according to some rule, e.g., interest rates are high when output/inflation are high

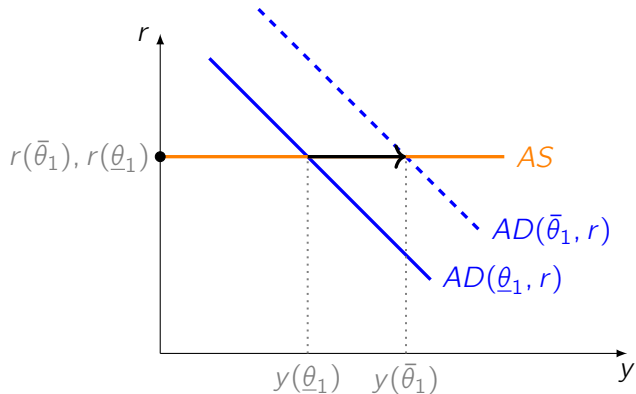
The most famous example of such a rule is a “Taylor rule”. Next time.

- This breaks the RBC model’s property of prices [= real interest rates] adjusting immediately to make the economy entirely supply-determined
 - Recall that real rates are a function of nominal interest rates and inflation.
 - Inflation moves sluggishly because prices are sticky, and nominal interest rates may move sluggishly as they are controlled by the central bank.

The New Keynesian model

- Next slide will have an instructive example: fixed r since ...
 1. Nominal prices are fully rigid [$\phi = 0$]
 2. The central bank fixes the nominal rate of interest
- In general:
 - NKPC is upward-sloping relation between y and π [because of $\phi > 0$], central bank behavior gives upward-sloping relation between real rates r and π ["Taylor principle", more next time]
 - Thus overall we will get an upward-sloping AS curve in y - r space
- Aside: you may ask, why does the central bank not set nominal rates equal to the RBC real rate, so that $\pi = 0$ replicates the RCB eq'm? will return to this

Demand shocks with horizontal AS



- Here demand shocks pass 1-1 into quantities and not prices!
 r is fixed because r^n is fixed (by assumption) and $\pi = 0$ (because $\phi = \infty$).
- We will later apply this logic to study the Great Recession.

Outlook

- We now finally have our framework in which we can get aggregate demand to matter (beyond just moving prices = real interest rates)
- Next time: **test** this framework, **analyze** it further, & **apply** it
 1. **Empirical evidence** on demand shocks mattering: how does monetary policy affect real economic activity?
 2. Solve a simple (static) version of the **New Keynesian model**
This will be just as easy (or hard?) as solving the static RBC model.
 3. Application: **Great Recession**
- After that: implications for monetary & fiscal policy design

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