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Capacity Constraints, Inflation and the Transmission Mechanism: Forward-Looking Versus Myopic Policy Rules

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Abstract

This paper develops a small model of the output-inflation process in the United States in order to examine the implications of alternative monetary policy rules. In particular, two types of policy rules are considered; a myopic rule where interest rates respond contemporaneously to output and inflation and a forward-looking policy rule that exploits information about the nature of transmission mechanism in the setting of interest rates. The model has two key features. First, there are significant lags between interest rates and aggregate demand conditions. Second, the model is based on an asymmetric model of inflation where positive deviations of aggregate demand from potential are more inflationary than negative deviations are disinflationary. As a consequence of this asymmetry, a policymaker that follows a myopic policy rule and allows the economy to overheat periodically will be forced to impose large recessions on the economy to keep inflation under control. The paper shows that the estimated degree of asymmetry implies that myopic policies can result in significant permanent losses in output. By contrast, policymakers that follow a forward-looking policy rule that avoids overheating will not only reduce the variance of output but also raise the mean level of output.

JEL Classification Numbers:

C51, E31, E52

1/ David Rose is a Research Advisor at the Bank of Canada. This paper has benefitted from discussions with Bill English, Tiff Macklem, Guy Meredith, John Roberts, Steven Symansky, Chris Towe, and Simon van Norden. The views expressed in this paper are those of the authors and do not necessarily reflect those of the International Monetary Fund or the Bank of Canada.

Contents

Summary

This paper explores the implications of alternative monetary policy reaction functions using a small model of the output-inflation process in the United States. The focus is on the extent to which the speed of the response of the monetary authorities to actual and expected inflation can dampen fluctuations in output. It is shown that the amplitude and length of cycles generated by demand shocks are larger when the policymaker is myopic and responds only to currently observed inflation than when the policymaker is forward-looking and adjusts interest rates in the current period in light of expected future inflation.

The model has two key features. First, there are significant lags between interest rates and aggregate demand conditions. Second, the model is based on an asymmetric model of inflation where positive deviations of aggregate demand from potential are more inflationary than negative deviations are disinflationary. This asymmetry implies that an early monetary policy response to counteract emerging inflation pressures can reduce the need to take stronger action later. As a consequence, a forward-looking monetary reaction function can in fact raise the average level of output by reducing the variance of output around the trend.

This result is derived using a simple model of the U.S. inflation process that captures certain key features of the interactions linking excess demand, inflation, and monetary policy. The model includes two estimated behavioral equations, one describing a Phillips curve and the other aggregate demand, which is specified in terms of the output gap. The empirical work indicates that there are important asymmetries in the U.S. output-inflation process. The model also includes a monetary policy reaction function in which the monetary authorities are assumed to vary the short-term interest rate to achieve their output and inflation objectives.

Both deterministic and stochastic simulations are used to derive the implications for macroeconomic performance of forward-looking and myopic monetary policy reaction functions. The conclusion of this analysis is that to the extent that the monetary authorities can avert or moderate periods of excess demand, particularly by pursuing a forward-looking approach in which the current stance of policy takes account of expected future inflation, they may be able to achieve significant benefits in terms of the realized average level of output.

I. Introduction

> *"Shifts in the stance of monetary policy influence the economy and financial markets with a considerable lag, as long as a year or more. The challenge of monetary policy is to interpret current data on the economy and financial markets with an eye to anticipating future inflationary forces and to countering them by taking action in advance."*
>
> *Allan Greenspan (1994, p. 609)*

The role of a monetary policymaker can be likened to an admiral piloting an aircraft carrier formation through a narrow passage in a bad storm. Given the long lags between changes in course and its effects on the future path of the carrier, it is important for the admiral to know as precisely as possible the effects of his actions on the current and future path of the aircraft carrier. As future sea and wind conditions which offset this path cannot be known with certainty, it is necessary to constantly monitor them and make the appropriate adjustments in course. Keeping track of these changing conditions is obviously facilitated by relying on sophisticated radar technology and other monitoring devices. A similar control problem exists for the monetary policymaker but two factors make the task of steering the economy considerably more daunting. First, the policymaker has a much less precise radar system, and consequently does not know what shocks will arrive in the future and does not know the structure of the economy with complete certainty. Secondly, the policymaker typically must defend an increase in interest rates from criticism, particularly in situations where there is no obvious evidence that inflation is about to rise. The admiral faces no such problem. Although the sailor who is swabbing the decks on a calm day may wonder why the carrier is suddenly turning, he has been trained and has learned to trust the Admiral's guidance system. By contrast, most monetary authorities have only a limited track record and must rely on theoretical and empirical analysis to defend their policy judgements.

This analogy has relevance for the task of inflation control which faces all monetary authorities. One of the characteristics of business cycles in industrial countries in the postwar period has been the tendency for inflation to rise as a consequence of excess demand pressures during boom periods. To bring inflation down has inevitably required a tightening of monetary policy to rein in aggregate demand to generate a gap between actual and potential output, as the cure for excessive inflation has typically required a period of slow or negative real growth. The seeds of recession have often been planted by a failure to recognize early on that inflationary forces were at work.

Policymakers have come to recognize that failure to resist the buildup of inflationary forces in an overheating economy will result in deeper and more protracted recessions. Moreover, in some cases there appears to be an explicit recognition that lags in the transmission mechanism necessitate forward-looking policy choices. A myopic strategy of responding only when inflation was evidently changing would condemn the economy to further delays in the stabilization process and engender or exacerbate boom and bust cycles. Indeed, this recognition has no doubt been a major consideration leading a number of countries to adopt as the primary goal of monetary policy the objective of maintaining a low and stable inflation rate. 1/ This requires that the conduct of monetary policy take full account of the lags between changes in the instruments of monetary policy and aggregate demand, as well as the lags between the demand pressure and inflation.

This paper explores the implications of alternative monetary policy reaction functions using a simple stylized model of the inflation process in the United States. The focus is on the extent to which the speed of the response of the monetary authorities to actual and expected inflation can dampen fluctuations in output. It is shown that the amplitude and length of cycles generated by demand shocks are larger when there is a delay in the response of monetary policy. A key feature of the model is that it is based on an asymmetric Phillips curve. As described in detail in a separate paper by Laxton, Meredith, and Rose (1994), nonlinearity has important implications for the output effects of monetary policy. In the case of a linear Phillips curve, positive and negative shocks to demand have symmetric effects on inflation so that the overall impact of these shocks to output averages out to zero regardless of the response of monetary policy. By contrast, in the asymmetric case of interest, positive shocks to demand raise inflation to a greater extent than negative shocks of the same magnitude lower it. This property implies that early action to counteract emerging inflation pressures can reduce the need to take stronger deflationary action later. As a consequence of this asymmetry, an appropriate monetary policy response function can in fact raise the average level of output by reducing the variance of output around its trend.

This paper is organized as follows. The following section describes recent cycles in U.S. inflation and output and the next section discusses the structure of the model and the estimation results. The forth section discusses the basic policy implications of short-run capacity constraints by focussing on simple deterministic simulation experiments. The fifth section then reports the results of stochastic simulations showing the implications for the variance and average level of output of alternative monetary policy reaction functions. The concluding section draws together the main findings of the analysis and provides some suggestions for further research.

1/ Five countries have officially announced explicit inflation targets: Canada, Finland, New Zealand, Sweden, and the United Kingdom. For an extensive discussion of the experience of three of these countries (Canada, New Zealand, and the United Kingdom), see Ammer and Freeman (1995).

II. Recent Cycles in U.S. Inflation and Output

This section reviews recent cycles in U.S. inflation and output. It highlights the importance of taking a forward-looking view in the conduct of monetary policy on the basis of U.S. experience over the past 30 years. Failure to take account of the lags between excess demand and inflation, and the lags between monetary policy action and aggregate demand, was reflected in a myopic response by the Federal Reserve to inflation in the 1970s. As a consequence, inflation accelerated to double-digit figures in 1974 and 1979-82 and the latter episode led to the most severe U.S. postwar recession in the early 1980s.

The key variables of interest in this study--aggregate demand, inflation, and interest rates--are shown in Chart 1 over the period 1964-94. 1/ The focus is on aggregate demand relative to potential output, i.e., the output gap, as the main factor affecting inflation, and the central role of monetary policy in influencing the rate of inflation through interest rate changes which affect aggregate demand. The concentration on these linkages should not be construed as implying that other factors are unimportant in determining the level of demand, the rate of inflation, and interest rates. These include, for example, changes in government spending associated with the Vietnam war and other significant U.S. fiscal policy actions, the oil price increases and other commodity price disturbances in the 1970s, and changes in real net exports in the 1980s related to movements in the foreign exchange value of the U.S. dollar. However, in this analysis we treat these factors simply as shocks that affect the output-inflation process. They enter the error terms in our equations explaining inflation and aggregate demand and our analysis does not depend on the specific nature of the shocks. In this paper the primary focus is on the speed with which the Federal Reserve responds to the effects of these shocks on current and future inflation. The view taken here is that the control of inflation by the monetary authorities ultimately depends on limiting excess demand pressures by means of changes in official interest rates which in turn affect market interest rates.

The upper panel in Chart 1 shows the level of real GDP and an estimate of potential output, both expressed in logs. As described in more detail below, the latter is generated by a simple 25-quarter centered moving average filter. 2/ The middle panel plots the output gap and inflation

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1/ For an excellent discussion of monetary policy during this period, see Mussa (1994). See also Meulendyke (1989).

2/ As shown in the estimation section below, this filter maximizes the fit of our basic inflation equation.

measured in terms of the consumer price index. 1/ One can see in this panel some rough correspondence between excess demand or supply (a positive or negative output gap) and inflation: a positive output gap is generally associated with high and rising inflation, and a negative output gap with declining inflation. The bottom panel again shows the inflation rate together with the Federal funds rate and the long-term interest rate, which is represented by the ten-year U.S. government bond yield; one can see in this panel the timing of official interest rate increases relative to changes in the inflation rate.

From the early 1950s to the mid-1960s, the inflation rate was quite low, averaging about 1.3 percent per annum. However, the second half of the 1960s was a period of excess demand and rising inflation which in part reflected military spending for the Vietnam war. As a consequence, the inflation rate rose from about 1½ percent in 1965 to 5½ percent in 1969. Monetary policy was tightened significantly only after price increases reached their peak at about 6 percent. This tightening, together with some contractionary fiscal policy measures, contributed to the recession which began in late 1968 and continued through 1970. As shown in the bottom panel of Chart 1, while adjustments in the Federal funds rate generally took place only after increases in inflation were observed, the level of the Funds rate, as well as the long-term interest rate, remained above the inflation rate over this period.

