This chapter is concerned with the microeconomic foundations of sluggish adjustment of nominal prices and wages. This subject is important for two reasons. First, it is central to Keynesian models. One of the models' main predictions is that monetary shocks have real effects, and the critical feature of the models that gives rise to this prediction is the presence of sluggish nominal adjustment. But, as described in the concluding section of the previous chapter, the evidence concerning whether monetary shocks have important real effects is controversial; thus the relevance of Keynesian models is not clear. One way to shed light on this issue is to investigate what microeconomic conditions are needed for nominal stickiness to arise. For example, some critics of traditional Keynesian models argue that the models' assumptions about price stickiness are inconsistent with any reasonable model of microeconomic behavior; they therefore conclude that microeconomic theory provides a strong case against the models' relevance. More generally, if the conditions needed for nominal stickiness appear implausible or inconsistent with microeconomic evidence, this would suggest that gradual nominal adjustment is unlikely to be important. If the needed conditions appear realistic, on the other hand, this would support the importance of nominal stickiness.

Second, the nature of incomplete nominal adjustment is important for policy. For example, we will see that if monetary shocks have real effects for the reasons described by the Lucas imperfect-information model (which is presented in Part A of the chapter), systematic feedback rules from economic developments to monetary policy have no effect on the real economy. Similarly, if nominal prices and wages are fully flexible, monetary policy is
irrelevant to real variables. At the other extreme, if there is a stable relationship between output and inflation, then (as we saw in Chapter 5) monetary policy can raise output permanently. And as we will see, the nature of incomplete nominal adjustment also has implications for such issues as the output costs of alternative approaches to reducing inflation, the output-inflation relationship under different conditions, and the impact of stabilization policy on average output.

It is important to emphasize that the issue we are interested in is incomplete adjustment of nominal prices and wages. There are many reasons— involving uncertainty, information and renegotiation costs, incentives, and so on—why prices and wages may not adjust freely to equate supply and demand, or that firms may not change their prices and wages completely and immediately in response to shocks. But simply introducing some departure from perfect markets is not enough to imply that nominal disturbances matter. All of the models of unemployment in Chapter 10, for example, are real models. If one appendes a monetary sector to those models without any further complications, the classical dichotomy continues to hold: monetary disturbances simply cause all nominal prices and wages to change, leaving the real equilibrium (with whatever non-Walrasian features it involves) unchanged. Any microeconomic basis for failure of the classical dichotomy requires some kind of nominal imperfection.

The models that follow examine three candidate nominal imperfections. In the model of Part A, which is based on the work of Lucas (1972) and Phelps (1970), the nominal imperfection is that producers do not observe the aggregate price level; as a result, they make their production decisions without full knowledge of the relative prices they will receive for their goods. In the models of staggered adjustment in Part B, monetary shocks have real effects because not all prices or wages are adjusted simultaneously. Finally, in Part C, the real effects of monetary changes stem from small costs of changing nominal prices or wages or from some other small friction in nominal adjustment.

**Part A The Lucas Imperfect-Information Model**

**6.1 Overview**

The central idea of the Lucas-Phelps model is that when a producer observes a change in the price of his or her product, he or she does not know whether it reflects a change in the good's relative price or a change in the aggregate price level. A change in the relative price alters the optimal amount to produce. A change in the aggregate price level, on the other hand, leaves optimal production unchanged.
When the price of the producer's good increases, there is some chance that the increase reflects a rise in the price level, and some chance that it reflects a rise in the good's relative price. The rational response for the producer is to attribute part of the change to an increase in the price level and part to an increase in the relative price, and therefore to increase output somewhat. This implies that the aggregate supply curve slopes up: when the aggregate price level rises, all producers see increases in the prices of their goods, and (not knowing that the increases reflect a rise in the price level) thus raise their output.

The next two sections develop this idea in a model where individuals produce goods using their own labor, sell their output in competitive markets, and use the proceeds to buy other producers' output. The model has two types of shocks. First, there are random shifts in preferences that change the relative demands for different goods. These shocks lead to changes in relative prices and in the relative production of different goods. Second, there are disturbances to the money supply, or more generally, to aggregate demand. When these shocks are observed, they change only the aggregate price level and have no real effects. But when they are unobserved, they change both the price level and aggregate output.

