A Dynamic Model of Aggregate Demand and Aggregate Supply

The important thing in science is not so much to obtain new facts as to discover new ways of thinking about them.

William Bragg

This chapter continues our analysis of short-run economic fluctuations. It presents a model that we will call the *dynamic model of aggregate demand and aggregate supply*. This model offers another lens through which to view the business cycle and the effects of monetary and fiscal policy.

As the name suggests, this new model emphasizes the dynamic nature of economic fluctuations. The dictionary defines the word “dynamic” as “relating to energy or objects in motion, characterized by continuous change or activity.” This definition applies readily to economic activity. The economy is continually bombarded by various shocks. These shocks have an immediate impact on the economy’s short-run equilibrium, and they also affect the subsequent path of output, inflation, and many other variables. The dynamic \( AD-AS \) model focuses attention on how output and inflation respond over time to exogenous changes in the economic environment.

In addition to placing greater emphasis on dynamics, the model differs from our previous models in another significant way: it explicitly incorporates the response of monetary policy to economic conditions. In previous chapters, we followed the conventional simplification that the central bank sets the money supply, which in turn is one determinant of the equilibrium interest rate. In the real world, however, many central banks set a target for the interest rate and allow the money supply to adjust to whatever level is necessary to achieve that target. Moreover, the target interest rate set by the central bank depends on economic conditions, including both inflation and output. The dynamic \( AD-AS \) model builds in these realistic features of monetary policy.

Although the dynamic \( AD-AS \) model is new to the reader, most of its components are not. Many of the building blocks of this model will be familiar from previous chapters, even though they sometimes take on slightly different forms. More important, these components are assembled in new ways. You can think of this model as a new recipe that mixes familiar ingredients to
create a surprisingly original meal. In this case, we will mix familiar economic relationships in a new way to produce deeper insights into the nature of short-run economic fluctuations.

Compared to the models in preceding chapters, the dynamic $AD-AS$ model is closer to those studied by economists at the research frontier. Moreover, economists involved in setting macroeconomic policy, including those working in central banks around the world, often use versions of this model when analyzing the impact of economic events on output and inflation.

# 14-1 Elements of the Model

Before examining the components of the dynamic $AD-AS$ model, we need to introduce one piece of notation: Throughout this chapter, the subscript $t$ on a variable represents time. For example, $Y$ is used to represent total output and national income, as it has been throughout this book. But now it takes the form $Y_t$, which represents national income in time period $t$. Similarly, $Y_{t-1}$ represents national income in period $t - 1$, and $Y_{t+1}$ represents national income in period $t + 1$. This new notation will allow us to keep track of variables as they change over time.

Let's now look at the five equations that make up the dynamic $AD-AS$ model.

## Output: The Demand for Goods and Services

The demand for goods and services is given by the equation

$$Y_t = \bar{Y}_t - \alpha (r_t - \rho) + \epsilon_t,$$

where $Y_t$ is the total output of goods and services, $\bar{Y}_t$ is the economy's natural level of output, $r_t$ is the real interest rate, $\epsilon_t$ is a random demand shock, and $\alpha$ and $\rho$ are parameters greater than zero. This equation is similar in spirit to the demand for goods and services equation in Chapter 3 and the $IS$ equation in Chapter 10. Because this equation is so central to the dynamic $AD-AS$ model, let's examine each of the terms with some care.

The key feature of this equation is the negative relationship between the real interest rate $r_t$ and the demand for goods and services $Y_t$. When the real interest rate increases, borrowing becomes more expensive, and saving yields a greater reward. As a result, firms engage in fewer investment projects, and consumers save more and spend less. Both of these effects reduce the demand for goods and services. (In addition, the dollar might appreciate in foreign-exchange markets, causing net exports to fall, but for our purposes in this chapter these open-economy effects need not play a central role and can largely be ignored.) The parameter $\alpha$ tells us how sensitive demand is to changes in the real interest rate. The larger the value of $\alpha$, the more the demand for goods and services responds to a given change in the real interest rate.
The first term on the right-hand side of the equation, \( \bar{Y}_t \), implies that the demand for goods and services rises with the economy's natural level of output. In most cases, we can simplify matters by taking this variable to be constant; that is, \( \bar{Y}_t \) will be assumed to be the same for every time period \( t \). We will, however, examine how this model can incorporate long-run growth, represented by exogenous increases in \( \bar{Y}_t \) over time. A key piece of that analysis is apparent in this demand equation: as long-run growth makes the economy richer, the demand for goods and services grows proportionately.

The last term in the demand equation, \( \epsilon_t \), represents exogenous shifts in demand. Think of \( \epsilon_t \) as a random variable—a variable whose values are determined by chance. It is zero on average but fluctuates over time. For example, if (as Keynes famously suggested) investors are driven in part by “animal spirits”—irrational waves of optimism and pessimism—those changes in sentiment would be captured by \( \epsilon_t \). When investors become optimistic, they increase their demand for goods and services, represented here by a positive value of \( \epsilon_t \). When they become pessimistic, they cut back on spending, and \( \epsilon_t \) is negative.

The variable \( \epsilon_t \) also captures changes in fiscal policy that affect the demand for goods and services. An increase in government spending or a tax cut that stimulates consumer spending means a positive value of \( \epsilon_t \). A cut in government spending or a tax hike means a negative value of \( \epsilon_t \). Thus, this variable captures a variety of exogenous influences on the demand for goods and services.

Finally, consider the parameter \( \rho \). From a mathematical perspective, \( \rho \) is just a constant, but it has a useful economic interpretation. It is the real interest rate at which, in the absence of any shock (\( \epsilon_t = 0 \)), the demand for goods and services equals the natural level of output. We can call \( \rho \) the natural rate of interest. Throughout this chapter, the natural rate of interest is assumed to be constant (although Problem 7 at the end of the chapter examines what happens if it changes). As we will see, in this model, the natural rate of interest plays a key role in the setting of monetary policy.

### The Real Interest Rate: The Fisher Equation

The real interest rate in this model is defined as it has been in earlier chapters. The real interest rate \( r_t \) is the nominal interest rate \( i_t \) minus the expected rate of future inflation \( E_t \pi_{t+1} \). That is,

\[
r_t = i_t - E_t \pi_{t+1}.
\]

This Fisher equation is similar to the one we first saw in Chapter 4. Here, \( E_t \pi_{t+1} \) represents the expectation formed in period \( t \) of inflation in period \( t + 1 \). The variable \( r_t \) is the ex ante real interest rate: the real interest rate that people anticipate based on their expectation of inflation.

A word on the notation and timing convention should clarify the meaning of these variables. The variables \( r_t \) and \( i_t \) are interest rates that prevail at time \( t \) and, therefore, represent a rate of return between periods \( t \) and \( t + 1 \). The variable \( \pi_t \) denotes the current inflation rate, which is the percentage change in the price
level between periods $t - 1$ and $t$. Similarly, $\pi_{t+1}$ is the percentage change in the price level that will occur between periods $t$ and $t + 1$. As of time period $t$, $\pi_{t+1}$ represents a future inflation rate and therefore is not yet known.

Note that the subscript on a variable tells us when the variable is determined. The nominal and *ex ante* real interest rates between $t$ and $t + 1$ are known at time $t$, so they are written as $i_t$ and $r_t$. By contrast, the inflation rate between $t$ and $t + 1$ is not known until time $t + 1$, so it is written as $\pi_{t+1}$.

This subscript rule also applies when the expectations operator $E$ precedes a variable, but here you have to be especially careful. As in previous chapters, the operator $E$ in front of a variable denotes the expectation of that variable prior to its realization. The subscript on the expectations operator tells us when that expectation is formed. So $E_t\pi_{t+1}$ is the expectation of what the inflation rate will be in period $t + 1$ (the subscript on $\pi$) based on information available in period $t$ (the subscript on $E$). While the inflation rate $\pi_{t+1}$ is not known until period $t + 1$, the expectation of future inflation, $E_t\pi_{t+1}$, is known at period $t$. As a result, even though the *ex post* real interest rate, which is given by $i_t - \pi_{t+1}$, will not be known until period $t + 1$, the *ex ante* real interest rate, $r_t = i_t - E_t\pi_{t+1}$, is known at time $t$.

**Inflation: The Phillips Curve**

Inflation in this economy is determined by a conventional Phillips curve augmented to include roles for expected inflation and exogenous supply shocks. The equation for inflation is

$$\pi_t = E_{t-1}\pi_t + \phi(Y_t - \bar{Y}_t) + \nu_t.$$  

This piece of the model is similar to the Phillips curve and short-run aggregate supply equation introduced in Chapter 13. According to this equation, inflation $\pi_t$ depends on previously expected inflation $E_{t-1}\pi_t$, the deviation of output from its natural level $(Y_t - \bar{Y}_t)$, and an exogenous supply shock $\nu_t$.