The decade of the 1970s was marked by periods of high and rapidly rising inflation which reflected a number of developments. First, there were the two oil price shocks: the first followed the Arab-Israeli war in October 1973 and the second occurred after the overthrow of the Shah of Iran in 1979. Second, there was an over estimation of the capacity output of the economy, in part reflecting an extrapolation of the favorable economic growth performance of the 1960s. 2/ Third, the underestimation of the effects of excess demand on inflation meant that the Federal Reserve did not respond sufficiently rapidly to prevent an acceleration in inflation from occurring. As a result, inflation expectations became entrenched and ultimately required a significant period of deflation to reduce the rate of inflation on a durable basis back to the levels seen in the 1960s. The seeds of the recessions of 1974-75 and 1981-82 were planted in the preceding

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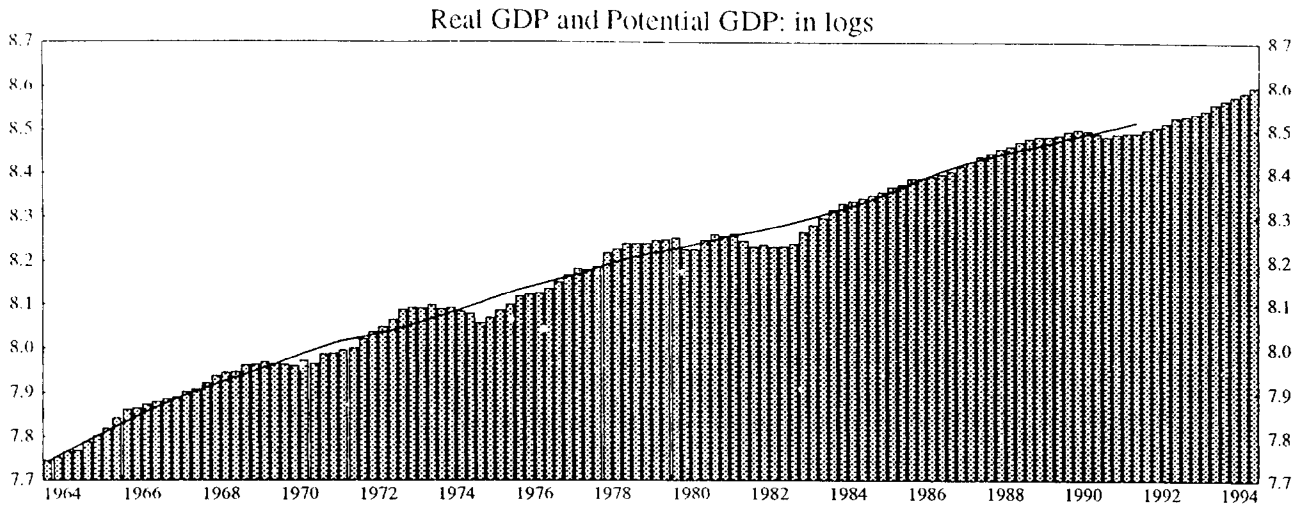
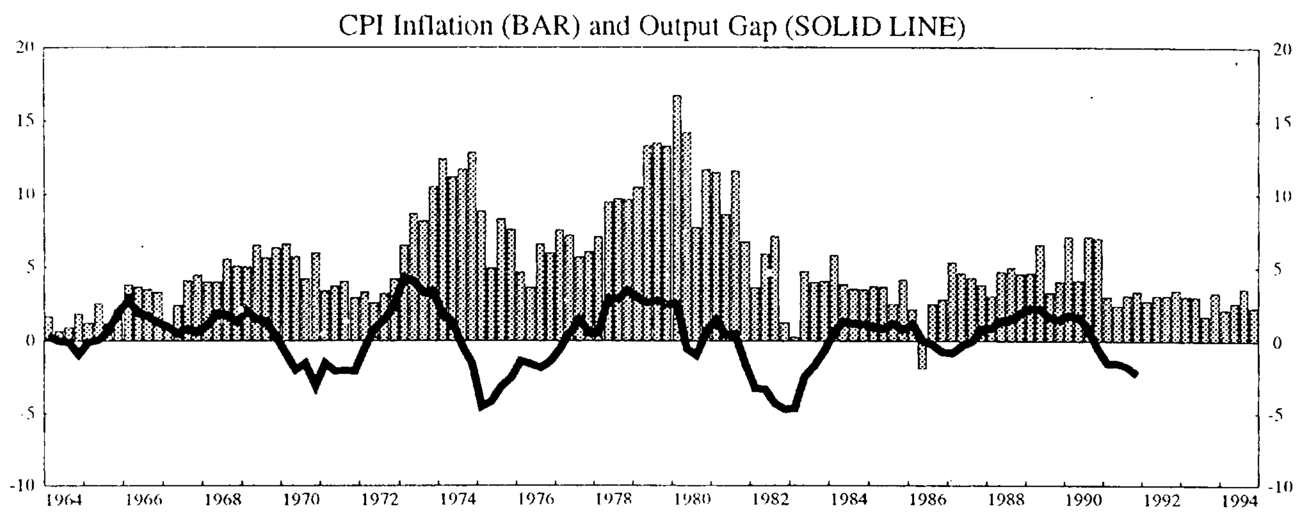
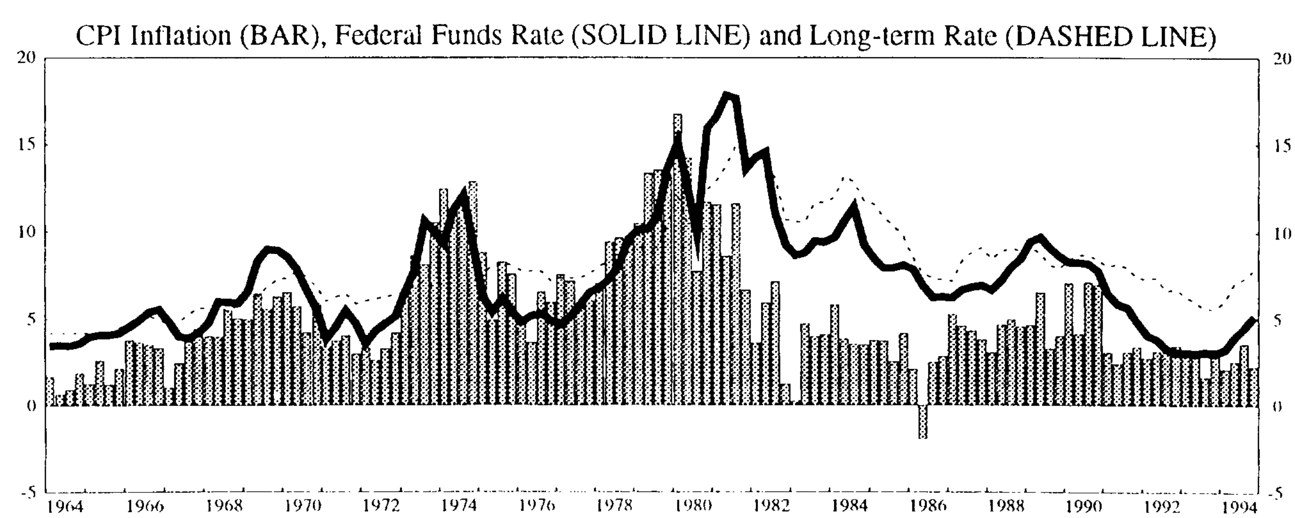
1/ The output gap is defined as the percentage difference between actual output and the estimated value of potential output. We refer to a "positive" output gap when actual output exceeds potential, and a "negative" gap when the reverse holds. Inflation is measured as by quarter-to-quarter change expressed at an annual rate.

2/ For example, Perry (1971, p. 560), projected that growth in potential output would average 4.3 percent annually during the 1970s. Subsequently, Adams and Coe (1990) estimated that potential output in the non-farm U.S. business sector grew at an 2¾ percent average annual rate during the 1970s, which is only slightly higher than the average growth rate of real GDP of 2.6 percent during 1970-80.

Chart 1: Output, Inflation and Interest Rates: 1964q1-94q4







periods of economic boom which brought demand above capacity output, as can be seen in the middle panel of Chart 1. The bottom panel shows what Mussa (1994, pp. 89-93) refers to as the Federal Reserve "falling behind the curve," i.e., it raised interest rates only in the face of contemporaneous evidence of increasing inflation. Because of the lags between interest rates and aggregate demand, the delayed monetary policy response led to a curve of rising inflation. As described in detail below, the negative consequences of the delayed response were exacerbated by the nonlinear shape of the curve relating the rate of inflation to excess demand.

The decade of the 1980s began with the most severe postwar recession, which can be seen in part as reflecting the determination of the Federal Reserve to wring inflation out of the economy once and for all and unequivocally reverse the upward trend in inflation from the late 1960s through the 1970s. This required an extended period of high unemployment and low capacity utilization to generate a rapid decline in actual inflation as well as a reduction in inflation expectations. As shown in the bottom panel of Chart 1, the tighter stance of monetary policy during this period is indicated by the fact that both the Federal funds rate and the long-term interest rate remained above the inflation rate for most of the 1980s; this is in sharp contrast with the 1970s, during which the Federal funds rate was often below the inflation rate. When a period of excess demand emerged at the end of the 1980s, the Federal Reserve increased the Federal funds rate by about twice the increase in inflation and the former peaked at 9.8 percent in the spring of 1989. This determination not to "fall behind the curve" in resisting price increases prevented an acceleration in inflation from emerging, with the result that the ensuing recession in the second half of 1990 and the first quarter of 1991 was relatively mild.

