# Lecture 7
# New Keynesian Model

Macroeconomics EC2B1

Benjamin Moll

London School of Economics, Lent 2023

# New Keynesian Model

- In a nutshell: New Keynesian model = RBC model with sticky prices
- Simple framework to think about relationship between monetary policy, inflation and the business cycle
- RBC model: cannot even think about these issues!
    - real variables are completely separate from nominal variables ("monetary neutrality", "classical dichotomy")
    - corollary: monetary policy has no effect on any real variables
- Sticky prices break "monetary neutrality"
- Sticky prices also break 1st welfare thm $\Rightarrow$ rationale for stabilization policy
- New Keynesian model is current workhorse model at central banks
- Some reason to believe that "demand shocks" (e.g. consumer confidence, "animal spirits") may drive business cycle
    - sticky prices = one way to get this story off the ground

# Why “New” and “Keynesian”?

“New” = methodological

- microfounded
- in contrast to “Old” Keynesian cross, IS-LM (or IS-MP-PC) and Keynesian large-scale macroeconometric models we discussed in Lecture 6

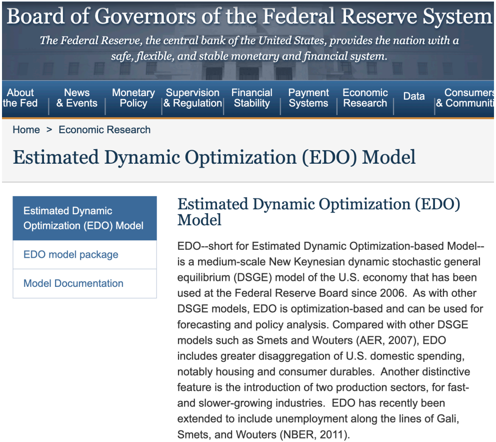
“Keynesian” = substantive

- like in “Old” Keynesian theories, aggregate demand matters, stabilization policy can be desirable
- in contrast to RBC model

Also see discussion in Kurlat, chapter 14.1

# New Keynesian models at the U.S. Fed and ECB

## U.S. Fed EDO model and ECB New Area Wide Model (NAWM)


Board of Governors of the Federal Reserve System

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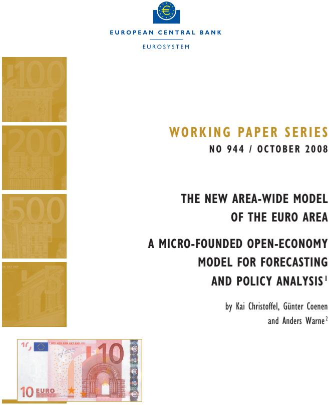
Estimated Dynamic Optimization (EDO) Model

- Estimated Dynamic Optimization (EDO) Model
- EDO model package
- Model Documentation

Estimated Dynamic Optimization (EDO) Model

EDO--short for Estimated Dynamic Optimization-based Model--is a medium-scale New Keynesian dynamic stochastic general equilibrium (DSGE) model of the U.S. economy that has been used at the Federal Reserve Board since 2006. As with other DSGE models, EDO is optimization-based and can be used for forecasting and policy analysis. Compared with other DSGE models such as Smets and Wouters (AER, 2007), EDO includes greater disaggregation of U.S. domestic spending, notably housing and consumer durables. Another distinctive feature is the introduction of two production sectors, for fast- and slower-growing industries. EDO has recently been extended to include unemployment along the lines of Gali, Smets, and Wouters (NBER, 2011).


EUROPEAN CENTRAL BANK

EUROSYSTEM

WORKING PAPER SERIES

NO 944 / OCTOBER 2008

THE NEW AREA-WIDE MODEL OF THE EURO AREA

A MICRO-FOUNDED OPEN-ECONOMY MODEL FOR FORECASTING AND POLICY ANALYSIS[1]

by Kai Christoffel, Günter Coenen and Anders Warne[2]

`https://www.federalreserve.gov/econres/edo-models-about.htm` & `https://www.ecb.europa.eu/pub/pdf/scpwps/ecbwp944.pdf`

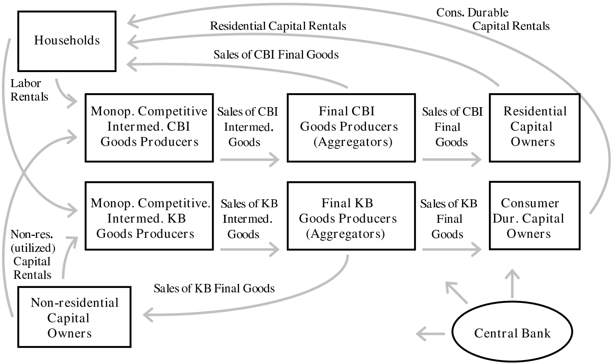
Also see `https://www.richmondfed.org/publications/research/econ_focus/2018/q2/federal_reserve`

# What we'll cover

- Standard New Keynesian model used in academia and central banks is beyond scope of course
    - dynamic stochastic general equilibrium (DSGE) model: like fully-fledged RBC model from last lecture but with sticky prices
    - see e.g. Gali textbook on slide with readings
- We will instead cover two-period version due to Mankiw and Weinzierl
- Most insights and policy implications similar to those of standard New Keynesian model

# New Keynesian models used by central banks are much more complicated but basic structure & logic are the same

Figure 1: Model Overview

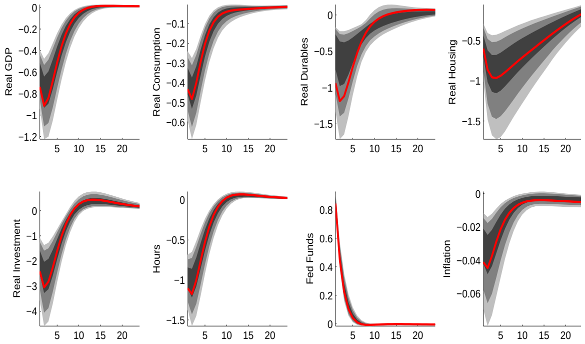



Chung, Kiley, Laforte "Documentation of the Estimated, Dynamic, Optimization-based (EDO) Model of the U.S. Economy: 2010 Version"

https://www.federalreserve.gov/econres/feds/documentation-of-the-estimated-dynamic-optimization-based-edo-model-of-the-us-economy-2010-version.htm

# Effects of interest rate hike in U.S. Fed's own New Keynesian model – our version will feature similar transmission mechanism

Figure 2: Impulse Responses: Funds Rate

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# Plan

1. Introducing money and inflation into the two-period RBC model

2. Flexible prices: monetary neutrality

3. Sticky prices: monetary non-neutrality

Next lecture: policy in the New Keynesian model

# Readings and supplementary materials

1. Supplement on moodle: write-up of model including all the derivations
2. Mankiw & Weinzierl (2011), "An Exploration of Optimal Stabilization Policy"
   - will often abbreviate as "MW"
   - read sections I-IV and IX-X (skip sections V-VIII)
3. EC1P1 Lectures 7 and 8 (parts on money, inflation, quantity theory)
4. Jones, Part 3 "The Short Run", in particular chapters 11 to 13
5. Section "Monetary Policy: What Is the Best Evidence We Have?" in Nakamura and Steinsson (2018) "Identification in Macroeconomics"
   https://eml.berkeley.edu/~enakamura/papers/macroempirics.pdf
6. Further readings for the interested (not examinable)
   - Wikipedia https://en.wikipedia.org/wiki/New_Keynesian_economics
   - Gali's book "Monetary Policy, Inflation, and the Business Cycle"
   - Clarida, Gali and Gertler (1999), "The Science of Monetary Policy: A New Keynesian Perspective"

