# A Dynamic Model of Economic Fluctuations

Chapter 17

Econ 313 – Intermediate Macroeconomics

University of Tennessee, Knoxville

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# IN THIS CHAPTER, YOU WILL LEARN:

- How to incorporate dynamics into the *AD–AS* model we previously studied
- How to use the dynamic *AD–AS* model to illustrate long-run economic growth
- How to use the dynamic *AD–AS* model to trace the effects over time of various shocks and policy changes on output, inflation, and other endogenous variables

# Introduction, part 1

- The dynamic model of aggregate demand and aggregate supply gives us more insight into how the economy works in the short run.
- It is a simplified version of a DSGE model, used in cutting-edge macroeconomic research.
  - DSGE = dynamic, stochastic, general equilibrium
  - Dynamic: traces the path of variables over time
  - Stochastic: incorporates the inherent randomness of economic life
  - General Equilibrium: takes into account that everything depends on everything else

# Introduction, part 2

The dynamic model of aggregate demand and aggregate supply is built from familiar concepts, such as:

- the *IS* curve, which negatively relates the real interest rate and demand for goods and services
  - the Phillips curve, which relates inflation to the gap between output and its natural level, expected inflation, and supply shocks
  - adaptive expectations, a simple model of inflation expectations

# How the dynamic AD–AS model is different from the standard model

- Instead of fixing the money supply, the central bank follows a monetary policy rule that adjusts interest rates when output or inflation changes.
- The vertical axis of the *DAD–DAS* diagram measures the inflation rate, not the price level.
- Subsequent time periods are linked together:Changes in inflation in one period alter expectations of future inflation, which changes aggregate supply in future periods, which further alters inflation and inflation expectations.

# Keeping track of time

The subscript $t$denotes time period; for example:

- $Y_t$ = real GDP in period $t$
  - $Y_{t-1}$ = real GDP in period $t-1$
  - $Y_{t+1}$ = real GDP in period $t+1$
- We can think of time periods as years; for example, if $t = 2021$, then
  - $Y_t = Y_{2022}$ = real GDP in 2022
  - $Y_{t-1} = Y_{2021}$ = real GDP in 2021
  - $Y_{t+1} = Y_{2023}$ = real GDP in 2023

# The model's elements

- The model has five equations and five endogenous variables: output, inflation, the real interest rate, the nominal interest rate, and expected inflation.
- The equations may use different notation, but they are conceptually similar to things you've already learned.
- The first equation is for output . . .

# Output: The demand for goods and services

Demand for goods and services:

- $Y_t$: Output at period $t$
- Natural level of output at period $t$
- $\alpha$: The responsiveness to the demand for goods and services to changes in the real interest rate, $\alpha > 0$
- $r_t$: Real interest rate at period $t$
- $\rho$: The natural rate of interest, $\rho > 0$
- $\varepsilon_t$: Shock to the demand for goods and services
- Negative relationship between output and interest rate, same intuition as with the *IS* curve.

# The real interest rate: The Fisher equation

$$r_t = i_t - E_t \pi_{t+1} \qquad \text{(Fisher equation)}$$

- $r_t$: Real interest rate at period $t$
- $i_t$: Nominal interest rate at period $t$
- $\pi_{t+1}$: Increase in price level from period $t$ to $t+1$, not known in period $t$
- $E_t \pi_{t+1}$: Expectation, formed in period $t$, of inflation from $t$ to $t+1$

# Inflation: The Phillips curve

Phillips curve equation:

- $\pi_t$: Current inflation
- $E_t$-$\mathbf{1}\pi_t$: Previously expected inflation
- $\varphi$: The responsiveness of inflation to deviations of output from the natural level of output, $\varphi > 0$
- $Y_t$: Output at period $t$
- Natural level of output at period $t$
- $v_t$: Shock to the Phillips curve (supply shock)

# Expected inflation: Adaptive expectations

Adaptive expectations:

- $E_t \pi_{t+1} = \pi_t$
- For simplicity, we assume that people expect prices to continue rising at the current inflation rate. This implies that
- $E_t\text{-}\mathbf{1}\pi_t = \pi_t\text{-}\mathbf{1}$

# The nominal interest rate: The monetary-policy rule

Monetary-policy rule:

- $i_t$: Nominal interest rate
- $\pi_t$: Inflation
- $\rho$: Natural rate of interest, $\rho > 0$
- $\theta_\pi$: The Central Bank's responsiveness of the nominal interest rate to inflation, $\theta_\pi > 0$
- $\pi*_t$: Central bank's inflation target in period $t$
- $\theta_Y$: The central bank's responsiveness of the nominal interest rate to output, $\theta_Y > 0$
- Natural level of output at period $t$

# CASE STUDY: The Taylor rule, part 1

Economist John Taylor proposed a monetary policy rule very similar to ours:

- $\mathbf{\textit{iff}} = \pi + 2 + 0.5\,(\pi - 2) + 0.5\,(\text{GDP gap})$
- where
  - $\mathbf{\textit{iff}}$ = nominal federal funds rate target
  - GDP gap = 100 $\times$
  - = percentage by which real GDP is below its natural rate
- The Taylor rule matched Fed policy fairly well . . . .

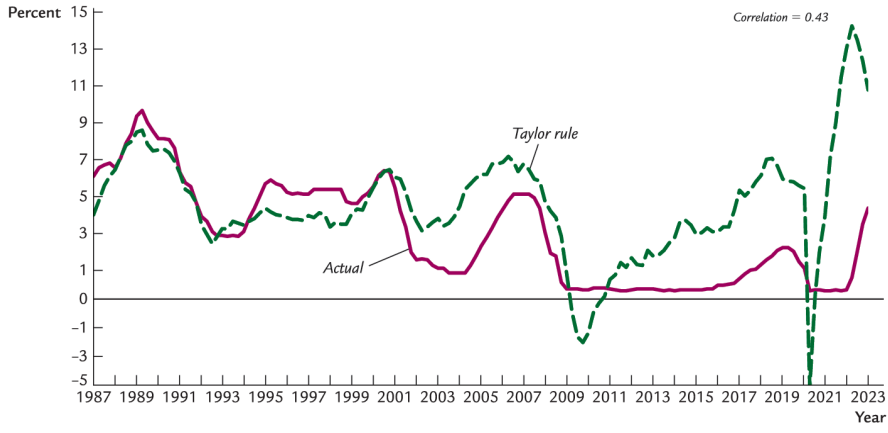


John B. Taylor (Stanford) proposed the rule in 1993.