By the same token, the recovery from that recession was quite muted and economic growth did not pick up rapidly until 1994. Notwithstanding a decline in the unemployment rate to below 5.5 percent (generally regarded as at, or below, the NAIRU) and a capacity utilization rate above 85 percent, when inflation pressure clearly emerged in previous expansions, there was little evidence during the year of an actual increase in inflation in either final goods prices or in wages. Nonetheless, the Federal Reserve raised the target Federal Funds rate from 3 percent at the beginning of 1994 to 5½ percent at the end of the year in a pre-emptive move to contain inflation as the economy approached potential output. Such a forward-looking view of monetary policy was clearly enunciated by Chairman Greenspan in his Congressional testimony on February 22, 1995: "Because the effects of monetary policy are felt only slowly and with a lag, policy will have a better chance of contributing to meeting the nation's macroeconomic objectives if we look forward as we act--however indistinct our view of the road ahead. Thus, over the past year [1994] we have firmed policy to head off inflation pressures not yet evident in the data." 1/

The discussion above implies that there has been a significant shift in the Federal Reserve's monetary policy reaction function in the last 30 years. Econometric evidence supporting such a shift has recently been reported by Brunner (1994) and Mehra (1994). By contrast, Fuhrer and Moore (1995) indicate that they did not find a statistically significant shift in the Fed's reaction function in pre- and post-1979 subsamples. Judd and Trehan (1995) used Mehra's reaction function to see what the Fed funds rate would have been in 1994 if the Fed had continued to adjust this rate on the basis of the reaction function estimated over the sample period 1979-92. They found that while the level of the Fed funds rate in 1994 was above that implied by the estimated reaction function, the difference was not statistically significant.

III. A Model with a Nonlinear Relationship Between Demand and Inflation

The above discussion of the cyclical behavior of output, inflation, and monetary policy over the last 30 years has emphasized the importance of a forward-looking approach to implementing monetary policy. This reflects the need to take account of both the lags between changes in the stance of policy and the impact on aggregate demand and the lagged response of inflation to changes in aggregate demand. Also important in the timing of changes in monetary policy is the reaction of inflation expectations; if market participants perceive a slow reaction by the monetary authorities to an acceleration in demand, their behavior is likely to be based on an extrapolation of inflation pressures, thereby prolonging and intensifying the extent to which monetary policy will need to be tightened to reduce actual inflation.

Another important aspect of the timing and intensity of the response of monetary policy to a demand shock relates to the asymmetric relationship between output and inflation. As emphasized in the original article by Phillips (1958), excess demand would be expected to have a much stronger effect in raising inflation than would a comparable degree of excess supply in lowering it. Such an asymmetric view of the inflation-output relationship would appear to underlie recent Congressional testimony of Chairman Greenspan, as suggested by the following quotation:

1/ Testimony of Chairman Greenspan before the Committee on Banking, Housing, and Urban Affairs, U.S. Senate, February 22, 1995, as reprinted in the Federal Reserve Bulletin, April 1995, pp. 384.

> Knowing in advance our true growth potential obviously would be useful in setting policy because history tells us that economies that strain labor force and capital stock limits tend to engender inflationary instabilities that undermine growth. Moreover, in such an environment asset prices can begin to rise unsustainably, contributing to an unstable financial and economic environment. .... the appropriate analogy is a flexible ceiling that can be stretched when pressed; but as the degree of pressure increases, the extent of flexibility diminishes. 1/

The importance of a nonlinear relationship between activity and inflation has been stressed by De Long and Summers (1988) and Laxton, Meredith and Rose (1994). The latter point out that the alternative assumption of a linear relationship implies that there is in principle no upper bound to the short-run impact on output of expansionary policies, whereas experience with inflation suggests that it starts to increase rapidly as aggregate demand exceeds capacity output. Moreover, as excess demand raises inflation by more than excess supply of the same magnitude lowers it, a sharper and/or more extended period of the latter will be required to offset the inflationary consequences of the former. The key implication of this asymmetry is that the greater the degree of nonlinearity and the greater the variance of output, the lower will be the average level of output.

1. Implications of asymmetry in the output-inflation process

In order to understand the implications of convexity in the Phillips curve, it is useful to assume for illustrative purposes that the inflation process can be described by the following quadratic function:

$$(1) \quad \pi = \pi^e + \beta \, gap^* + \lambda (gap^*)^2$$

where π is the rate of inflation, $gap^* = y - y^*$, and $\beta, \lambda > 0$. 2/ y^* is the level of output at which there is no tendency for inflation to either rise or fall in the absence of shocks to the economy. However, in the presence of shocks to the system, y^* will not be equal to the observed average level of output, as shown below.

Taking expectations of both sides of equation (1) gives:

$$(2) \quad E[\pi] = E[\pi^e] + \beta \, E[gap^*] + \lambda \, E[(gap^*)^2] \ .$$

1/ Ibid, pp. 343.

2/ The quadratic functional form is chosen only for analytical convenience; it does not give rise to a sensible Phillips curve because at some point large negative gaps will result in an increase in inflationary pressures.

In a sustainable equilibrium with a constant rate of inflation and no systematic error in inflation expectations, $E[\pi] = E[\pi^e]$. It follows that:

(3) $\beta E[gap^*] + \lambda E[(gap^*)^2] = 0$.

Making use of the definition of the variance (VAR) of gap^*, equation (3) can be expressed as:

(4) $\beta E[gap^*] + \lambda [VAR(gap^*) + E[gap^*]^2] = 0.$

It follows that the expected value of gap^* is equal to:

(5) $E[gap^*] = \frac{-\lambda}{\beta}[VAR(gap^*) + E[gap^*]^2]$.

As long as there is some convexity in the Phillips curve, i.e., $\lambda > 0$, and there is some variance in output, then the average level of gap^* will be negative. Recalling that $gap^* = y - y^*$, and representing the right-hand side of (5) by α, we have:

(6) $E[gap^*] = E[y] - E[y^*] = \alpha,$

i.e., $\bar{y} - y^* = \alpha$, or $\bar{y} = y^* + \alpha$ where $\alpha < 0$. Thus the important implication of a nonlinear Phillips curve is that the average level of output lies below the level that would be observed in the absence of shocks. The economic intuition underlying this result is that if output were maintained, on average, equal to y^*, then the nonlinearity in the response of prices to aggregate demand shocks would make it impossible to maintain a constant inflation rate. Because deviations of demand above y^* have a larger positive effect on inflation than deviations of the same magnitude below y^* have in reducing inflation, an attempt to keep $y = y^*$ would lead to an acceleration in inflation without bound. Therefore the only way that this outcome can be avoided is if the average level of output lies below y^*. This implies that relative to the notional level of output attainable in the absence of shocks, periods of disinflation below this level will be more severe or of longer duration than periods of excess demand above this level. 1/

1/ The implications of convexity for economic stabilization policies have been pointed out by Mankiw (1988, p. 483) in his comments on De Long and Summers (1988): "Because of capacity constraints, increases in aggregate demand raise prices more quickly than decreases in aggregate demand lower them. This aggregate supply curve, or indeed any convex aggregate supply curve, will imply that stabilization increases mean output." Subsequently, however, Ball and Mankiw (1994) presented a model where macroeconomic stabilization does not raise the mean level of output in the presence of asymmetric price adjustment at the firm level.

2. An asymmetric model of the U.S. output-inflation process

In this section we present a simple model of the U.S. inflation process that captures certain key features of the interactions linking excess demand, inflation and monetary policy. The model consists of two estimated behavioral equations, one describing a Phillips curve and the other aggregate demand which is specified in terms of the output gap. In order to close the model, a monetary policy reaction function is specified in which the monetary authorities are assumed to vary the short-term interest rate to achieve their output and inflation objectives. This stylized model highlights the inflation generating process as primarily dependent on excess demand, i.e., the output gap, and the role of the monetary authorities in influencing the rate of inflation by controlling the short-term interest rate and thereby aggregate demand. The monetary control mechanism is not perfect, however, as the economy is subject to shocks which cannot be foreseen. Moreover, the influence of monetary policy on aggregate demand through interest rates operates with a lag. Thus, given the existence of short-run capacity constraints, the characteristics of the monetary policy reaction function have important implications for the dynamic behavior and overall performance of the economy.

Although the existence of short-run capacity constraints suggests that there may be asymmetries in the Phillips curve, economic theory does not provide much guidance in terms of a functional form. Furthermore, even if the true functional form were known with certainty, there would still be substantial difficulties in identifying its parameters in small samples. Indeed, one reason why statisticians prefer linear models is that they are far less sensitive to outliers than nonlinear models. In Laxton, Meredith, and Rose (1994), this problem was overcome by using a pooled-time series cross-section data set for the G-7 countries to estimate a nonlinear function. In this paper, by contrast, we are focusing only on one country, the United States, and therefore the number of observations of cyclical periods of excess demand and supply is quite restricted. Given the limited number of business cycles in the U.S. data, our estimation strategy is to take a linear approximation of a general convex function in which positive gaps have larger effects on inflation than negative gaps. This involves adding a separate term for the gap^* when it is positive, as shown in equation (6) below:

$$(6) \quad \pi_t = \delta\pi^e_{t+4} + (1-\delta)\pi_{t-1} + \beta\, gap^*_t + \gamma\, gappos^*_t + \epsilon^\pi_t$$

where:

π^e_{t+4} = weighted average of expected inflation over the next four quarters

gap^* = $y - y^*$

y^* = $\bar{y} - \alpha$ where $\alpha < 0$

$\bar{y}$ = average value of y

$gappos^*$ = positive values of gap^*.

When $y > y^*$, there is inflationary pressure over and above the contribution of the linear term (gap*), which also measures the disinflationary pressure when $y < y^*$. This estimation strategy is meant to strike a better balance between the statistical robustness that one achieves from assuming linearity compared to the policy errors that would be induced from assuming global linearity, i.e., $\gamma = 0$. 1/ A major advantage of this approach is that it is easy to test the restriction of linearity, even though the "kinked" function may not be the best choice for a policy simulation model.

While the specification of the effect of the gap on inflation has been linearized, it is important to note that the estimates of β and γ involve the simultaneous estimation of α, which, as noted above, is the difference between $\bar{y}$ and y^*. Thus our estimate of the output gap which is relevant for explaining inflation, which we denote by gap*, is equal to the difference between the actual level of output and the notional upper limit on output, y^*, which could only be achieved in the absence of stochastic shocks to the economy. As noted below, if α is omitted from the estimation, the estimate of γ will be biased downwards. This underscores the fact that the proper specification of the measure of excess demand is essential in identifying the effect that asymmetry has on inflation.

Traditional "backward-looking" Phillips curves relied on past inflation to reflect inertia in the wage- and price-contracting process as well as to proxy for expectations of future inflation. In contrast, more recent theoretical models of overlapping contracts with forward-looking agents (such as Calvo (1983)) represent inflation as a function of its expected future realization based on all available information about the state of the economy. The inclusion in our specification of a weighted average of past and expected future inflation reflects elements of both approaches, with the importance of each determined empirically. 2/ In our work, expected future inflation is proxied by the Michigan survey measure of inflation expectations. The estimated weights on past $(1-\delta)$ and expected future inflation (δ) determine the relative importance of the "forward" and "backward" looking components of the inflation process. Imposing the constraint that these weights sum to unity ensures that no long-run trade-

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1/ In other words, we think that econometricians should be as concerned about Type I and Type II policy errors as they are about Type I and Type II statistical errors. Here, the Type 1 policy error is rejecting the hypothesis of nonlinearity when it is true. The implication of the analysis in this paper is that if monetary policy were based on the assumption of a linear Phillips curve, when in fact the relationship between inflation and capacity is nonlinear, macroeconomic performance would be adversely affected because the tendency for the economy to overheat would require significant periods of slack to reduce inflation back to the target level.