# Introducing Money and Inflation

# Starting point: competitive equilibrium in baby RBC model

**Definition:** a competitive equilibrium are quantities $(C_1, C_2, I_1, K_2, Y_1, Y_2)$ and an interest rate $r_1$ such that

1. Utility maximization: taking as given $r_1$ and $W$, households choose $(C_1, C_2)$ to solve

$$\max_{C_1, C_2} U(C_1) + \beta U(C_2) \quad \text{s.t.} \quad C_1 + \frac{C_2}{1 + r_1} = W$$

   where $W$ is the PDV of firm profits (because households own firms)

2. Profit maximization: firms maximize $W = \Pi_1 + \frac{\Pi_2}{1+r_1}$ or equivalently

$$W = \max_{K_2} \left\{ A_1 K_1 - I_1 + \frac{A_2 K_2}{1 + r_1} \right\}, \qquad K_2 = I_1, \; Y_1 = A_1 K_1, \; Y_2 = A_2 K_2$$

3. Market clearing: demand = supply for goods

$$\text{goods in period 1:} \quad C_1 + I_1 = Y_1$$

$$\text{goods in period 2:} \quad C_2 = Y_2$$

# Reintroducing Nominal Prices

- So far: simply set price of final consumption goods $P_1 = P_2 = 1$
  - without loss of generality: express price $r_1$ in terms of units consumption good (e.g. apples)
- Now: reintroduce nominal prices
- Example: instead of writing household budget constraint as

$$C_1 + \frac{C_2}{1+r_1} = \Pi_1 + \frac{\Pi_2}{1+r_1}$$

  we now write

$$P_1 C_1 + \frac{P_2 C_2}{1+i_1} = P_1 \Pi_1 + \frac{P_2 \Pi_2}{1+i_1}$$

  where $i_1$ = nominal interest rate, i.e. in terms of \$ rather than apples
- For reasons that will become clear: also introduce “period 0”
  - reference price $P_0$ determined some time before period 1, before households and firms know economic conditions like $A_1, A_2$ etc

# Inflation, real interest rate, Fisher equation

- Definition: the inflation rate is

$$\pi_2 = \frac{P_2 - P_1}{P_1} \quad \text{and} \quad \pi_1 = \frac{P_1 - P_0}{P_0}$$

- Note: main role of "pre-period" 0 = being able to define $\pi_1$
- Definition: real interest rate is nominal interest rate adjusted for inflation

$$1 + r_1 = \frac{1 + i_1}{P_2 / P_1} = \frac{1 + i_1}{1 + \pi_2}$$

- Useful approximation when $r_1 \pi_2$ is small:

$$i_1 \approx r_1 + \pi_2 \qquad (*)$$

- Derivation of approximation

$$1 + i_1 = (1 + r_1)(1 + \pi_2) = 1 + r_1 + \pi_2 + \underbrace{r_1 \pi_2}_{\approx 0} \approx 1 + r_1 + \pi_2$$

- $(*)$ is called "Fisher equation"

# Introducing money: money supply and demand

- Price level $P_t$ will end up being determined by monetary policy and equilibrium in the money market
  - money demand = money supply, $M_t^D = M_t^S$
  - will sometimes drop $D$ and $S$ superscripts and just write $M_t$
  - note: $M_t$ = stock of money
- Money supply: central bank (monetary policy) sets money supply $M_t^S$
- Money demand: follow Mankiw-Weinzierl and assume (see p.216)

$$M_t^D = P_t C_t$$

- Next two slides explain where money demand comes from and reminds you of some key concepts from EC1B1: "velocity" and "quantity equation"

# Recall from EC1B1: “velocity” and “quantity equation”

- **Definition:** Velocity $V_t$ is the average number of times a piece of money turns over (i.e. changes hands) in a year
- Consider economy w nominal GDP = total \$ amount of purchases = $P_t Y_t$
- Velocity answers Q: how large is economy’s required money stock?
  - If money can be used only once $V_t = 1 \Rightarrow M_t^D = P_t Y_t$
  - If money can be used twice $V_t = 2 \Rightarrow M_t^D = P_t Y_t / 2$
  - If money can be used $V_t$ times

$$M_t^D V_t = P_t Y_t \qquad (*)$$

- Equation $(*)$ is called quantity equation
- Really just an accounting identity, one use: observe nominal GDP $P_t Y_t$ and money stock $M_t$, then velocity $V_t = P_t Y_t / M_t$

# Different theories of velocity or (equivalently) money demand

(Note: 2-4 not examinable, only have to know that there exist different theories)

1. Quantity theory: $V_t = V$ fixed and hence $M_t V = P_t Y_t$
2. Other theories of money demand covered in EC1B1, for example the one Lecture 8 in which velocity is given by $\log V_t = \phi i_t + v_t$
3. Baumol-Tobin model: see supplement
4. Cash-in-advance (CIA) models: purchasing goods requires some cash-on-hand which has to be put aside in advance $P_t C_t \leq M_t$

# Mankiw-Weinzierl's version of quantity equation

- Follow Mankiw-Weinzierl and assume quantity theory with fixed velocity
- But MW write things slightly differently (see p.216)

$$\mathbb{M}_t = \phi P_t C_t$$

- Two differences to standard quantity theory $M_t V = P_t Y_t$
  1. MW's quantity equation only applies to purchases of consumption goods (like in CIA model) $\mathbb{M}_t V = P_t C_t$
  2. MW use different notation $V = \frac{1}{\phi}$
- Finally, MW simply redefine $M_t = \mathbb{M}_t V = \mathbb{M}_t / \phi$ and write

$$M_t = P_t C_t$$

- Will use this version going forward

# Monetary policy in this model: $i_1$ and $M_2$

- Follow MW and assume central bank has two policy instruments
  1. $i_1$: nominal interest rate between periods 1 and 2
  2. $M_2^S$: money supply in period 2

- Money supply in period 1, $M_1^S$, will be whatever is needed to implement $i_1$
  - more on this later

- Why is monetary policy not only setting $i_1$? Why not only $(M_1^S, M_2^S)$?
  - more on this later

# Flexible Prices: Monetary Neutrality

# Flexible prices: monetary neutrality

- Start by considering version with flexible prices $P_1$ and $P_2$
- Next: sticky prices = defining assumption of New Keynesian model
- **Definition:** Neutrality of money means that a change in monetary variables like nominal interest rates or the stock of money
  - affects only nominal variables such as prices and nominal wages
  - but has no effect on real (inflation-adjusted) variables, like employment, real GDP, and real consumption
- Will show: with flexible prices, monetary neutrality holds in our economy
  - real variables $(C_1, C_2, I_1, Y_1, Y_2)$ do not depend on central bank's policy tools, $i_1$ or $M_2$
  - only nominal variables, $P_1$ and $P_2$ do
  - later: with sticky prices monetary neutrality no longer holds