Inflation depends on expected inflation because some firms set prices in advance. When these firms expect high inflation, they anticipate that their costs will be rising quickly and that their competitors will be implementing substantial price hikes. The expectation of high inflation thereby induces these firms to announce significant price increases for their own products. These price increases in turn cause high actual inflation in the overall economy. Conversely, when firms expect low inflation, they forecast that costs and competitors’ prices will rise only modestly. In this case, they keep their own price increases down, leading to low actual inflation.

The parameter $\phi$, which is greater than zero, tells us how much inflation responds when output fluctuates around its natural level. Other things equal, when the economy is booming and output rises above its natural level, firms experience increasing marginal costs, and so they raise prices. When the economy is in recession and output is below its natural level, marginal cost falls, and firms cut prices. The parameter $\phi$ reflects both how much marginal cost responds
to the state of economic activity and how quickly firms adjust prices in response to changes in cost.

In this model, the state of the business cycle is measured by the deviation of output from its natural level \( (Y_t - \bar{Y}_t) \). The Phillips curves in Chapter 13 sometimes emphasized the deviation of unemployment from its natural rate. This difference is not significant, however. Recall Okun’s law from Chapter 9: Short-run fluctuations in output and unemployment are strongly and negatively correlated. When output is above its natural level, unemployment is below its natural rate, and vice versa. As we continue to develop this model, keep in mind that unemployment fluctuates along with output, but in the opposite direction.

The supply shock \( u_t \) is a random variable that averages to zero but could, in any given period, be positive or negative. This variable captures all influences on inflation other than expectations of inflation (which is captured in the first term, \( E_{t-1}\pi_t \)) and short-run economic conditions (which are captured in the second term, \( \phi(Y_t - \bar{Y}_t) \)). For example, if an aggressive oil cartel pushes up world oil prices, thus increasing overall inflation, that event would be represented by a positive value of \( u_t \). If cooperation within the oil cartel breaks down and world oil prices plummet, causing inflation to fall, \( u_t \) would be negative. In short, \( u_t \) reflects all exogenous events that directly influence inflation.

**Expected Inflation: Adaptive Expectations**

As we have seen, expected inflation plays a key role in both the Phillips curve equation for inflation and the Fisher equation relating nominal and real interest rates. To keep the dynamic AD–AS model simple, we assume that people form their expectations of inflation based on the inflation they have recently observed. That is, people expect prices to continue rising at the same rate they have been rising. This is sometimes called the assumption of *adaptive expectations*. It can be written as

\[
E_t\pi_{t+1} = \pi_t.
\]

When forecasting in period \( t \) what inflation rate will prevail in period \( t + 1 \), people simply look at inflation in period \( t \) and extrapolate it forward.

The same assumption applies in every period. Thus, when inflation was observed in period \( t - 1 \), people expected that rate to continue. This implies that \( E_{t-1}\pi_t = \pi_{t-1} \).

This assumption about inflation expectations is admittedly crude. Many people are probably more sophisticated in forming their expectations. As we discussed in Chapter 13, some economists advocate an approach called *rational expectations*, according to which people optimally use all available information when forecasting the future. Incorporating rational expectations into the model is, however, beyond the scope of this book. (Moreover, the empirical validity of rational expectations is open to dispute.) The assumption of adaptive expectations greatly simplifies the exposition of the theory without losing many of the model's insights.
The Nominal Interest Rate: The Monetary-Policy Rule

The last piece of the model is the equation for monetary policy. We assume that the central bank sets a target for the nominal interest rate \( i_t \) based on inflation and output using this rule:

\[
i_t = \pi_t + \rho + \theta_x(\pi_t - \pi^*_x) + \theta_Y(Y_t - Y)\bar{Y}_t.
\]

In this equation, \( \pi^*_x \) is the central bank’s target for the inflation rate. (For most purposes, target inflation can be assumed to be constant, but we will keep a time subscript on this variable so we can examine later what happens when the central bank changes its target.) Two key policy parameters are \( \theta_x \) and \( \theta_Y \), which are both assumed to be greater than zero. They indicate how much the central bank allows the interest rate target to respond to fluctuations in inflation and output. The larger the value of \( \theta_x \), the more responsive the central bank is to the deviation of inflation from its target; the larger the value of \( \theta_Y \), the more responsive the central bank is to the deviation of income from its natural level. Recall that \( \rho \), the constant in this equation, is the natural rate of interest (the real interest rate at which, in the absence of any shock, the demand for goods and services equals the natural level of output). This equation tells us how the central bank uses monetary policy to respond to any situation it faces. That is, it tells us how the target for the nominal interest rate chosen by the central bank responds to macroeconomic conditions.

To interpret this equation, it is best to focus not just on the nominal interest rate \( i_t \), but also on the real interest rate \( r_t \). Recall that the real interest rate, rather than the nominal interest rate, influences the demand for goods and services. So, although the central bank sets a target for the nominal interest rate \( i_t \), the bank’s influence on the economy works through the real interest rate \( r_t \). By definition, the real interest rate is \( r_t = i_t - \pi_t \). With our expectation equation \( E_t \pi_{t+1} = \pi_t \), we can also rewrite the real interest rate as \( r_t = i_t - \pi_t \). According to the equation for monetary policy, if inflation is at its target (\( \pi_t = \pi^*_x \)) and output is at its natural level (\( Y_t = Y \)), the last two terms in the equation are zero, and so the real interest rate equals the natural rate of interest \( \rho \). As inflation rises above its target (\( \pi_t > \pi^*_x \)) or output rises above its natural level (\( Y_t > Y \)), the real interest rate rises. And as inflation falls below its target (\( \pi_t < \pi^*_x \)) or output falls below its natural level (\( Y_t < Y \)), the real interest rate falls.

At this point, one might naturally ask: what about the money supply? In previous chapters, such as Chapters 10 and 11, the money supply was typically taken to be the policy instrument of the central bank, and the interest rate adjusted to bring money supply and money demand into equilibrium. Here, we turn that logic on its head. The central bank is assumed to set a target for the nominal interest rate. It then adjusts the money supply to whatever level is necessary to ensure that the equilibrium interest rate (which balances money supply and demand) hits the target.

The main advantage of using the interest rate, rather than the money supply, as the policy instrument in the dynamic AD–AS model is that it is more realistic. Today, most central banks, including the Federal Reserve, set a short-term target for the nominal interest rate. Keep in mind, though, that
hitting that target requires adjustments in the money supply. For this model, we do not need to specify the equilibrium condition for the money market, but we should remember that it is lurking in the background. When a central bank decides to change the interest rate, it is also committing itself to adjust the money supply accordingly.

**CASE STUDY**

### The Taylor Rule

If you wanted to set interest rates to achieve low, stable inflation while avoiding large fluctuations in output and employment, how would you do it? This is exactly the question that the governors of the Federal Reserve must ask themselves every day. The short-term policy instrument that the Fed now sets is the **federal funds rate**—the short-term interest rate at which banks make loans to one another. Whenever the Federal Open Market Committee meets, it chooses a target for the federal funds rate. The Fed’s bond traders are then told to conduct open-market operations to hit the desired target.

The hard part of the Fed’s job is choosing the target for the federal funds rate. Two general guidelines are clear. First, when inflation heats up, the federal funds rate should rise. An increase in the interest rate will mean a smaller money supply and, eventually, lower investment, lower output, higher unemployment, and reduced inflation. Second, when real economic activity slows—as reflected in real GDP or unemployment—the federal funds rate should fall. A decrease in the interest rate will mean a larger money supply and, eventually, higher investment, higher output, and lower unemployment. These two guidelines are represented by the monetary-policy equation in the dynamic \( AD-AS \) model.

The Fed needs to go beyond these general guidelines, however, and decide exactly how much to respond to changes in inflation and real economic activity. Stanford University economist John Taylor has proposed the following rule for the federal funds rate:

\[
\text{Nominal Federal Funds Rate} = \text{Inflation} + 2.0 + 0.5 \times (\text{Inflation} - 2.0) + 0.5 \times (\text{GDP gap}).
\]

The GDP gap is the percentage by which real GDP deviates from an estimate of its natural level. (For consistency with our dynamic \( AD-AS \) model, the GDP gap here is taken to be positive if GDP rises above its natural level and negative if it falls below it.)

According to the Taylor rule, the real federal funds rate—the nominal rate minus inflation—responds to inflation and the GDP gap. According to this rule,

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the real federal funds rate equals 2 percent when inflation is 2 percent and GDP is at its natural level. The first constant of 2 percent in this equation can be interpreted as an estimate of the natural rate of interest \( r \), and the second constant of 2 percent subtracted from inflation can be interpreted as the Fed's inflation target \( \pi^* \). For each percentage point that inflation rises above 2 percent, the real federal funds rate rises by 0.5 percent. For each percentage point that real GDP rises above its natural level, the real federal funds rate rises by 0.5 percent. If inflation falls below 2 percent or GDP moves below its natural level, the real federal funds rate falls accordingly.

