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Asymmetry in the U.S. Output-Inflation Nexus: Issues and Evidence

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Abstract

This paper presents empirical evidence supporting the proposition that there is a significant asymmetry in the U.S. output-inflation process, which implies that excess demand conditions are much more inflationary than excess supply conditions are disinflationary. The important policy implication of this asymmetry is that it can be very costly if the economy overheats because this will necessitate a severe tightening in monetary conditions in order to reestablish inflation control. The small model of the U.S. output-inflation process developed in the paper shows that the seeds of large recessions, such as that in 1981-82, are planted by allowing the economy to overheat. This type of asymmetry implies that the measure of excess demand which is appropriate in estimating the Phillips curve cannot have a zero mean; instead, this mean must be negative if inflation is to be stationary. The paper also shows that a failure to account for this important implication of asymmetry can explain why some other researchers may have been misled into falsely accepting the linear model. The empirical results presented in the paper show that the conclusions regarding asymmetry are robust to a number of tests for sensitivity to changes in the method used to estimate potential output and in the specification of the Phillips curve.

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 Bob Amano, Tamim Bayoumi, Steven Braun, Paula De Masi, Bill English, Bill Lee, Tiff Macklem, Guy Meredith, Eswar Prasad, Carmen Reinhart, John Roberts, Steven Symansky, Bob Tetlow, 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.

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Summary

This paper presents empirical evidence supporting the proposition that there is a statistically significant and large asymmetry in the U.S. Phillips curve, namely, excess demand conditions are much more inflationary than excess supply conditions are disinflationary. This asymmetry implies that potential output--defined as the level of output that can be attained, on average, in an asymmetric stochastic economy--lies below what could be attained in the same economy without shocks. The measure of excess demand that is appropriate for an asymmetric Phillips curve, therefore, cannot have a zero mean; rather, this mean must be negative if inflation is to be stationary. The proper measure of excess demand needs to be taken into account in estimation in order to obtain unbiased tests of a restriction to linearity. Failure to do so can explain why some other researchers may have been misled into falsely accepting the linear model. The conclusions regarding the presence of asymmetry in the U.S. Phillips curve are shown to be robust to a number of tests for sensitivity to changes in the specification.

The paper sketches some of the implications of this asymmetry for monetary policy using a small macro model calibrated to reflect the properties of the U.S. data. Simulations of this model contrast the effects of delaying the monetary response to a demand shock obtained from a linear model with those from a model with the estimated asymmetric Phillips curve. The simulations show that if the output-inflation process is linear, then there is no strong case for a speedy monetary policy response to a shock that creates excess demand. Dramatically different results emerge if the economy features the type of asymmetry revealed in the estimation results, namely, delaying the response results in higher inflation and necessitates a significantly stronger monetary tightening to bring inflation back under control. This model thus predicts that the seeds of large contractions are sown when the monetary authority temporizes in dealing with rising inflation and allows conditions of excess demand to become entrenched.

A key policy insight from the analysis is that the degree to which potential output in a stochastic asymmetric economy lies below that obtainable without shocks depends on the variability of output, and hence on the degree of success of the monetary authority in stabilizing the output cycle. Indeed, the results reported in the paper show that policies that allow the economy to overheat periodically can have very significant deleterious effects on the level of potential output. Moreover, because linear models of the output-inflation process predict that the costs from overheating are small, these results suggest that there could be significant output costs associated with basing monetary policy on the predictions of a linear model.

I. Introduction

"In modern economies output levels may not be so rigidly constrained in the short run as they used to be when large segments of output were governed by facilities such as the old hearth steel furnaces that had rated capacities that could not be exceeded for long without breakdown. Rather, the appropriate analogy is a flexible ceiling that can be stretched when pressed, but as the degree of pressure increases, the extent of the flexibility diminishes."

Allan Greenspan (1995, p. 257)

The decision to tighten the stance of U.S. monetary policy last year (1994) was based on a view that there could be large costs associated with allowing the U.S. economy to overheat. In several statements to Congress, Chairman Greenspan presented a strong case that if U.S. monetary policy were not tightened, the inflationary risks associated with exceeding potential output would be large and the process of containing these inflationary forces would then require a much more severe tightening in monetary conditions in the future.

This view appears to be based on a model with an asymmetric output-inflation nexus in which inflation responds more to positive output gaps than it does to negative gaps. 1/ If this view of the world is correct, then allowing the economy to produce in excess of its potential will be costly because monetary tightening and large negative output gaps will be required later to rein in inflationary pressures. Indeed, as Clark, Laxton and Rose (1995) show, policy rules that fail to guard against overheating will result in significantly larger monetary business cycles and permanent losses in output. Moreover, policy rules that guard against the emergence of excess demand will reduce the variance of aggregate demand and raise the mean level of output.

This view of the business cycle is significantly different from that embodied in linear models of the output-inflation process. Indeed, linear models suggest that there are small costs or perhaps even some benefits from delaying interest rate hikes in the face of positive aggregate demand shocks--see Laxton, Meredith, and Rose (1994).

Despite the obvious importance of this issue for the conduct of monetary policy, there is little econometric evidence available for the United States that supports the view that capacity constraints imply that

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1/ We measure output gaps such that positive values are associated with excess demand and upward pressure on inflation. Some researchers follow Arthur Okun's convention and define gaps the other way round.

there is an important nonlinearity in the output-inflation nexus. 1/ Indeed, Braun (1984) and Gordon (1994), for example, claim that there is no evidence of nonlinearity in the U.S. data, while Eisner (1994) presents evidence that inflation may respond more to negative gaps than to positive gaps. 2/ The linear models estimated by Braun and Gordon imply that the average level of output will be independent of the parameters in the monetary policy rule, while Eisner's model predicts that policies that increase the variance of output will actually raise the average level of output.

In this paper, we present evidence that there is significant asymmetry in the U.S. output-inflation nexus. We argue that the contrary empirical work noted above has been biased against finding evidence of asymmetry, in part because of the way that researchers have measured the output gap and specified how it should enter the Phillips curve. As the basic notion behind the Phillips curve is that inflation is driven by an unobservable output gap, it is not surprising that the econometric results and policy conclusions of different studies have been sensitive to the methods that were used to identify these output gaps. 3/ As we shall argue, however, it is not so much the measurement of the gaps that causes the problem, but rather the specification of how those measures should enter the Phillips curve. In a stochastic economy with an asymmetric Phillips curve, the gaps that enter the Phillips curve cannot have zero means, as generated by standard detrending techniques. We show that taking this into account is crucial for the identification of the output-inflation nexus and for avoiding bias in econometric tests for the presence of asymmetry.

The econometric identification problem is especially problematic in small samples, where "small" refers to the number of observations of cycles. Moreover, if policymakers became more successful in preventing their economies from overheating, and thereby reduced the frequency of sharp outbreaks of inflation followed by painful corrections, identifying the existence or importance of capacity constraints, at least from the relationship between output and inflation, would become correspondingly more

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1/ There is, however, a growing literature that provides examples of how asymmetric aggregate properties can arise from agent behavior. See, for example, Ball and Mankiw (1994) and Tsiddon (1991, 1993).

2/ Eisner's model uses unemployment gaps. He finds that a reduction in unemployment is less inflationary if the economy is booming and unemployment is initially below the natural rate than if unemployment is initially above the natural rate. The statement in the text assumes that there is a direct relationship between excess demand conditions in the goods market and excess demand conditions in the labor market.

3/ Laxton, Rose, and Tetlow (1993a) present Monte Carlo evidence that reliance on traditional detrending techniques to measure gaps can explain why some researchers may have falsely rejected asymmetries.

difficult. In fact, it is episodes with major policy errors that give the econometrician the clearest information. 1/

Given the limited U.S. experience with inflationary surges, one obvious empirical strategy is to draw on a much larger set of monetary policy errors by using data from different countries. In this vein, Laxton, Meredith, and Rose (1994) show that if one assumes that the Phillips curve is identical in the G-7 economies, then there is fairly strong evidence of asymmetry. In a recent paper, Turner (1995) relaxes this identification restriction and finds that there is some evidence of asymmetry in the Phillips curves of three of the seven major industrialized countries, including the United States. 2/

This paper builds on Turner's work using U.S. data. One advantage of focusing on the U.S. data is that survey measures of inflation expectations are available and have been found to have significant predictive content for inflation--see Roberts (1994b, 1994c). The availability of such measures is important for two reasons. First, it makes it easier to distinguish between intrinsic dynamics and expectational dynamics. This separation is important for models that are constructed for policy experiments because, as is now well understood from the literature on the "Lucas critique," it can be seriously misleading to assume that expectations formation will remain the same in the face of a change in monetary policy. It is also important for econometric work; recent evidence by Evans and Wachtel (1992) and by Ricketts and Rose (1995) suggests that traditional fixed-parameter reduced-form models may provide an inaccurate characterization of inflation expectations. Second, the use of survey measures of inflation expectations eliminates the econometric problems associated with using instrumental variables in models with forward-looking behavior and allows one to focus more clearly on issues concerning the role of the output gap in inflation dynamics.

The remainder of this paper is organized as follows. In Section II we provide some empirical evidence that (unlike the earlier studies by Braun and by Gordon) confirms Turner's finding that there is significant evidence of asymmetry in the U.S. data. Section III contains a simple macro model of the U.S. output-inflation process. We compare some predictions of a linear version of this model with those of our asymmetric version. In Section IV, we provide some further tests of the robustness of our conclusions, discuss some of the implications of our results for policy analysis, and explore

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1/ Of course, asymmetry in the output-inflation nexus will have implications for other endogenous macro variables, such as interest rates. Indeed, one of concerns voiced by Chairman Greenspan is that bumping into capacity limits increases the uncertainty about future inflation and creates more volatility in financial markets.