*Wikimedia, PD*

▸ Compute for 3 scenarios

# CASE STUDY: The Taylor rule, part 2



# CASE STUDY: The Taylor rule, part 3

- Taylor rule matched well, until the Great Recession of 2008 and the aftermath.
- Potential explanations for the deviation from the Taylor Rule:
  - The natural rate of interest ($\rho$) has fallen. A federal funds rate below the suggested rate and the low-to-moderate inflation seen since 2008 is consistent with a falling natural rate of interest.
  - Rates below the suggested interest rate were needed to make up for the time when the Taylor rule suggested negative interest rates.

# The model's variables and parameters, part 1

Endogenous variables:

- $Y_t$: Output
- $r_t$: Real interest rate
- $i_t$: Nominal interest rate
- $\pi_t$: Inflation
- $E_t\pi_{t+1}$: Expected inflation

# The model's variables and parameters, part 2

Exogenous variables:

- Natural level of output
- $\pi_t^*$: Central bank's inflation target
- $\varepsilon_t$: Demand shock
- $v_t$: Supply Shock
- Predetermined variable:
- $\pi_t$-**1**: Previous period's inflation

# The model's variables and parameters, part 3

Parameters:

- $\alpha$: The responsiveness to the demand for goods and services to changes in the real interest rate, $\alpha > 0$
- $\rho$: Natural rate of interest, $\rho > 0$
- $\varphi$: The responsiveness of inflation to deviations of output from the natural level of output, $\varphi > 0$
- $\theta_\pi$:The central bank's responsiveness of the nominal interest rate to inflation, $\theta_\pi > 0$
- $\theta_Y$: The Central Bank's responsiveness of the nominal interest rate to output, $\theta_Y > 0$

# The model's variables and parameters, part 4

- Predetermined Variable: $\pi_t$-**1**

# The model's long-run equilibrium, part 1

- Long-run equilibrium is the normal state around which the economy fluctuates.
- Two conditions required for long-run equilibrium:
  - There are no shocks: $\varepsilon_t = v_t = 0$
  - Inflation is constant: $\pi_t = \pi_t$-$\mathbf{1}$

# The model's long-run equilibrium, part 2

- Using the Phillips curve and adaptive expectations,
- In long-run equilibrium $v_t = 0$,
- Using another equilibrium condition, $\pi_t = \pi_t$-**1**, gives
- Which yields
- Resulting in

# The model's long-run equilibrium, part 3

- Using the result in the previous slide
- and that in long-run equilibrium $\varepsilon_t = 0$, our goods and services equation
- Becomes
- Which yields
- $r_t = \rho$

# The model's long-run equilibrium, part 4

- Using the result in the previous slides
- our monetary policy equation
  - Becomes
  - $i_t = \pi_t + r_t + \theta_\pi \ (\pi_t \text{ - } \pi_t^*)$
  - Rearranging
  - $i_t - \pi_t = r_t + \theta_\pi(\pi_t - \pi_t^*)$
  - Making use of adaptive expectations and an equilibrium condition ($\pi_t = \pi_t$-**1**)
  - $i_t \text{ - } E_t\pi_{t+1} = r_t + \theta_\pi(\pi_t \text{ - } \pi_t^*)$
  - Canceling out via the Fisher equation ($i_t \text{ - } E_t\pi_{t+1} = r_t$) and solving out yields
  - $\pi_t = \pi_t^*$

# The model's long-run equilibrium, part 5

Combined with the above values, plugging $\pi_t = \pi_t^*$ in for adaptive expectations and the Fisher equation yields these long-run values:

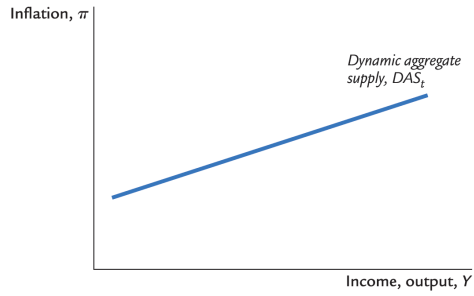
- $Y_t =$
- Output equals the natural rate of output.
- $r_t = \rho$: Real interest rate equals the natural rate of interest.
- $\pi_t = \pi_t^*$: Inflation equals the central bank's target.
- $E_t\pi_{t+1} = \pi_t^*$: Inflation expectations are accurate.
- $i_t = \rho + \pi_t^*$: Nominal interest rate equals the natural interest rate plus the central bank target inflation rate.

# The dynamic aggregate supply

- The *DAS* curve shows a relationship between output and inflation that comes from the Phillips curve and adaptive expectations.
- *DAS*:

# The dynamic aggregate supply curve

- *DAS* slopes upward: High levels of output are associated with high inflation.
- *DAS* shifts in response to changes in the natural level of output, previous inflation, and supply shocks.



# The dynamic aggregate demand curve, part 1

- To derive the *DAD* curve, we will combine four equations and then eliminate all the endogenous variables other than output and inflation.
- Start with the demand for goods and services:

$$Y_t = \overline{Y}_t - \alpha(r_t - \rho) + \varepsilon_t$$

using the Fisher equation

$$Y_t = \overline{Y}_t - \alpha(i_t - E_t \pi_{t+1} - \rho) + \varepsilon_t$$

# The dynamic aggregate demand curve, part 2

result from previous slide

$$Y_t = \bar{Y}_t - \alpha(i_t - E_t\,\pi_{t+1} - \rho) + \varepsilon_t$$

using the expectations equation

$$Y_t = \bar{Y}_t - \alpha(i_t - \pi_t - \rho) + \varepsilon_t$$

using monetary policy rule

$$Y_t = \bar{Y}_t - \alpha[\pi_t + \rho + \theta_\pi(\pi_t - \pi_t^*) + \theta_Y(Y_t - \bar{Y}_t) - \pi_t - \rho] + \varepsilon_t$$