In addition to being simple and reasonable, the Taylor rule for monetary policy also resembles actual Fed behavior in recent years. Figure 14-1 shows the actual nominal federal funds rate and the target rate as determined by Taylor’s proposed rule. Notice how the two series tend to move together. John Taylor’s monetary rule may be more than an academic suggestion. To some degree, it may be the rule that the Federal Reserve governors have been subconsciously following.

**FIGURE 14-1**

**The Federal Funds Rate: Actual and Suggested** This figure shows the federal funds rate set by the Federal Reserve and the target rate that John Taylor’s rule for monetary policy would recommend. Notice that the two series move closely together.

*Source:* Federal Reserve Board, U.S. Department of Commerce, U.S. Department of Labor, and author’s calculations. To implement the Taylor rule, the inflation rate is measured as the percentage change in the GDP deflator over the previous four quarters, and the GDP gap is measured as negative two times the deviation of the unemployment rate from its natural rate (as shown in Figure 6-1).
14.2 Solving the Model

We have now looked at each of the pieces of the dynamic AD–AS model. To summarize, here are the five equations that make up the model:

\[ Y_t = \bar{Y}_t - \alpha (r_t - \rho) + \epsilon_t \quad \text{The Demand for Goods and Services} \]

\[ r_t = i_t - E_{t} \pi_{t+1} \quad \text{The Fisher Equation} \]

\[ \pi_t = E_{t-1} \pi_t + \phi (Y_t - \bar{Y}_t) + \nu_t \quad \text{The Phillips Curve} \]

\[ E_{t} \pi_{t+1} = \pi_t \quad \text{Adaptive Expectations} \]

\[ i_t = \pi_t + \rho + \theta_{\pi}(\pi_t - \bar{\pi}_t) + \theta_{Y}(Y_t - \bar{Y}_t) \quad \text{The Monetary-Policy Rule} \]

These five equations determine the paths of the model's five endogenous variables: output \( Y_t \), the real interest rate \( r_t \), inflation \( \pi_t \), expected inflation \( E_{t} \pi_{t+1} \), and the nominal interest rate \( i_t \).

Table 14-1 lists all the variables and parameters in the model. In any period, the five endogenous variables are influenced by the four exogenous variables in

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the equations as well as the previous period’s inflation rate. Lagged inflation \( \pi_{t-1} \) is called a *predetermined variable*. That is, it is a variable that was endogenous in the past but, because it is fixed by the time we arrive in period \( t \), is essentially exogenous for the purposes of finding the current equilibrium.

We are almost ready to put these pieces together to see how various shocks to the economy influence the paths of these variables over time. Before doing so, however, we need to establish the starting point for our analysis: the economy’s long-run equilibrium.

**The Long-Run Equilibrium**

The long-run equilibrium represents the normal state around which the economy fluctuates. It occurs when there are no shocks \( (\epsilon_t = \nu_t = 0) \) and inflation has stabilized \( (\pi_t = \pi_{t-1}) \).

Straightforward algebra applied to the above five equations can be used to verify these long-run values:

\[
Y_t = \bar{Y}_t, \\
\rho = \rho, \\
\pi_t = \pi_t^*, \\
E_t \pi_{t+1} = \pi_t^*, \\
i_t = \rho + \pi_t^*.
\]

In words, the long-run equilibrium is described as follows: output and the real interest rate are at their natural values, inflation and expected inflation are at the target rate of inflation, and the nominal interest rate equals the natural rate of interest plus target inflation.

The long-run equilibrium of this model reflects two related principles: the classical dichotomy and monetary neutrality. Recall that the classical dichotomy is the separation of real from nominal variables, and monetary neutrality is the property according to which monetary policy does not influence real variables. The equations immediately above show that the central bank’s inflation target \( \pi_t^* \) influences only inflation \( \pi_t \), expected inflation \( E_t \pi_{t+1} \), and the nominal interest rate \( i_t \). If the central bank raises its inflation target, then inflation, expected inflation, and the nominal interest rate all increase by the same amount. The real variables—output \( Y_t \) and the real interest rate \( \rho \)—do not depend on monetary policy. In these ways, the long-run equilibrium of the dynamic \( AD-AS \) model mirrors the classical models we examined in Chapters 3 to 8.

**The Dynamic Aggregate Supply Curve**

To study the behavior of this economy in the short run, it is useful to analyze the model graphically. Because graphs have two axes, we need to focus on two variables. We will use output \( Y_t \) and inflation \( \pi_t \) as the variables on the two axes because these
are the variables of central interest. As in the conventional AD–AS model, output will be on the horizontal axis. But because the price level has now faded into the background, the vertical axis in our graphs will now represent the inflation rate.

To generate this graph, we need two equations that summarize the relationships between output $Y_t$ and inflation $\pi_t$. These equations are derived from the five equations of the model we have already seen. To isolate the relationships between $Y_t$ and $\pi_t$, however, we need to use a bit of algebra to eliminate the other three endogenous variables ($r_t$, $i_t$, and $E_{t-1}\pi_t$).

The first relationship between output and inflation comes almost directly from the Phillips curve equation. We can get rid of the one endogenous variable in the equation ($E_{t-1}\pi_t$) by using the expectations equation ($E_{t-1}\pi_t = \pi_{t-1}$) to substitute past inflation $\pi_{t-1}$ for expected inflation $E_{t-1}\pi_t$. With this substitution, the equation for the Phillips curve becomes

$$\pi_t = \pi_{t-1} + \phi(Y_t - \bar{Y}_t) + \nu_t,$$

(DAS)

This equation relates inflation $\pi_t$ and output $Y_t$ for given values of two exogenous variables ($\bar{Y}_t$ and $\nu_t$) and a predetermined variable ($\pi_{t-1}$).

Figure 14-2 graphs the relationship between inflation $\pi_t$ and output $Y_t$ described by this equation. We call this upward-sloping curve the dynamic aggregate supply curve, or DAS. The dynamic aggregate supply curve is similar to the aggregate supply curve we saw in Chapter 13, except that inflation rather than the price level is on the vertical axis. The DAS curve shows how inflation is related to output in the short run. Its upward slope reflects the Phillips curve: Other things equal, high levels of economic activity are associated with high inflation.

The DAS curve is drawn for given values of past inflation $\pi_{t-1}$, the natural level of output $\bar{Y}_t$, and the supply shock $\nu_t$. If any one of these three variables changes, the DAS curve shifts. One of our tasks ahead is to trace out the implications of such shifts. But first, we need another curve.

**Figure 14-2**

**The Dynamic Aggregate Supply Curve** The dynamic aggregate supply curve $DAS_t$ shows a positive association between output $Y_t$ and inflation $\pi_t$. Its upward slope reflects the Phillips curve relationship: Other things equal, high levels of economic activity are associated with high inflation. The dynamic aggregate supply curve is drawn for given values of past inflation $\pi_{t-1}$, the natural level of output $\bar{Y}_t$, and the supply shock $\nu_t$. When these variables change, the curve shifts.
The Dynamic Aggregate Demand Curve

The dynamic aggregate supply curve is one of the two relationships between output and inflation that determine the economy’s short-run equilibrium. The other relationship is (no surprise) the dynamic aggregate demand curve. We derive it by combining four equations from the model and then eliminating all the endogenous variables other than output and inflation.

We begin with the demand for goods and services:

\[ Y_t = \bar{Y}_t + \alpha (r_t - \rho) + \epsilon_t. \]

To eliminate the endogenous variable \( r_t \), the real interest rate, we use the Fisher equation to substitute \( i_t - E_t \pi_{t+1} \) for \( r_t \):

\[ Y_t = \bar{Y}_t - \alpha (i_t - E_t \pi_{t+1} - \rho) + \epsilon_t. \]

To eliminate another endogenous variable, the nominal interest rate \( i_t \), we use the monetary-policy equation to substitute for \( i_t \):

\[ Y_t = \bar{Y}_t - \alpha [\pi_t + \rho + \theta_n (\pi_t - \pi_t^*) + \theta_Y (Y_t - \bar{Y}_t) - E_t \pi_{t+1} - \rho] + \epsilon_t. \]

Next, to eliminate the endogenous variable of expected inflation \( E_t \pi_{t+1} \), we use our equation for inflation expectations to substitute \( \pi_t \) for \( E_t \pi_{t+1} \):

\[ Y_t = \bar{Y}_t - \alpha [\pi_t + \rho + \theta_n (\pi_t - \pi_t^*) + \theta_Y (Y_t - \bar{Y}_t) - \pi_t - \rho] + \epsilon_t. \]

Notice that the positive \( \pi_t \) and \( \rho \) inside the brackets cancel the negative ones. The equation simplifies to

\[ Y_t = \bar{Y}_t - \alpha [\theta_n (\pi_t - \pi_t^*) + \theta_Y (Y_t - \bar{Y}_t)] + \epsilon_t. \]

If we now bring like terms together and solve for \( Y_t \), we obtain

\[ Y_t = \bar{Y}_t - [\alpha \theta_n/ (1 + \alpha \theta_Y)] (\pi_t - \pi_t^*) + [1/(1 + \alpha \theta_Y)] \epsilon_t. \quad (DAD) \]

This equation relates output \( Y_t \) to inflation \( \pi_t \), for given values of three exogenous variables \( (\bar{Y}_t, \pi_t^*, \text{and } \epsilon_t) \).