2/ The other countries for which Turner finds significant asymmetry are Canada and Japan. Laxton, Rose, and Tetlow (1993b) also provide evidence for asymmetry in the Canadian Phillips curve.

several important methodological issues in the specification and estimation of Phillips curves. Finally, Section V provides a brief summary of our conclusions.

II. The U.S. Phillips Curve

1. The basic linear model

The essential notion of the Phillips curve is that inflation is driven by inflation expectations and the output gap. The simplest form of the model can be written as:

$$\pi_t = \pi^e_{t+1} + \beta \; gap_t + \epsilon^{\pi}{}_t \qquad (1)$$

where: π is inflation, π^e is expected inflation, "gap" is the output gap (or the unemployment gap) and ϵ^{π} represents a stochastic disturbance term. 1/ The disturbance term also includes special factors (other than aggregate excess demand conditions and expectations) that can affect the inflation process from time to time. This could include, for example, cost-push factors such as an exogenous increase in wage demands or a change in the price of crude oil.

Equation (1) is often motivated by appealing to costly price level adjustment, as in the models of Calvo (1983) or Rotemberg (1987), for example. Strictly speaking, however, these models consider price levels and not inflation rates. The simple theoretical framework has been extended by some authors (e.g., Cozier, 1989) by assuming that the change in prices is costly to adjust. In our view, however, Buiter and Miller (1985) and Roberts (1994c) describe this appropriately when they refer to it as "slipping a derivative" into the firm's optimization problem.

The simple form of the model in equation (1) implies that the main source of inertia in inflation dynamics is rigidities in expectations. If combined with an assumption of model-consistent or rational expectations, the model implies that inflation can, in principle, be adjusted costlessly. In other words, an announced reduction in the target inflation rate can be achieved without any output costs as long as the expected inflation term in equation (1) moves one-for-one with the announced change in the target. For this to be so, however, one needs more than simple consistency with the

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1/ We focus on modelling price dynamics in this paper and our empirical work uses the output gap. This is not to deny that there are interesting issues in linking labor and output markets in macro models and discussions of inflation. However, we have chosen to keep our macro model as simple as possible and do not include a separate treatment of the labor market.

predictions of a dynamic model; one needs full credibility of the announced policy change.

Experience suggests that it is impossible to reduce inflation without creating a negative output gap. This can be rationalized through either one of two simple extensions to the above discussion. One extension adds the notion of intrinsic dynamics to equation (1), as would be suggested by a model with costly adjustment, be it from contracts or whatever. This would imply that an additional term in the lag(s) of inflation would have to be added to equation (1). The second extension focuses on how expectations are formed. If there is a backward-looking element to expectations formation, and we re-interpret expectations in equation (1) as the model-consistent component of overall expectations, then another rationalization of additional lags emerges. In other words, additional lags in equation (1) can arise either from intrinsic elements of inflation dynamics, which are independent of expectations, or from inertia in expectations formation itself (a backward-looking component), or both. 1/

Although there are differing interpretations of precisely why, there seems to be reasonably broad agreement among researchers working in this area that the simple model must be extended to account for inertia over and above what is possible in equation (1). 2/ The resulting model is often referred to as the "backward- and forward-looking components" model--see Buiter and Miller (1985). In this model, inflation in any time period is tied down, at least partially, by historical conditions (the backward-looking component), while the forward-looking component responds to new information about the future in a model-consistent fashion. The extended dynamic model can be written as:

$$\pi_t = A(L)\pi_{t-1} + B(L)\pi^e_{t+1} + \beta \ gap_t + \epsilon^\pi{}_t \qquad (2)$$

This version of the linear model provides the starting point for our extension to include asymmetry and the null hypothesis in tests of restriction to linearity of the asymmetric alternative. 3/

1/ See Buiter and Miller (1985) or Fuhrer and Moore (1995) for further discussion of these issues.

2/ Taylor (1980) was an important contribution to this literature.

3/ In the simulations presented in Section III, we adopt the pure intrinsic dynamics interpretation of equation (2). That is, we simulate under the assumption of model-consistent expectations and treat the backward-looking component of the equation as coming entirely from intrinsic rigidities and not expectations.

2. Extending the model for asymmetric effects

The most straightforward test of state-dependent asymmetry is to add positive output gaps to the model and test if the estimated parameter(s) on the additional term(s) can help explain inflation. Robert Gordon (1994) provides some econometric evidence of this nature by augmenting his simple, backward-looking, inflation-unemployment model with positive unemployment gaps. Although Gordon focuses his attention on Eisner's version of asymmetry--that inflation falls more when the economy is in a recession than it rises when the economy is booming--his statistical evidence can be easily re-interpreted as a test for asymmetry arising from capacity constraints. Gordon's results reveal no statistical evidence in favor of either form of asymmetry.

These results stand in sharp contrast with some recent empirical results reported by Laxton, Meredith, and Rose (1994), who claim to have found strong empirical evidence for the major industrial countries that positive output gaps have more powerful effects on inflation than negative output gaps. One possible reconciliation of these results could reflect insufficient business cycle variation in the U.S. data for researchers to be able to say anything with confidence about the role of capacity constraints on the basis of U.S. experience alone. However, since Turner (1995) finds evidence of significant asymmetry in the U.S. data, and we report corroborating evidence in this paper, it appears that the explanation must come from something else in the methodology.

One of the points argued by Laxton, Meredith, and Rose is that it is critical for econometricians to recognize the implications of asymmetry for the measurement of the output gaps that enter the Phillips curve in order to identify properly the asymmetric model. In particular, the mean value of the gap that enters the Phillips curve will be negative under the assumption of convexity and positive under the assumption of concavity in the functional form. We pursue this argument in Section IV.2 and show that only in the case of global linearity will it be appropriate to impose a mean value of zero on the gaps that enter the Phillips curve. Laxton, Meredith, and Rose demonstrate, in the context of the pooled G-7 data, that failing to recognize this point will change the nature of test results toward not rejecting a restriction to linearity. Turner takes this into account in his specification and tests, and we show below that the Laxton, Meredith, and Rose conclusions regarding tests for linearity carry over to applications with the U.S. data.

With this issue in mind, we specify an asymmetric Phillips curve as follows:

$$\pi_t = A(L)\pi_{t-1} + B(L)\pi^e_{t+1} + \beta \text{ gap}^*{}_t + \gamma \text{ gappos}^*{}_t + \epsilon^\pi{}_t \tag{3}$$

where gap* = $y - \bar{y} + \alpha$ and where gappos* represents the positive values of these adjusted gaps. The variable y is the log of output and we define $\bar{y}$ to be potential output, that is, the level of output that is attainable on average in an economy subject to continual shocks. 1/ Thus, the gap measured as $y - \bar{y}$ will have a mean of zero in large samples. In an economy with a linear symmetric Phillips curve, this would also be an appropriate property for the gap measure used in the Phillips curve. However, with asymmetry where positive gaps have larger effects than negative gaps--if $\gamma > 0$ in equation (3)--and assuming that there is some variance in aggregate demand conditions, α must be less than zero for inflation to be bounded. In other words, the gap that enters a convex asymmetric Phillips curve must have a *negative* mean. A formal proof is provided in Section IV.2.

Equation (3) embodies the simplest empirical form of asymmetry--a piecewise linear function with the possibility of a kink at the point where gap* begins to exert upward pressure on inflation. We think of this representation as an approximation of any convex functional form. Its advantage is that we can test for asymmetry in a very simple and direct manner. Laxton, Meredith, and Rose (1994) argue that there are advantages to more complicated functions with marginal convexity. We do not dispute this; but with the limited data available to identify the nature of the function, we prefer to keep the empirical exercise as simple as possible. Equation (3) allows us to test for the presence of asymmetry, which is our prime objective here. Although we go on to use this particular model for some policy experiments, both here and in a companion paper (see Clark, Laxton, and Rose 1995), we consider this work illustrative. For policy analysis, it may be appropriate to assume alternative functional forms.

So far we have not taken a stand on how one should measure potential output in practice. In any study of the Phillips curve, the choice of a measure of the output gap is very important. We shall show, however, that for the issues addressed here, it becomes less important once proper care has been taken to specify the functional form of the Phillips curve to be consistent with the hypothesis being tested. We report results using a variety of methodologies. To begin, however, we follow Laxton, Meredith, and Rose (1994) and measure the trend level of output using a simple two-sided moving average filter of actual output. In their study with annual data, they measure trend output as a five-year, centered moving average of actual output (a two-year horizon, forwards and backwards). In this paper, we use the same approach but report results for a range of alternative horizons (the parameter k in equation (4) below) in the two-sided filter. We later test the sensitivity of our conclusions to this methodology by repeating the estimation with a number of alternative measures of the output gap.

1/ Output is measured in logarithms so that in a growing economy gaps constructed with a *symmetric* two-sided filter will have a zero mean in large samples.

$$\bar{y} = \frac{1}{2K+1}\left[y_t + \sum_{i=1}^{K} (y_{t+i} + y_{t-i}) \right] \tag{4}$$

With this filter, a small value of k implies that potential output is highly correlated with actual output and, in the limit, when $k = 0$, potential output is equal to actual output at all points in time. This calibration would be consistent with an extreme real-business-cycle view of the world, where prices adjust instantaneously to changes in excess demand. In such a world, it obviously makes no sense to estimate a Phillips curve. At the other extreme, a large value of k would be consistent with a view that most of the variation in observed output at business cycle frequencies is associated with movements in the output gap and not with potential output. Since there is considerable uncertainty about the role of demand and supply shocks in the economy and since imposing a false restriction can result in invalid statistical inferences, one way to proceed is to report results, and hypothesis tests, for a wide range of values of k. 1/ This is the strategy we adopt.