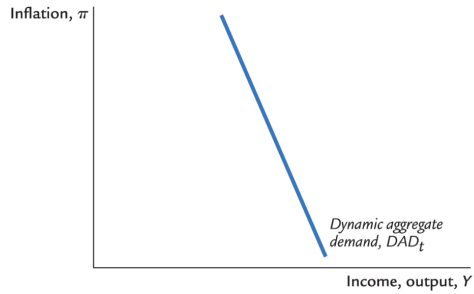
$$Y_t = \bar{Y}_t - \alpha[\theta_\pi(\pi_t - \pi_t^*) + \theta_Y(Y_t - \bar{Y}_t)] + \varepsilon_t$$

# The dynamic aggregate demand curve, part 3

- result from previous slide
- combine like terms, solve for $Y$

# The dynamic aggregate demand curve, part 4

- *DAD* slopes downward: When inflation rises, the central bank raises the real interest rate, reducing the demand for goods and services.
- *DAD* shifts in response to changes in the natural level of output, the inflation target, and demand shocks.



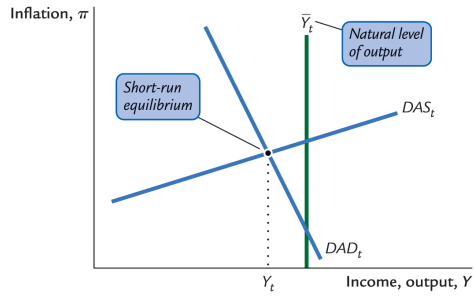
# The short-run equilibrium, part 1

In the short-run, our long-run equilibrium conditions do not hold:

- $\varepsilon_t$ 0
- $v_t$ 0
- $\pi_t$ $\pi_t$-**1**
- Therefore, our short-run equilibrium is determined by the intersection of the *DAD* and *DAS* curves:
- *DAD*:
- *DAS*:
- The intersection then depends on our parameters and exogenous variables.

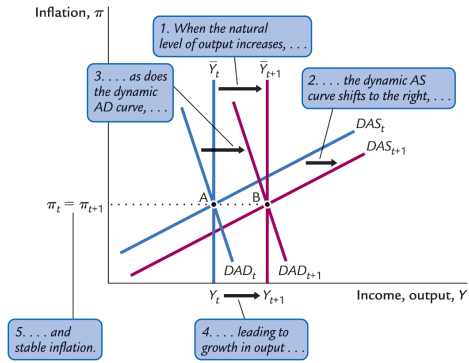
# The short-run equilibrium, part 2

- In each period, the intersection of *DAD* and *DAS* determines the short-run equilibrium values of inflation and output.
- In the equilibrium shown here at *A*, output is below its natural level.



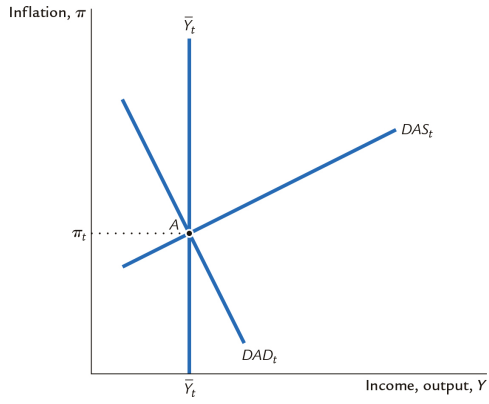
# Long-run growth (1 of 7)

- There is an initial increase in
- This also causes *DAD* and *DAS* to shift out. With a new equilibrium at *B*.



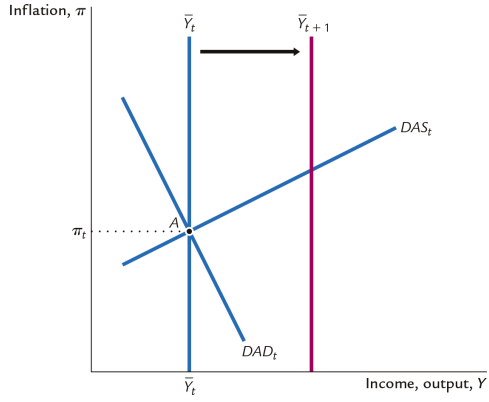
# Long-run growth (2 of 7)

- Initial equilibrium in period $t$, at point $A$.



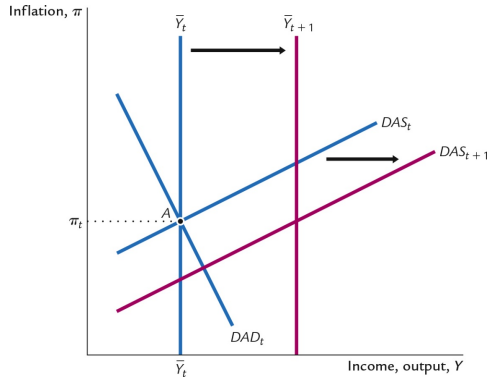
# Long-run growth (3 of 7)

- Period $t + \mathbf{1}$: Long-run growth increases the natural rate of output.



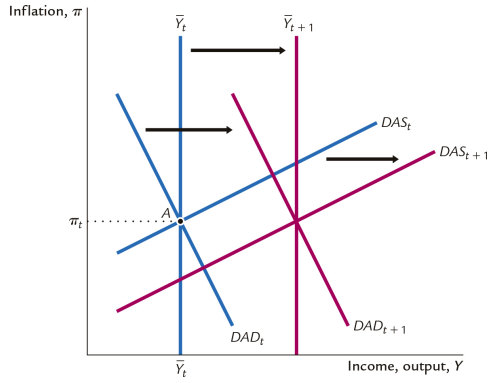
# Long-run growth (4 of 7)

- *DAS* shifts because economy can produce more goods and services.



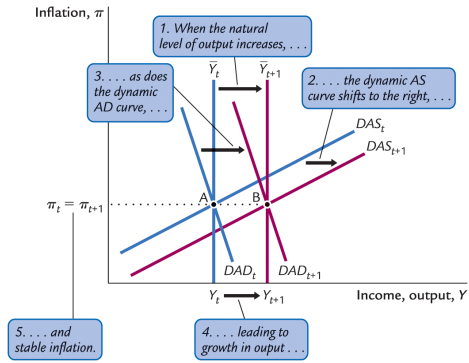
# Long-run growth (5 of 7)

- *DAD* shifts because higher income raises demand for goods and services.