As a preliminary, Section 6.2 considers the case where the money stock is publicly observed; in this situation, money is neutral. Section 6.3 then turns to the case where the money stock is not observed.

## 6.2 The Case of Perfect Information

### Producer Behavior

There are many different goods in the economy. Consider a representative producer of a typical good, good \( i \). The individual's production function is simply

\[
Q_i = L_i, \tag{6.1}
\]

where \( L_i \) is the amount that the individual works and \( Q_i \) the amount he or she produces. The individual's consumption, \( C_i \), equals his or her real income; this equals revenue, \( P_i Q_i \), divided by the price of the market basket of goods, \( P_i \). \( P \) is an index of the prices of all goods (see equation [6.9], below).

Utility depends positively on consumption and negatively on the amount worked. For simplicity, it takes the form

\[
U_i = C_i - \frac{1}{\gamma} L_i^\gamma, \quad \gamma > 1. \tag{6.2}
\]

Thus there is constant marginal utility of consumption and increasing marginal disutility of work.
When the aggregate price level $P$ is known, the individual’s maximization problem is simple. Substituting $C_i = P_i Q_i / P$ and $Q_i = L_i$ into (6.2), we can rewrite utility as

$$U_i = \frac{P_i L_i}{P} - \frac{1}{\gamma} L_i^\gamma. \quad (6.3)$$

Since markets are assumed to be competitive, the individual chooses $L_i$ to maximize utility taking $P_i$ and $P$ as given. The first-order condition is

$$\frac{P_i}{P} - L_i^{\gamma-1} = 0, \quad (6.4)$$

or

$$L_i = (P_i / P)^{1/(\gamma-1)}. \quad (6.5)$$

Letting lowercase letters denote the logarithms of the corresponding uppercase variables, we can rewrite this condition as

$$\ell_i = \frac{1}{\gamma - 1} (p_i - p). \quad (6.6)$$

Thus the individual’s labor supply and production are increasing in the relative price of his or her product.

**Demand**

Producers’ behavior determines the supply curves of the various goods. Determining the equilibrium in each market requires specifying the demand curves as well. The demand for a given good is assumed to depend on three factors: real income, the good’s relative price, and a random disturbance to preferences. For tractability, demand is log-linear. Specifically, the demand for good $i$ is

$$q_i = y + z_i - \eta (p_i - p), \quad \eta > 0, \quad (6.7)$$

where $y$ is log aggregate real income, $z_i$ is the shock to the demand for good $i$, and $\eta$ is the elasticity of demand for each good. $q_i$ is the demand per producer of good $i$. The $z_i$’s have a mean of zero across goods; thus they are purely relative demand shocks. $y$ is assumed to equal the average across goods of the $q_i$’s, and $p$ is the average of the $p_i$’s:

$$y = \bar{q}_i, \quad (6.8)$$

---

1That is, the total (log) demand for good $i$ is $\ln N + y + z_i - \eta (p_i - p)$, where $N$ is the number of producers of each good.
\[ p = \overline{p}_i. \] (6.9)

Intuitively, (6.7)–(6.9) state that the demand for a good is higher when total production (and thus total income) is higher, when its price is low relative to other prices, and when individuals have stronger preferences for it.\(^2\)

Finally, the aggregate demand side of the model is

\[ y = m - p. \] (6.10)

There are various interpretations of (6.10). The simplest, and most appropriate for our purposes, is that it is just a shortcut approach to modeling aggregate demand. Equation (6.10) implies an inverse relationship between the price level and output, which is the essential feature of aggregate demand. Since our focus is on aggregate supply, there is little point in modeling aggregate demand more fully. Under this interpretation, \( M \) should be thought of as a generic variable affecting aggregate demand rather than as money.

It is also possible to derive (6.10) from models with more complete monetary specifications. Blanchard and Kiyotaki (1987), for example, replace \( C_i \) in the utility function, (6.2), with a Cobb–Douglas combination of \( C_i \) and the individual's real money balances, \( M_i / P \). With an appropriate specification of how money enters the budget constraint, this gives rise to (6.10). Rotemberg (1987) derives (6.10) from a cash-in-advance constraint. Under Blanchard and Kiyotaki’s and Rotemberg’s interpretations of (6.10), it is natural to think of \( m \) as literally money; in this case the right-hand side should be modified to be \( m + \nu - p \), where \( \nu \) captures aggregate demand disturbances other than shifts in money supply.