As emphasized above, this (or any mean zero) measure of the output gap may be a seriously biased proxy for the gap that is appropriate for use in the Phillips curve. It is to correct for this potential bias that we introduce the level shift to the filter measures of the output gap for use in the identification of the Phillips curve. This level shift is assumed to be fixed over our sample period and is estimated as the parameter α. 2/ If short-run capacity constraints are truly a feature of the U.S. economy, imposing α to be zero will bias γ toward zero and bias standard tests for the presence of asymmetry toward false rejection. 3/ We will show that this point is of the utmost importance in assessing the empirical evidence.

3. Is there asymmetry in the U.S. Phillips curve?

In this section, we report estimates of the U.S. Phillips curve and tests for whether it has significant asymmetry. We begin with our specification and tests, and we then turn to supporting evidence in the form

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1/ See Eichenbaum (1990) for an excellent discussion of why econometric techniques cannot provide reliable estimates of the relative variance of demand and supply shocks. We pursue this issue in Section IV.3.

2/ We have noted already and will argue more formally later in the paper that the extent of this shift will depend on the nature of the monetary reaction function and the consequent cyclical properties of the economy. There may be good reason to doubt that the same monetary reaction function has been operating throughout our estimation sample. However, we leave this complication to future research and interpret the estimated shift parameter as reflecting average historical behavior.

3/ See Section IV.2 for a discussion of the statistical properties of asymmetric models when researchers fail to account for their logical implications.

of documentation of what happens when the logical implications of asymmetry are not taken into account in the estimation and testing.

a. Unbiased tests for asymmetry in the U.S. Phillips curve

Table 1 reports the results of estimating our model with α determined simultaneously along with the other parameters. We report estimates for values of k ranging from 2 to 16 (quarters). Because we wanted to hold the estimation period fixed to see how alternative gap measures performed in explaining the same data on inflation, the sample for the dependent variable (for all regressions) must end in 1990Q4. (The two-sided filter with $k = 16$, requires data on actual output for the years 1991 to 1994.)

The details of the model to be estimated are provided at the top of Table 1. We wanted to keep the model parsimonious because in such a small sample it is difficult to identify more than a few key parameters with any precision. This led us, for example, to limit the output gap effects to contemporaneous measures. Second, we use the Michigan Survey measure of inflation expectations. We knew from the work of Roberts (1994) that this measure has considerable information content for explaining movements in actual inflation, but the most important reason for using a survey measure is that we think that having a forward-looking element to expectations is important in estimation as well as in policy analysis. The use of the survey measure allows us to avoid the difficult econometric issues implied by explicit model-consistent expectations (e.g., the use of instrumental variables, as in Laxton, Meredith, and Rose, 1994). We chose a specification that includes the contemporaneous value of one-year-ahead inflation expectations as well as four lags, where each lag is assumed to have the same weight. In addition, a lagged inflation term was added to allow for intrinsic inertia in inflation dynamics. 1/

The results in Table 1 were obtained using nonlinear least squares in RATS. The value of k that minimizes the standard error of the inflation equation is 12 quarters. This estimate suggests that variation in the output gap, as opposed to potential output, is the dominant source of variation in output at business cycle frequencies. Based on this preferred model, there is clear evidence that positive gaps have larger effects on inflation than negative gaps. Indeed, the estimated total coefficient on the positive gaps ($\beta + \gamma$) is 1.1 or about five times greater than the coefficient on the negative gaps (β alone). This is a very similar finding to that reported in Laxton, Meredith, and Rose (1994).

The estimated value of α is -1.3; this implies that the gap* measures that are used in the Phillips curve are 1.3 percentage points smaller than

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1/ This choice of lag structure does not affect our conclusions. We obtain basically the same results if we estimate an unrestricted model with 4 lags on inflation and inflation expectations or impose a triangular distribution on lagged inflation expectations.

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

(t-statistics in parentheses)

Estimated equation:

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

where:

$$gap^* = y - y^* = y - \overline{y} + \alpha, \qquad gappos^* = \text{positive values of } gap^*$$

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

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

$$\pi^e_{t+4} \equiv \text{Michigan Survey measure of inflation expectations}$$

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

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

the gaps based on our simple filter. Chart 1 illustrates the results for the asymmetric model. In this case, "potential" output in the top panel is raised by 0.013, relative to the trend measure from the filter, so that we can illustrate the "gaps" that enter the Phillips curve. It is important to remember that this level of output is *not* attainable in the stochastic economy.

The estimated value of δ is just under 0.6, leaving a weight of just over 0.4 on the lagged value of inflation. Regardless of how one chooses to interpret these coefficients (see the discussion in the previous subsection), the results suggest that there is important inertia (a backward-looking component) in inflation dynamics. There is also, however, an important forward-looking component that enters through the expectations.

Examination of the residuals from the preferred estimation indicated that there was some minor autocorrelation, primarily at the third lag. For this reason we have used the robust standard errors option in RATS to obtain the t-tests reported in parentheses. Note that the t-test for γ indicates that the simple restriction to linearity ($\gamma = 0$) is strongly rejected and that this result is robust over a wide range of values of k. Note, further, that α is strongly significantly different from zero, a result which is also robust to substantial variation in k. Finally, we report a Wald test of the joint restriction, $\alpha,\ \gamma = 0$, which imposes the full conditions of the linear null hypothesis. This test is done conditional on the maintained hypothesis that β is strictly positive, which is not rejected by a direct test. 1/ It indicates that the joint restriction is rejected at the 99.9 percent confidence level for our preferred result (the table reports the significance levels for the tests).

b. <u>Biased tests for asymmetry in the U.S. Phillips curve</u>

In discussing the motivation for including shift effect captured by the parameter α in our model, we argued that this was essential to obtain unbiased tests for the presence of asymmetry. We now return to this important issue. Table 2 reports some econometric estimates of the same model under the assumption that $\alpha = 0$, again for a range of values of k. The standard errors for the t-statistics (reported in parentheses) are again computed using the robust errors option of RATS.

In this case, the value of k that minimizes the standard error of the inflation equation is 8. This still has substantial smoothing of the data in the implied profile of trend output, but less than in the model of Table 1. The relative weight estimated on the forward- and backward-looking components of the dynamics is not much affected by the restriction on α.

1/ The notional restriction on β is necessary so that α is identified under the null hypothesis. This avoids the necessity to compute a more complicated test of the restriction when there is a nuisance parameter. See, for example, Andrews and Ploberger (1994).

Table 2. Some Biased Tests of Asymmetry

(t-statistics in parentheses)

Estimated

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

where: $\text{gap}^* = y - y^* = y - \bar{y} + \alpha$, 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

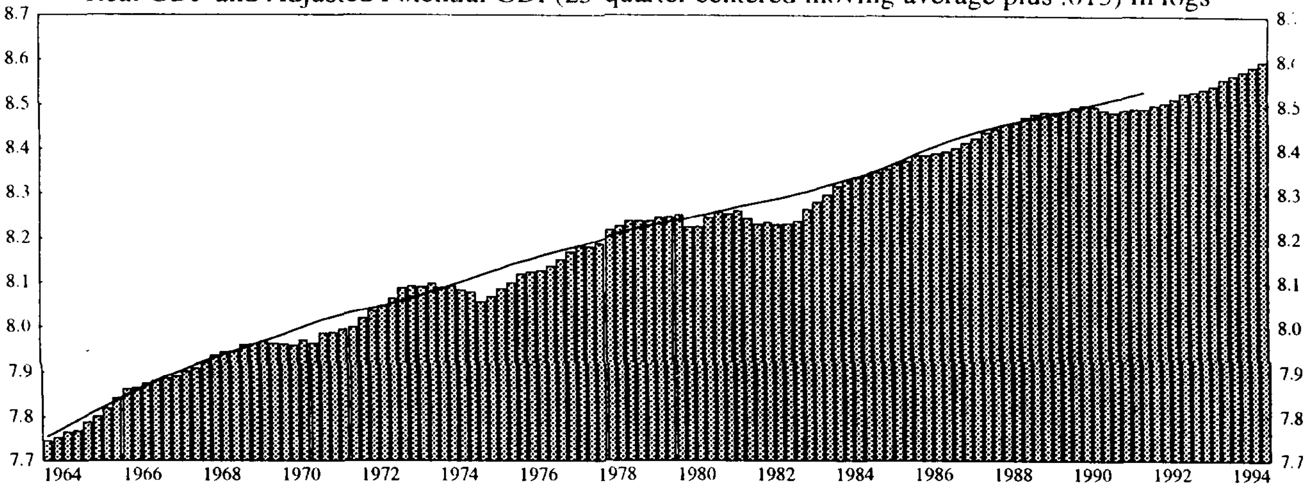
$\bar{y} \equiv \frac{1}{2k+1}\left[y_t + \sum_{i=1}^{k} y_{t+i} + y_{t-i} \right]$