# Competitive equilibrium with flexible prices

**Definition:** a competitive equilibrium are quantities $(C_1, C_2, I_1, K_2, Y_1, Y_2, M_1, M_2)$ and prices $(i_1, P_1, P_2)$ such that

1. Utility maximization: taking as given $(i_1, P_1, P_2)$ and $\Omega$, households choose $(C_1, C_2)$ to solve

$$\max_{C_1, C_2} U(C_1) + \beta U(C_2) \quad \text{s.t.} \quad P_1 C_1 + \frac{P_2 C_2}{1 + i_1} = \Omega$$

   where $\Omega$ is the PDV of nominal firm profits (because households own firms)

2. Profit maximization: firms maximize $\Omega = P_1 \Pi_1 + \frac{P_2 \Pi_2}{1+i_1}$ or equivalently

$$\Omega = \max_{K_2} \left\{ P_1 (A_1 K_1 - I_1) + \frac{P_2 A_2 K_2}{1 + i_1} \right\}, \quad K_2 = I_1, \; Y_1 = A_1 K_1, \; Y_2 = A_2 K_2$$

3. Market clearing: demand = supply for goods

$$\begin{aligned} \text{goods:} \quad & C_1 + I_1 = Y_1, \qquad C_2 = Y_2 \\ \text{money:} \quad & P_1 C_1 = M_1, \qquad P_2 C_2 = M_2 \end{aligned}$$

4. Policy: $(i_1, M_2)$ are set exogenously by monetary policy

# Flexible prices: monetary neutrality

Proof that flexible prices $\Rightarrow$ monetary neutrality is simple and general

This slide: steps of general proof that works in large class of models

Next slides: apply steps to particular 2-period model we're covering

Steps of general proof: with flexible prices

1. can rewrite all equations in real terms by dividing through by price level
2. this results in a block of self-contained equilibrium conditions for the real variables that do not depend on any nominal variables
3. therefore the equilibrium real variables do not depend on nominal variables $\Rightarrow$ monetary neutrality

# Flexible prices: monetary neutrality

Application to our particular 2-period model: with flexible prices

1. can rewrite all equations in real terms by dividing through by price level
   - divide through by $P_1$
2. this results in a block of self-contained equilibrium conditions for the real variables that do not depend on any nominal variables
   - this block = same as equilibrium conditions in “baby RBC model”
3. therefore the equilibrium real variables do not depend on nominal variables $\Rightarrow$ monetary neutrality
   - real allocation same as in baby RBC model

# Example of step 1: rewrite budget constraint in real terms

- Recall household budget constraint in nominal terms

$$P_1 C_1 + \frac{P_2 C_2}{1 + i_1} = P_1 \Pi_1 + \frac{P_2 \Pi_2}{1 + i_1}$$

- Divide by $P_1$

$$C_1 + \frac{P_2 C_2}{P_1(1 + i_1)} = \Pi_1 + \frac{P_2 \Pi_2}{P_1(1 + i_1)}$$

- Use definition of real interest rate $1 + r_1 = (1 + i_1)P_1/P_2$

$$C_1 + \frac{C_2}{1 + r_1} = \Pi_1 + \frac{\Pi_2}{1 + r_1}$$

- Therefore clearly, solution to household's problem is same as before

- Next follow same logic for entire economy

# Step 1: rewrite all equations in real terms ...

**Definition:** a competitive equilibrium are quantities $(C_1, C_2, I_1, K_2, Y_1, Y_2, M_1, M_2)$ and prices $(i_1, P_1, P_2)$ such that

1. Utility maximization: taking as given $(i_1, P_1, P_2)$ and $\Omega$, households choose $(C_1, C_2)$ to solve

$$\max_{C_1, C_2} U(C_1) + \beta U(C_2) \quad \text{s.t.} \quad P_1 C_1 + \frac{P_2 C_2}{1 + i_1} = \Omega$$

   where $\Omega$ is the PDV of nominal firm profits (because households own firms)

2. Profit maximization: firms maximize $\Omega = P_1 \Pi_1 + \frac{P_2 \Pi_2}{1+i_1}$ or equivalently

$$\Omega = \max_{K_2} \left\{ P_1 (A_1 K_1 - I_1) + \frac{P_2 A_2 K_2}{1 + i_1} \right\}, \quad K_2 = I_1, \; Y_1 = A_1 K_1, \; Y_2 = A_2 K_2$$

3. Market clearing: demand = supply for goods

$$\text{goods:} \quad C_1 + I_1 = Y_1, \qquad C_2 = Y_2$$
$$\text{money:} \quad P_1 C_1 = M_1, \qquad P_2 C_2 = M_2$$

4. Policy: $(i_1, M_2)$ are set exogenously by monetary policy

# Step 1: ... divide by $P_1$

**Definition:** a competitive equilibrium are quantities $(C_1, C_2, I_1, K_2, Y_1, Y_2, M_1, M_2)$ and prices $(i_1, P_1, P_2)$ such that

1. Utility maximization: taking as given $(i_1, P_1, P_2)$ and $\Omega$, households choose $(C_1, C_2)$ to solve
$$\max_{C_1, C_2} U(C_1) + \beta U(C_2) \quad \text{s.t.} \quad C_1 + \frac{P_2 C_2}{P_1(1+i_1)} = \frac{\Omega}{P_1}$$
where $\Omega$ is the PDV of nominal firm profits (because households own firms)
2. Profit maximization: firms maximize $\Omega / P_1 = \Pi_1 + \frac{P_2 \Pi_2}{P_1(1+i_1)}$ or equivalently
$$\frac{\Omega}{P_1} = \max_{K_2} \left\{ A_1 K_1 - I_1 + \frac{P_2 A_2 K_2}{P_1(1+i_1)} \right\}, \quad K_2 = I_1, \; Y_1 = A_1 K_1, \; Y_2 = A_2 K_2$$
3. Market clearing: demand = supply for goods
$$\begin{aligned} \text{goods:} \quad & C_1 + I_1 = Y_1, \qquad C_2 = Y_2 \\ \text{money:} \quad & P_1 C_1 = M_1, \qquad P_2 C_2 = M_2 \end{aligned}$$
4. Policy: $(i_1, M_2)$ are set exogenously by monetary policy

# Step 1: ... and use $1+r_1=(1+i_1)P_1/P_2$ and real firm value $W=\Omega/P_1$

**Definition:** a competitive equilibrium are quantities $(C_1, C_2, I_1, K_2, Y_1, Y_2, M_1, M_2)$ and prices $(i_1, P_1, P_2)$ such that

1. Utility maximization: taking as given $1+r_1=(1+i_1)P_1/P_2$ and $W$, households choose $(C_1, C_2)$ to solve

$$\max_{C_1,C_2} U(C_1)+\beta U(C_2) \quad \text{s.t.} \quad C_1+\frac{C_2}{1+r_1}=W$$

   where $W$ is the PDV of real firm profits (because households own firms)

2. Profit maximization: firms maximize $W=\Pi_1+\frac{\Pi_2}{1+r_1}$ or equivalently

$$W=\max_{K_2}\left\{A_1K_1-I_1+\frac{A_2K_2}{1+r_1}\right\}, \quad K_2=I_1,\ Y_1=A_1K_1,\ Y_2=A_2K_2$$