2/ A more formal justification for the presence of lagged inflation is given by Taylor (1980) in a model of overlapping wage contracts expressed in growth rates.

off exists between the level of inflation and excess demand pressures; it is in this sense that the natural rate hypothesis holds in our model.

The use of a survey measure of inflation expectations eliminates the problem of using fixed-parameter, reduced-form models and imposing inappropriate restrictions which arise when the typical procedure is used of regressing actual inflation on an information set known at the time expectations are formed. The survey measure, by contrast, can more flexibly accommodate the changing importance of different factors; in particular, it can incorporate more rapidly than other measures responses to changes in actual and prospective economic policies. In this way the survey measure would appear to be less subject to the Lucas critique, compared with other approaches that simply extrapolate in a mechanical fashion the impact of changes of variables in the past on expectations of future inflation.

There are numerous approaches to measuring the mean or trend level of output. We chose a simple and transparent approach, namely, the two-sided moving average of the logarithm of actual GDP which was used in Laxton, Meredith, and Rose (1994). In the estimation results shown in Table 1, we varied K, the number of quarters on each side of the center of the moving average, over a fairly wide range. 1/ Table 1 shows that the goodness of fit is maximized at $K = 12$. It also shows the parameter estimates are not very sensitive to moderate variations in K. Also, in interpreting $\bar{y}$ as a measure of trend or capacity output, the fairly long moving-average process suggests that demand shocks--movements in the gap $(y-\bar{y})$--are more important for explaining the variation in observed output than movements in potential output.

In terms of the estimation results themselves, in the preferred equation with $K = 12$, all the coefficients have the expected signs and are statistically significant. 2/ In particular, the sum of the estimated coefficients β and γ imply a significantly larger impact of positive excess demand on inflation than a comparable degree of excess supply would have in reducing inflation, which is equal to β. 3/ In addition, the estimate of α indicates a plausible and non-negligible difference of 1.3 percent between the y^* and $\bar{y}$, i.e., the average or trend level of output lies 1.3 percent below the notional level of output that is achievable in the absence of

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1/ The estimation results in this paper were estimated with the nonlinear least squares routine in RATS.

2/ Initial estimates of the inflation equation showed some evidence of third-order autocorrelation in the residuals. We then re-estimated the equations with the ROBUST ERRORS option in RATS. The t-statistics and Wald tests reported in Table 1 are based on the corrected variance-covariance matrix from this estimation procedure.

3/ This finding is similar to that of Turner (1995), who found in the case of three out of the seven major industrial countries that in allowing for an asymmetric impact of the output gap, the inflationary effect of positive gaps is up to four times the deflationary effect of negative gaps.

Table 1. A Simple Asymmetric Model of the U.S. Output-Inflation Process

(T-statistics in parentheses)

Estimated equation: $\pi_t = \delta \bar{\pi}^e_{t+4} + (1-\delta)\pi_{t-1} + \beta\ gap^*_t + \gamma\ gappos^*_t + \epsilon^\pi_t$

where: $gap^* = y - y^* = y - \bar{y} + \alpha$, $\quad gappos^*$ = positive values of gap^*

$\bar{\pi}^e_{t+4} = .2\,({}_t\pi^e_{t+4} + {}_{t-1}\pi^e_{t+3} + {}_{t-2}\pi^e_{t+2} + {}_{t-3}\pi^e_{t+1} + {}_{t-4}\pi^e_t)$

$\pi \equiv$ Percent change in the CPI at annual rates

$\pi^e_{t+4} \equiv$ Michigan Survey Measure of Inflation Expectations

$$\bar{y} \equiv \frac{1}{2K+1}\left[y_t + \sum_{i=1}^{k} y_{t+i} + y_{t-i} \right]$$

Data: U.S. Quarterly Data, 1964Q1-90Q4.

K	α	γ	β	δ	R^2	σ	Wald Test: SL(α, γ = 0)
5	-0.354 (0.99)	0.878 (1.83)	0.458 (2.59)	0.566 (4.65)	.7776	1.6445	0.087
6	-0.441 (1.23)	0.873 (2.19)	0.384 (2.64)	0.576 (4.91)	.7816	1.6296	0.032
7	-0.547 (1.44)	0.813 (2.36)	0.337 (2.55)	0.582 (5.01)	.7821	1.6275	0.022
8	-0.670 (1.73)	0.780 (2.64)	0.308 (2.61)	0.585 (5.20)	.7844	1.6192	0.015
9	-0.770 (2.09)	0.758 (3.21)	0.282 (2.60)	0.586 (5.48)	.7850	1.6168	0.004
10	-0.893 (2.72)	0.772 (3.00)	0.254 (2.52)	0.587 (5.87)	.7851	1.6164	0.010
11	-1.149 (3.27)	0.918 (2.99)	0.218 (2.47)	0.591 (6.07)	.7873	1.6081	0.004
12	-1.256 (3.66)	0.925 (3.16)	0.202 (2.43)	0.593 (6.13)	.7892	1.6010	0.001
13	-1.369 (3.67)	0.916 (3.13)	0.189 (2.47)	0.600 (5.99)	.7890	1.6017	0.001
14	-1.478 (3.13)	0.896 (2.72)	0.177 (2.43)	0.595 (5.88)	.7879	1.6058	0.007
15	-1.661 (3.38)	0.919 (2.69)	0.166 (2.47)	0.593 (5.79)	.7862	1.6123	0.002
16	-1.712 (3.02)	0.866 (2.56)	0.161 (2.49)	0.587 (5.58)	.7834	1.6229	0.010

shocks. As discussed in more detail below, α provides a measure of the extent to which the average level of output was reduced over the sample period by fluctuations in aggregate demand.

Chart 2 shows in the top panel the adjusted level of potential output, which, as noted above, lies 1.3 percent above the average level of output used as the measure of potential output in Chart 1. The middle panel plots our measure of inflation expectations, the Michigan Survey, and actual inflation. It is noteworthy that following the high-inflation period of the 1970s and early 1980s, expected inflation typically exceeded actual inflation in subsequent years. The bottom panel plots the difference between actual and expected inflation, as well as the adjusted output gap, i.e., gap^*. It shows that after taking account of inflation expectations, actual inflation tends to rise (sometimes with a lag) when the output gap is positive and to fall when the output gap is negative. Because of the asymmetry in the Phillips curve, periods of excess supply (a negative output gap) are more persistent and severe than periods of excess demand. This is most noticeable in the 1980s and early 1990s.

As already noted above, the ability to obtain reasonable estimate of γ depends crucially on specifying the output gap appropriately to include a joint estimate of α. This intrinsic relationship can be demonstrated by estimating the equation (6) but setting $\alpha = 0$. The results are shown as equation (1b) in Table 2. Ignoring α in the equation results in a misspecification of the output gap and the estimated coefficient of the positive value of the gap, γ, is only 0.13 and is not significantly different from zero. This shows that finding evidence of asymmetry in the output-inflation process requires careful attention to modeling the manner in which excess demand gets translated into upward price movements. Ignoring the α shift in a test for convexity is tantamount to ignoring a key implication of the hypothesis being tested. Our results show clearly that this has important implications for the power of econometric identification of the parameters and the test for convexity itself. 1/

Table 2 also presents some estimation results when we use alternative measures of the output gap. These include the Hodrick-Prescott filter under a number of alternative assumptions regarding the curvature restriction. Since ad hoc filters such as the Hodrick-Prescott filter or the simple

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1/ As discussed below, the value of α depends on the monetary policy reaction function. As noted above, there is evidence that the Fed's reaction function shifted over the sample period considered here. This implies that our estimate of α may be some average value reflecting the effects of different monetary policy response functions. In principle, it would be desirable to test for different values of α under different policy regimes. However, a strong test for such differences would appear to be difficult on account of the small sample of observations. In Section V below we use stochastic simulations to show the sensitivity of α to the nature of the reaction function.

Table 2. Tests with Alternative Measures of the Output Gap

(T-statistics in parentheses)

Estimated equation: $\pi_t = \delta\pi^e_{t+4} + (1-\delta)\pi_{t-1} + \beta\ gap^*_t + \gamma\ gappos^*_t + \epsilon^\pi_t$

Where: $gap^* = y - y^* = y - y + \alpha$, $gappos^*$ = positive values of gap^*

$\overline{\pi}^e_{t+4} = .2\,({}_t\pi^e_{t+4} + {}_{t-1}\pi^e_{t+3} + {}_{t-2}\pi^e_{t+2} + {}_{t-3}\pi^e_{t+1} + {}_{t-4}\pi^e_t)$