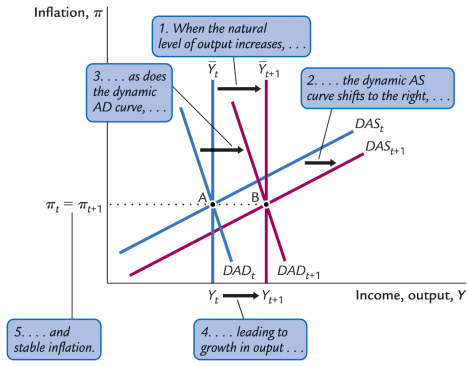
# Long-run growth (6 of 7)

- The economy reaches a new equilibrium at *B*.



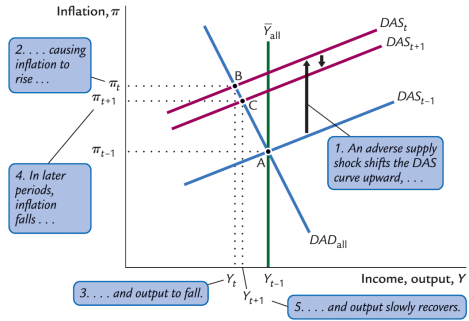
# Long-run growth (7 of 7)

- Income grows while inflation remains stable.
- Notice that the economy goes from $A$ to $B$ in *one period*. There are no short-run transition dynamics.



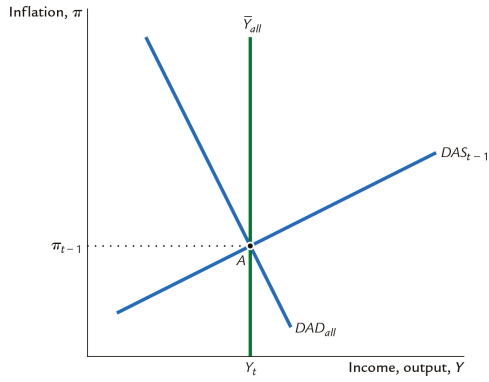
# A shock to aggregate supply (1 of 5)

- The economy is hit with a negative supply shock in period $t$. The supply shock then goes away, but inflation expectations remain high. The economy slowly returns to the initial equilibrium.



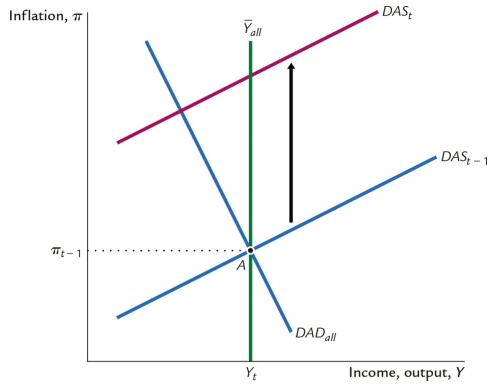
# A shock to aggregate supply (2 of 5)

- Initial equilibrium at $A$ at period $t-1$.



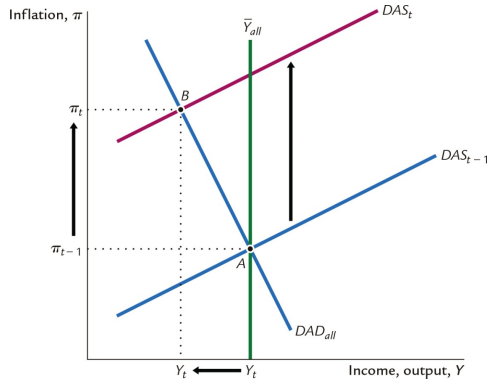
# A shock to aggregate supply (3 of 5)

- A negative supply shock at period $t$ shifts the *DAS* curve.



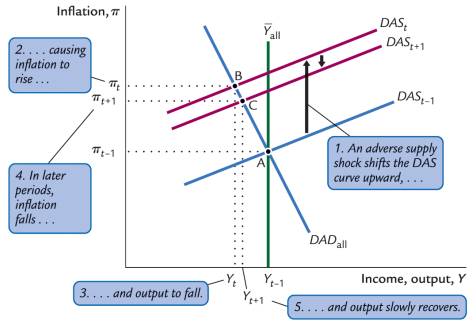
# A shock to aggregate supply (4 of 5)

- The new equilibrium in period $t$ is at $B$, with higher inflation and lower output.



# A shock to aggregate supply (5 of 5)

- In period $t+1$, the supply shock is gone; however, inflation expectations have increased. Therefore, *DAS* does not return to its initial position.
- Inflation begins to fall, and output begins to increase.
- The economy will gradually return to $A$ as inflation expectations fall.

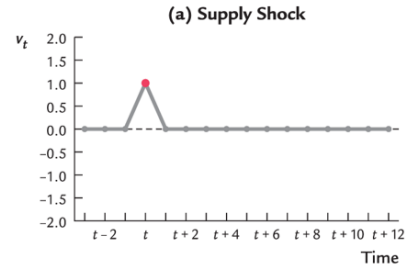


# Parameter values for simulations

- as the percentage deviation of output from its natural level.
- $\pi*_t = 2.0$
- Central bank's inflation target is 2 percent.
- $\alpha$ =1.0
- A 1-percentage-point increase in the real interest rate reduces output demand by 1 percent of its natural level.
- $\rho = 2.0$
- The natural rate of interest is 2 percent.
- $\phi = 0.25$
- When output is 1 percent above its natural level, inflation rises by 0.25 percentage point.
- $\theta\pi$=0.5
- $\theta_Y = 0.5$
- These values are from the Taylor rule, which approximates the actual behavior of the Federal Reserve.