Figure 14-3 graphs the relationship between inflation \( \pi_t \) and output \( Y_t \) described by this equation. We call this downward-sloping curve the dynamic aggregate demand curve, or DAD. The DAD curve shows how the quantity of output demanded is related to inflation in the short run. It is drawn holding constant the natural level of output \( \bar{Y}_t \), the inflation target \( \pi_t^* \), and the demand shock \( \epsilon_t \). If any one of these three variables changes, the DAD curve shifts. We will examine the effect of such shifts shortly.

It is tempting to think of this dynamic aggregate demand curve as nothing more than the standard aggregate demand curve from Chapter 11 with inflation, rather than the price level, on the vertical axis. In some ways, they are similar: they both embody the link between the interest rate and the demand for goods and services. But there is an important difference. The conventional aggregate demand curve in Chapter 11 is drawn for a given money supply. By contrast, because the monetary-policy rule was used to derive the dynamic aggregate demand equation, the dynamic aggregate demand curve is drawn for a given rule for monetary policy. Under that rule, the central bank sets the
The Dynamic Aggregate Demand Curve The dynamic aggregate demand curve shows a negative association between output and inflation. Its downward slope reflects monetary policy and the demand for goods and services: a high level of inflation causes the central bank to raise nominal and real interest rates, which in turn reduces the demand for goods and services. The dynamic aggregate demand curve is drawn for given values of the natural level of output $\bar{Y}$, the inflation target $\pi^\ast$, and the demand shock $\epsilon$. When these exogenous variables change, the curve shifts.

interest rate based on macroeconomic conditions, and it allows the money supply to adjust accordingly.

The dynamic aggregate demand curve is downward sloping because of the following mechanism. When inflation rises, the central bank follows its rule and responds by increasing the nominal interest rate. Because the rule specifies that the central bank raise the nominal interest rate by more than the increase in inflation, the real interest rate rises as well. The increase in the real interest rate reduces the quantity of goods and services demanded. This negative association between inflation and quantity demanded, working through central bank policy, makes the dynamic aggregate demand curve slope downward.

The dynamic aggregate demand curve shifts in response to changes in fiscal and monetary policy. As we noted earlier, the shock variable $\epsilon$ reflects changes in government spending and taxes (among other things). Any change in fiscal policy that increases the demand for goods and services means a positive value of $\epsilon$ and a shift of the $DAD$ curve to the right. Any change in fiscal policy that decreases the demand for goods and services means a negative value of $\epsilon$ and a shift of the $DAD$ curve to the left.

Monetary policy enters the dynamic aggregate demand curve through the target inflation rate $\pi^\ast$. The $DAD$ equation shows that, other things equal, an increase in $\pi^\ast$ raises the quantity of output demanded. (There are two negative signs in front of $\pi^\ast$ so the effect is positive.) Here is the mechanism that lies behind this mathematical result: When the central bank raises its target for inflation, it pursues a more expansionary monetary policy by reducing the nominal interest rate. The lower nominal interest rate in turn means a lower real interest rate, which stimulates spending on goods and services. Thus, output is higher for any given inflation rate, so the dynamic aggregate demand curve shifts to the right. Conversely, when the central bank reduces its target for inflation, it raises nominal and real interest rates, thereby dampening demand for goods and services and shifting the dynamic aggregate demand curve to the left.
The Short-Run Equilibrium

The economy's short-run equilibrium is determined by the intersection of the dynamic aggregate demand curve and the dynamic aggregate supply curve. The economy can be represented algebraically using the two equations we have just derived:

\[ Y_t = \overline{Y}_t - \left[ \alpha z_n / (1 + \alpha z_n) \right] (\pi_t - \pi_t^*) + \left[ 1 / (1 + \alpha z_n) \right] \epsilon_t. \]  
\[ (DAD) \]

\[ \pi_t = \pi_{t-1} + \phi (Y_t - \overline{Y}_t) + \nu_t. \]
\[ (DAS) \]

In any period \( t \), these equations together determine two endogenous variables: inflation \( \pi_t \) and output \( Y_t \). The solution depends on five other variables that are exogenous (or at least determined prior to period \( t \)). These exogenous (and predetermined) variables are the natural level of output \( \overline{Y}_t \), the central bank's target inflation rate \( \pi_t^* \), the shock to demand \( \epsilon_t \), the shock to supply \( \nu_t \), and the previous period's rate of inflation \( \pi_{t-1} \).

Taking these exogenous variables as given, we can illustrate the economy's short-run equilibrium as the intersection of the dynamic aggregate demand curve and the dynamic aggregate supply curve, as in Figure 14-4. The short-run equilibrium level of output \( Y_t \) can be less than its natural level \( \overline{Y}_t \), as it is in this figure, greater than its natural level, or equal to it. As we have seen, when the economy is in long-run equilibrium, output is at its natural level \( (Y_t = \overline{Y}_t) \).

The short-run equilibrium determines not only the level of output \( Y_t \) but also the inflation rate \( \pi_t \). In the subsequent period \( (t + 1) \), this inflation rate will become the lagged inflation rate that influences the position of the dynamic aggregate supply curve. This connection between periods generates the dynamic patterns that we will examine below. That is, one period of time is linked to the next through expectations about inflation. A shock in period \( t \) affects inflation in period \( t \), which in turn affects the inflation that people expect for period \( t + 1 \). Expected inflation in period \( t + 1 \) in turn affects the position of the dynamic

**Figure 14-4**

The Short-Run Equilibrium The short-run equilibrium is determined by the intersection of the dynamic aggregate demand curve and the dynamic aggregate supply curve. This equilibrium determines the inflation rate and level of output that prevail in period \( t \). In the equilibrium shown in this figure, the short-run equilibrium level of output \( Y_t \) falls short of the economy's natural level of output \( \overline{Y}_t \).
aggregate supply curve in that period, which in turn affects output and inflation in period \( t + 1 \), which then affects expected inflation in period \( t + 2 \), and so on. These linkages of economic outcomes across time periods will become clear as we work through a series of examples.

### 14.3 Using the Model

Let's now use the dynamic AD–AS model to analyze how the economy responds to changes in the exogenous variables. The four exogenous variables in the model are the natural level of output \( \bar{Y} \), the supply shock \( \epsilon \), the demand shock \( e_n \), and the central bank's inflation target \( \pi^* \). To keep things simple, we will assume that the economy always begins in long-run equilibrium and is then subject to a change in one of the exogenous variables. We also assume that the other exogenous variables are held constant.

#### Long-Run Growth

The economy's natural level of output \( \bar{Y} \) changes over time because of population growth, capital accumulation, and technological progress, as discussed in Chapters 7 and 8. Figure 14-5 illustrates the effect of an increase in \( \bar{Y} \). Because this variable affects both the dynamic aggregate demand curve and the dynamic aggregate supply curve, both curves shift. In fact, they both shift to the right by exactly the amount that \( \bar{Y} \) has increased.

![Figure 14-5](image)

**An Increase in the Natural Level of Output** If the natural level of output \( \bar{Y} \) increases, both the dynamic aggregate demand curve and the dynamic aggregate supply curve shift to the right by the same amount. Output \( Y_t \) increases, but inflation \( \pi_t \) remains the same.

**FIGURE 14-5**

- **Inflation, \( \pi \)**
- **1. When the natural level of output increases, ...**
- **2. ... the dynamic AS curve shifts to the right, ...**
- **3. ... as does the dynamic AD curve, ...**
- **4. ... leading to growth in output ...**
- **5. ... and stable inflation.**
The shifts in these curves move the economy's equilibrium in the figure from point A to point B. Output $Y_t$ increases by exactly as much as the natural level $\overline{Y}_t$. Inflation is unchanged.