**Equilibrium**

Equilibrium in the market for good \( i \) requires that demand per producer equal supply. From (6.6) and (6.7), this requires

\[ \frac{1}{\gamma - 1} (p_i - p) = y + z_i - \eta (p_i - p). \] (6.11)

Solving this expression for \( p_i \) yields

\[ p_i = \frac{\gamma - 1}{1 + \eta \gamma - \eta} (y + z_i) + p. \] (6.12)

\(^2\)Although (6.7)–(6.9) are intuitive, deriving these exact functional forms from individuals' preferences over the various goods requires some approximations. The difficulty is that if preferences are such that demand for each good takes the constant-elasticity form in (6.7), the corresponding (log) price index is exactly equal to the average of the individual \( p_i \)'s only in the special case of \( \eta = 1 \). See Problem 6.2. This issue has no effect on the basic messages of the model.
Averaging the $p_i$'s and using the fact that the average of the $z_i$'s is zero, we obtain

$$p = \frac{\gamma - 1}{1 + \eta \gamma - \eta} y + p.$$  \hfill (6.13)

Equation (6.13) implies that the equilibrium value of $y$ is simply

$$y = 0.$$  \hfill (6.14)

Finally, (6.14) and (6.10) imply

$$m = p.$$  \hfill (6.15)

Not surprisingly, money is neutral in this version of the model: an increase in $m$ leads to an equal increase in all $p_i$'s, and hence in the overall price index, $p$. No real variables are affected.

### 6.3 The Case of Imperfect Information

We now consider the more interesting case where producers observe the prices of their own goods but not the aggregate price level.

#### Producer Behavior

Defining the relative price of good $i$ by $r_i = p_i - p$, we can write

$$p_i = p + (p_i - p) = p + r_i.$$  \hfill (6.16)

Thus, in logs, the variable that the individual observes—the price of his or her good—equals the sum of the aggregate price level and the good's relative price.

The individual would like to base his or her production decision on $r_i$ alone (see (6.6)). The individual does not observe $r_i$, but must estimate it given the observation of $p_i$.\(^4\) At this point, Lucas makes two simplifying assumptions. First, he assumes that the individual finds the expectation of $r_i$ given $p_i$, and then produces as much as he or she would if this estimate were certain. Thus (6.6) becomes

\[^3\]The result that equilibrium log output is zero implies that the equilibrium level of output is 1. This results from the $1/\gamma$ term multiplying $L^\gamma$ in the utility function (6.2).

\[^4\]If the individual knew others' prices as a result of making purchases, he or she could deduce $p$, and hence $r_i$. This can be ruled out in several ways. One approach is to assume that the household consists of two individuals, a “producer” and a “shopper,” and that communication between them is limited. In Lucas’s original model, the problem is avoided by assuming an overlapping-generations structure where individuals produce in the first period of their lives and make purchases in the second.
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\[ \ell_i = \frac{1}{\gamma - 1} E[r_i \mid p_i]. \] (6.17)

As Problem 6.1 shows, this certainty-equivalence behavior is not identical to maximizing expected utility: in general, the utility-maximizing choice of \( \ell_i \) depends not just on the individual's estimate of \( r_i \), but also on his or her uncertainty about \( r_i \). The assumption that individuals use certainty equivalence, however, simplifies the analysis and has no effect on the central messages of the model.

Second, and very importantly, Lucas assumes that the producer finds the expectation of \( r_i \) given \( p_i \) rationally. That is, \( E[r_i \mid p_i] \) is assumed to be the true expectation of \( r_i \) given \( p_i \) and given the actual joint distribution of the two variables. Today, this assumption of rational expectations seems no more peculiar than the assumption that individuals maximize utility. When Lucas introduced Muth's (1960, 1961) idea of rational expectations into macroeconomics, however, it was highly controversial. As we will see, it is one source—but by no means the only one—of the strong implications of Lucas's model.