3. Market clearing: demand = supply for goods

$$\begin{aligned} \text{goods:} \quad & C_1+I_1=Y_1, \qquad C_2=Y_2 \\ \text{money:} \quad & P_1C_1=M_1, \qquad P_2C_2=M_2 \end{aligned}$$

4. Policy: $(i_1, M_2)$ are set exogenously by monetary policy

# Step 2: real variables solve eqn's that do not depend on nominal stuff

Real quantities $(C_1, C_2, I_1, K_2, Y_1, Y_2)$ and the price $r_1$ are such that

1. Utility maximization: taking as given $r_1, W$, households choose $(C_1, C_2)$ to solve
$$\max_{C_1, C_2} U(C_1) + \beta U(C_2) \quad \text{s.t.} \quad C_1 + \frac{C_2}{1+r_1} = W$$
where $W$ is the PDV of real firm profits (because households own firms)

2. Profit maximization: firms maximize $W = \Pi_1 + \frac{\Pi_2}{1+r_1}$ or equivalently
$$W = \max_{K_2} \left\{ A_1 K_1 - I_1 + \frac{A_2 K_2}{1+r_1} \right\}, \quad K_2 = I_1,\ Y_1 = A_1 K_1,\ Y_2 = A_2 K_2$$

3. Market clearing: $C_1 + I_1 = Y_1$ and $C_2 = Y_2$

Nominal quantities $(M_1, M_2)$ and prices $(i_1, P_1, P_2)$ are such that

1. Money market: $P_1 C_1 = M_1$ and $P_2 C_2 = M_2$
2. Policy: $(i_1, M_2)$ are set exogenously by monetary policy
3. Definition of real interest rate: $(1+i_1)P_1/P_2 = 1 + r_1$

# Step 3: therefore solution does not depend on nominal stuff

Equilibrium real quantities $(C_1, C_2, I_1, K_2, Y_1, Y_2)$ and the price $r_1$ are given by

$$
\begin{aligned}
C_1 &= \frac{\left(\frac{1}{\beta A_2}\right)^{\sigma} A_2}{1 + \left(\frac{1}{\beta A_2}\right)^{\sigma} A_2} A_1 K_1 \\
C_2 &= \frac{A_2}{1 + \left(\frac{1}{\beta A_2}\right)^{\sigma} A_2} A_1 K_1 \\
K_2 = I_1 &= \frac{1}{1 + \left(\frac{1}{\beta A_2}\right)^{\sigma} A_2} A_1 K_1 \\
Y_1 &= A_1 K_1 \\
Y_2 &= \frac{A_2}{1 + \left(\frac{1}{\beta A_2}\right)^{\sigma} A_2} A_1 K_1 \\
1 + r_1 &= A_2
\end{aligned}
$$

Clearly solution does not depend on nominal variables $\Rightarrow$ monetary neutrality!

# What about the nominal variables?

Recall: Nominal quantities $(M_1, M_2)$ and prices $(i_1, P_1, P_2)$ are such that

1. Money market: $P_1 C_1 = M_1$ and $P_2 C_2 = M_2$
2. Policy: $(i_1, M_2)$ are set exogenously by monetary policy
3. Definition of real interest rate: $(1 + i_1) P_1 / P_2 = 1 + r_1$

Already know $(C_1, C_2, r_1)$ so have 3 equations for 3 unknowns $(P_1, P_2, M_1)$

Can show (see supplement):

$$P_1 = \frac{1 + \left(\frac{1}{\beta A_2}\right)^{\sigma} A_2}{A_1 K_1} \frac{M_2}{1 + i_1}$$

$$P_2 = \frac{1 + \left(\frac{1}{\beta A_2}\right)^{\sigma} A_2}{A_2 A_1 K_1} M_2$$

$$M_1 = \left(\frac{1}{\beta A_2}\right)^{\sigma} A_2 \frac{M_2}{1 + i_1}$$

# Classical dichotomy

- **Definition:** an economy displays the classical dichotomy if all real variables are determined independently of the nominal variables and therefore real and nominal variables can be analyzed separately
- Clearly the model with flexible prices has this feature
- Also see wikipedia: `https://en.wikipedia.org/wiki/Classical_dichotomy`

# Classical dichotomy can be seen clearly in this slide

Real quantities $(C_1, C_2, I_1, K_2, Y_1, Y_2)$ and the price $r_1$ are such that

1. Utility maximization: taking as given $r_1, W$, households choose $(C_1, C_2)$ to solve
$$\max_{C_1, C_2} U(C_1) + \beta U(C_2) \quad \text{s.t.} \quad C_1 + \frac{C_2}{1+r_1} = W$$
where $W$ is the PDV of real firm profits (because households own firms)
2. Profit maximization: firms maximize $W = \Pi_1 + \frac{\Pi_2}{1+r_1}$ or equivalently
$$W = \max_{K_2} \left\{ A_1 K_1 - I_1 + \frac{A_2 K_2}{1+r_1} \right\}, \quad K_2 = I_1, \; Y_1 = A_1 K_1, \; Y_2 = A_2 K_2$$
3. Market clearing: $C_1 + I_1 = Y_1$ and $C_2 = Y_2$

Nominal quantities $(M_1, M_2)$ and prices $(i_1, P_1, P_2)$ are such that

1. Money market: $P_1 C_1 = M_1$ and $P_2 C_2 = M_2$
2. Policy: $(i_1, M_2)$ are set exogenously by monetary policy
3. Definition of real interest rate: $(1 + i_1) P_1 / P_2 = 1 + r_1$

# Monetary policy only affects price level and inflation

- Recall monetary policy instruments $(i_1, M_2)$
- What if central bank cuts interest rate $i_1$ or prints more money $M_2$?
- Already know: monetary policy has no effect on real variables. Does it affect anything?
- Yes: price level and inflation. Recall:

$$P_1 = \frac{1 + \left(\frac{1}{\beta A_2}\right)^\sigma A_2}{A_1 K_1} \frac{M_2}{1+i_1}, \quad P_2 = \frac{1 + \left(\frac{1}{\beta A_2}\right)^\sigma A_2}{A_2 A_1 K_1} M_2, \quad 1 + \pi_2 = \frac{P_2}{P_1} = \frac{1+i_1}{A_2}$$

- Printing money $M_2$ increases price level $P_1$, $P_2$ (classic quantity theory)
  - can also show: higher money growth $M_2/M_1 \Rightarrow$ higher inflation $\pi_2$
- Interest rate cut $i_1 \downarrow$
  - raises price level $P_1$ and short-run inflation, $1 + \pi_1 = P_1/P_0$
  - counterintuitively, lowers long-run inflation $\pi_2$, i.e. interest rate cuts are deflationary in long-run ("Neo-Fisherism")