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

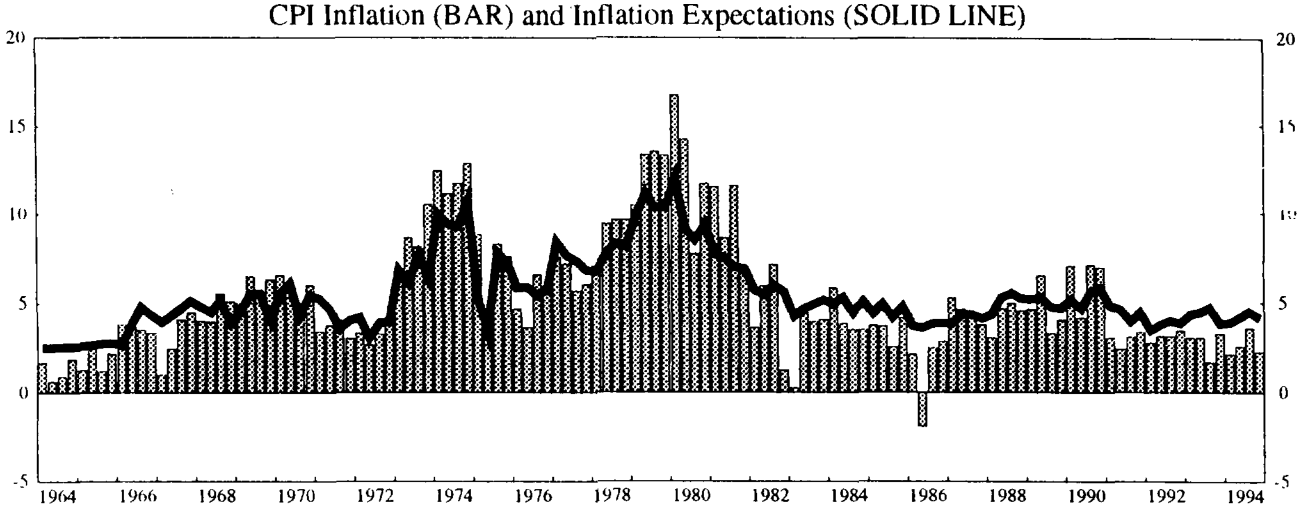
k	α	γ	β	δ	R^2	σ
5	0.00	0.285 (0.96)	0.593 (3.34)	0.547 (4.73)	.7739	1.6499
6	0.00	0.302 (1.20)	0.497 (3.32)	0.556 (4.91)	.7761	1.6296
7	0.00	0.281 (1.27)	0.435 (3.10)	0.562 (5.02)	.7769	1.6387
8	0.00	0.231 (1.12)	0.414 (3.13)	0.564 (5.07)	.7787	1.6321
9	0.00	0.192 (0.99)	0.391 (3.15)	0.564 (5.14)	.7785	1.6331
9	0.00	0.00	0.484 (4.54)	0.552 (4.61)	.7765	1.6328
10	0.00	0.174 (0.93)	0.362 (3.12)	0.563 (5.25)	.7774	1.6371
11	0.00	0.154 (0.86)	0.341 (3.09)	0.560 (5.31)	.7765	1.6403
12	0.00	0.134 (0.79)	0.326 (3.14)	0.557 (5.33)	.7761	1.6421
13	0.00	0.110 (0.67)	0.316 (3.22)	0.555 (5.28)	.7747	1.6469
14	0.00	0.907 (0.57)	0.308 (3.29)	0.552 (5.21)	.7736	1.6510
15	0.00	0.745 (0.48)	0.301 (3.39)	0.549 (5.13)	.7725	1.6548
16	0.00	0.059 (0.39)	0.296 (3.48)	0.545 (5.04)	.7713	1.6594

Chart 1: Interpreting U.S. Inflation with an Asymmetric Model

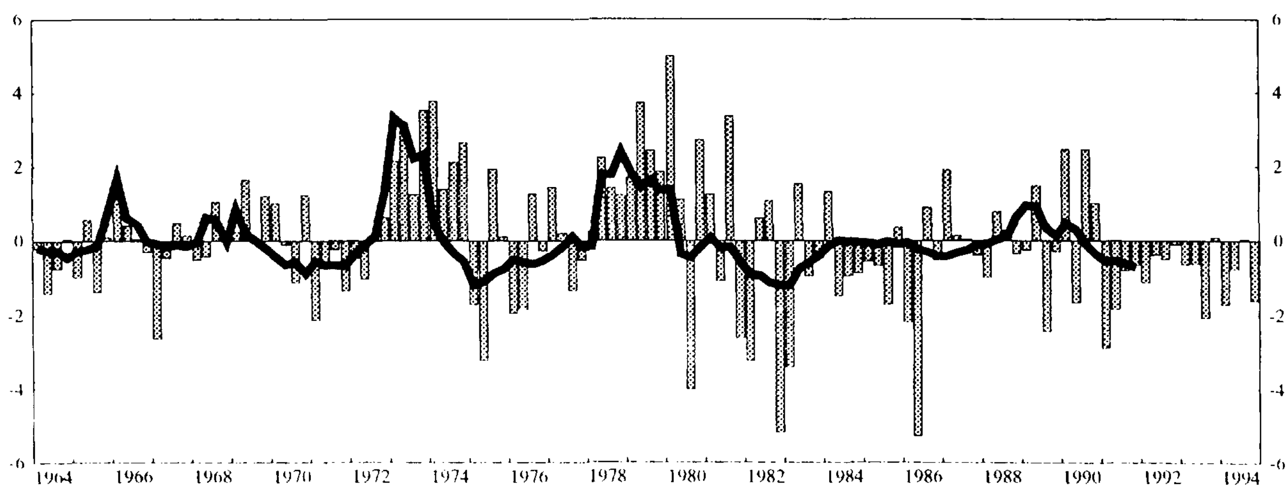
Real GDP and Adjusted Potential GDP(25-quarter centered moving average plus .013) in logs



CPI Inflation (BAR) and Inflation Expectations (SOLID LINE)



$\pi_t - .59\bar{\pi}^e_{t+4} - .41\pi_{t-1}$ (BAR) $.20\, gap_t + .93\, gappos_t$ (SOLID LINE)



However, the preferred model here has two noteworthy features that are very different. First, the econometrician would reject the hypothesis that $\gamma > 0$ at the usual confidence levels and conclude that there was no compelling evidence of asymmetry in the U.S. Phillips curve. Second, the coefficient on the output gap is statistically significant, so there is evidence that inflation is related to the output gap--a Phillips curve exists. Again, these results are robust over a substantial range of values of k.

Chart 2 provides a graphical representation of the linear Phillips curve when we impose α, $\gamma = 0$ and choose the model that maximizes the fit of the inflation equation. The regression results are shown in Table 2 in the second line with $k = 9$, which gives the best fit under these restrictions. The top panel of the chart plots our filter measure of potential output. The middle panel presents the percent change in the CPI measured at annual rates along with the Michigan Survey measure of one-year-ahead CPI inflation expectations. The bottom panel presents the difference between inflation and its backward- and forward-looking components, $\pi_t - \delta\bar{\pi}^e_t - (1-\delta)\pi_{t-1}$, and the contribution of the output gap, as measured by the coefficient times the output gap, βgap_t. As can be seen in the chart, there is a tendency for the linear model to underpredict inflation during the two inflationary episodes in the 1970s when there was large and persistent excess demand.

In conclusion, we find evidence of significant asymmetry in the U.S. Phillips curve, confirming the result in Turner (1995) (and the result in Laxton, Meredith, and Rose (1994) for the pooled G-7 data). A major distinguishing feature of this work, which sets it apart from other work that finds no such evidence for the U.S. data, is the explicit attention to the implications of asymmetry for the manner in which the gaps must enter the estimated Phillips curve. It is clear that procedures that do not allow for the logical implications of the alternative hypothesis can produce biased results in tests of restriction(s) to the null hypothesis. We maintain that the failure of some researchers to account for how the output gap should enter the Phillips curve in an asymmetric world has biased their tests results toward false rejection of the presence of asymmetry. We have shown that the results of tests for asymmetry in the U.S. Phillips curve are changed dramatically towards not rejecting the linear null hypothesis if α is suppressed, echoing a similar result shown by Laxton, Meredith, and Rose (1994) for the G-7. We return to this issue in Section IV below.

III. Asymmetric Versus Linear Models of the Inflation Process

This section provides a brief discussion of some properties of the estimated linear and asymmetric models of inflation dynamics described in Section II. In particular, we compare the trade-offs faced by a monetary authority in dealing with a shock to aggregate demand using deterministic simulations of a small model of the macroeconomy and the policy control process. The model, which is essentially the same as the one used in Clark, Laxton, and Rose (1995), is sketched below.

As the simulations embody model-consistent expectations, the monetary policy reaction function plays a key role in conditioning the overall dynamics of the economy. Indeed, the essential task of the monetary authority in the model is to act such that inflation and inflation expectations are eventually anchored to the target rate of inflation. The simulations compare the consequences of delaying the monetary response to a demand shock in the two versions of the model. They show that, in contrast to the linear case where delay is relatively costless, in the world with asymmetric inflation dynamics, delaying interest rate hikes in the face of excess demand results in a substantial cumulative output loss as the monetary authority is then forced to impose a more severe monetary reaction in order to reign in the higher inflationary pressures. Indeed, an important prediction of the asymmetric model is that the seeds of large recessions are planted when an economy is allowed to exceed its potential.

1. *A simple model of the U.S. output-inflation process*

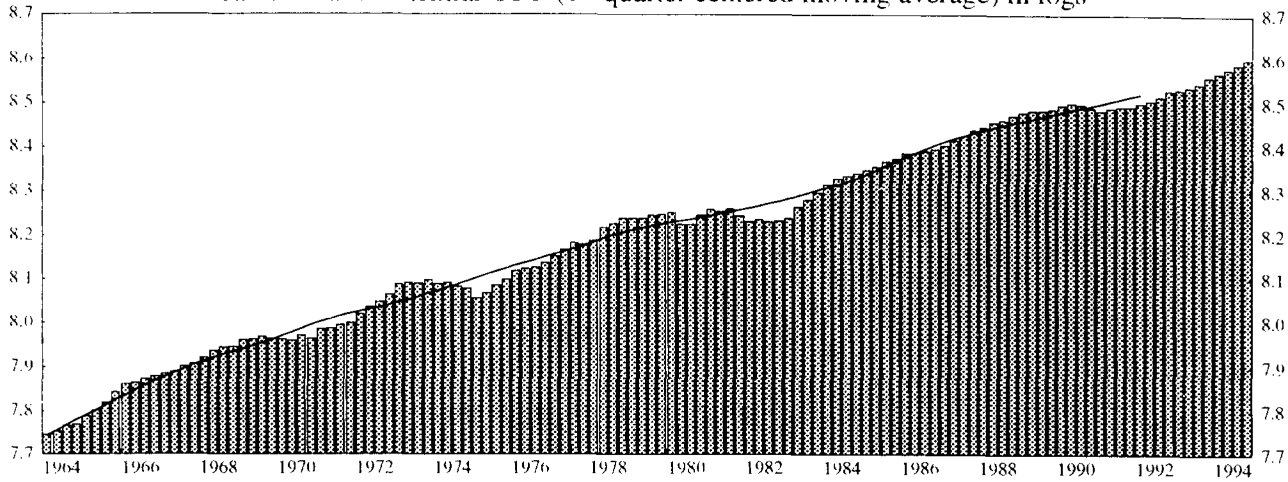
The equations of the model are listed in Table 3. In addition to the two versions of the Phillips curve and some definitions, the model has two equations: one that describes the dynamics of the output gap and the mechanism by which monetary policy influences aggregate demand, and another that describes a policy reaction function designed to keep inflation in the neighborhood of a chosen target level.