The story behind these conclusions is as follows: When the natural level of output increases, the economy can produce a larger quantity of goods and services. This is represented by the rightward shift in the dynamic aggregate supply curve. At the same time, the increase in the natural level of output makes people richer. Other things equal, they want to buy more goods and services. This is represented by the rightward shift in the dynamic aggregate demand curve. The simultaneous shifts in supply and demand increase the economy's output without putting either upward or downward pressure on inflation. In this way, the economy can experience long-run growth and a stable inflation rate.

A Shock to Aggregate Supply

Consider now a shock to aggregate supply. In particular, suppose that $\nu_t$ rises to 1 percent for one period and subsequently returns to zero. This shock to the Phillips curve might occur, for example, because an international oil cartel pushes up prices or because new union agreements raise wages and, thereby, the costs of production. In general, the supply shock $\nu_t$ captures any event that influences inflation beyond expected inflation $E_{t-1} \pi_t$ and current economic activity, as measured by $Y_t - \overline{Y}_t$.

Figure 14-6 shows the result. In period $t$, when the shock occurs, the dynamic aggregate supply curve shifts upward from $DAS_{t-1}$ to $DAS_t$. To be precise, the

---

**FIGURE 14-6**

Inflation, $\pi$

2. ... causing inflation to rise...

$\pi_t$

$\pi_{t+1}$

$\pi_{t-1}$

Income, output, $Y$

3. ... and output to fall.

$Y_t$

$Y_{t-1}$

$Y_{t+1}$

A Supply Shock A supply shock in period $t$ shifts the dynamic aggregate supply curve upward from $DAS_{t-1}$ to $DAS_t$. The dynamic aggregate demand curve is unchanged. The economy's short-run equilibrium moves from point A to point B. Inflation rises and output falls. In the subsequent period ($t+1$), the dynamic aggregate supply curve shifts to $DAS_{t+1}$ and the economy moves to point C. The supply shock has returned to its normal value of zero, but inflation expectations remain high. As a result, the economy returns only gradually to its initial equilibrium, point A.
curve shifts upward by exactly the size of the shock, which we assumed to be 1 percentage point. Because the supply shock $u_t$ is not a variable in the dynamic aggregate demand equation, the $DAD$ curve is unchanged. Therefore, the economy moves along the dynamic aggregate demand curve from point A to point B. As the figure illustrates, the supply shock in period $t$ causes inflation to rise to $\pi_t$ and output to fall to $Y_t$.

These effects work in part through the reaction of monetary policy to the shock. When the supply shock causes inflation to rise, the central bank responds by following its policy rule and raising nominal and real interest rates. The higher real interest rate reduces the quantity of goods and services demanded, which depresses output below its natural level. (This series of events is represented by the movement along the $DAD$ curve from point A to point B.) The lower level of output dampens the inflationary pressure to some degree, so inflation rises somewhat less than the initial shock.

The Numerical Calibration and Simulation

The text presents some numerical simulations of the dynamic $AD$–$AS$ model. When interpreting these results, it is easiest to think of each period as representing one year. We examine the impact of the change in the year of the shock (period $t$) and over the subsequent 12 years.

The simulations use these parameter values:

\[ \bar{Y}_t = 100. \]
\[ \pi_t^* = 2.0. \]
\[ \alpha = 1.0. \]
\[ \rho = 2.0. \]
\[ H = 0.25. \]
\[ \theta_r = 0.5. \]
\[ \theta_r = 0.5. \]

Here is how to interpret these numbers. The natural level of output $\bar{Y}_t$ is 100; as a result of choosing this convenient number, fluctuations in $Y_t - \bar{Y}_t$ can be viewed as percentage deviations of output from its natural level. The central bank’s inflation target $\pi_t^*$ is 2 percent. The parameter $\alpha = 1.0$ implies that a 1-percentage-point increase in the real interest rate reduces output demand by 1, which is 1 percent of its natural level. The economy’s natural rate of interest $\rho$ is 2 percent. The Phillips curve parameter $H = 0.25$ implies that when output is 1 percent above its natural level, inflation rises by 0.25 percentage point. The parameters for the monetary policy rule $\theta_r = 0.5$ and $\theta_r = 0.5$ are those suggested by John Taylor and are reasonable approximations of the behavior of the Federal Reserve.

In all cases, the simulations assume a change of 1 percentage point in the exogenous variable of interest. Larger shocks would have qualitatively similar effects, but the magnitudes would be proportionately greater. For example, a shock of 3 percentage points would affect all the variables in the same way as a shock of 1 percentage point, but the movements would be three times as large as in the simulation shown.

The graphs of the time paths of the variables after a shock (shown in Figures 14-7, 14-9, and 14-11) are called impulse response functions. The word “impulse” refers to the shock, and “response function” refers to how the endogenous variables respond to the shock over time. These simulated impulse response functions are one way to illustrate how the model works. They show how the endogenous variables move when a shock hits the economy, how these variables adjust in subsequent periods, and how they are correlated with one another over time.
In the periods after the shock occurs, expected inflation is higher because expectations depend on past inflation. In period \( t + 1 \), for instance, the economy is at point C. Even though the shock variable \( v_i \) returns to its normal value of zero, the dynamic aggregate supply curve does not immediately return to its initial position. Instead, it slowly shifts back downward toward its initial position \( DAS_{t-1} \) as a lower level of economic activity reduces inflation and thereby expectations of future inflation. Throughout this process, output remains below its natural level.

Figure 14-7 shows the time paths of the key variables in the model in response to the shock. (These simulations are based on realistic parameter values; see the

**FIGURE 14-7**

(a) Supply Shock

(b) Output

(c) Real Interest Rate

(d) Inflation

(e) Nominal Interest Rate

The Dynamic Response to a Supply Shock This figure shows the responses of the key variables over time to a one-time supply shock.
nearby FYI box for their description.) As panel (a) shows, the shock $u_t$ spikes upward by 1 percentage point in period $t$ and then returns to zero in subsequent periods. Inflation, shown in panel (d), rises by 0.9 percentage point and gradually returns to its target of 2 percent over a long period of time. Output, shown in panel (b), falls in response to the supply shock but also eventually returns to its natural level.

The figure also shows the paths of nominal and real interest rates. In the period of the supply shock, the nominal interest rate, shown in panel (e), increases by 1.2 percentage points, and the real interest rate, in panel (c), increases by 0.3 percentage points. Both interest rates return to their normal values as the economy returns to its long-run equilibrium.

These figures illustrate the phenomenon of *stagflation* in the dynamic $AD-AS$ model. A supply shock causes inflation to rise, which in turn increases expected inflation. As the central bank applies its rule for monetary policy and responds by raising interest rates, it gradually squeezes inflation out of the system, but only at the cost of a prolonged downturn in economic activity.

**A Shock to Aggregate Demand**

Now let’s consider a shock to aggregate demand. To be realistic, the shock is assumed to persist over several periods. In particular, suppose that $\epsilon_t = 1$ for five periods and then returns to its normal value of zero. This positive shock $\epsilon_t$ might represent, for example, a war that increases government purchases or a stock market bubble that increases wealth and thereby consumption spending. In general, the demand shock captures any event that influences the demand for goods and services for given values of the natural level of output $\bar{Y}$, and the real interest rate $r$.

Figure 14-8 shows the result. In period $t$, when the shock occurs, the dynamic aggregate demand curve shifts to the right from $DAD_{t-1}$ to $DAD_t$. Because the demand shock $\epsilon_t$ is not a variable in the dynamic aggregate supply equation, the $DAS$ curve is unchanged from period $t-1$ to period $t$. The economy moves along the dynamic aggregate supply curve from point A to point B. Output and inflation both increase.

Once again, these effects work in part through the reaction of monetary policy to the shock. When the demand shock causes output and inflation to rise, the central bank responds by increasing the nominal and real interest rates. Because a higher real interest rate reduces the quantity of goods and services demanded, it partly offsets the expansionary effects of the demand shock.

In the periods after the shock occurs, expected inflation is higher because expectations depend on past inflation. As a result, the dynamic aggregate supply curve shifts upward repeatedly; as it does so, it continually reduces output and increases inflation. In the figure, the economy goes from point B in the initial period of the shock to points C, D, E, and F in subsequent periods.

In the sixth period ($t + 5$), the demand shock disappears. At this time, the dynamic aggregate demand curve returns to its initial position. However, the
A Demand Shock  This figure shows the effects of a positive demand shock in period \( t \) that lasts for five periods. The shock immediately shifts the dynamic aggregate demand curve to the right from \( DAD_{t-1} \) to \( DAD_t \). The economy moves from point A to point B. Both inflation and output rise. In the next period, the dynamic aggregate supply curve shifts to \( DAS_{t+1} \) because of increased expected inflation. The economy moves from point B to point C, and then in subsequent periods to points D, E, and F. When the demand shock disappears after five periods, the dynamic aggregate demand curve shifts back to its initial position, and the economy moves from point F to point G. Output falls below its natural level, and inflation starts to fall. Over time, the dynamic aggregate supply curve starts shifting downward, and the economy gradually returns to its initial equilibrium, point A.