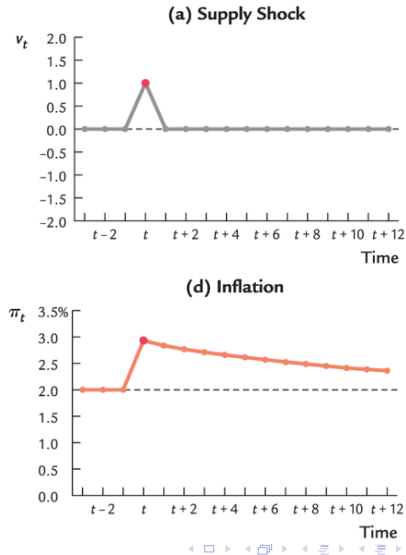
# The dynamic response to a supply shock, part 1

- These graphs are called *impulseresponsefunctions*. They show the *response* of the endogenous variables to the *impulse* (the shock).
- A one-period supply shock affects output for many periods.
- Note: period need not mean a year.



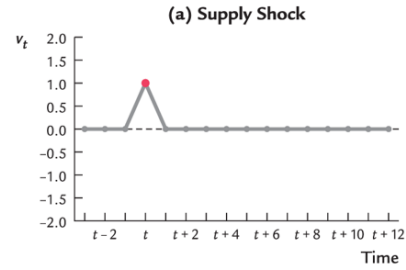
# The dynamic response to a supply shock, part 2

- Because inflation expectations adjust slowly, actual inflation remains high for many periods.



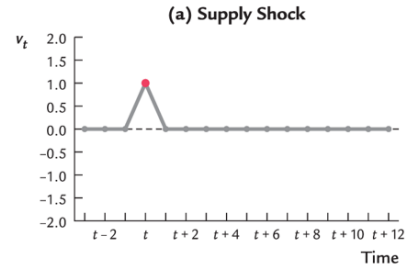
# The dynamic response to a supply shock, part 3

- The real interest rate takes many periods to return to its natural rate.



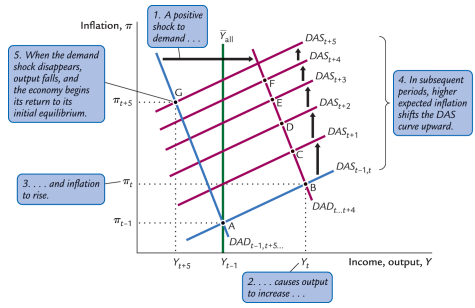
# The dynamic response to a supply shock, part 4

- The behavior of the nominal interest rate depends on that of the inflation and real interest rates.



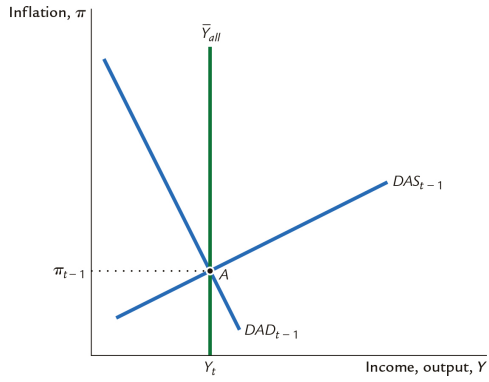
# A shock to aggregate demand (1 of 6)

- A demand shock lasts five periods ($t...t+4$) and then ends.
- Even though the demand shock has dissipated, inflation expectations remain high.



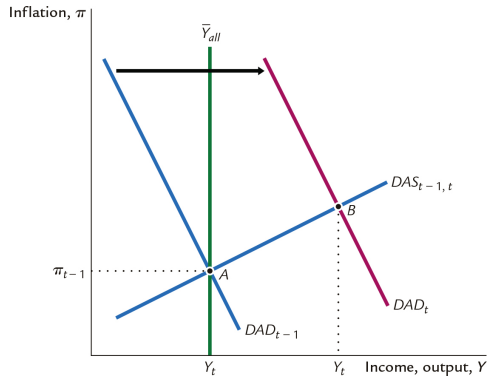
# A shock to aggregate demand (2 of 6)

- Period $t - \mathbf{1}$: initial equilibrium at $A$



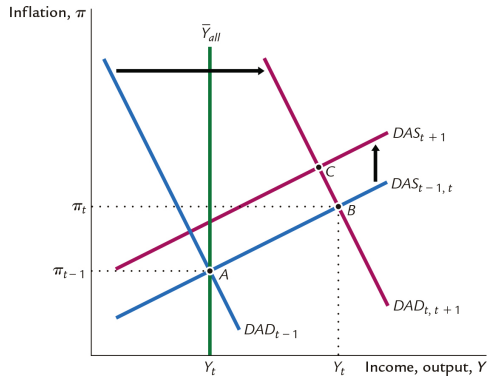
# A shock to aggregate demand (3 of 6)

- Period $t$: Positive demand shock ($\varepsilon > 0$) (*lasts five periods)* shifts *DAD* to the right; output and inflation rise.



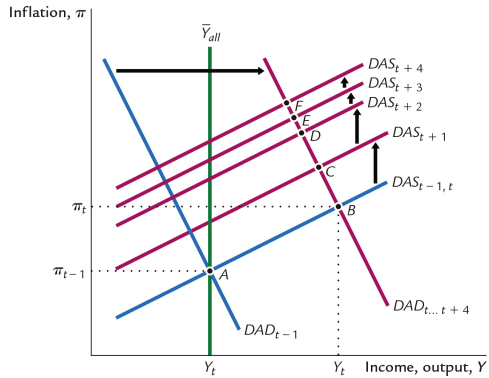
# A shock to aggregate demand (4 of 6)

- Period $t + 1$ : Higher inflation in $t$ raised inflation expectations for $t + 1$, shifting $DAS$ up. Inflation rises more, output falls.



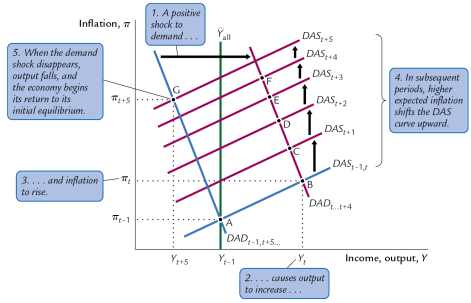
# A shock to aggregate demand (5 of 6)

- Periods $t + 2tot + 4$: Higher inflation in previous period raises inflation expectations, shifts *DAS* up. Inflation rises, output falls.