The equation for output dynamics has two features that are important for these experiments. First, there are lags in the effect of the monetary control variable. Second, there is an autoregressive propagation structure that, all else equal, initially amplifies the effects of shocks to aggregate demand and then sustains them for some time. The monetary control variable in the model, i.e., the variable that provides the transmission mechanism for monetary policy, is a short-term real interest rate. We treat the Fed funds rate as the policy instrument, but it is an ex ante real interest rate that enters the demand equation. The model is specified with a two-quarter delay before changes in the real interest rate begin to have an influence on aggregate demand. Thereafter, the effect builds such that after 5-6 quarters a persistent real interest rate hike of 100 basis point that is sustained for 4 quarters, would reduce the output gap by 0.4 percentage points. The propagation of demand shocks is represented by a second-order autoregressive structure. All else equal, the effects of a shock are amplified in the second period and then die out slowly. These properties are roughly consistent with the evidence from both reduced-form models of the transmission mechanism (e.g., Roberts 1994a) and more structural models (e.g., Mauskaupf 1990).

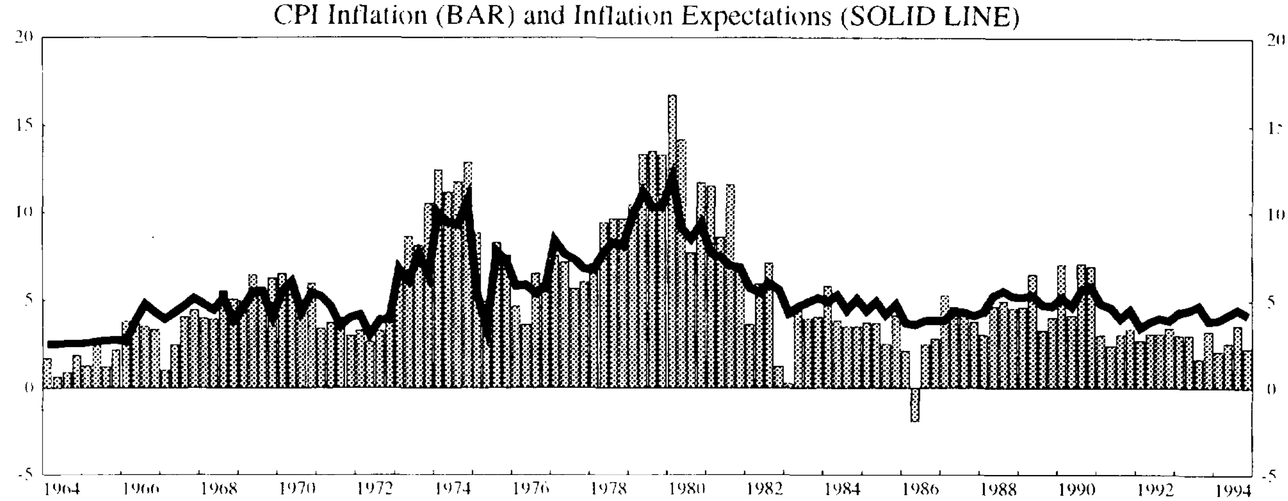
These properties of output dynamics and the monetary policy transmission mechanism have an important implication for the design of monetary policy rules--monetary policy cannot offset completely the effects of shocks. There will be cycles in economic activity and there will be temporary deviations of inflation from its target level. This makes it especially important for the monetary authority to be forward-looking in its

Chart 2: Interpreting U.S. Inflation with a Linear Model

Real GDP and Potential GDP (19-quarter centered moving average) in logs



CPI Inflation (BAR) and Inflation Expectations (SOLID LINE)



$\pi_t - .56\bar{\pi}^e_{t+4} - .44\pi_{t-1}$ (BAR) $.39\ gap_t$ (SOLID LINE)

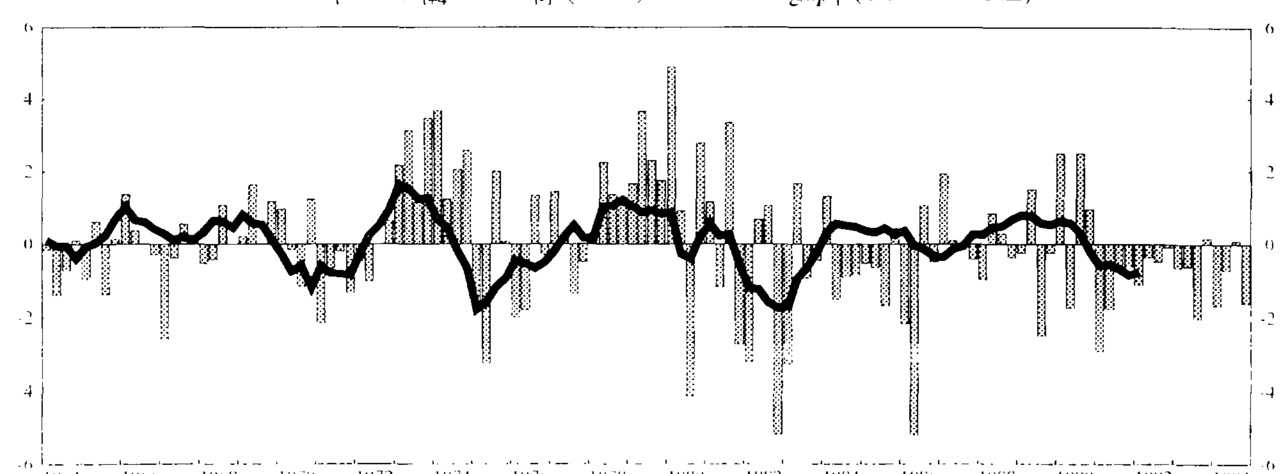


Table 3. A Small Simulation Model of the U.S. Output-Inflation Process

Asymmetric Phillips curve:

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

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

Linear Phillips curve:

$$\pi_t = .548\bar{\pi}^e_{t+4} + (1-.548)\pi_{t-1} + .524\ gap_t + \varepsilon^\pi_t$$

Real interest rate:

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

Inflation and inflation expectations:

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

Aggregate demand equation:

$$gap_t = 1.074\ gap_{t-1} - .290\ gap_{t-2} - .158\ rr_{t-2} + \varepsilon^{gap}_t$$

Policy reaction function:

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

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

actions. The particular forward-looking policy reaction function that we use is a variant of the rule considered by Bryant, Hooper, and Mann (1993). In setting the short-term interest rate, the monetary authority acts to raise the real rate that enters the output equation when inflation is expected to be above the target level three quarters ahead or there is excess demand in the economy. The particular calibration adopted is designed to assure that inflation remains in the region of the target level and returns to the target level within a reasonably short period (two years) following a shock to aggregate demand.

2. The effects of delaying monetary response to a demand shock

The simulations show what happens when there is an impulse shock of 1 percent to aggregate demand, i.e., a 1 percentage point output gap opens on impact and there are no further shocks. 1/ We compare the consequences of delaying the monetary policy response by just one quarter for the two versions of the model. The delay is implemented by simply holding the Fed funds rate at its control value for one quarter (i.e., the normal reaction function is turned off for one quarter and then operates normally). 2/ The results from the model with a linear Phillips curve are shown in Charts 3 (no delay) and 4 (delay). Charts 5 and 6 show the comparable results from the model with asymmetry.

If the economy is linear, the effects of delay are relatively innocuous. With an immediate response, amounting to a 270 basis point increase in the short-term interest rate in the first quarter, inflation peaks at about 1 percent above control and there is a cumulative gain of output of about 2 percent. With a delayed monetary response, there is a larger hike in short-term interest rates, and inflation edges slightly higher, peaking at about 1.3 percentage points above control, but the cumulative gain in output is even larger, amounting to about 2.5 percent by the end of the simulation. These results show that if the world is linear there is no strong case for aggressive monetary resistance to inflationary demand shocks. While the monetary authority may be concerned to see inflation rise above the target by more and for a longer period of time, it would be difficult to argue that there are any real costs to delaying interest rate hikes when output exceeds potential output.

The picture looks quite different if there are capacity constraints that result in asymmetry in inflation dynamics. Despite a much stronger

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1/ The simulations reported here are deterministic. Although these types of experiments are useful for developing the basic intuition behind the model, they do not do justice to the full policy implications. See Clark, Laxton and Rose (1995) for a more extensive analysis of the policy implications of asymmetry in inflation dynamics in a stochastic environment.

2/ These simulations were carried out using the "stacked time" algorithm in TROLL. See Armstrong, Black, Laxton and Rose (1995) for a description of this algorithm and its properties.