The economy does not immediately return to its initial equilibrium, point A. The period of high demand has increased inflation and thereby expected inflation. High expected inflation keeps the dynamic aggregate supply curve higher than it was initially. As a result, when demand falls off, the economy's equilibrium moves to point G, and output falls to \( Y_{t+5} \), which is below its natural level. The economy then gradually recovers, as the higher-than-target inflation is squeezed out of the system.

Figure 14-9 shows the time path of the key variables in the model in response to the demand shock. Note that the positive demand shock increases real and nominal interest rates. When the demand shock disappears, both interest rates fall. These responses occur because when the central bank sets the nominal interest rate, it takes into account both inflation rates and deviations of output from its natural level.
A Shift in Monetary Policy

Suppose that the central bank decides to reduce its target for the inflation rate. Specifically, imagine that, in period \( t \), \( \pi_t^{\ast} \) falls from 2 percent to 1 percent and thereafter remains at that lower level. Let’s consider how the economy will react to this change in monetary policy.

Recall that the inflation target enters the model as an exogenous variable in the dynamic aggregate demand curve. When the inflation target falls, the \( DAD \)
curve shifts to the left, as shown in Figure 14-10. (To be precise, it shifts downward by exactly 1 percentage point.) Because target inflation does not enter the dynamic aggregate supply equation, the DAS curve does not shift initially. The economy moves from its initial equilibrium, point A, to a new equilibrium, point B. Output and inflation both fall.

Monetary policy is, not surprisingly, key to the explanation of this outcome. When the central bank lowers its target for inflation, current inflation is now above the target, so the central bank follows its policy rule and raises real and nominal interest rates. The higher real interest rate reduces the demand for goods and services. When output falls, the Phillips curve tells us that inflation falls as well.

Lower inflation, in turn, reduces the inflation rate that people expect to prevail in the next period. In period \(t+1\), lower expected inflation shifts the dynamic aggregate supply curve downward, to \(DAS_{t+1}\). (To be precise, the curve shifts downward by exactly the fall in expected inflation.) This shift moves the economy from point B to point C, further reducing inflation and expanding output. Over time, as inflation continues to fall and the DAS curve continues to shift.

**FIGURE 14-10**

1. A reduction in target inflation shifts the DAD curve downward,

\[
\pi_{t-1} = 2\% \quad \pi_t
\]

3. ... and inflation to fall as well.

\[
\pi_{final} = 1\%
\]

2. ... causing output to fall...

\[
Y_t - Y_{t-1} = Y_{final}
\]

4. In subsequent periods, lower expected inflation shifts the DAS curve downward.

5. Eventually, the economy approaches a final equilibrium, with output at its natural level and inflation at its new, lower target.

**A Reduction in Target Inflation** A permanent reduction in target inflation in period \(t\) shifts the dynamic aggregate demand curve to the left from \(DAD_{t-1}\) to \(DAD_{t, t+1}\). Initially, the economy moves from point A to point B. Both inflation and output fall. In the subsequent period, because expected inflation falls, the dynamic aggregate supply curve shifts downward. The economy moves from point B to point C in period \(t+1\). Over time, as expected inflation falls and the dynamic aggregate supply curve repeatedly shifts downward, the economy approaches a new equilibrium at point Z. Output returns to its natural level \(Y_{all}\), and inflation ends at its new, lower target (\(\pi_{final} = 1\) percent).
toward $DAS_{final}$, the economy approaches a new long-run equilibrium at point $Z$, where output is back at its natural level ($Y_{final} = \overline{Y}_{all}$) and inflation is at its new lower target ($\pi_{t+1}^* = 1$ percent).

Figure 14-11 shows the response of the variables over time to a reduction in target inflation. Note in panel (e) the time path of the nominal interest rate $i_t$. Before the change in policy, the nominal interest rate is at its long-run value of 4.0 percent (which equals the natural real interest rate $\rho$ of 2 percent plus target inflation $\pi_{t-1}^*$ of 2 percent). When target inflation falls to 1 percent, the nominal interest rate rises.
to 4.2 percent. Over time, however, the nominal interest rate falls as inflation and expected inflation fall toward the new target rate; eventually, \( i \) approaches its new long-run value of 3.0 percent. Thus, a shift toward a lower inflation target increases the nominal interest rate in the short run but decreases it in the long run.

We close with a caveat: Throughout this analysis we have maintained the assumption of adaptive expectations. That is, we have assumed that people form their expectations of inflation based on the inflation they have recently experienced. It is possible, however, that if the central bank makes a credible announcement of its new policy of lower target inflation, people will respond by altering their expectations of inflation immediately. That is, they may form expectations rationally, based on the policy announcement, rather than adaptively, based on what they have experienced. (We discussed this possibility in Chapter 13.) If so, the dynamic aggregate supply curve will shift downward immediately upon the change in policy, just when the dynamic aggregate demand curve shifts downward. In this case, the economy will instantly reach its new long-run equilibrium. By contrast, if people do not believe an announced policy of low inflation until they see it, then the assumption of adaptive expectations is appropriate, and the transition path to lower inflation will involve a period of lost output, as shown in Figure 14-11.

### 14.4 Two Applications: Lessons for Monetary Policy

So far in this chapter, we have assembled a dynamic model of inflation and output and used it to show how various shocks affect the time paths of output, inflation, and interest rates. We now use the model to shed light on the design of monetary policy.

It is worth pausing at this point to consider what we mean by the phrase "the design of monetary policy." So far in this analysis, the central bank has had a simple role: it merely had to adjust the money supply to ensure that the nominal interest rate hit the target level prescribed by the monetary policy rule. The two key parameters of that policy rule are \( \theta_r \) (the responsiveness of the target interest rate to inflation) and \( \theta_v \) (the responsiveness of the target interest rate to output). We have taken these parameters as given without discussing how they are chosen. Now that we know how the model works, we can consider a deeper question: what should the parameters of the monetary policy rule be?

#### The Tradeoff Between Output Variability and Inflation Variability

Consider the impact of a supply shock on output and inflation. According to the dynamic \( AD-AS \) model, the impact of this shock depends crucially on the slope of the dynamic aggregate demand curve. In particular, the slope of the \( DAD \) curve determines whether a supply shock has a large or small impact on output and inflation.
This phenomenon is illustrated in Figure 14-12. In the two panels of this figure, the economy experiences the same supply shock. In panel (a), the dynamic aggregate demand curve is nearly flat, so the shock has a small effect on inflation but a large effect on output. In panel (b), the dynamic aggregate demand curve is steep, so the shock has a large effect on inflation but a small effect on output.

Why is this important for monetary policy? Because the central bank can influence the slope of the dynamic aggregate demand curve. Recall the equation for the DAD curve:

\[
Y_t = \bar{Y}_t - \left[ \alpha \theta_\pi / (1 + \alpha \theta_\eta) \right] (\pi_t - \pi_t^*) + \left[ 1 / (1 + \alpha \theta_\eta) \right] \epsilon_t.
\]

Two Possible Responses to a Supply Shock When the dynamic aggregate demand curve is relatively flat, as in panel (a), a supply shock has a small effect on inflation but a large effect on output. When the dynamic aggregate demand curve is relatively steep, as in panel (b), the same supply shock has a large effect on inflation but a small effect on output. The slope of the dynamic aggregate demand curve is based in part on the parameters of monetary policy \((\theta_\pi \text{ and } \theta_\eta)\), which describe how much interest rates respond to changes in inflation and output. When choosing these parameters, the central bank faces a tradeoff between the variability of inflation and the variability of output.
Two key parameters here are $\theta_\pi$ and $\theta_Y$, which govern how much the central bank's interest rate target responds to changes in inflation and output. When the central bank chooses these policy parameters, it determines the slope of the $DAD$ curve and thus the economy's short-run response to supply shocks.

On the one hand, suppose that, when setting the interest rate, the central bank responds strongly to inflation ($\theta_\pi$ is large) and weakly to output ($\theta_Y$ is small). In this case, the coefficient on inflation in the above equation is large. That is, a small change in inflation has a large effect on output. As a result, the dynamic aggregate demand curve is relatively flat, and supply shocks have large effects on output but small effects on inflation. The story goes like this: When the economy experiences a supply shock that pushes up inflation, the central bank's policy rule has it respond vigorously with higher interest rates. Sharply higher interest rates significantly reduce the quantity of goods and services demanded, thereby leading to a large recession that dampens the inflationary impact of the shock (which was the purpose of the monetary policy response).