# Alternative way of thinking about determination of $P_1$: aggregate demand = aggregate supply (only useful later)

- Recall goods market clearing condition in period 1

$$C_1 + I_1 = Y_1 \quad \text{with} \quad Y_1 = A_1 K_1$$

- Can think about left-hand side as aggregate demand

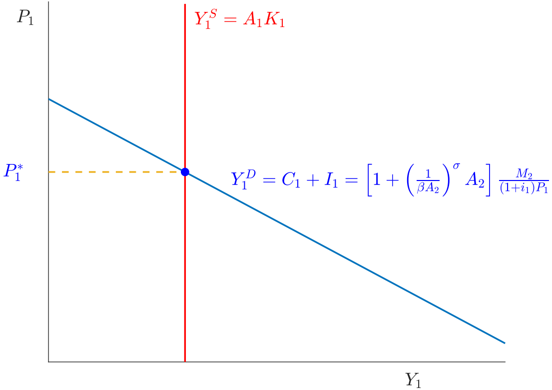
$$Y_1^D = C_1 + I_1$$

and right-hand side as aggregate supply

$$Y_1^S = A_1 K_1$$

- By doing some algebra, can write $Y_1^D$ as function of price level $P_1$
- Note: this mixes real and nominal variables
  - given classical dichotomy, a very strange thing to do
  - but let's do it anyway because it will be useful later when classical dichotomy fails with sticky prices

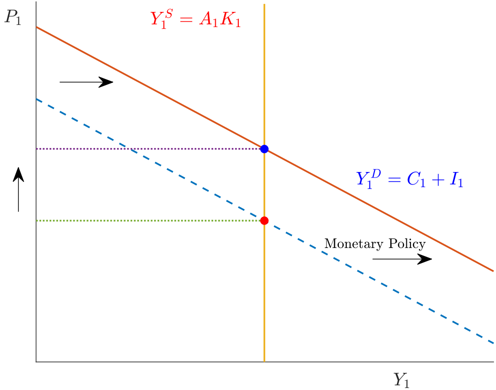
# Aggregate demand = aggregate supply (only useful later)




Can check: price level that equates aggregate demand and supply is

$$P_1^* = \frac{1 + \left(\frac{1}{\beta A_2}\right)^\sigma A_2}{A_1 K_1} \frac{M_2}{1 + i_1}$$

# Monetary policy only affects price level and inflation




Monetary policy $i_1 \downarrow$ or $M_2 \uparrow$ increases $Y_1^D$ but this only shows up in $P_1 \uparrow$

$$Y_1^D = \left[1 + \left(\frac{1}{\beta A_2}\right)^{\sigma} A_2\right] \frac{M_2}{(1 + i_1) P_1}$$

# Flexible prices: summary and policy implications

- Real variables are completely separate from nominal variables ("monetary neutrality", "classical dichotomy")
- Corollary: monetary policy has no effect on any real variables
- Monetary policy affects only price level and inflation
- 1st welfare theorem still holds: policy intervention undesirable in first place
- Stabilization policy? When there is a recession (e.g. due to $A_1$ or $A_2 \downarrow$)
  - stabilization via fiscal policy is undesirable
  - stabilization via monetary policy is not possible (even if it were, it would be undesirable)
- Role of central bank? It can manage price level and inflation but those do not matter so may as well close down central bank

# Only one problem: empirical evidence rejects monetary neutrality

- For summary of evidence, see section "Monetary Policy: What Is the Best Evidence We Have?" in Nakamura and Steinsson (2018)
- One test of neutrality: do real interest rates change when the central bank changes nominal interest rates? If they do, so will other real variables.
  - monetary neutrality: they don't, only inflation responds
  - in our model: $1 + r_1 = A_2$ regardless of $i_1$
- A number of papers study real rates and find non-neutrality. Example:

HIGH-FREQUENCY IDENTIFICATION OF MONETARY NON-NEUTRALITY: THE INFORMATION EFFECT*

EMI NAKAMURA AND JÓN STEINSSON

We present estimates of monetary non-neutrality based on evidence from high-frequency responses of real interest rates, expected inflation, and expected output growth. Our identifying assumption is that unexpected changes in interest rates in a 30-minute window surrounding scheduled Federal Reserve announcements arise from news about monetary policy. In response to an interest rate hike, nominal and real interest rates increase roughly one-for-one, several years out into the term structure, while the response of expected inflation is small. At the same time,

# Sticky Prices: Monetary Non-Neutrality

# Sticky prices

- Will change one single assumption
    - that prices are perfectly flexible in the short run (period 1)
- This will change results and policy implications dramatically
- Recall: first welfare theorem holds when there are no “frictions”
- Sticky prices are exactly such a friction $\Rightarrow$ break first welfare theorem
- Alternative assumption with similar implications: sticky wages
- Before developing model: why do we think prices could be sticky?

# Reasons for price stickiness

Many different theories of sticky prices. Two most common ones:

1. Menu costs:
    - firm pays fixed cost to change prices (e.g. print new restaurant menu)
    - $\Rightarrow$ only change price when payoff is large enough to cover fixed cost
2. (Rational) inattention:
    - acquiring information is costly
    - firms optimally choose to not pay attention to what's going on all the time, in particular monetary policy

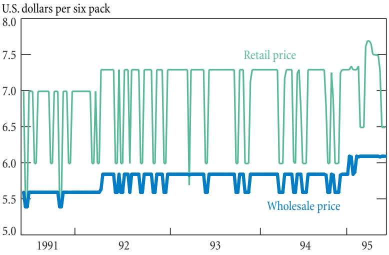
# Empirical evidence on price stickiness

**Sticky Prices: Why Firms Hesitate to Adjust the Price of Their Goods**

***Pinelopi Goldberg and Rebecca Hellerstein***

*Price stickiness—the tendency of prices to remain constant despite changes in supply and demand—has been linked to firms' unwillingness to pay the costs entailed in setting, implementing, and advertising new prices. However, there is little consensus on the size and importance of these "repricing costs." Taking the imported beer market as their subject, the authors of this study find repricing costs to be markedly higher for manufacturers than for retailers and conclude that, at the wholesale level, these costs are a significant deterrent to price adjustment.*

Weekly Retail and Wholesale Prices for *Britannia* Beer



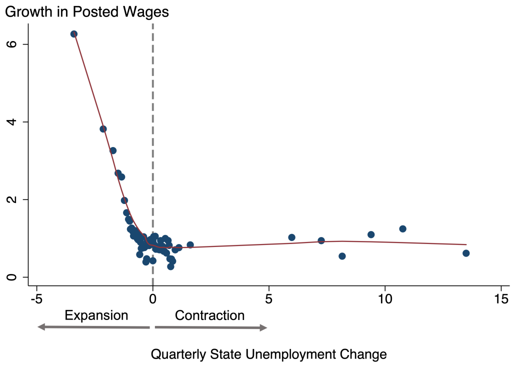

Note: Britannia = fictional name of "popular British beer brand"

Source: Goldberg and Hellerstein (2007) "Sticky Prices: Why Firms Hesitate to Adjust the Price of Their Goods"

https://www.newyorkfed.org/medialibrary/media/research/current_issues/ci13-10.pdf

# Empirical evidence on wage stickiness

**Figure 1:** Nominal Posted Wage Growth at the Job Level and Unemployment Changes




Notes: the graph plots wage growth of nominal posted wages, in percent, from Burning Glass; and state by quarter unemployment changes, in percentage points, from the Local Area Unemployment Statistics. The sample period is 2010Q1-2020Q2. To construct wage growth, we take the mean wage within each job and quarter, and then take log differences at the job level. We collect wage growth and unemployment changes into 100 bins, and add a non-parametric regression line.