$\pi \equiv$ Percent change in the CPI at annual rates

π^e_{t+4} Michigan Survey Measure of Inflation Expectations

Model #1: Case of k = 12 from Table 1

Model #2: Harvey and Jaeger (1993)'s Trend Plus Cycle Model

Model #3: Hodrick-Prescot Filter with λ=1600

Model #4: Hodrick-Prescot Filter with λ=5000

Model #5: Hodrick-Prescot Filter with λ=10000

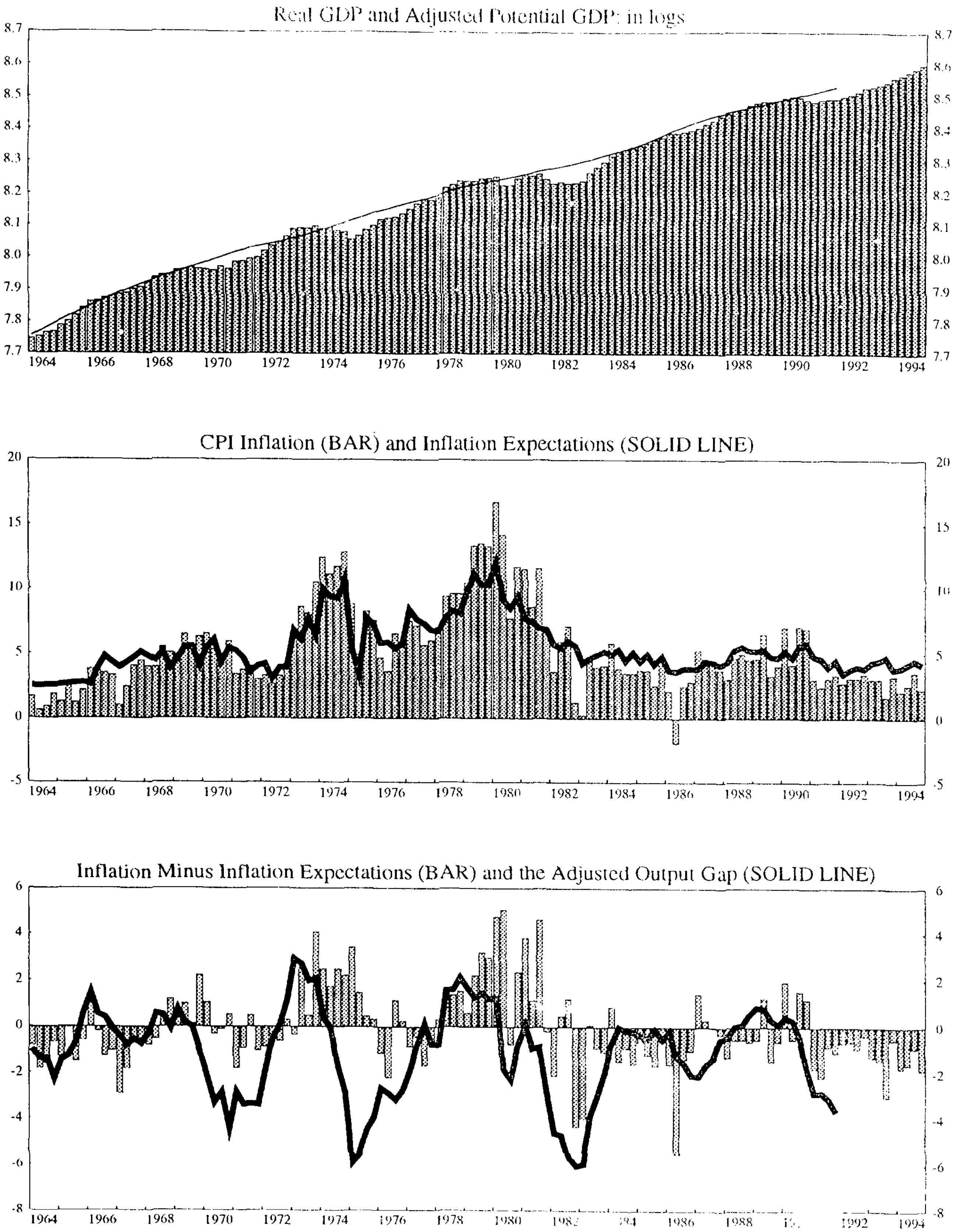
Model #6: Hodrick-Prescot Filter with λ=100000

Model #7: Quadratic Time Trend (SMPL 1961Q1-94Q4)

Inflation equation estimation period: SMPL 1964Q1-90Q4

Mod.	α	γ	β	δ	R^2	σ	Wald Test SL(α,γ = 0)
1a	-1.256 (3.66)	0.925 (3.16)	0.202 (2.43)	0.593 (6.13)	.7892	1.6010	0.001
1b	0.000	0.134 (0.79)	0.326 (3.14)	0.557 (5.33)	.7761	1.6421	
2a	-0.791 (2.48)	1.092 (2.80)	0.281 (2.40)	0.611 (6.18)	.7927	1.5877	0.018
2b	0.000	0.331 (1.52)	0.403 (2.75)	0.583 (5.58)	.7849	1.6094	
3a	-0.848 (2.34)	0.943 (3.05)	0.248 (2.46)	0.611 (5.88)	.7927	1.5874	0.008
3b	0.000	0.283 (1.52)	0.344 (2.94)	0.581 (5.40)	.7827	1.6175	
4a	-1.326 (4.02)	1.073 (3.17)	0.192 (2.52)	0.600 (5.44)	.7874	1.6077	0.000
4b	0.000	0.194 (1.12)	0.311 (3.36)	0.568 (5.12)	.7778	1.6358	
5a	-1.498 (4.28)	1.081 (3.03)	0.175 (2.67)	0.589 (5.25)	.7833	1.6231	0.000
5b	0.000	0.148 (0.88)	0.298 (3.63)	0.558 (5.00)	.7745	1.6477	
6a	-0.506 (0.53)	0.176 (0.70)	0.226 (2.71)	0.530 (4.69)	.7652	1.6895	0.782
6b	0.000	0.046 (0.29)	0.266 (4.00)	0.528 (4.62)	.7649	1.6826	
7a	1.458 (1.74)	-0.205 (1.57)	0.335 (3.28)	0.515 (4.15)	.7581	1.7148	0.160
7b	0.000	-0.013 (0.10)	0.222 (3.86)	0.512 (4.29)	.7567	1.7117	

Chart 2: Inflation, Inflation Expectations, and Output: 1964q1-94q4



two-sided moving average filter employed in Table 1 are in general suboptimal for developing trend estimates of output, one can use more sophisticated models which can be optimized to explain the time series properties of U.S. output. Indeed, Harvey and Jaeger (1993) show that estimates from the Hodrick-Prescott filter will only be optimal--in the class of univariate filters--under very specific parameterizations. Their unobserved components (UC) model of trend-plus-cycle is quite flexible and can be thought of as a simple reduced-form of a more general dynamic stochastic structural model of the U.S. economy. They argue that their simple UC model has several advantages over simple time trends or segmented time trends. Using several series as examples, they also use the UC model to show how the H-P filter can result in biased estimates of the cyclical component and can even induce spurious correlations if two series are detrended with the H-P filter. Despite this general argument--which is true in principle--they show that at least for U.S. GNP the UC model produces estimates that are very similar to the HP1600 estimates.

Table 2 reports estimates of the inflation model which are based on these alternative estimates of the output gap. Again, to give some indication of the potential bias associated with using unadjusted measures of the output gap, we also report results where α is imposed to be equal to zero. Equation (2a) reports the coefficients using the UC model of Harvey-Jaeger to construct the output gap. It is interesting that the fit of the model is slightly better than the best fit which was obtained when we varied the horizon in the simple two-sided filter to maximize the fit of the inflation equation, with both γ and β are slightly larger than in equation (1a). All the parameters are statistically significantly different from zero and a Wald test indicates that we can reject the joint restriction that α, γ = 0 with considerable confidence. Equation 2b reports the results when α is imposed to be equal to zero; in this case the estimate of the coefficient on the positive output gaps (γ) falls from 1.092 in the unrestricted model to 0.331. In addition, the coefficient on the output gap (β) increases from 0.281 in the unrestricted model to 0.403 in the restricted model.

Equation 3a reports the results when we use the HP1600 filter to measure the output gaps. The results confirm the earlier indication that these gaps are not significantly different from the gaps produced by the UC model. Indeed, the model's parameter estimates are almost identical to Equation 2a. Again, the case for asymmetries weakens when we impose $\alpha = 0$ in equation (3b).

In general, all univariate techniques can be expected to produce very uncertain estimates of the true relative variance of the gap term. Consequently, it may be reasonable to presume that potential output is smoother than what is implied by the HP1600 or the UC model. To test the sensitivity of our results to this assumption we reestimated our model with larger weights on the curvature part of the HP penalty function. In the limit, an extremely high weight implies that potential output could be proxied with a linear time trend. Equation (4a) - (6a) provide additional estimates when λ is set equal to 5,000, 10,000 and 100,000 respectively. Note that the fit of the inflation equation deteriorates monotonically as larger values of λ are imposed. Thus, a view that supply shocks are irrelevant for changing the growth rate of potential output is inconsistent with explaining both the time series properties of both U.S. output and inflation.

Roberts (1994) has estimated inflation models which use quadratic time trend approximations to measure potential output. These estimates are reported in equation (7a) of Table 2. When we estimate our model with these gaps, we obtain a positive estimate of α and a negative estimate of γ. This result is very similar to the finding of Eisner (1994) and has the exact opposite policy implications of short-run capacity constraints. However, this particular model has the worst fit of any of the other models.

The next stage in constructing the model involves estimating the link between the instrument controlled by the monetary authorities, the short-term interest rate, and aggregate demand. We follow the approach recently described by Fuhrer and Moore (1995), namely, we estimate an equation for the output gap as a function of lagged values of the gap and the real short-term interest rate. We do not attempt to identify any nonlinearities on the demand side; consequently, we assume that the aggregate demand curve is linear (in logs) and the gap is the conventional measure of $y - \bar{y}$, where $\bar{y}$ is the 25 quarter centered moving average. The aggregate demand equation determines the deviation of output from its supply-determined value which is assumed to be exogenous. Our specification reflects two stylized facts that are critical to the ability of policymakers to control the economy. First, there are presumed to be significant lags between changes in interest rates and their full effects on aggregate demand. Second, there is persistence in movements in the output gap, implying that shocks to aggregate demand propagate to future periods. These features are important because they make the economy more difficult to control than if the dynamics linking demand shocks, interest rates and output were purely contemporaneous.

In estimating the response of aggregate demand to interest rates, a choice must be made between a short-term versus a long-term measure. A longer maturity would clearly be most relevant for such interest-sensitive expenditures as residential investment and business-fixed investment. A medium-term maturity, e.g., three to five years, would be appropriate for consumer durables, especially automobiles. However, we have chosen to use the nominal interest rate controlled directly by the Federal Reserve, namely, the Federal funds rate. This simplifies the model by avoiding the need to specify a term-structure equation, but there is a cost in terms of introducing a specification error. 1/ This nominal rate is converted to a

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1/ Our approach is similar to that of Roberts (1994), who used reduced form regressions linking the quarterly percent change in real GDP to lagged changes in Federal funds rate.

real interest rate by subtracting the one-year ahead inflation expectations as measured by the Michigan Survey.

The estimation results are reported in Table 3. The results of the estimated regression with two lags on the gap and eight on real interest rates are shown in column (1). The only significant interest rate effects show up with a lag of two quarters. Indeed, if we constrain all other interest rate coefficients to zero we end up with a parsimonious representation of the monetary transmission mechanism shown in column (2). We chose to estimate this equation over a shorter sample than that used for the Phillips curve because the results over the entire sample, shown in column (3), gave what appear to us to be an implausibly low estimate of the interest elasticity of aggregate demand. The shorter sample was chosen to avoid including the effect of the rise in real interest rates between the 1960s and the 1980s due to the substantial increase in government debt in the latter period. As our aim is to isolate the effect on aggregate demand of changes in real interest rates caused by monetary policy actions, we wished to exclude possible effects arising from fiscal policy. It should be noted that using the estimated coefficients from the equation in column (3) do not change the qualitative results below, but the variation in the interest rate is, of course, much larger.