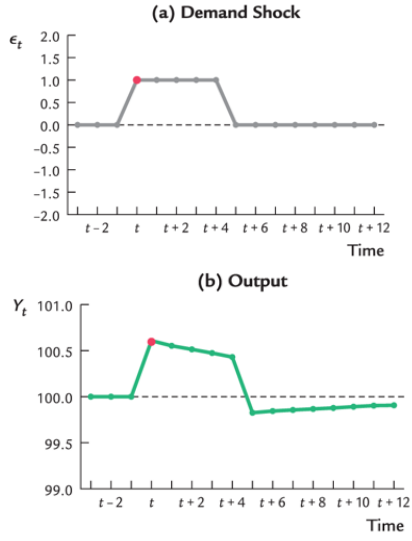
# A shock to aggregate demand (6 of 6)

- Period $t + \mathbf{5}$: *DAS* is higher due to higher inflation in preceding period, but demand shock ends and *DAD* returns to its initial position. Equilibrium at *G*.
- In later periods, inflation expectations fall and *DAS* gradually shifts down.



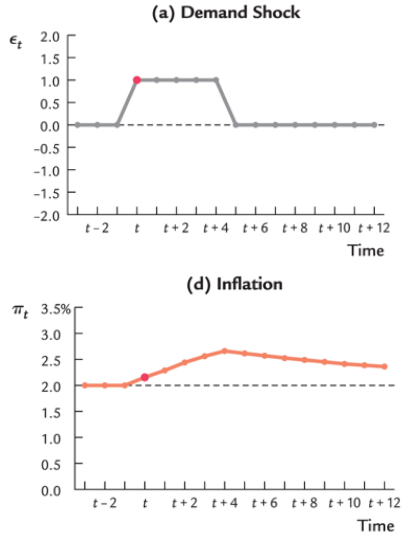
# The dynamic response to a demand shock, part 1

- The demand shock raises output for five periods. When the shock ends, output falls below its natural level and recovers gradually.



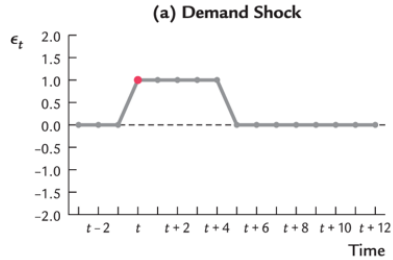
# The dynamic response to a demand shock, part 2

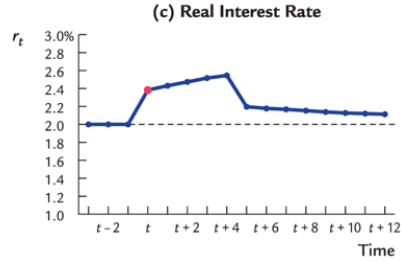
- The demand shock causes inflation to rise. When the shock ends, inflation gradually falls toward its initial level.



# The dynamic response to a demand shock, part 3

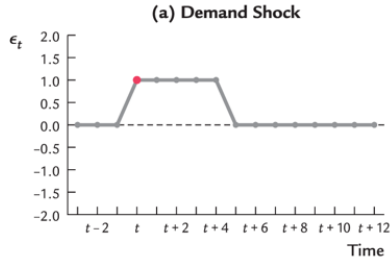
- The demand shock raises the real interest rate. After the shock ends, the real interest rate falls and approaches its initial level.

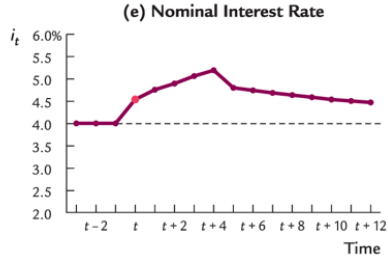


# The dynamic response to a demand shock, part 4

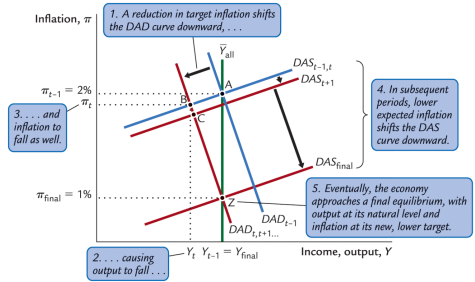
- The behavior of the nominal interest rate depends on that of the inflation and real interest rates.



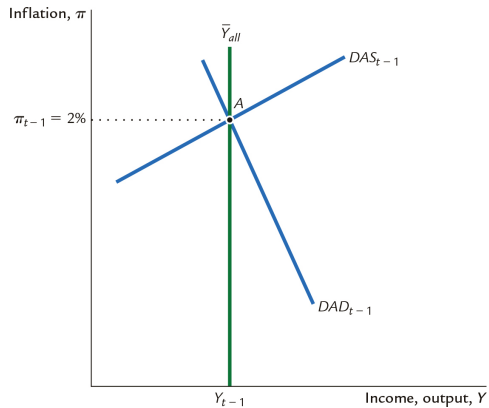
# A shift in monetary policy (1 of 5)

- The central bank lowers its inflation target from 2 percent to 1 percent,
- shifting *DAD* in.
- Slowly inflation expectations fall, shifting *DAS* down, and the economy reaches a final equilibrium at *Z*.



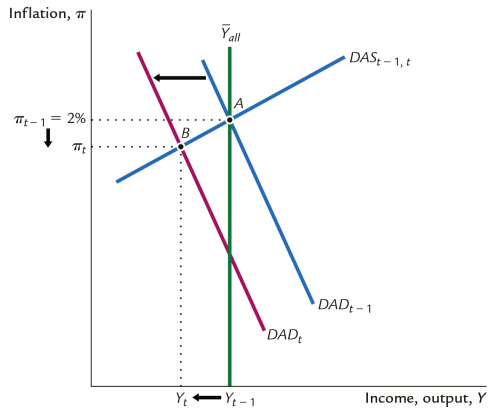
# A shift in monetary policy (2 of 5)

- The initial equilibrium in period $t-1$ at $A$, with a 2 percent inflation target.