To make the computation of \( E[r_i \mid p_i] \) tractable, the monetary shock \( m \) and the shocks to the demands for the individual goods (the \( z_i \)'s) are assumed to be normally distributed. \( m \) has a mean of \( E[m] \) and a variance of \( V_m \). The \( z_i \)'s have a mean of zero and a variance of \( V_z \), and are independent of \( m \). We will see that these assumptions imply that \( p \) and \( r_i \) are normal and independent. Since \( p_i \) equals \( p + r_i \), this means that it is also normal; its mean is the sum of the means of \( p \) and \( r_i \), and its variance is the sum of their variances. As we will see, the means of \( p \) and \( r_i \), \( E[p] \) and \( E[r_i] \), are equal to \( E[m] \) and zero, respectively; and their variances, \( V_p \) and \( V_r \), are complicated functions of \( V_m \) and \( V_z \) and of the other parameters of the model.

The individual's problem is to find the expectation of \( r_i \) given \( p_i \). An important result in statistics is that when two variables are jointly normally distributed (as with \( r_i \) and \( p_i \) here), the expectation of one is a linear function of the observation of the other (see, for example, Mood, Graybill, and Boes, 1974, pp. 167–168, or some other introductory statistics textbook). Thus \( E[r_i \mid p_i] \) takes the form

\[ E[r_i \mid p_i] = \alpha + \beta p_i. \] (6.18)

In this particular case, where \( p_i \) equals \( r_i \) plus an independent variable, (6.18) takes the specific form:

\[ E[r_i \mid p_i] = \frac{V_r}{V_r + V_p} E[p] + \frac{V_r}{V_r + V_p} p_i \]

\[ = \frac{V_r}{V_r + V_p} (p_i - E[p]). \] (6.19)
Equation (6.19) is intuitive. First, it implies that if $p_i$ equals its mean, the expectation of $r_i$ equals its mean (which is zero). Second, it states that the expectation of $r_i$ exceeds its mean if $p_i$ exceeds its mean, and is less than its mean if $p_i$ is less than its mean. Third, it tells us that the fraction of the departure of $p_i$ from its mean that is estimated to be due to the departure of $r_i$ from its mean is $V_r/(V_r + V_p)$; this is the fraction of the overall variance of $p_i$ ($V_r + V_p$) that is due to the variance of $r_i$ ($V_r$). If, for example, $V_p$ is zero, all of the variation in $p_i$ is due to $r_i$, and so $E[r_i | p_i] = p_i - E[p]$. If $V_r$ and $V_p$ are equal, half of the variance in $p_i$ is due to $r_i$, and so $E[r_i | p_i] = (p_i - E[p])/2$. And so on.\(^5\)

Substituting (6.19) into (6.17) yields the individual’s labor supply:

$$\ell_i = \frac{1}{\gamma - 1} \frac{V_r}{V_r + V_p} (p_i - E[p]) \quad (6.20)$$

$$\equiv b(p_i - E[p]).$$

Averaging (6.20) across producers (and using the definitions of $\gamma$ and $p$) gives us an expression for overall output:

$$y = b(p - E[p]). \quad (6.21)$$

Equation (6.21) is the Lucas supply curve. It states that the departure of output from its normal level (which is zero in the model) is an increasing function of the surprise in the price level.

The Lucas supply curve is essentially the same as the expectations-augmented Phillips curve of Chapter 5 with core inflation replaced by expected inflation (see equation [5.38]). Both state that, if we neglect disturbances to supply, output is above normal only to the extent that inflation (and hence the price level) is greater than expected. Thus the Lucas model provides microeconomic foundations for this view of aggregate supply.

**Equilibrium**

Combining the Lucas supply curve, (6.21), with the aggregate demand equation, (6.10), and solving for $p$ and $y$ yields

$$p = \frac{1}{1 + b} m + \frac{b}{1 + b} E[p], \quad (6.22)$$

---

\(^5\)This conditional-expectations problem is referred to as *signal extraction*. The variable that the individual observes, $p_i$, equals the *signal*, $r_i$, plus *noise*, $p$. Equation (6.19) shows how the individual can best extract an estimate of the signal from the observation of $p_i$. The ratio of $V_r$ to $V_p$ is referred to as the *signal-to-noise ratio*. 
6.3 The Case of Imperfect Information

\[ y = \frac{b}{1+b} m - \frac{b}{1+b} E[p]. \]  

(6.23)

We can use (6.22) to find \( E[p] \). Ex post, after \( m \) is determined, the two sides of (6.22) are equal. Thus it must be that ex ante, before \( m \) is determined, the expectations of the two sides are equal. Taking the expectations of both sides of (6.22), we obtain

\[ E[p] = \frac{1}{1+b} E[m] + \frac{b}{1+b} E[p], \]  