To compare the estimated quarterly models more formally, and also to compare them with structural models, we conducted some simple simulations. Table 4 reports the effects on real GDP for a temporary monetary-induced 100 basis points increase in the Federal funds rate derived from two versions of the MPS model, as well as the results for the same experiment conducted using Roberts' reduced-form equation. 1/ The results for the MPS model and Robert's (1994) model are for a temporary four-quarter increase of 100 basis points in the Federal funds rate. The results for our equation are for the same shock applied to the real short-term interest rate. For this reason our results tend to be smaller because we are holding inflation expectations fixed. In other words, a monetary-induced shock to the nominal interest rate implies lower inflation expectations and a growing shock to the real interest rate.

We have included results for two versions of the MPS model because there is some uncertainty about the strength of real-financial linkages in the current version of the model. The results for the first version are obtained from a full-model simulation of the standard model. The results for the second version are obtained by excluding the effects of the price-earnings ratio on investment, as there is some disagreement as to whether these effects are too large in the standard model. Roberts' reduced-form equation produces estimates that fall between the two MPS estimates. In terms of timing, all four models suggest that there are significant lags in the monetary transmission mechanism.

1/ For a description of the MPS model and simulation results, see Mauskoff (1990).

Table 3: Estimation Results for Quarterly U.S. Output Gap Equation

(T-statistics in parentheses)

Estimated

equation: $gap_t = \alpha_0 + \gamma_1\, gap_{t-1} + \gamma_2\, gap_{t-2} + \beta_1\, rr_{t-1} + \ldots + \beta_8\, rr_{t-8} + \varepsilon_t^{gap}$

where:

α_0	=	constant term
gap	=	100*(y - $\bar{y}$)
y	=	log of real GDP
$\bar{y}$	=	25-quarter centered moving average estimate of trend GDP
rr_t	=	real interest rate ($rs_t - \pi^e_{t+4}$)
rs_t	=	federal funds rate
π^e_{t+4}	=	one-year-ahead measure of inflation expectations taken from the Michigan Survey data
ϵ_t	=	disturbance term

Quarterly U.S.Data	#1: 1978Q1-91Q4	#2:1978Q1-91Q4	#3: 1964Q1-91Q4
α	0.513 (1.78)	0.579 (3.06)	0.228 (2.16)
τ_1	1.023 (7.00)	1.074 (8.72)	1.110 (12.21)
τ_2	-0.240 (-1.60)	-0.290 (-2.45)	-0.268 (2.97)
β_1	0.049 (0.57)	-0.157 (-3.61)	-0.095 (-2.95)
β_2	-0.181 (-1.71)		
β_3	-0.004 (-0.03)		
β_4	0.042 (0.42)		
β_5	-0.058 (-0.59)		
β_6	-0.101 (-1.02)		
β_7	-0.035 (0.34)		
β_8	0.082 (1.03)		
Standard Error	0.776	0.756	0.825
R^2	0.846	0.854	0.832

Table 4. Lags in the Transmission Mechanism in the MPS and Simple Reduced-Form Models

(Percent response of real GDP)

Quarter	Federal Reserve Board's MPS Model Version #1	Federal Reserve Board's MPS Model Version #2	Reduced-form Models Roberts (1994) 1/	Reduced-form Models Our Equation 2/
0	0.0	0.0	0.0	0.0
1	0.0	0.0	0.0	0.0
2	-0.1	-0.1	-0.3	-0.2
3	-0.2	-0.1	-0.4	-0.3
4	-0.3	-0.2	-0.5	-0.4
5	-0.4	-0.2	-0.7	-0.4
6	-0.5	-0.3	-0.5	-0.3
7	-0.6	-0.3	-0.5	-0.3
8	-0.7	-0.3	-0.5	-0.2

1/ Results based on the reduced-form equation reported in column (3) of Table 1 in Roberts (1994).
2/ Results based on the reduced-form equation reported in column (2) of Table 3.

The complete model is described in Table 5. The only new element is the monetary policy reaction function. In keeping with the traditional approach to implementing policy feedback rules in simulation models our policy reaction function is represented by an interest rate rule: interest rates rise when inflation is above target and fall when it is below. As the policymaker also is assumed to give some weight to developments in real activity, the gap between actual and potential output is included in the reaction function. The resulting policy reaction function is a slight generalization of the one employed extensively in model simulation work reported by Bryant, Hooper and Mann (1993). This basic rule has been shown to have desirable properties compared to other simple alternatives such as money control and fixed exchange rates in a wide class of macroeconomic models. The parameters were chosen to reestablish the initial level of inflation within two years following a shock to aggregate demand. Experiments using this model indicated that weights of 2.0 on the deviation of inflation from the target and 1.0 on the output gap would bring inflation back to control roughly within this time span.

Finally, an important part of our analysis in the next section involves comparing the effects of a forward-looking policy reaction function, where the monetary authorities adjust the current interest rate in response to expected future inflation, and a myopic reaction function in which the short-term rate is adjusted only in response to the contemporaneous

Table 5. A Small Simulation Model of the U.S. Output-Inflation Process

Phillips Curve:

$$\pi_t = .593\,\bar{\pi}^e_{t+4} + (1-.593)\,\pi_{t-1} + .202\ gap^{*t} + .925\ gappos^*_t + \varepsilon^\pi_t$$

$$\bar{\pi}^e_{t+4} = .2\,(_t\pi^e_{t+4} + {}_{t-1}\pi^e_{t+3} + {}_{t-2}\pi^e_{t+2} + {}_{t-3}\pi^e_{t+1} + {}_{t-4}\pi^e_t)$$

Real Interest Rate:

$$rr_t = rs_t - \pi^e_{t+4}$$

Inflation and Inflation Expectations:

$$\pi_t = \left[(P_t/P_{t-1})^4 - 1\right] * 100\ ,\ \pi^e_{t+4} = (P_{t+4}/P_t - 1) * 100$$

Aggregate Demand Equation:

$$gap_t = 1.074\ gap_{t-1} - .290\ gap_{t-2} - .157\ rr_{t-2} + \varepsilon^{gap}_t$$

Forward-Looking Policy Reaction Function:

$$rs_t - \pi^e_{t+4} = 2\,(\pi_{t+3} - \pi^*) + gap_t$$

Myopic Policy Reaction Function:

$$rs_t - \pi^e_{t+4} = 2\,(\pi_t - \pi^*) + gap_t$$

π	≡	CPI inflation at annual rates
gap	≡	output gap $(y-\bar{y})$
gap^*	≡	$y - y^* = y - \bar{y} + \alpha$
rr	≡	real interest rate
rs	≡	Federal funds rate
π^e_{t+4}	≡	one-year-ahead inflation expectations
Π^*	≡	inflation target
Pt	=	price level

inflation and the output gap. 1/ As discussed in detail in the next section, given that there are lags in the monetary transmission process and an asymmetric inflation-output relation, the nature of the policy reaction function has a substantial impact on the macroeconomic performance of the economy.

IV. Boom and Bust Cycles: Some Illustrative Simulations

This section examines some of the policy implications of a nonlinear response of inflation to aggregate demand that can be derived from the small simulation model described in Table 5. This model economy is subjected to demand shocks, and we focus on the effects of these shocks on output and inflation, particularly on the degree to which these effects depend on the response of the policymaker to the shock. The performance of the economy is shown to depend intimately on the speed with which the monetary authorities respond to the inflation pressures induced by the demand shock; a slower response leads to cycles in which excess demand results in a higher persistent average rate of inflation, which in turn requires a longer period of excess supply to bring inflation back to the target on a sustained basis.

This result is shown by comparing two scenarios in which there are different speeds in the reaction to the shock: in one case the policymaker is forward-looking and adjusts interest rates in the current period in light of expected future inflation, and in the other the policymaker responds only to currently observed inflation. In these simulations all variables are initially set at their deterministic equilibrium values, which are the "control solution" in a deterministic steady state. In both cases the shock is a change in the disturbance term in the equation describing aggregate demand--the gap equation--that raises demand by 1.0 percent relative to the control value in the first quarter and then is set equal to zero in all subsequent quarters so that the behavior of the economy from then on reflects solely the dynamics of the model. Such an upward shift in demand could come about, for example, from a change in fiscal policy, exports, or an autonomous increase in investment. Shocks could also appear in the disturbance term in the inflation equation, e.g., changes in crude oil prices, but these price shocks are not explored in this paper.

In these two simulations the inflation expectations of the private sector are model consistent, i.e., they are the solution values of the model for current and all future periods. This implies that agents take full account of the consequences for inflation of the nonlinear Phillips curve. This includes all the propagating mechanisms in the dynamic equation for

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1/ For an extensive discussion of reaction functions that rely on economic forecasts, see Anderson and Enzler (1987). See also Brunner (1994) and Mehra (1994) for more recent estimates of the monetary policy reaction function of the Federal Reserve.