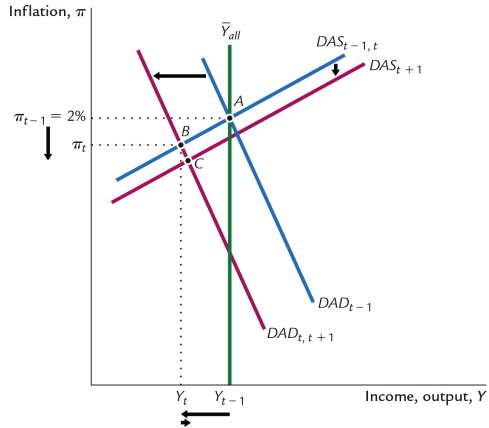
# A shift in monetary policy (3 of 5)

- In period $t$, the central bank announces a new, lower inflation target of 1 percent.
- $DAD$ shifts in, and the new equilibrium is at $B$, with lower inflation and output.



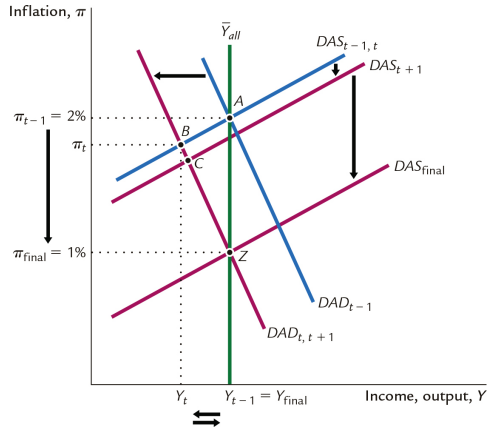
# A shift in monetary policy (4 of 5)

- In period $t+1$, inflation expectations have fallen, causing *DAS* to shift down.



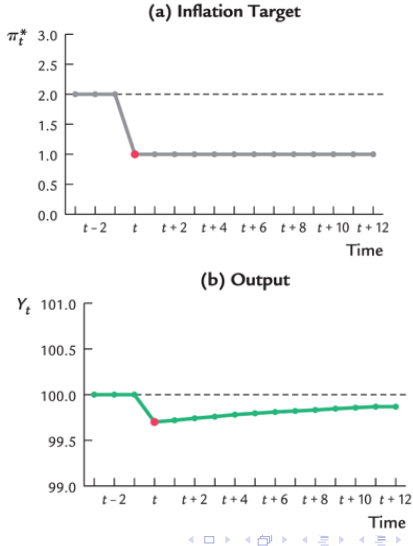
# A shift in monetary policy (5 of 5)

- In subsequent periods, inflation expectations slowly fall until inflationary expectations equal the 1 percent inflation target, continually shifting *DAS* down.
- The final equilibrium at *Z* with output back at the natural level.



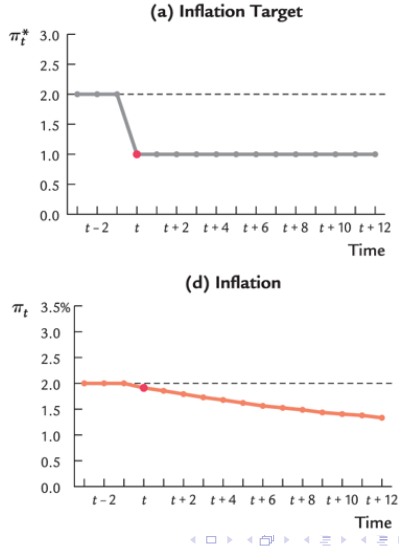
# The dynamic response to a reduction in target inflation, part 1

- Reducing the target inflation rate causes output to fall below its natural level for a while. Output recovers gradually.



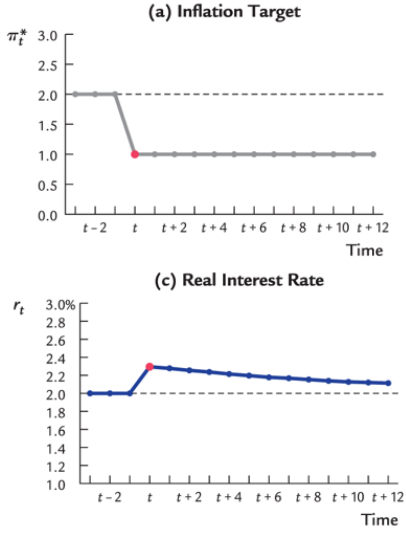
# The dynamic response to a reduction in target inflation, part 2

- Because expectations adjust slowly, it takes many periods for inflation to reach the new target.



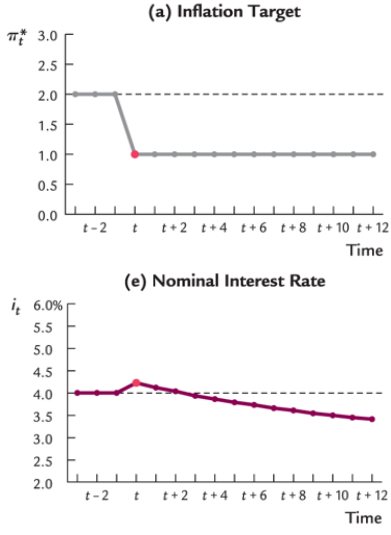
# The dynamic response to a reduction in target inflation, part 3

- To reduce inflation, the central bank raises the real interest rate to reduce aggregate demand. The real interest rate gradually returns to its natural rate.



# The dynamic response to a reduction in target inflation, part 4

- The initial increase in the real interest rate raises the nominal interest rate. As the inflation and real interest rates fall, the nominal rate falls.

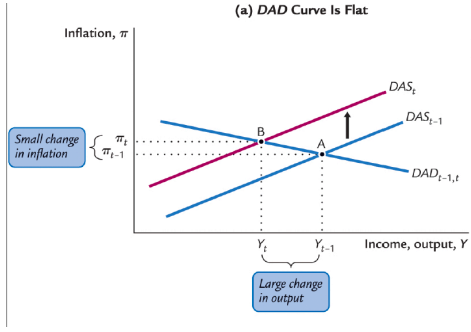


# APPLICATION: Output variability versus inflation variability, part 1

- A supply shock reduces output (bad) and raises inflation (also bad).
- The central bank faces a tradeoff between these "bads": It can reduce the effect on output but only by tolerating an increase in the effect on inflation.