Chart 3: Linear Model Responses to a Temporary 1 Percent Positive Demand Shock

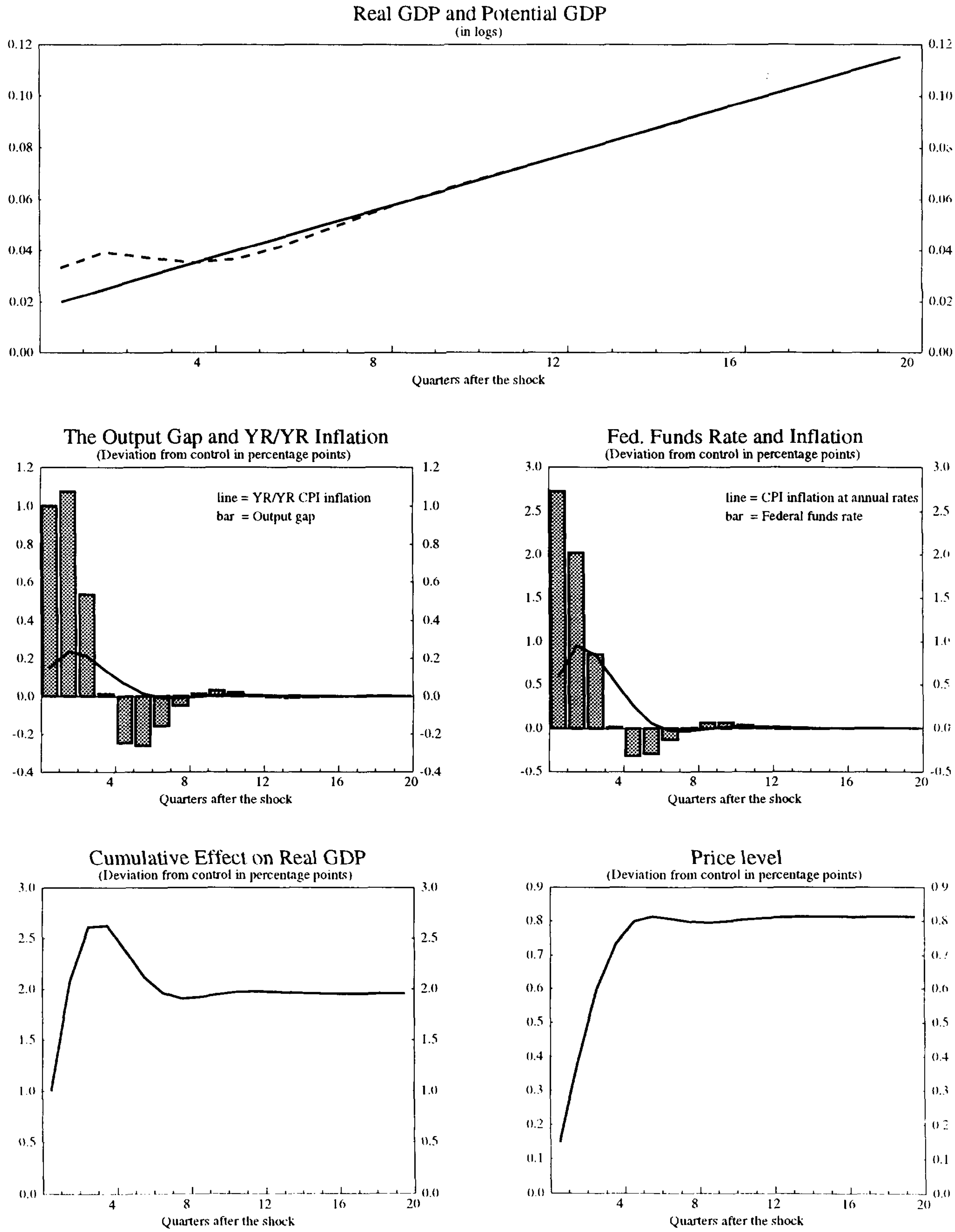


Chart 4: Linear Model Responses to a Temporary 1 Percent Positive Demand Shock:
Delayed Monetary Policy Response