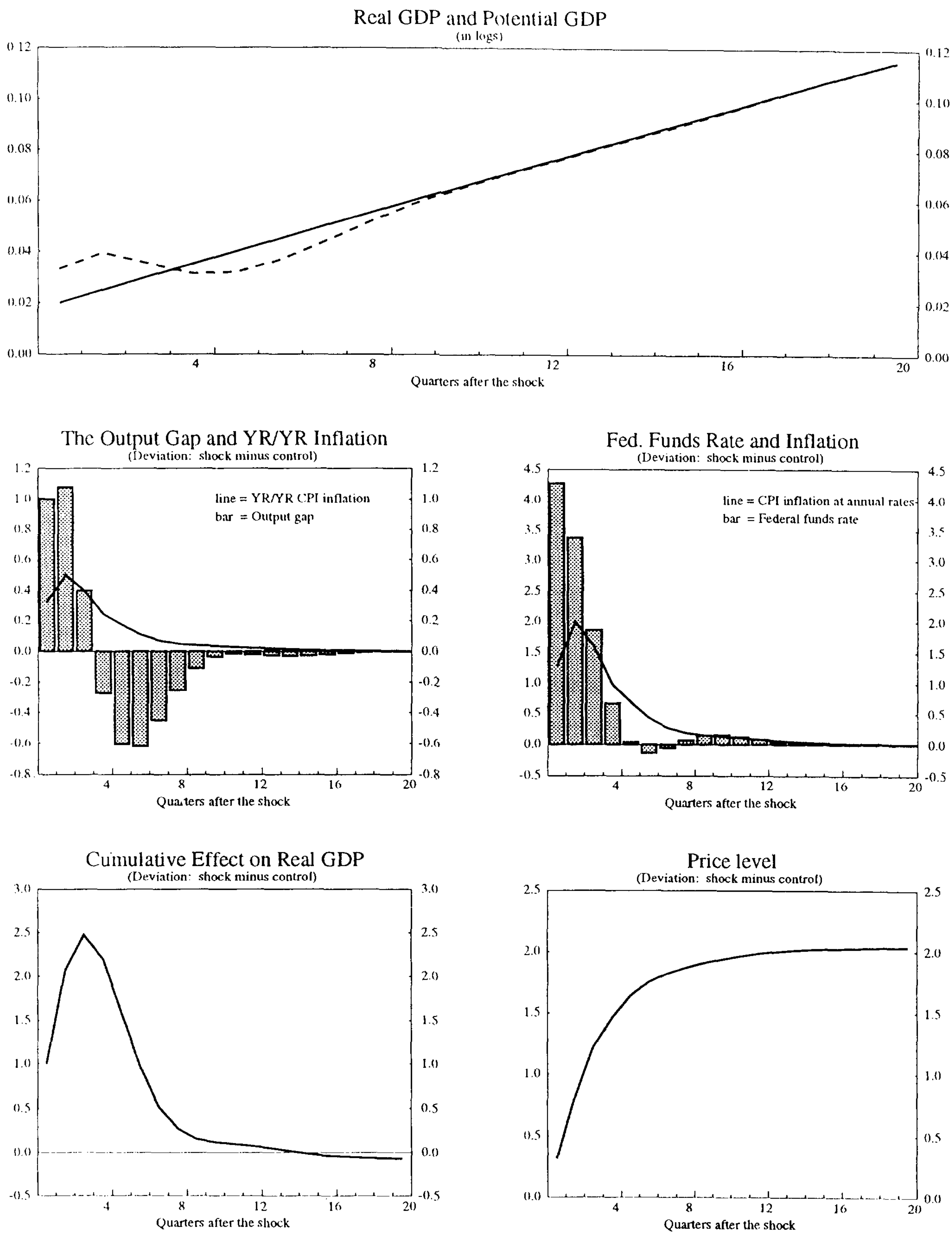
output. Thus, as the current level of inflation depends on inflation expectations, demand shocks that persist into the future also affect today's inflation rate. Finally, inflation expectations, and therefore actual inflation, are influenced importantly by the nature of the monetary policy reaction function. While the parameters of the behavioral equations are invariant to different monetary policy response functions, the behavior of agents takes account through the price expectations process of the response of the authorities to inflation, and in this sense our simulations are not subject to the Lucas critique.

The simulation in Chart 3 shows the dynamic response of the economy to a forward-looking policy rule. In this case the monetary authorities are assumed to make decisions on the current stance of monetary policy on the basis of their prediction of future inflation. Rather than reacting only to incoming data on the current level of inflation, the policymaker takes account of the lagged response of aggregate demand to real interest rate changes and raises interest rates in advance of projected increases in inflation. Such pre-emptive adjustments in the monetary control instrument provide the means to moderate and possibly avert periods of excess demand ("booms") and thereby minimize the extent to which prolonged periods of output below capacity ("busts") are needed to achieve a given inflation target.

To illustrate the importance of a forward-looking policy reaction function, the policymaker is assumed to use the model to forecast future inflation. Thus the expectations of the private sector and the monetary authorities are both model consistent. In the particular forward-looking reaction function shown in Table 5, the nominal short-term interest rate is adjusted one-for-one by the expected inflation rate over the next four quarters as the monetary authorities are assumed to target the real interest rate in order to influence aggregate demand. The real interest rate is adjusted in proportion to the difference between inflation projected three quarters ahead, π^e_{t+3}, and the inflation target. As π^e_{t+3} incorporates the effect of projected demand conditions in the future, these determinants of future inflation are not included separately in the reaction function. However, the current level of the gap is included in the reaction function because the policymaker is assumed to give some direct weight to smoothing fluctuations in output for its own sake.

Turning to Chart 3, the shock to demand--which is not anticipated by the monetary authorities--raises aggregate demand by 1.0 percent of baseline. In this deterministic simulation the variance of output is zero and $\alpha = 0$, so that $\bar{y} = y^*$, i.e., there is no difference between the mean level of output and the notional level of output at which there is no tendency for inflation to rise or fall. The shock to output takes place at an initial equilibrium position where $y = \bar{y}$. Inflation rises on impact by roughly 0.25 percent on a year-over-year basis (left middle panel) and by about 1.0 percent at an annual rate (right middle panel); the model has been calibrated such that the policymaker responds to this measure of inflation, i.e., the quarter-to-quarter change expressed at an annual rate. With the

Chart 3: Aggregate Demand Shock with a Forward-Looking Policy Rule



forward-looking policy reaction function the nominal interest rate rises nearly 5 percentage points in response to the output gap and the increase in expected inflation relative to target. This policy action has no effect on aggregate demand in the first and second quarters because of the two-quarter lag in the response of demand to the real interest rate, and output rises by more than 1.0 percent above control in the second quarter as a result of multiplier effects. Starting in the third quarter, however, the higher real interest rate dampens aggregate demand and by the fourth quarter output falls below potential. Output must remain below potential for a period of six quarters to bring inflation back to the target level. By the middle of the third year output and inflation are back to control with very little overshooting.

It is noteworthy that even though inflation increases from the first to the second quarter, the nominal interest rate declines after rising to its maximum level above control in the first quarter. This reflects the forward-looking character of the reaction function; knowing that the jump in nominal and real interest rates will dampen demand below capacity and put inflation on a downward trajectory, the policymaker can cut interest rates before there is evidence in the actual data that inflation has indeed begun to return to the target level. Moreover, the private sector knows the nature of the reaction function of the authorities in terms of its effect on the path of future inflation, and this in turn also dampens current inflation through the expectations term in the Phillips curve.

The behavior of the economy when the policymaker follows a myopic policy rule is shown in Chart 4. In this case the real interest rate is adjusted in response to deviations of the current inflation rate from the target level, rather than to the inflation rate expected three quarters in the future. As a result the nominal short-term interest rate follows roughly the same cycle as inflation, rising above control when the latter is above target and vice versa. This myopic response induces cycles in output and inflation and leads to a significantly larger cumulative loss in output compared with the results shown in Chart 3. This can be seen in the top panel of Chart 4, where it is clear that the economy is below potential for a longer period of time than it is above potential.

The key difference between the two reaction functions is that forward-looking policy action dampens excess demand pressures sooner, as can be seen in the front-loaded increase in the Federal funds rate in Chart 3, which essentially avoids overshooting. The myopic reaction function, by contrast, results in periods of overshooting and as a result of the nonlinear Phillips curve there are increases in inflation above control over and above that associated with the positive demand shock in the first quarter. These increases in future inflation become embodied in inflation expectations which leads to greater persistence of inflation above target. Consequently a longer period of excess supply is needed to bring inflation eventually back to the target of level.

The basic lesson to be drawn from the two simulations is that a forward-looking monetary policy reaction function will lead to a smoother path of output and limit the cycles that result of an initial demand shock. By contrast, a myopic response to a demand shock results in cycles in output and in demand overshooting capacity output. The higher variance of output in Chart 4 leads to a lower average level of output, as seen in bottom left-hand panel, which is consistent with the result derived analytically in the preceding section. However, this inverse relationship between the variance and the average level of output has been shown above only for one deterministic simulation. To determine the quantitative importance of this inverse relationship we must solve the model in a stochastic setting.

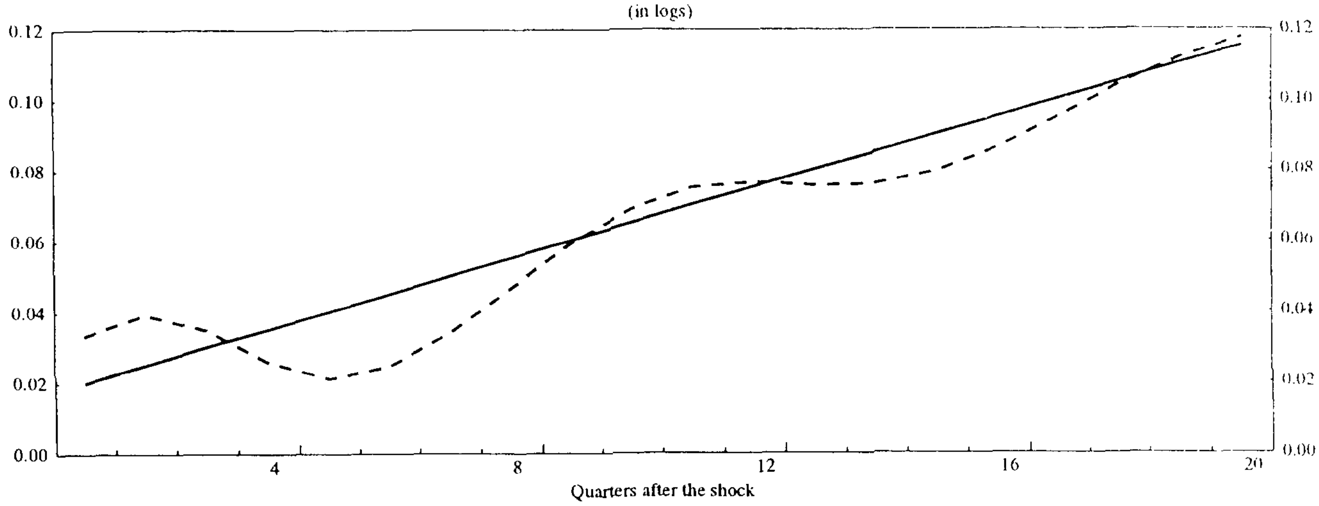
V. Stochastic Simulations of Alternative Policy Rules

In this section we present the results of stochastic simulations that are designed to estimate the extent to which the average level of output depends on the two different monetary policy reaction functions. In the preceding section it was shown that the myopic policy rule resulted in a lower average level of output following a demand shock than the forward-looking reaction function. In this section we move to a stochastic environment and subject the model economy to a wide range of shocks to both the aggregate demand and the Phillips curve equations. As discussed in Section II, when the economy is subject to shocks an asymmetric Phillips curve results in an average level of output, $\bar{y}$, which is below the level of output, y^*, that could be achieved in the absence of shocks. The larger the variance of output, the larger the difference (α) between y^* and $\bar{y}$. Hence the role of monetary policy can be seen as trying to reduce the variability of output, and in particular to resist pressures pushing aggregate demand to exceed capacity output; if successful in this regard, monetary policy can improve the overall performance of the economy by raising the average level of output at the same time that it reduces the volatility of output.