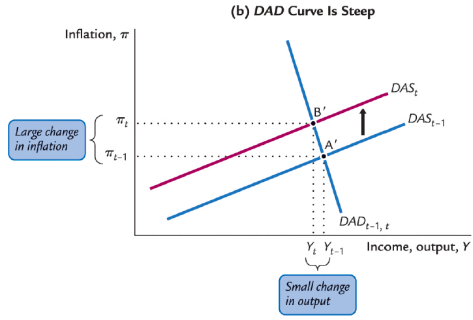
# APPLICATION: Output variability versus inflation variability, part 2

- **CASE 1**: $\theta_\pi$ is large; $\theta_Y$ is small



# APPLICATION: Output variability versus inflation variability, part 3

- **CASE 2**: $\theta_\pi$ is small; $\theta_Y$ is large



# APPLICATION: The Taylor principle, part 1

- The **Taylor principle** (named after John Taylor): the proposition that a central bank should respond to an increase in inflation with an even greater increase in the nominal interest rate (so that the real interest rate rises).
  That is, the central bank should set $\theta_\pi > 0$.
- Otherwise, *DAD* will slope upward, the economy may be unstable, and inflation may spiral out of control.

# APPLICATION: The Taylor principle, part 2

$$Y_t = \bar{Y}_t - \frac{\alpha\theta_\pi}{1+\alpha\theta_Y}(\pi_t - \pi_t^*) + \frac{1}{1+\alpha\theta_Y}\varepsilon_t \qquad (DAD)$$

$$i_t = \pi_t + \rho + \theta_\pi(\pi_t - \pi_t^*) + \theta_Y(Y_t - \bar{Y}_t) \qquad (MP\ rule)$$

If $\theta_\pi > 0$:

- When inflation rises, the central bank increases the nominal interest rate even more, which increases the real interest rate and reduces the demand for goods and services.
- *DAD* has a negative slope.

# APPLICATION: The Taylor principle, part 3

$$Y_t = \bar{Y}_t - \frac{\alpha\theta_\pi}{1+\alpha\theta_Y}(\pi_t - \pi_t^*) + \frac{1}{1+\alpha\theta_Y}\varepsilon_t \qquad (DAD)$$

$$i_t = \pi_t + \rho + \theta_\pi(\pi_t - \pi_t^*) + \theta_Y(Y_t - \bar{Y}_t) \qquad (MP\ rule)$$

If $\theta_\pi < 0$:

- When inflation rises, the central bank increases the nominal interest rate by a smaller amount. The real interest rate falls, which increases the demand for goods and services.
- *DAD* has a positive slope.

# APPLICATION: The Taylor principle, part 4

- If *DAD* is upward sloping and steeper than *DAS*, then the economy is unstable: Output will not return to its natural level, and inflation will spiral upward (for positive demand shocks) or downward (for negative ones).
- Estimates of $\theta_\pi$ from published research:
  - $\theta_\pi = -0.14$ from 1960 to 1978, before Paul Volcker became Fed chair. Inflation was high during this time, especially during the 1970s.
  - $\theta_\pi = 0.72$ during the Volcker and Greenspan years. Inflation was much lower during these years.

# CHAPTER SUMMARY, PART 1

- The *DAD–DAS* model combines five relationships: an *IS-curve-like* equation of the goods market, the Fisher equation, a Phillips curve equation, an equation for expected inflation, and a monetary policy rule.
- The long-run equilibrium of the model is classical. Output and the real interest rate are at their natural levels, independent of monetary policy. The central bank's inflation target determines inflation, expected inflation, and the nominal interest rate.

# CHAPTER SUMMARY, PART 2

- The *DAD–DAS* model can be used to determine the immediate impact of any shock on the economy and can be used to trace the effects of the shock over time.
- The parameters of the monetary policy rule influence the slope of the *DAS* curve, so they determine whether a supply shock has a greater effect on output or inflation. Thus, the central bank faces a tradeoff between output variability and inflation variability.

# CHAPTER SUMMARY, PART 3

- The *DAD–DAS* model assumes that the Taylor principle holds—that is, that the central bank responds to an increase in inflation by raising the real interest rate. Otherwise, the economy may become unstable, and inflation may spiral out of control.

# Appendix: Taylor rule — three scenarios

The rule:

$$i^{ff} = \pi + 2 + 0.5\,(\pi - 2) + 0.5\,(\text{GDP gap}).$$

$\pi$ is the current inflation rate; GDP gap is the deviation of real output from potential, in percentage points.

**Scenario 1 — neutral economy.** $\pi = 2\%$, gap $= 0$:

$$i^{ff} = 2 + 2 + 0.5(0) + 0.5(0) = 4\%.$$

So the "neutral" fed-funds rate is $4\%$ when everything is at target.

**Scenario 2 — recession + low inflation.** $\pi = 1\%$, gap $= -3\%$:

$$i^{ff} = 1 + 2 + 0.5(-1) + 0.5(-3) = 1\%.$$

Rate should be far below neutral. In 2009 the Fed hit the zero lower bound.

back

# Appendix — Volcker-era Taylor number

**Scenario 3 — overheating.** $\pi = 8\%$ (early 1980s), gap $= +2\%$:

$$i^{ff} = 8 + 2 + 0.5\,(6) + 0.5\,(2) = 14\%.$$

The rule prescribes a very high rate. Volcker's actual fed-funds hit $\sim 20\%$ — more aggressive still.

**Scenario 4 — 2022 stagflation-lite.** $\pi = 8\%$ (2022 spike), gap $\approx 0$:

$$i^{ff} = 8 + 2 + 0.5(6) + 0.5(0) = 13\%.$$

Fed funds actually peaked at $5.5\%$ in 2023 — the rule would have called for more.

The Taylor rule embeds two ideas:

1. **Taylor principle:** raise *real* rates when inflation exceeds target ($i^{ff}$ rises *more than one-for-one* with $\pi$).
2. **Dual mandate:** also react to the output gap.

The coefficients $(0.5, 0.5)$ are calibrated to roughly match U.S. Fed behavior 1987–92.