Source: Hazell (2022) "Downward Rigidity in the Wage for New Hires"

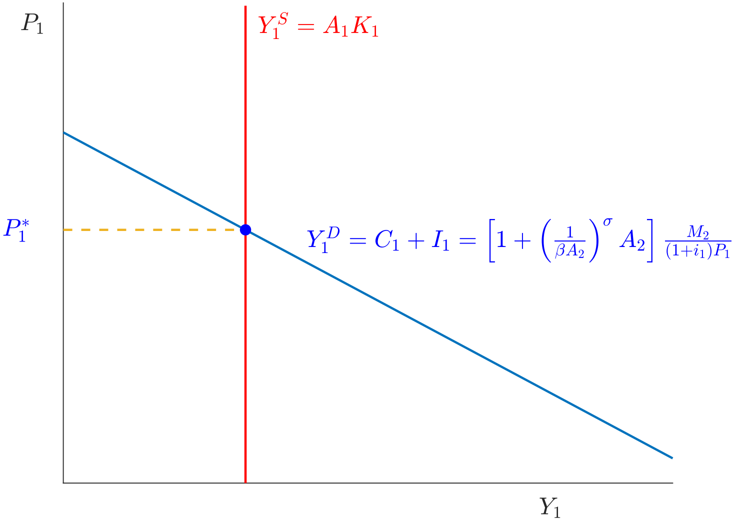
# Modeling price stickiness in practice

- Menu costs, inattention are simple ideas but surprisingly hard to model
  - models usually too complicated to embed in full macro model
- In practice often Calvo pricing: firms are allowed to change price with exogenous probability $\alpha$ ("Calvo fairy")
- Calvo pricing is example of time-dependent sticky prices
- In contrast to state-dependent models, e.g. menu costs, inattention
- State-depedent models often considered more satisfactory
- Paul Krugman in characteristically provocative fashion: "While I regard the evidence for such stickiness as overwhelming, the assumption of at least temporarily rigid nominal prices is one of those things that works beautifully in practice but very badly in theory." (https://web.mit.edu/krugman/www/islm.html)

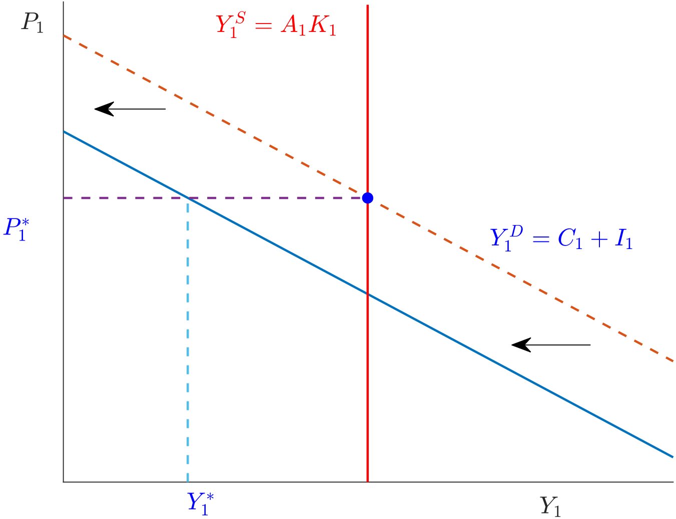
# Our assumption: $P_1$ is completely fixed

- Will make even more simplistic assumption: $P_1$ is completely fixed
  - idea: firms have set prices some time before period 1, before knowing economic conditions like $A_1, A_2$ etc, can not change them anymore
  - so $P_1 = P_0$ where $P_0$ is reference price set in pre-period 0 from earlier
- In contrast $P_2$ is flexible
- Captures common idea in macroeconomics: prices are sticky in short run (period 1) but flexible in long run (period 2)
- End of slides: briefly discuss less extreme assumption = partial stickiness

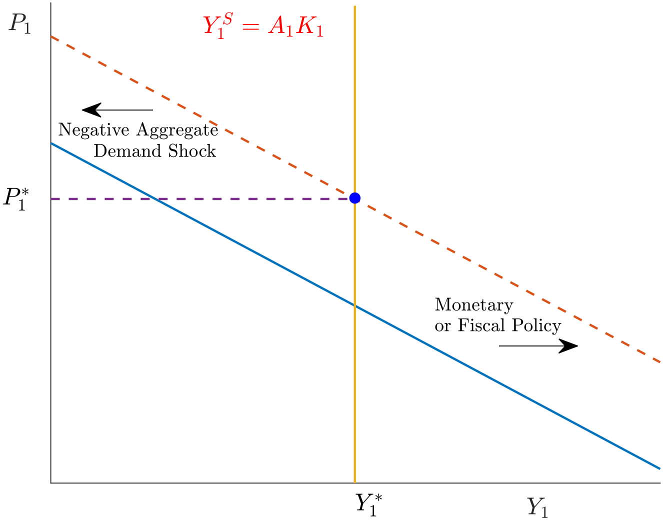
# Preview: equilibrium with sticky prices



## Preview: with sticky prices, a negative demand shock causes recession



# Preview: monetary or fiscal policy can counteract recession



# What is a negative demand shock?

In our simple model, two parameter capture demand effects

1. A change in beliefs at $t = 1$ that future productivity $A_2 \downarrow$ so that households suddenly become more pessimistic about the future
   - called a “news shock” in economics literature
   - drop in $A_2$ does not even have to materialize, it’s enough that households believe it will happen
   - if drop in $A_2$ materializes, $A_2 \downarrow$ is also a supply shock at $t = 2$
2. Patience $\beta \uparrow$ so that households suddenly become more thrifty, want to spend less and save more

Will see clearly in equations below why these two parameters capture demand effects

# Equilibrium with sticky prices

**Def'n:** an equilibrium are quantities $(C_1, C_2, I_1, K_2, Y_1, Y_2, M_1, M_2)$ & prices $(i_1, P_1, P_2)$

1. Utility maximization: taking as given $(i_1, P_1, P_2)$ and $\Omega$, households choose $(C_1, C_2)$ to solve

$$\max_{C_1, C_2} U(C_1) + \beta U(C_2) \quad \text{s.t.} \quad P_1 C_1 + \frac{P_2 C_2}{1 + i_1} = \Omega$$

   where $\Omega$ is the PDV of nominal firm profits (because households own firms)

2. Profit maximization: firms maximize $\Omega = P_1 \Pi_1 + \frac{P_2 \Pi_2}{1+i_1}$ or equivalently

$$\Omega = \max_{K_2} \left\{ P_1 (Y_1 - I_1) + \frac{P_2 A_2 K_2}{1 + i_1} \right\}, \quad K_2 = I_1, \ Y_1^S = A_1 K_1, \ Y_2 = A_2 K_2$$

3. Market clearing: demand = supply for goods

$$\text{goods:} \quad Y_1 = \min\{Y_1^D, Y_1^S\} \ \text{ with } \ Y_1^D = C_1 + I_1, \qquad C_2 = Y_2$$

$$\text{money:} \quad P_1 C_1 = M_1, \qquad P_2 C_2 = M_2$$

4. Policy: $(i_1, M_2)$ are set exogenously by monetary policy
5. Sticky prices: $P_1$ is completely fixed at some exogenous value