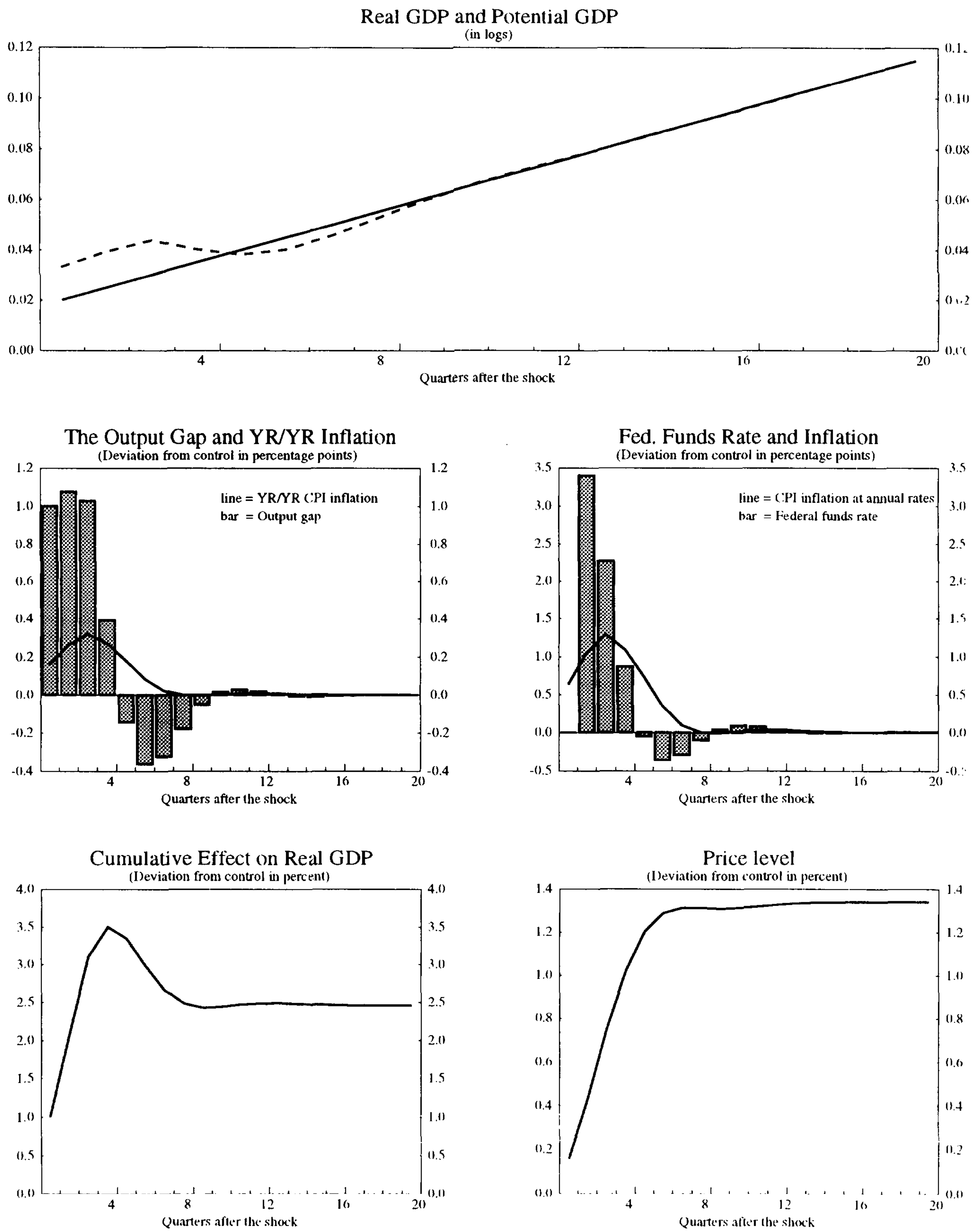


Chart 5: Asymmetric Model Responses to a 1 Percent Positive Demand Shock

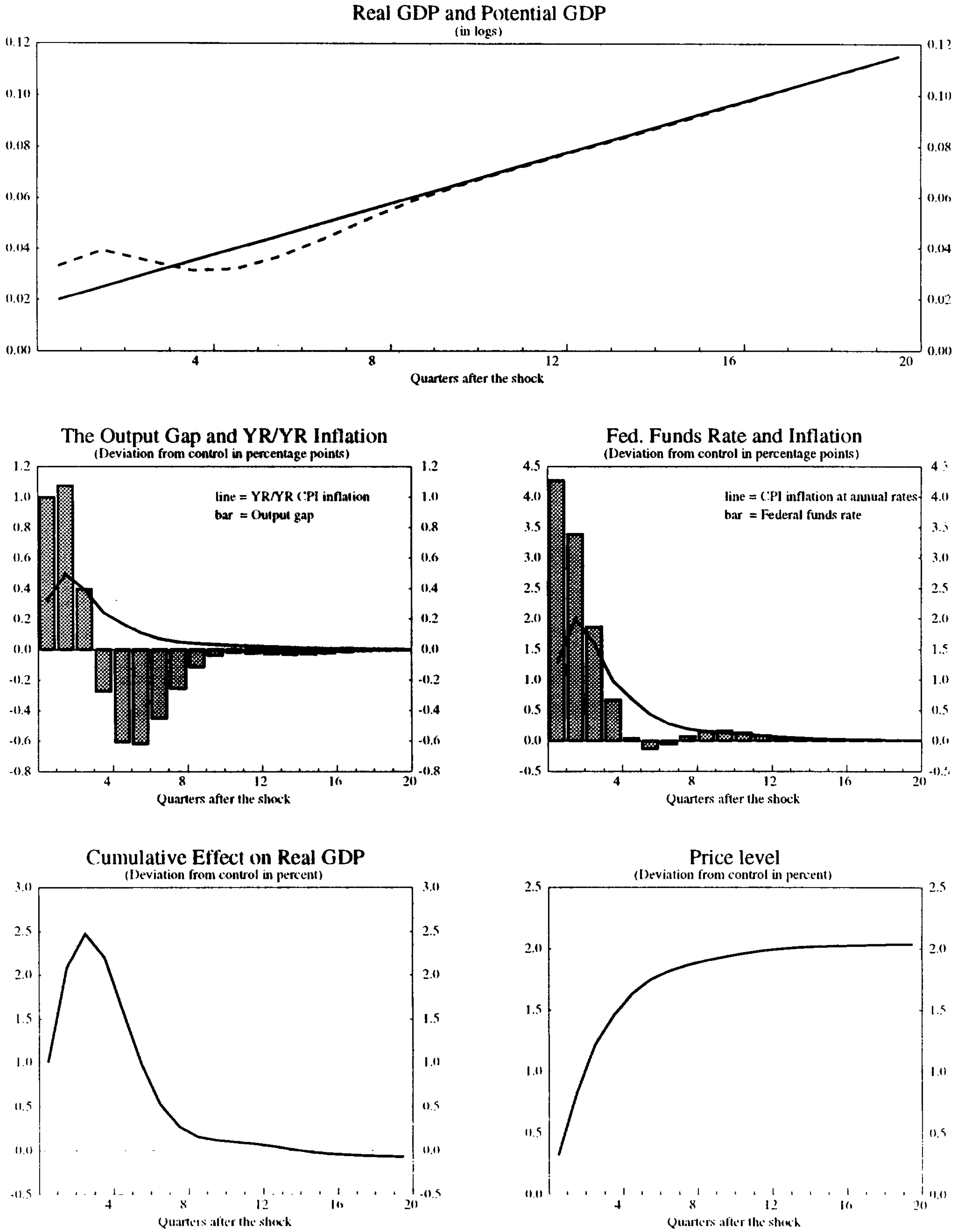
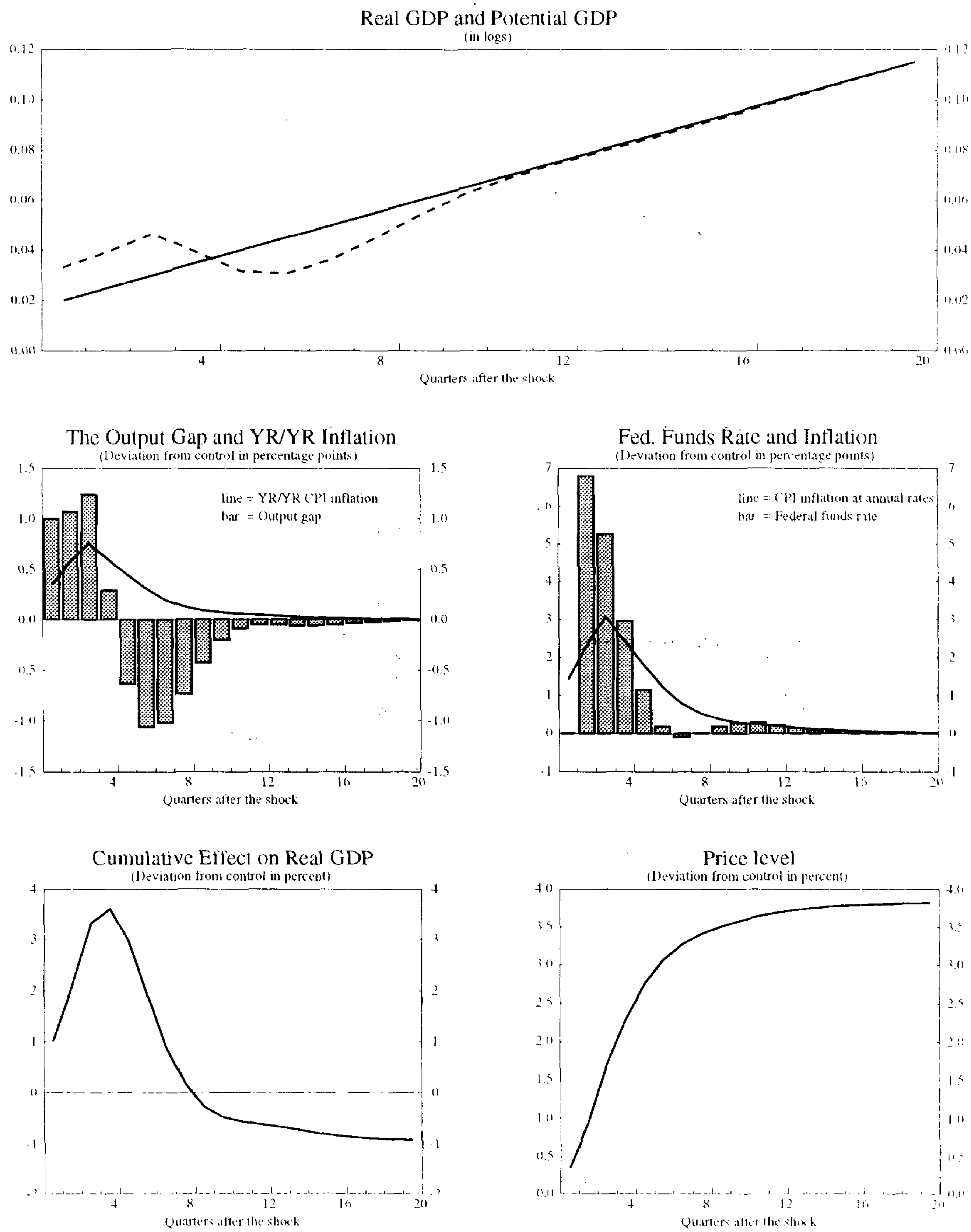


Chart 6: Asymmetric Model Responses to a 1 Percent Positive Demand Shock

Delayed Monetary Policy Response



policy response in the no-delay scenario, with short-term interest rates up by over 400 basis points in the first quarter, inflation peaks at about 2 percentage points above control. While the course of output is roughly similar over the first few quarters, the task of reigning in the higher inflationary consequences of the same shock in this model requires a much deeper secondary contraction and the elimination of any cumulative gain in output. In fact, there is a small cumulative loss of output.

The consequences of delaying the monetary response to the shock are much more dramatic in this case. Short-term interest rates must be raised substantially higher to combat the cumulating inflationary pressures as expectations respond to the more sustained excess demand and rising inflation. Inflation now peaks at 3 percentage points above control. To bring inflation back under control in this environment requires a much more severe contraction. Indeed, the cumulative change in output is now substantially negative because a large contraction is needed to counteract the inflationary effects that are caused by the initial temporary boom.

The model with asymmetry has many of the features of the world that most central bankers point to in discussing the role of monetary policy. It provides a clear and compelling reason for forward-looking action by the monetary authority to act to forestall any tendency for the economy to move into excess demand. To fail to do so necessitates even tougher action later to keep inflation in check with unfortunate but unavoidable macroeconomic consequences. The apparent preoccupation with inflation on the part of monetary authorities reflects a concern about the consequences for the real economy; to temporize with inflation is to force the economy to suffer both a cumulative loss of output and more extreme variation in economic conditions.

IV. Some Issues in the Specification and Estimation of Phillips Curves

1. Asymmetry, linearity, and the burden of proof

The policy implications of models that feature explicit short-run capacity constraints differ considerably from those of models based on simple linear versions of the Phillips curve. The former suggest that there are large risks from allowing the economy to overheat, while the latter suggest there are very small risks. While the functional form of the Phillips curve is essentially an empirical issue, policymakers have a valid reason to discount somewhat empirical evidence that rejects the asymmetric view, particularly when such evidence is based on a small sample of business cycles.

Econometricians are interested in minimizing statistical errors, while policymakers are interested in minimizing policy errors. A purely statistical analysis would be concerned about trading off Type I and Type II statistical errors. A Type I statistical error is made when one rejects a hypothesis when it is true, whereas a Type II statistical error is made when one accepts a hypothesis when it was false. However, as the outcomes for the economy will depend on which model the policymaker chooses, a rational policymaker will be more concerned with the implications of choosing the incorrect model. For this reason, even though the balance of the evidence may point to one model being true, it may nonetheless still be appropriate for the policymaker to act as if the other model were true or at least to give some weight to this possibility. 1/

For illustrative purposes, suppose that after reviewing the evidence a policymaker's staff advises that there is a 75 percent probability that the linear model is true and only a 25 percent probability that the asymmetric model is true. It may still be rational in such circumstances for the policymaker to act as if there were a 50 percent probability that the asymmetric model is true, even if the policymaker believes that the staff has provided a completely unbiased assessment of the evidence. The reason for this is that the policymaker realizes that he may impose larger costs on the economy by falsely rejecting the asymmetric model than would be the case if he falsely rejected the linear model. In other words, if the policymaker were to guide monetary policy on the expectation that the inflationary consequences of exceeding capacity were small, and it turned out that they were large, he knows that there is good chance that he might have to implement a severe tightening in monetary conditions to reestablish control over inflation. In such circumstances, the rational policymaker who places a high weight on avoiding severe contractions, such as the 1981-82 recession, may choose to act as if there were a significant asymmetry in the output-inflation nexus, even if the balance of the empirical evidence leaned in favor of the linear model.

Policymakers have an additional reason for discounting the conclusions of studies that purport to reject the asymmetric model. In most cases, although the authors of these studies cannot reject global linearity, they also cannot reject asymmetry (although this is rarely tested). The problem is that conventional statistical inference in small samples will depend to a large extent on which model the researcher chooses to place on the pedestal when conducting hypothesis tests. Recent work on Phillips curves has placed the linear version on the pedestal by treating it as a maintained hypothesis that has to be disproved to be abandoned. With the exception of Turner

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1/ This argument is developed more formally in Laxton, Rose and Tetlow (1993c) using stochastic simulations of a small macro model.