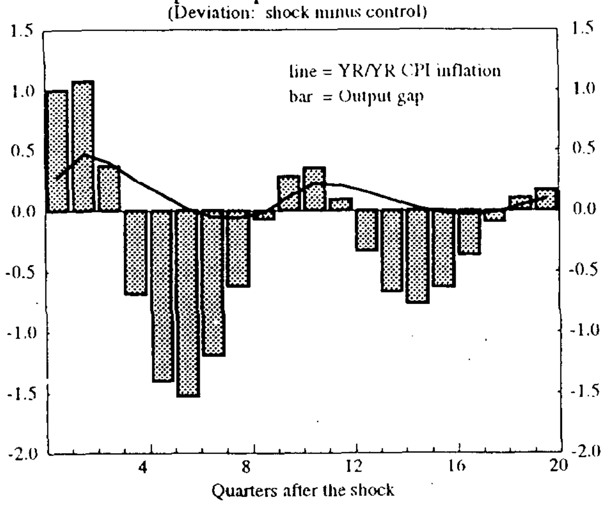
The basic approach in the stochastic simulations is to subject the economy to a large number of shocks and calculate the mean level of output under alternative monetary reaction functions. A difficulty in the calculation procedure is that $\bar{y}$ depends on the stochastic properties of the economy, and in particular, on the particular monetary policy reaction function that is operating. Consequently, it is necessary to undertake an iterative process that involves choosing a starting value for α, simulating the model, computing a new value for α, and then resimulating the model subject to the same series of shocks until convergence is reached on the value of α. We have found that convergence is relatively rapid irrespective of the starting value of α. For most cases, three such iterations were needed until the values of $\bar{y}$ and α converged. This iteration process was undertaken separately for the two different monetary policy reaction functions.

Chart 4: Aggregate Demand Shock with a Myopic Policy Rule

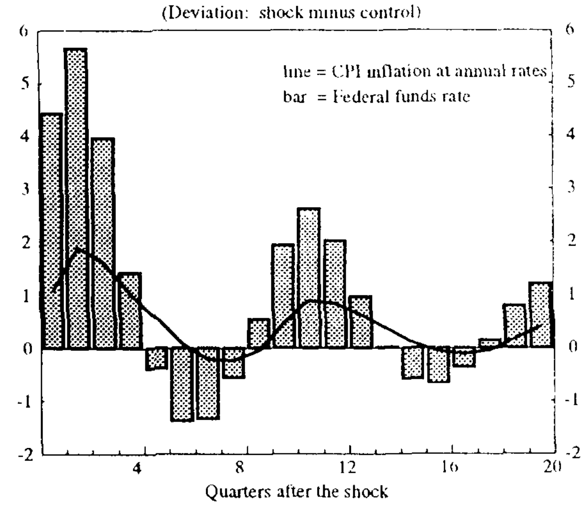
Real GDP and Potential GDP
(in logs)



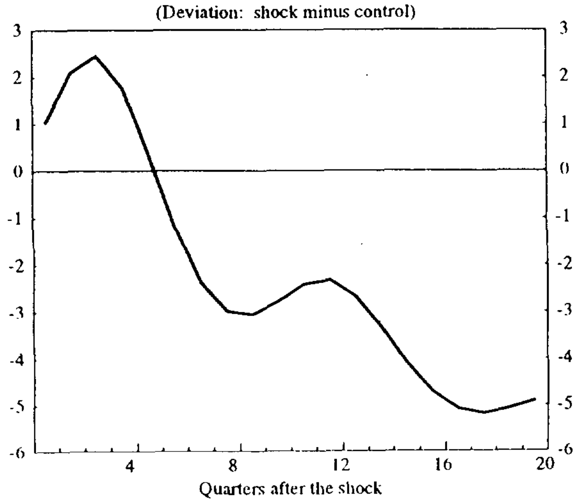
The Output Gap and YR/YR Inflation
(Deviation: shock minus control)



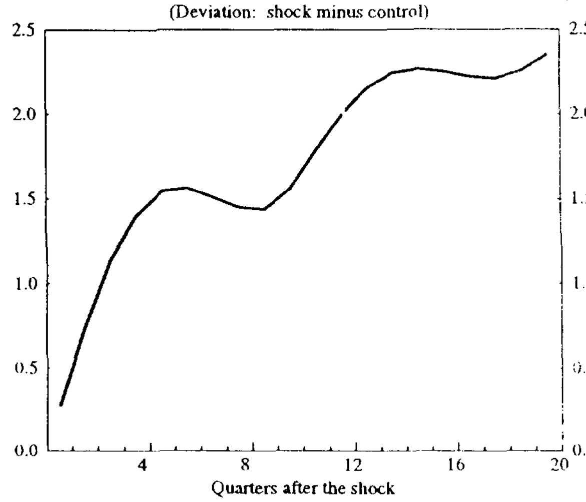
Fed. Funds Rate and Inflation
(Deviation: shock minus control)



Cumulative Effect on Real GDP
(Deviation: shock minus control)



Price level
(Deviation: shock minus control)



In the simulations, the economy is subjected to shocks to the disturbance terms of both the Phillips curve and aggregate demand curve. These had standard deviations of 1.6 percent and 0.76 percent, respectively, and the distribution of the shocks was assumed to be normal. In the first quarter, the model is solved with drawings from these two distributions. Unlike the simulations in the preceding section, in the second quarter the economy is again subjected to two new shocks drawn from the same distributions and the model is solved on the basis of the solution values of the variables from the first quarter. This process continues for a period of 40 quarters, i.e., ten years. This procedure is then repeated 200 times (8000 draws in total). Each sequence provides a distribution of the output gap, inflation, and other variables. The distribution of the mean values of the output gap across the 200 trials then provides us with estimates of $\bar{y}$ and α.

The results of the stochastic simulations are reported in Table 6. They show that fluctuations in output and interest rates, as measured by the standard deviations of the distribution of the mean outcomes, are considerably larger with the myopic policy rule, whereas the variability of inflation is about the same. The key finding is that as a result of the greater volatility in output with the myopic policy rule, there is a larger difference (-1.12 percent versus -0.44 percent) between the average level of output and the hypothetical level of output attainable in the absence of shocks. 1/ The conclusion of this analysis is that to the extent that the monetary authorities can avert or moderate periods of excess demand, particularly by pursuing a forward-looking approach in which the current stance of policy takes account of expected future inflation, they may be able to achieve significant benefits in terms of the realized average level of output.

Table 7 provides some indication of the sensitivity of the stochastic simulation results to the degree of asymmetry in the Phillips curve. The stochastic simulations were repeated under the assumption that the estimated value of γ, which is the coefficient on gappos*, is half the estimated value, i.e., the value of γ is reduced from 0.925 to 0.462. The results in Table 7 reveal the expected effect, namely, a reduction in the calculated values of α under both policy rules, with the difference between the two cut about in half. The reduction in the value of α is greater in the case of the myopic policy rule, which shows the sensitivity of macroeconomic performance to the degree of asymmetry for this type of monetary policy reaction function.

1/ It is useful to compare the estimated value of α over the historical sample period of -1.26, shown in Table 1, with the computed values of -0.43 and -1.11 in Table 6. The fact that the sample estimate is close to the higher figures suggests that a myopic policy response function dominated the sample period.

Table 6. Stochastic Simulation Results: Base Case

	Policy Rule Assumption: Forward-looking (1)	Myopic (2)	(2)-(1)
Mean level of the Output Gap			
$\bar{y} - y^* = \alpha$	-0.43	-1.11	-0.68
Standard deviations:			
σ_y	1.36	2.17	0.81
σ_π	2.24	2.43	0.21
σ_{RS}	3.13	6.45	3.32

Table 7. Stochastic Simulation Results: Smaller Asymmetries

	Policy Rule Assumption: Forward-looking (1)	Myopic (2)	(2)-(1)
Mean level of the Output Gap			
$\bar{y} - y^* = \alpha$	-0.28	-0.65	-0.37
Standard deviations:			
σ_y	1.35	1.99	0.64
σ_π	2.05	2.10	0.10
σ_{RS}	2.75	5.57	2.82

VI. Conclusions and Directions for Further Research

The focus of this paper has been on the implications for monetary policy of an asymmetry in the relationship between inflation and excess demand. The analysis is based on empirical work that indicates that there are indeed important asymmetries in the U.S. output-inflation process. We present some of that evidence in this paper. Elsewhere (see Clark, Laxton and Rose, 1995), we document that this result is reasonably robust to a variety of changes of specification and measurement. We also provide in part here, and in more detail in the companion paper, empirically-based explanations of why other researchers have reached different conclusions. Although it is important to remember that our results are based on a small sample and that there remains considerable uncertainty as to the precise form of the output-inflation relationship, we would argue that the array of evidence we have provided constitutes a strong case for an important asymmetry in the U.S. output-inflation process that must be taken seriously.

This paper has shown that if the assumption of asymmetry is true, there are rather important implications for the conduct of monetary policy. In particular, the costs of running into capacity constraints can be high, as the periods of excess supply needed to undo the inflationary effects are sharper and longer than the periods of excess demand. The implication for monetary policy is that there is a premium on avoiding bouts of inflation arising from overshooting capacity output by taking policy actions in the present which will keep aggregate demand from generating inflation in the future.

There is obviously a great deal of further work to be done to refine the preliminary results in this paper. One area requiring further research relates to the measurement of output gaps. For example, the methods used in this paper could be extended to yield more efficient estimates of the output gap by employing system-based multivariate techniques that make full use of the structure of the model.

Clearly, one important aspect of the approach taken in this paper that needs to be modified is the assumption that the monetary authority has precise knowledge about the inflation-generating process in the economy. We have assumed that the policymaker knows the true model and that the only source of uncertainty arises from random shocks. This is obviously unrealistic and a key extension of the work presented in this paper involves exploring how the results would be affected by uncertainty in the parameter values and, in particular, the level of potential output and the nature of the monetary transmission mechanism. There is considerable uncertainty in any forecast of inflation and uncertainty about the policy control process. What needs to be done, therefore, is to analyze the design of monetary policy rules which takes this uncertainty into account in a systematic manner in the presence of asymmetry in the inflation-generating process.

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