# Explanation of new terms on previous slide

- Perfectly sticky $P_1 \Rightarrow$ goods market at $t = 1$ not necessarily in equilibrium
  - see graph on earlier slide
  - recall: agg demand $= Y_1^D = C_1 + I_1$, agg supply $= Y_1^S = A_1 K_1$
- Actual GDP $Y_1$ is determined by short side of the market
  - when demand is strong, GDP is at potential: $Y_1 = Y_1^S = A_1 K_1$
  - when demand is weak, GDP is below potential: $Y_1 = Y_1^D < A_1 K_1$
  - more precisely $Y_1 = \min\{Y_1^D, Y_1^S\}$ $= \min\{C_1 + I_1, A_1 K_1\}$
- Will sometimes call $Y_1^S = A_1 K_1 =$ "potential GDP" and $Y_1 =$ "actual GDP" and gap between the two $Y_1 - Y_1^S =$ "output gap"
- Interesting case: a negative demand shock pushes GDP below potential
- **Assumption:** parameters are such that $Y_1^D \leq Y_1^S$, i.e. demand is either at potential or below (never have excess demand, $Y_1^D > Y_1^S$)

# Equilibrium with sticky prices (also see Mankiw-Weinzierl's equations)

The equilibrium allocation with perfectly sticky $P_1$ equals

$$C_1 = \left(\frac{1}{\beta A_2}\right)^{\sigma} A_2 \frac{M_2}{(1+i_1)P_1}$$

$$C_2 = A_2 \frac{M_2}{(1+i_1)P_1}$$

$$I_1 = \frac{M_2}{(1+i_1)P_1}$$

$$Y_1 = \left[1 + \left(\frac{1}{\beta A_2}\right)^{\sigma} A_2\right] \frac{M_2}{(1+i_1)P_1}$$

$$Y_2 = A_2 \frac{M_2}{(1+i_1)P_1}$$

$$P_2 = \frac{1+i_1}{A_2} P_1$$

Note: equations are identical to MW's equations (31)-(36) with $G_1 = 0$ and $g_2 = 0$

# Sticky prices break monetary neutrality

Clearly allocation now depends on nominal variables $\Rightarrow$ ~~monetary neutrality~~!

$$C_1 = \left(\frac{1}{\beta A_2}\right)^{\sigma} A_2 \frac{M_2}{(1+i_1)P_1}$$

$$C_2 = A_2 \frac{M_2}{(1+i_1)P_1}$$

$$I_1 = \frac{M_2}{(1+i_1)P_1}$$

$$Y_1 = \left[1 + \left(\frac{1}{\beta A_2}\right)^{\sigma} A_2\right] \frac{M_2}{(1+i_1)P_1}$$

$$Y_2 = A_2 \frac{M_2}{(1+i_1)P_1}$$

$$P_2 = \frac{1+i_1}{A_2} P_1$$

# With sticky prices, a negative demand shock causes a recession

Recall: two parameter capture demand effects

1. A change in beliefs at $t = 1$ that $A_2 \downarrow$ so that households suddenly become more pessimistic about the future

2. Patience $\beta \uparrow$ so that households want to spend less and save more

These cause recession at $t = 1$ (recall assumption that $\sigma < 1$ – see lecture 5):

$$C_1 = \left(\frac{1}{\beta A_2}\right)^{\sigma} A_2 \frac{M_2}{(1+i_1)P_1}$$

$$Y_1 = \left[1 + \left(\frac{1}{\beta A_2}\right)^{\sigma} A_2\right] \frac{M_2}{(1+i_1)P_1}$$

In contrast, with flexible prices, GDP $Y_1 = A_1 K_1$ is unaffected when $A_2 \downarrow$ or $\beta \uparrow$

# With sticky prices, a negative demand shock causes a recession

Recall: two parameter capture demand effects

1. A change in beliefs at $t = 1$ that $A_2 \downarrow$ so that households suddenly become more pessimistic about the future
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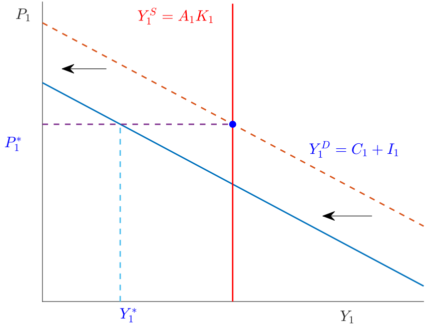


# Key observation: with sticky prices household income depends on aggregate demand

Recall household budget constraint and firm's problem

$$P_1 C_1 + \frac{P_2 C_2}{1+i_1} = \Omega, \qquad \Omega = \max_{K_2} \left\{ P_1(Y_1 - I_1) + \frac{P_2 A_2 K_2}{1+i_1} \right\}, \quad Y_1 = Y_1^D$$

Using optimality condition for investment: $P_1 = P_2 A_2/(1+i_1)$

$$P_1 C_1 + \frac{P_2 C_2}{1+i_1} = \Omega, \qquad \Omega = P_1 Y_1, \qquad Y_1 = Y_1^D$$

Intuition: **one person's spending is someone else's income**

Generates Keynesian-cross-type feedback loop:

- $C_1 \downarrow \Rightarrow Y_1^D = C_1 + I_1 \downarrow \Rightarrow Y_1 = Y_1^D \downarrow \Rightarrow \Omega = P_1 Y_1 \downarrow \Rightarrow C_1 \downarrow$ and so on
- Here this works through dividend payments: demand $\uparrow \Rightarrow$ firm production $\uparrow \Rightarrow$ firm profits and dividend payments $\uparrow \Rightarrow$ household capital income $\uparrow$
- In more general models also through labor income: demand $\uparrow \Rightarrow$ firm production $\uparrow \Rightarrow$ household labor income $\uparrow$

# More on $\beta \uparrow$: the "Paradox of Thrift"

Compare effect of $\beta \uparrow$ = want to spend less, save more

- **Flexible prices:**

$$C_1 = \frac{\left(\frac{1}{\beta A_2}\right)^{\sigma} A_2}{1 + \left(\frac{1}{\beta A_2}\right)^{\sigma} A_2} A_1 K_1 \quad \downarrow$$

$$I_1 = \frac{1}{1 + \left(\frac{1}{\beta A_2}\right)^{\sigma} A_2} A_1 K_1 \quad \uparrow$$

$$Y_1 = A_1 K_1 \quad \text{unaffected}$$

$$C_2 = Y_2 = \frac{A_2}{1 + \left(\frac{1}{\beta A_2}\right)^{\sigma} A_2} A_1 K_1 \quad \uparrow$$

- **Sticky prices:**

# More on $\beta \uparrow$: the "Paradox of Thrift"

Compare effect of $\beta \uparrow$ = want to spend less, save more

- **Flexible prices:** aggregate saving and investment increase as households cut current consumption in return for future consumption

$$Y_1 \text{ unaffected}, \quad C_1 \downarrow, \quad I_1,\ C_2,\ Y_2 \text{ all} \uparrow$$

- **Sticky prices:**

# More on $\beta \uparrow$: the "Paradox of Thrift"

Compare effect of $\beta \uparrow$ = want to spend less, save more

- **Flexible prices:** aggregate saving and investment increase as households cut current consumption in return for future consumption

$$Y_1 \text{ unaffected}, \quad C_1 \downarrow, \quad I_1, \; C_2, \; Y_2 \text{ all} \uparrow$$