(6.24)

or

\[ E[p] = E[m]. \]  

(6.25)

Using (6.25) and the fact that \( m = E[m] + (m - E[m]) \), we can rewrite (6.22) and (6.23) as

\[ p = E[m] + \frac{1}{1+b} (m - E[m]), \]  

(6.26)

\[ y = \frac{b}{1+b} (m - E[m]). \]  

(6.27)

Equations (6.26) and (6.27) show the key implications of the model: the component of aggregate demand that is observed, \( E[m] \), affects only prices, but the component that is not observed, \( m - E[m] \), has real effects. Consider, for concreteness, an unobserved increase in \( m \)—that is, a higher realization of \( m \) given its distribution. This increase in the money supply raises aggregate demand, and thus produces an outward shift in the demand curve for each good. Since the increase is not observed, each supplier's best guess is that some portion of the rise in the demand for his or her product reflects a relative price shock. Thus producers increase their output.

The effects of an observed increase in \( m \) are very different. Specifically, consider the effects of an upward shift in the entire distribution of \( m \), with the realization of \( m - E[m] \) held fixed. In this case, each supplier attributes the rise in the demand for his or her product to money, and thus does not change his or her output. Of course, the taste shocks cause variations in relative prices and in output across goods (just as they do in the case of an unobserved shock), but on average real output does not rise. Thus observed changes in aggregate demand affect only prices.

To complete the model, we must express \( b \) in terms of underlying parameters rather than in terms of the variances of \( p \) and \( r_1 \). Recall that \( b = [1/(\gamma - 1)][V_r/(V_r + V_p)] \) (see [6.20]). Equation (6.26) implies \( V_p = V_m/(1+b)^2 \). The demand curve, (6.7), and the supply curve, (6.20), can be used to find \( V_r \), the variance of \( p_i - p \). Specifically, we can substitute \( y = b(p - E[p]) \) into
(6.7) to obtain \( q_i = b(p - E[p]) + z_i - \eta(p_i - p) \), and we can rewrite (6.20) as \( \ell_i = b(p_i - p) + b(p - E[p]) \). Solving these two equations for \( p_i - p \) then yields \( p_i - p = z_i / (\eta + b) \). Thus \( V_r = V_z / (\eta + b)^2 \).

Substituting the expressions for \( V_p \) and \( V_r \) into the definition of \( b \) (see [6.20]) yields
\[
 b = \frac{1}{\gamma - 1} \left[ \frac{V_z}{V_z + (\eta + b)^2 V_m} \right]. \tag{6.28}
\]

Equation (6.28) implicitly defines \( b \) in terms of \( V_z, V_m, \) and \( \gamma \), and thus completes the model. It is straightforward to show that \( b \) is increasing in \( V_z \) and decreasing in \( V_m \). In the special case of \( \eta = 1 \), we can obtain a closed-form expression for \( b \):
\[
b = \frac{1}{\gamma - 1} \frac{V_z}{V_z + V_m}. \tag{6.29}
\]

Finally, note that the results that \( p = E[m] + [1/(1 + b)](m - E[m]) \) and \( r_i = z_i / (\eta + b) \) imply that \( p \) and \( r_i \) are linear functions of \( m \) and \( z_i \). Since \( m \) and \( z_i \) are independent, \( p \) and \( r_i \) are independent; and since linear functions of normal variables are normal, \( p \) and \( r_i \) are normal. This confirms the assumptions made above about these variables.

### 6.4 Implications and Limitations

**The Phillips Curve and the Lucas Critique**

Lucas's model implies that unexpectedly high realizations of aggregate demand lead to both higher output and higher-than-expected prices. As a result, for reasonable specifications of the behavior of aggregate demand, the model implies a positive association between output and inflation. Suppose, for example, that \( m \) is a random walk with drift:
\[
m_t = m_{t-1} + c + u_t, \tag{6.30}
\]
where \( u \) is white noise. Thus the expectation of \( m_t \) is \( m_{t-1} + c \), and the unobserved component of \( m_t \) is \( u_t \). Thus, from (6.26) and (6.27),
\[
p_t = m_{t-1} + c + \frac{1}{1 + b} u_t, \tag{6.31}
\]
\[
y_t = \frac{b}{1 + b} u_t. \tag{6.32}
\]