On the other hand, suppose that, when setting the interest rate, the central bank responds weakly to inflation ($\theta_\pi$ is small) but strongly to output ($\theta_Y$ is large). In this case, the coefficient on inflation in the above equation is small, which means that even a large change in inflation has only a small effect on output. As a result, the dynamic aggregate demand curve is relatively steep, and supply shocks have small effects on output but large effects on inflation. The story is just the opposite as before: Now, when the economy experiences a supply shock that pushes up inflation, the central bank's policy rule has it respond with only slightly higher interest rates. This small policy response avoids a large recession but accommodates the inflationary shock.

In its choice of monetary policy, the central bank determines which of these two scenarios will play out. That is, when setting the policy parameters $\theta_\pi$ and $\theta_Y$, the central bank chooses whether to make the economy look more like panel (a) or more like panel (b) of Figure 14-12. When making this choice, the central bank faces a tradeoff between output variability and inflation variability. The central bank can be a hard-line inflation fighter, as in panel (a), in which case inflation is stable but output is volatile. Alternatively, it can be more accommodative, as in panel (b), in which case inflation is volatile but output is more stable. It can also choose some position in between these two extremes.

One job of a central bank is to promote economic stability. There are, however, various dimensions to this charge. When there are tradeoffs to be made, the central bank has to determine what kind of stability to pursue. The dynamic $AD-AS$ model shows that one fundamental tradeoff is between the variability in inflation and the variability in output.

Note that this tradeoff is very different from a simple tradeoff between inflation and output. In the long run of this model, inflation goes to its target, and output goes to its natural level. Consistent with classical macroeconomic theory, policymakers do not face a long-run tradeoff between inflation and output. Instead, they face a choice about which of these two measures of
macroeconomic performance they want to stabilize. When deciding on the parameters of the monetary-policy rule, they determine whether supply shocks lead to inflation variability, output variability, or some combination of the two.

**CASE STUDY**

**The Fed Versus the European Central Bank**

According to the dynamic AD–AS model, a key policy choice facing any central bank concerns the parameters of its policy rule. The monetary parameters $\theta_r$ and $\theta_y$ determine how much the interest rate responds to macroeconomic conditions. As we have just seen, these responses in turn determine the volatility of inflation and output.

The U.S. Federal Reserve and the European Central Bank (ECB) appear to have different approaches to this decision. The legislation that created the Fed states explicitly that its goal is “to promote effectively the goals of maximum employment, stable prices, and moderate long-term interest rates.” Because the Fed is supposed to stabilize both employment and prices, it is said to have a dual mandate. (The third goal—moderate long-term interest rates—should follow naturally from stable prices.) By contrast, the ECB says on its Web site that “the primary objective of the ECB’s monetary policy is to maintain price stability. The ECB aims at inflation rates of below, but close to, 2% over the medium term.” All other macroeconomic goals, including stability of output and employment, appear to be secondary.

We can interpret these differences in light of our model. Compared to the Fed, the ECB seems to give more weight to inflation stability and less weight to output stability. This difference in objectives should be reflected in the parameters of the monetary-policy rules. To achieve its dual mandate, the Fed would respond more to output and less to inflation than the ECB would.

A case in point occurred in 2008 when the world economy was experiencing rising oil prices, a financial crisis, and a slowdown in economic activity. The Fed responded to these events by lowering interest rates from about 5 percent to a range of 0 to 0.25 percent over the course of a year. The ECB, facing a similar situation, also cut interest rates—but by much less. The ECB was less concerned about recession and more concerned about keeping inflation in check.

The dynamic AD–AS model predicts that, other things equal, the policy of the ECB should, over time, lead to more variable output and more stable inflation. Testing this prediction, however, is difficult for two reasons. First, because the ECB was established only in 1998, there is not yet enough data to establish the long-term effects of its policy. Second, and perhaps more important, other things are not always equal. Europe and the United States differ in many ways beyond the policies of their central banks, and these other differences may affect output and inflation in ways unrelated to differences in monetary-policy priorities.
The Taylor Principle

How much should the nominal interest rate set by the central bank respond to changes in inflation? The dynamic AD–AS model does not give a definitive answer, but it does offer an important guideline.

Recall the equation for monetary policy:

\[ i_t = \pi_t + \rho \left( \pi_t - \pi_t^* \right) + \theta_y \left( Y_t - \bar{Y}_t \right). \]

According to this equation, a 1-percentage-point increase in inflation \( \pi_t \) induces an increase in the nominal interest rate \( i_t \) of \( 1 + \theta_y \) percentage points. Because we assume that \( \theta_y \) is greater than zero, whenever inflation increases, the central bank raises the nominal interest rate by an even larger amount.

Imagine, however, that the central bank behaved differently and, instead, increased the nominal interest rate by less than the increase in inflation. In this case, the monetary policy parameter \( \theta_y \) would be less than zero. This change would profoundly alter the model. Recall that the dynamic aggregate demand equation is:

\[ Y_t = \bar{Y}_t - \left[ \alpha \theta_y / (1 + \alpha \theta_y) \right] (\pi_t - \pi_t^*) + [1/(1 + \alpha \theta_y)] \varepsilon_t. \]

If \( \theta_y \) is negative, then an increase in inflation would increase the quantity of output demanded, and the dynamic aggregate demand curve would be upward sloping.

An upward-sloping DAD curve leads to unstable inflation, as illustrated in Figure 14-13. Suppose that in period \( t \) there is a one-time positive shock to aggregate demand. That is, for one period only, the dynamic aggregate demand curve shifts to the right, to \( \text{DAD}_t \); in the next period, it returns to its original position. In period \( t \), the economy moves from point A to point B. Output and inflation rise. In the next period, because higher inflation has increased expected inflation, the dynamic aggregate supply curve shifts upward, to \( \text{DAS}_{t+1} \). The economy moves from point B to point C. But because we are assuming in this case that the dynamic aggregate demand curve is upward sloping, output remains above the natural level, even though demand shock has disappeared. Thus, inflation rises yet again, shifting the DAS curve farther upward in the next period, moving the economy to point D. And so on. Inflation continues to rise with no end in sight.

The economic intuition may be easier to understand than the geometry. A positive demand shock increases output and inflation. If the central bank does not increase the nominal interest rate sufficiently, the real interest rate falls. A lower real interest rate increases the quantity of goods and services demanded. Higher output puts further upward pressure on inflation, which in turn lowers the real interest rate yet again. The result is inflation spiraling out of control.

The dynamic AD–AS model leads to a strong conclusion: For inflation to be stable, the central bank must respond to an increase in inflation with an even greater increase in the nominal interest rate. This conclusion is sometimes called the
**The Importance of the Taylor Principle** This figure shows the impact of a demand shock in an economy that does not satisfy the Taylor principle, so the dynamic aggregate demand curve is upward sloping. A demand shock moves the DAD curve to the right for one period, to DAD_{t+1}, and the economy moves from point A to point B. Both output and inflation increase. The rise in inflation increases expected inflation and, in the next period, shifts the dynamic aggregate supply curve upward to DAS_{t+1}. Therefore, in period t + 1, the economy then moves from point B to point C. Because the DAD curve is upward sloping, output is still above the natural level, so inflation continues to increase. In period t + 2, the economy moves to point D, where output and inflation are even higher. Inflation spirals out of control.

**Taylor principle**, after economist John Taylor, who emphasized its importance in the design of monetary policy. Most of our analysis in this chapter assumed that the Taylor principle holds (that is, we assumed that $\theta_r > 0$). We can see now that there is good reason for a central bank to adhere to this guideline.

**CASE STUDY**

**What Caused the Great Inflation?**

In the 1970s, inflation in the United States got out of hand. As we saw in previous chapters, the inflation rate during this decade reached double-digit levels. Rising prices were widely considered the major economic problem of the time. In 1979, Paul Volcker, the recently appointed chairman of the Federal Reserve,
announced a change in monetary policy that eventually brought inflation back under control. Volcker and his successor, Alan Greenspan, then presided over low and stable inflation for the next quarter century.

The dynamic $AD–AS$ model offers a new perspective on these events. According to research by monetary economists Richard Clarida, Jordi Gali, and Mark Gertler, the key is the Taylor principle. Clarida and colleagues examined the data on interest rates, output, and inflation and estimated the parameters of the monetary policy rule. They found that the Volcker–Greenspan monetary policy obeyed the Taylor principle, whereas earlier monetary policy did not. In particular, the parameter $\theta_0$ was estimated to be 0.72 during the Volcker–Greenspan regime after 1979, close to Taylor’s proposed value of 0.5, but it was −0.14 during the pre-Volcker era from 1960 to 1978.$^2$ The negative value of $\theta_0$ during the pre-Volcker era means that monetary policy did not satisfy the Taylor principle.