- **Sticky prices:**

$$C_1 = \left(\frac{1}{\beta A_2}\right)^{\sigma} A_2 \frac{M_2}{(1+i_1)P_1} \qquad \downarrow$$

$$I_1 = \frac{M_2}{(1+i_1)P_1} \qquad \text{unaffected}$$

$$Y_1 = \left[1 + \left(\frac{1}{\beta A_2}\right)^{\sigma} A_2\right] \frac{M_2}{(1+i_1)P_1} \qquad \downarrow$$

$$C_2 = Y_2 = A_2 \frac{M_2}{(1+i_1)P_1} \qquad \text{unaffected}$$

# More on $\beta\uparrow$: the "Paradox of Thrift"

Compare effect of $\beta\uparrow$ = want to spend less, save more

- **Flexible prices:** aggregate saving and investment increase as households cut current consumption in return for future consumption

$$Y_1 \text{ unaffected}, \quad C_1\downarrow, \quad I_1,\ C_2,\ Y_2 \text{ all}\uparrow$$

- **Sticky prices:** even though everyone wants to save more, aggregate saving and investment do not increase = "paradox of thrift"

$$C_1\downarrow, \quad Y_1\downarrow, \quad I_1,\ C_2,\ Y_2 \text{ all unaffected}$$

# More on $\beta \uparrow$: the "Paradox of Thrift"

Compare effect of $\beta \uparrow$ = want to spend less, save more

- **Flexible prices:** aggregate saving and investment increase as households cut current consumption in return for future consumption
- **Sticky prices:** even though everyone wants to save more, aggregate saving and investment do not increase = "paradox of thrift"

$$C_1 \downarrow, \quad Y_1 \downarrow, \quad I_1, \; C_2, \; Y_2 \text{ all unaffected}$$

Intuition in Mankiw-Weinzierl's words:

- "If $\beta$ rises, households will want to consume less and save more"
- "In equilibrium, however, saving and investment are unchanged, because output falls"
- "That is, because aggregate demand influences output, more thriftiness does not increase equilibrium saving"

# Paradox of thrift: more detailed intuition

Recall: $\beta \uparrow$ = want to spend less, save more and

$$\beta \uparrow \quad \Rightarrow \quad C_1 \downarrow, \quad Y_1 \downarrow, \quad I_1, \; C_2, \; Y_2 \text{ all unaffected}$$

What's going on under the hood, i.e. what's transmission mechanism?

- $\beta \uparrow \Rightarrow$ household consumption $C_1 \downarrow, C_2 \uparrow$ from Euler eqn $C_1 = C_2[\beta(1 + r_1)]^{-\sigma}$ (intertemporal substitution)
- also $\beta \uparrow \Rightarrow$ household saving $\uparrow \Rightarrow I_1 \uparrow$
- $C_1 \downarrow \Rightarrow$ aggregate demand $Y_1^D = C_1 + I_1 \downarrow$
- $Y_1^D \downarrow \Rightarrow$ output $Y_1 \downarrow \Rightarrow$ household income $\Omega = P_1 Y_1 \downarrow \Rightarrow C_1 \downarrow$ (income effect) $\Rightarrow$ aggregate demand $Y_1^D \downarrow \Rightarrow$ ... (Keynesian cross logic)
- also household income $\Omega = P_1 Y_1 \downarrow \Rightarrow$ household saving $\downarrow \Rightarrow I_1 \downarrow$

In equilibrium, the fall in household income is such that $I_1 \uparrow$ and $I_1 \downarrow$ above exactly offset and $I_1$ is unaffected. Therefore so are $C_2 = Y_2 = A_2 K_2$.

## Comment: equilibrium real interest rate in MW version of NK model

- Odd model property: real interest rate is $1 + r_1 = A_2$ regardless of $i_1, M_2$
  - see this from $P_2 = \frac{1+i_1}{A_2} P_1$ and definition $1 + r_1 = (1 + i_1)P_1/P_2$
  - in equilibrium, no passthrough from nominal to real interest rate
  - surprising given we just made big deal out of monetary non-neutrality
- What's going on? Answer: just an artefact of particular model assumption
  - linear production $Y_2 = A_2 K_2 \Rightarrow$ infinitely elastic capital demand
    $\Rightarrow$ equilibrium real interest rate is $1 + r_1 = A_2$ always
  - an assumption we made only for tractability
  - there definitely is passthrough from $i_1$ to $r_1$ and money is non-neutral
    (whole issue is that it's "too non-neutral" because of $\infty$ elasticity)
- Supplement: relax this assumption $Y_2 = F(K_2) = A_2 K_2^{\alpha}, 0 < \alpha \leq 1$

$$1 + r_1 = \alpha^{\alpha} A_2 \left( \frac{(1 + i_1)P_1}{M_2} \right)^{1-\alpha} \qquad \text{so that } r_1 \text{ depends on } i_1 \text{ as expected}$$

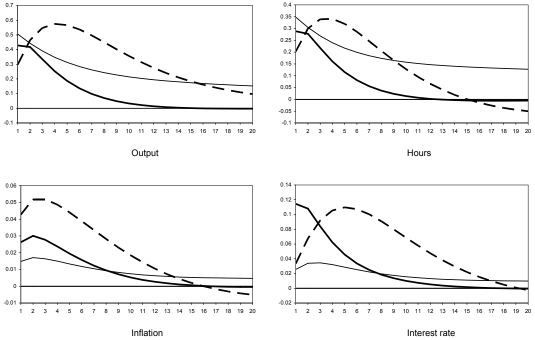
# New Keynesian model and inflation (partial price stickiness)

- So far: $P_1$ completely fixed $= P_0$
  - $\Rightarrow$ short-run inflation $\pi_1 = (P_1 - P_0)/P_0 = 0$ by assumption
- Contrasts with common intuition and prediction from IS-MP-PC model: aggregate demand $\uparrow \Rightarrow$ short-run inflation $\uparrow$
- Standard New Keynesian model (the one in textbooks e.g. Gali) features partial price stickiness, typically Calvo pricing
  - need firm price-setting power ($\neq$ competitive equilibrium)
  - see Kurlat chapters 14.2 and 14.3 for good discussion
- In standard NK model, aggregate demand $\uparrow \Rightarrow$ short-run inflation $\uparrow$
  - one way of thinking about this: aggregate demand/supply diagram with prices adjusting partially

# Various demand shocks in a fully-fledged New Keynesian model

Note: figure shows positive demand shocks, not negative ones like previous slides

**Figure 2: The estimated mean impulse responses to "demand" shocks**




Notes: Bold solid line: risk premium shock; thin solid line: exogenous spending shock; dashed line: investment shock.

Source: Smets and Wouters (2007) "Shocks and Frictions in US Business Cycles"
https://www.aeaweb.org/articles?id=10.1257/aer.97.3.586

# Next lecture: policy in the New Keynesian model

1. Monetary policy
    - already part of model, can use as is
2. Fiscal policy
    - not in model yet, will have to extend it

Key observation: sticky prices break first welfare theorem

- sticky prices = "friction"
- $\Rightarrow$ rationalizes some sort of policy intervention