Since the model also implies that \( p_{t-1} = m_{t-2} + c + [u_{t-1}/(1 + b)] \), the rate of inflation (measured as the change in the log price level) is
\[
\pi_t = (m_{t-1} - m_{t-2}) + \frac{1}{1 + b} u_t - \frac{1}{1 + b} u_{t-1}
\]
\[
= c + \frac{b}{1 + b} u_{t-1} + \frac{1}{1 + b} u_t.
\] (6.33)

Note that \( u_t \) appears in both (6.32) and (6.33) with a positive sign, and that \( u_t \) and \( u_{t-1} \) are uncorrelated. These facts imply that output and inflation are positively correlated. Intuitively, high unexpected money growth leads, through the Lucas supply curve, to increases in both prices and output. The model therefore implies a positive relationship between output and inflation—a Phillips curve.

But although there is a statistical output-inflation relationship, there is no exploitable tradeoff between high output and low inflation. Suppose that policymakers decide to raise average money growth (for example, by raising \( c \) in equation [6.30]). If the change is not publicly known, there is an interval when unobserved money growth is typically positive and output is therefore usually above normal. Once individuals determine that the change has occurred, however, unobserved money growth is again on average zero, and so average real output is unchanged. And if the increase in average money growth is known, expected money growth jumps immediately and there is not even a brief interval of high output. The idea that the statistical relationship between output and inflation may change if policymakers attempt to take advantage of it is not just a theoretical curiosity: as we saw in Chapter 5, when average inflation rose in the late 1960s and early 1970s, the traditional output-inflation relationship collapsed.

The central idea underlying this analysis is of wider relevance. Expectations are likely to be important to many relationships among aggregate variables, and changes in policy are likely to affect those expectations. As a result, shifts in policy can change aggregate relationships. In short, if policymakers attempt to take advantage of statistical relationships, effects operating through expectations may cause the relationships to break down. This is the famous Lucas critique (Lucas, 1976).

The Phillips curve is the most famous application of the Lucas critique. Another example is temporary changes in taxes. There is a close relationship between disposable income and consumption spending. Yet to some extent this relationship arises not because current disposable income determines current spending, but because current income is strongly correlated with permanent income (see Chapter 7)—that is, it is highly correlated with households' expectations of their disposable incomes in the future. If policymakers attempt to reduce consumption through a tax increase that is known to be temporary, the relationship between current income and expected future income, and hence the relationship between current income and spending, will change. Again this is not just a theoretical possibility. The United States enacted a temporary tax surcharge in 1968, and the impact
on consumption was considerably smaller than was expected on the basis of the statistical relationship between disposable income and spending (see, for example, Dolde, 1979).

Anticipated and Unanticipated Money

The result that only unobserved aggregate demand shocks have real effects has a strong implication: monetary policy can stabilize output only if policymakers have information that is not available to private agents. Any portion of policy that is a response to publicly available information—such as interest rates, the unemployment rate, or the index of leading indicators—is irrelevant to the real economy (Sargent and Wallace, 1975; Barro, 1976).

To see this, let aggregate demand, $m$, equal $m^* + \nu$, where $m^*$ is a policy variable and $\nu$ a disturbance outside the government's control. If the government does not pursue activist policy but simply keeps $m^*$ constant (or growing at a steady rate), the unobserved shock to aggregate demand in some period is the realization of $\nu$ less the expectation of $\nu$ given the information available to private agents. If $m^*$ is instead a function of public information, individuals can deduce $m^*$, and so the situation is unchanged. Thus systematic policy rules cannot stabilize output.

If the government observes variables correlated with $\nu$ that are not known to the public, it can use this information to stabilize output: it can change $m^*$ to offset the movements in $\nu$ that it expects on the basis of its private information. But this is not an appealing defense of Keynesian stabilization policy, for two reasons. First, a central element of conventional stabilization policy involves reactions to general, publicly available information that the economy is in a boom or a recession. Second, if superior information is the basis for potential stabilization, there is a much easier way for the government to accomplish that stabilization than following a complex policy rule: it can simply announce the information that the public does not have.6

Ball (1991), building on the work of Sargent (1983), argues that the Lucas model’s predictions concerning observed policy can be tested by looking at