This finding suggests a potential cause of the great inflation of the 1970s. When the U.S. economy was hit by demand shocks (such as government spending on the Vietnam War) and supply shocks (such as the OPEC oil-price increases), the Fed raised nominal interest rates in response to rising inflation but not by enough. Therefore, despite the increase in nominal interest rates, real interest rates fell. The insufficient monetary response not only failed to squash the inflationary pressures but actually exacerbated them. The problem of spiraling inflation was not solved until the monetary-policy rule was changed to include a more vigorous response of interest rates to inflation.

An open question is why policymakers were so passive in the earlier era. Here are some conjectures from Clarida, Gali, and Gertler:

Why is it that during the pre-1979 period the Federal Reserve followed a rule that was clearly inferior? Another way to look at the issue is to ask why it is that the Fed maintained persistently low short-term real rates in the face of high or rising inflation. One possibility . . . is that the Fed thought the natural rate of unemployment at this time was much lower than it really was (or equivalently, that the output gap was much smaller) . . .

Another somewhat related possibility is that, at that time, neither the Fed nor the economics profession understood the dynamics of inflation very well. Indeed, it was not until the mid-to-late 1970s that intermediate textbooks began emphasizing the absence of a long-run trade-off between inflation and output. The ideas that expectations may matter in generating inflation and that credibility is important in policymaking were simply not well established during that era. What all this suggests is that in understanding historical economic behavior, it is important to take into account the state of policymakers’ knowledge of the economy and how it may have evolved over time.

Conclusion: Toward DSGE Models

If you go on to take more advanced courses in macroeconomics, you will likely learn about a class of models called dynamic, stochastic, general equilibrium models, often abbreviated as DSGE models. These models are dynamic because they trace the path of variables over time. They are stochastic because they incorporate the inherent randomness of economic life. They are general equilibrium because they take into account the fact that everything depends on everything else. In many ways, they are the state-of-the-art models in the analysis of short-run economic fluctuations.

The dynamic AD–AS model we have presented in this chapter is a simplified version of these DSGE models. Unlike analysts using advanced DSGE models, we have not started with the household and firm optimizing decisions that underlie the macroeconomic relationships. But the macro relationships that this chapter has posited are similar to those found in more sophisticated DSGE models. The dynamic AD–AS model is a good stepping-stone between the basic model of aggregate demand and aggregate supply we saw in earlier chapters and the more complex DSGE models you might see in a more advanced course.

The dynamic AD–AS model also yields some important lessons. It shows how various macroeconomic variables—output, inflation, and real and nominal interest rates—respond to shocks and interact with one another over time. It demonstrates that, in the design of monetary policy, central banks face a tradeoff between variability in inflation and variability in output. Finally, it suggests that central banks need to respond vigorously to inflation to prevent it from getting out of control. If you ever find yourself running a central bank, these are good lessons to keep in mind.

Summary

1. The dynamic model of aggregate demand and aggregate supply combines five economic relationships: an equation for the goods market, which relates quantity demanded to the real interest rate; the Fisher equation, which relates real and nominal interest rates; the Phillips curve equation, which determines inflation; an equation for expected inflation; and a rule for monetary policy, according to which the central bank sets the nominal interest rate as a function of inflation and output.

2. 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.
3. The dynamic \( AD-AS \) model can be used to determine the immediate impact on the economy of any shock and can also be used to trace out the effects of the shock over time.

4. Because the parameters of the monetary-policy rule influence the slope of the dynamic aggregate demand curve, they determine whether a supply shock has a greater effect on output or inflation. When choosing the parameters for monetary policy, a central bank faces a tradeoff between output variability and inflation variability.

5. The dynamic \( AD-AS \) model typically assumes that the central bank responds to a 1-percentage-point increase in inflation by increasing the nominal interest rate by more than 1 percentage point, so the real interest rate rises as well. If the central bank responds less vigorously to inflation, the economy becomes unstable. A shock can send inflation spiraling out of control.

**KEY CONCEPTS**

- Taylor rule
- Taylor principle

**QUESTIONS FOR REVIEW**

1. On a carefully labeled graph, draw the dynamic aggregate supply curve. Explain why it has the slope it has.

2. On a carefully labeled graph, draw the dynamic aggregate demand curve. Explain why it has the slope it has.

3. A central bank has a new head, who decides to raise the target inflation rate from 2 to 3 percent. Using a graph of the dynamic \( AD-AS \) model, show the effect of this change. What happens to the nominal interest rate immediately upon the change in policy and in the long run? Explain.

4. A central bank has a new head, who decides to increase the response of interest rates to inflation. How does this change in policy alter the response of the economy to a supply shock? Give both a graphical answer and a more intuitive economic explanation.

**PROBLEMS AND APPLICATIONS**

1. Derive the long-run equilibrium for the dynamic \( AD-AS \) model. Assume there are no shocks to demand or supply \((\varepsilon = \eta = 0)\) and inflation has stabilized \((\pi_t = \pi_{t-1})\), and then use the five equations to derive the value of each variable in the model. Be sure to show each step you follow.
2. Suppose the monetary-policy rule has the wrong natural rate of interest. That is, the central bank follows this rule:

\[ i_t = \pi_t + \rho' + \theta_d(\pi_t - \pi_t^*) + \theta_y(Y_t - \bar{Y}_t) \]

where \( \rho' \) does not equal \( \rho \), the natural rate of interest in the equation for goods demand. The rest of the dynamic AD–AS model is the same as in the chapter. Solve for the long-run equilibrium under this policy rule. Explain in words the intuition behind your solution.

3. “If a central bank wants to achieve lower nominal interest rates, it has to raise the nominal interest rate.” Explain in what way this statement makes sense.

4. The sacrifice ratio is the accumulated loss in output that results when the central bank lowers its target for inflation by 1 percentage point. For the parameters used in the text simulation, what is the implied sacrifice ratio? Explain.

5. The text analyzes the case of a temporary shock to the demand for goods and services. Suppose, however, that \( \epsilon_t \) were to increase permanently. What would happen to the economy over time? In particular, would the inflation rate return to its target in the long run? Why or why not? (Hint: It might be helpful to solve for the long-run equilibrium without the assumption that \( \epsilon_t \) equals zero.) How might the central bank alter its policy rule to deal with this issue?

6. Suppose a central bank does not satisfy the Taylor principle; that is, \( \theta_d \) is less than zero. Use a graph to analyze the impact of a supply shock. Does this analysis contradict or reinforce the Taylor principle as a guideline for the design of monetary policy?

7. The text assumes that the natural rate of interest \( \rho \) is a constant parameter. Suppose instead that it varies over time, so now it has to be written as \( \rho_t \).

a. How would this change affect the equations for dynamic aggregate demand and dynamic aggregate supply?

b. How would a shock to \( \rho_t \) affect output, inflation, the nominal interest rate, and the real interest rate?

c. Can you see any practical difficulties that a central bank might face if \( \rho_t \) varied over time?

8. Suppose that people’s expectations of inflation are subject to random shocks. That is, instead of being merely adaptive, expected inflation in period \( t \), as seen in period \( t - 1 \), is \( E_{t-1} \pi_t = \pi_{t-1} + \eta_{t-1} \), where \( \eta_{t-1} \) is a random shock. This shock is normally zero, but it deviates from zero when some event beyond past inflation causes expected inflation to change. Similarly, \( E_t \pi_{t+1} = \pi_t + \eta_t \).

a. Derive the two equations for dynamic aggregate demand and dynamic aggregate supply in this slightly more general model.

b. Suppose that the economy experiences an inflation scare. That is, in period \( t \), for some reason people come to believe that inflation in period \( t + 1 \) is going to be higher, so \( \eta_t \) is greater than zero (for this period only). What happens to the DAD and DAS curves in period \( t \)? What happens to output, inflation, and nominal and real interest rates in that period? Explain.

c. What happens to the DAD and DAS curves in period \( t + 1 \)? What happens to output, inflation, and nominal and real interest rates in that period? Explain.

d. What happens to the economy in subsequent periods?

e. In what sense are inflation scares self-fulfilling?

9. Use the dynamic AD–AS model to solve for inflation as a function of only lagged inflation and the supply and demand shocks. (Assume target inflation is a constant.)

a. According to the equation you have derived, does inflation return to its target after a shock? Explain. (Hint: Look at the coefficient on lagged inflation.)

b. Suppose the central bank does not respond to changes in output but only to changes in inflation, so that \( \theta_y = 0 \). How, if at all, would this fact change your answer to part (a)?
c. Suppose the central bank does not respond to changes in inflation but only to changes in output, so that \( \theta_r = 0 \). How, if at all, would this fact change your answer to part (a)?

d. Suppose the central bank does not follow the Taylor principle but instead raises the nominal interest rate only 0.8 percentage point for each percentage-point increase in inflation. In this case, what is \( \theta_r \)? How does a shock to demand or supply influence the path of inflation?