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6A large literature, pioneered by Barro (1977a, 1978) and significantly extended by Mishkin (1982, 1983), tests Lucas’s predictions concerning the impacts of observed and unobserved monetary policy using the money stock as the measure of policy. In Barro’s formulation, the basic idea is to regress output on measures of forecastable and unforecastable money growth and a set of control variables. Unfortunately, these tests suffer from the same difficulties as regressions of money on output (see Section 3.6). For example, a positive correlation between unexpected changes in the money stock and output movements can reflect an impact of output on money demand rather than an impact of money on output. Similarly, the absence of an association between predictable movements in money and changes in output can arise not because observed monetary changes have no real effects, but because the Federal Reserve is adjusting the money supply to offset the impact of other factors on output. See also Problem 6.3.
times of announced shifts to tighter monetary policy to combat inflation. The Lucas model predicts that there should be no systematic relationship between real variables and any publicly known information about monetary policy. Thus it implies that output growth should not be on average different from normal following such announcements. But Ball argues that when policymakers do not carry through with the announced policy, inflation typically changes little and output growth generally remains about normal, and that when they do carry through, inflation typically declines and output growth usually falls below normal. Thus, he concludes, output growth is on average below normal following the announcements, which is not consistent with Lucas's model.

**Empirical Application: International Evidence on Output-Inflation Tradeoffs**

In the Lucas model, suppliers' responses to changes in prices are determined by the relative importance of aggregate and idiosyncratic shocks. If aggregate shocks are large, for example, suppliers attribute most of the changes in the prices of their goods to changes in the price level, and so they alter their production relatively little in response to variations in prices (see [6.20]). The Lucas model therefore predicts that the real effect of a given aggregate demand shock is smaller in an economy where the variance of those shocks is larger.

To test this prediction, one must find a measure of aggregate demand shocks. Lucas (1973) uses the change in the log of nominal GDP. For this to be precisely correct, two conditions must be satisfied. First, the aggregate demand curve must be unit-elastic; in this case, changes in aggregate supply affect $P$ and $Y$ but not their product, and so nominal GDP is determined entirely by aggregate demand. Second, the change in log nominal GDP must not be predictable or observable; that is, letting $x$ denote log nominal GDP, $\Delta x$ must take the form $a + u_t$, where $u_t$ is white noise. With this process, the change in log nominal GDP (relative to its average change) is also the unobserved change. Although these conditions are surely not satisfied exactly, they may be accurate enough to be reasonable first approximations.

Under these assumptions, the real effects of an aggregate demand shock in a given country can be estimated by regressing log real GDP (or the change in log real GDP) on the change in log nominal GDP and control variables. The specification Lucas employs is

$$y_t = c + \gamma \ell + \tau \Delta x_t + \lambda y_{t-1},$$

(6.34)

where $y$ is log real GDP, $t$ is time, and $\Delta x$ is the change in log nominal GDP.

Lucas estimates (6.34) separately for various countries. He then asks whether the estimated $\tau$'s—the estimates of the responsiveness of output to aggregate demand movements—are related to the average size of countries'
aggregate demand shocks. A simple way to do this is to estimate

\[ \tau_i = \alpha + \beta \sigma_{\Delta x, i}, \]  

(6.35)

where \( \tau_i \) is the estimate of the real impact of an aggregate demand shift obtained by estimating (6.34) for country \( i \) and \( \sigma_{\Delta x, i} \) is the standard deviation of the change in log nominal GDP in country \( i \). Lucas's theory predicts that nominal shocks have smaller real effects in settings where aggregate demand is more volatile, and thus that \( \beta \) is negative.

Lucas employs a relatively small sample. His test has been extended to much larger samples, with various modifications in specification, in several studies. Figure 6.1, from Ball, Mankiw, and D. Romer (1988), is typical of the results. It shows a scatterplot of \( \tau \) against \( \sigma_{\Delta x} \) for 43 countries. The corresponding regression is

\[
\tau_i = 0.388 - 1.639 \sigma_{\Delta x, i}, \\
(0.057) \quad (0.482) 
\]  

(6.36)

\[ R^2 = 0.201, \quad \text{s.e.e.} = 0.245, \]

where the numbers in parentheses are standard errors. Thus there is a highly statistically significant negative relationship between the variability of nominal GDP growth and the estimated effect of a given change in aggregate demand, just as the model predicts.

**FIGURE 6.1** The output-inflation tradeoff and the variability of aggregate demand (from Ball, Mankiw, and Romer, 1988)