(1995), studies using U.S. data have been unable reject the linear model with this methodology. 1/

Indeed, as can be seen in Table 2, which reports conventional tests for asymmetry that ignore our point regarding α, one would arrive at precisely the same conclusion using classical tests. The model that predicts inflation best in this table suggests that the coefficient on the output gap (β) is 0.41 and the coefficient on the positive output gap (γ) is 0.23. From the standard test of the hypothesis that the coefficient on the positive gap is equal to zero, with a t-value of 1.1, we would not be able to reject the zero restriction at the 10 percent level of significance. This is the type of result that most researchers have described as providing no evidence of an asymmetry.

Suppose, however, that after balancing the policy risks of the alternative models, the monetary authorities decided that it would be appropriate to base their actions on an assumption that the effects of excess demand on inflation were twice as powerful as the effects of excess supply gaps--in our model this is equivalent to presuming that $\gamma = \beta$, since β is the symmetric effect of both positive and negative output gaps. In such circumstances, the policymaker might want to ask the econometrician if this presumption was inconsistent with the regressions reported in Table 2. Taking the estimate of β as given, this amounts to testing if the coefficient on γ is equal to 0.41. When we test this hypothesis, we compute a t-statistic of 0.8. 2/ The econometrician would have to agree that using traditional confidence levels the empirical evidence does not rule out the existence of an important asymmetry. The main point here is that choice of which model is placed on the pedestal by the rational policymaker should, in principle, depend on the potential costs that are imposed on the economy from basing policy on the incorrect model.

1/ A good example of this is provided in Chadha, Masson and Meredith (1992). These authors present a statistical test of a restriction of an asymmetric Phillips curve to a linear formulation, which rejects the restriction at the 95 percent confidence level, but not at the 97.5 percent confidence level. Because they had placed the linear model on the pedestal, they concluded that this was not strong enough evidence to reject the simpler linear version, and they went on to do policy analysis with the linear model. Had they taken the perspective that there was good reason to put the asymmetric model on the pedestal, in view of the importance this would have for the policy analysis, the statistical evidence would likely have been interpreted as supporting the asymmetric model.

2/ We remind the reader that we consider these tests biased. We think that the statistical case for the presence of an asymmetry is stronger than discussed here. The point here is that there is no strong case against asymmetry even in the analysis based on biased tests.

2. On the implications of asymmetry for estimation and hypothesis tests

As noted in the Section II, conventional tests for asymmetry may have been biased because researchers failed to take into account the full implications of asymmetry when they chose the gaps for the estimation of their Phillips curves. Laxton, Rose, and Tetlow (1993a) present Monte Carlo evidence which shows that researchers who employ traditional detrending techniques will have difficulty finding a statistically significant nonlinear structure in Phillips curves where such nonlinearity is in fact a part of the true data-generating process.

The problem is that most techniques measure output gaps by using a mean-squared-error criterion to define a curve representing potential output as a measure of central tendency of the series for actual output. If the Phillips curve is asymmetric, however, such that excess demand tends to be more inflationary than excess supply is disinflationary, the mean value of the output gap that enters the Phillips curve will have to be negative in order for inflation to be stationary. This is the case because the shocks that lead to inflationary conditions will have a larger effect than those that lead to disinflationary conditions. 1/

To understand this point formally, consider the following simplified version of an asymmetric Phillips curve:

$$\pi - \pi^e = f(y-y^*) + \epsilon, \quad \text{where } f(0) = 0 \text{ and } f'() \geq 0 . \tag{5}$$

The variable ϵ represents a random disturbance term with zero mean and $(y-y^*)$ represents the output gap, which is also assumed to be stochastic. Consider the case where f() is continuous and globally convex:

$$\{f(y1-y^*) + f(y2-y^*)\} / 2 \geq f(\{(y1+y2)/2\} - y^*) \quad \forall \quad y1, y2 \tag{6}$$

with strict inequality holding for (at least) some values of y1, y2.

Now consider the properties of a stochastic equilibrium, defined as a situation in which there is no systematic difference between π and π^e. Taking the unconditional expectation of equation (5), where E() denotes the expectations operator, and noting that $E(\epsilon)=0$, this implies:

$$E(\ f(y-y^*)\ ) = 0 . \tag{7}$$

1/ For further discussion of this point, see DeLong and Summers (1988), Laxton, Rose and Tetlow (1993c) and Laxton, Meredith and Rose (1994).

Given the continuity of f() and convexity (6), it follows from Jensen's inequality that: 1/

$$f(\ E(y-y^*)\ ) \ = \ f(\ E(y)-y^*\ ) \ \leq \ E\ (\ f(y-y^*)\ ) \ = \ 0\ , \qquad (8)$$

with strict inequality holding if f() is strictly convex and the variance of *y* is nonzero.

Given the restriction that the effect on inflation cannot decrease as excess demand rises (i.e., that $f'() \geq 0$), it follows from (8) that:

$$E(y) - y^* \leq 0\ , \qquad (9)$$

with strict inequality holding as long as f() is strictly convex and *y* has nonzero variance. Thus, the mean level of output in a stochastic economy with a convex Phillips curve lies below the equilibrium of the economy without shocks to output.

The important implications of this result for stabilization policy have been explored by Clark, Laxton, and Rose (1995), Laxton, Meredith, and Rose (1994) and Delong and Summers (1988). Here, we want to focus on its econometric implications. Failure to account for the logical implication of convexity creates two types of problems in estimated Phillips curves. First, the estimated degree of convexity will be biased downwards. Second, statistical tests will be biased toward false rejection of the nonlinear model at standard significance levels.

The first point is shown in the Monte Carlo experiment reported by Laxton, Rose, and Tetlow (1993a), which confirms that the coefficient on the excess demand component, γ, will be biased downwards and that the coefficient on the gap, β, will be biased upwards. As the gap measures derived from mean-squared-error methods will tend to be too large from the perspective of the asymmetric Phillips curve, the estimator is forced to lower the identified effect of excess demand on inflation. Laxton, Meredith, and Rose (1994) show that this is consistent with what emerges from the pooled data for the G-7 countries. We also see this in our results using U.S. data.

The second point is also shown clearly by the same Monte Carlo study. The results show that econometricians who use unadjusted gap measures and 5 percent significance levels for their tests would falsely reject the asymmetric model over 50 percent of the time. Thus, if short-run capacity

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1/ Proofs are widely available. See, for example, Mood, Graybill and Boes (1974), p. 72.

constraints are truly a feature of the real world, the process of testing for asymmetry in small samples with traditional techniques is similar to the process of tossing a coin.

3. On methods of measuring potential output and their implications

This study might be criticized on the grounds that it has relied on an ad hoc two-sided, moving average filter to measure potential output. In principle, it would be preferable to write down a dynamic structural model which nested both the linear and asymmetric views of the world and to derive model-consistent measures of the output gap under both hypotheses. This would place the models on an equal statistical footing and, in principle, permit a clearer test of the restriction to linearity. Although such an endeavor might well be worthwhile, it is not clear that it would be possible to identify many more parameters and to discriminate between more complex models, given the limited number of observations of business cycles available in the data. We leave this as an interesting topic for future research. 1/ We would be remiss, however, not to check whether our results stand up if we use other univariate techniques to measure potential output. This could be important; Harvey and Jaeger (1993), for example, have shown that reliance on simple filters may induce spurious relationships in regressions. 2/ A related example is provided in Laxton, Shoom, and Tetlow (1992). They show that use of simple univariate filters to measure gaps can cause spurious change-in-the-gap terms to have significant coefficients in estimated Phillips curves in cases where the true data generating process has only pure level gap effects. 3/ Thus, there could be a concern that our use of the two-sided moving average filter to measure potential output has somehow biased our results in favor of the asymmetric model.

Harvey and Jaeger (1993) present a trend-plus-cycle or unobserved components (UC) model that is quite flexible and encompasses many other popular detrending procedures. For our purposes, their model can be thought of as a simple reduced form of a more general dynamic stochastic structural model of the U.S. economy. They show that the Hodrick-Prescott filter and our two-sided moving average filter are generally suboptimal for estimating

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1/ Kuttner (1991) implements a Kalmon filter procedure to provide model-consistent estimates of the gap when the Phillips Curve is linear. An obvious extension of our work is to develop a similar procedure that can be used for nonlinear models.

2/ See also Nelson and Kang (1981) and Cogley (1990).

3/ It is not uncommon for researchers to use such techniques and then discard level gap variables because their estimated coefficients are not significantly different from zero, despite the implications this has for monetary policy. The lack of any level gap effects in the Phillips Curve is sometimes interpreted as evidence of hysteresis.

trends of economic variables. 1/ Indeed, they show that estimates from the Hodrick-Prescott filter will be optimal--in the class of univariate filters--only under very specific parameterizations, which will vary from case to case. Using several economic series as examples, they show how arbitrary use of the HP filter can result in biased estimates of the cyclical component and can even induce spurious correlations and regression results where the variables are detrended this way. These potential problems also apply to our filter.

Harvey and Jaeger also argue that their model has several advantages over simple time trends or segmented time trends. Despite the fact that it is impossible to discriminate between deterministic segmented time trends and stochastic representations of output in small samples, they argue that the latter is preferable because segmented time trends are based on arbitrary assumptions about when the trends break. 2/

The validity of their general argument notwithstanding, Harvey and Jaeger show that in the particular case of U.S. GNP their model produces estimates that are very similar to the HP1600 estimates. They conclude (p. 236) that this "suggests that the HP filter is tailor-made for extracting the business cycle component from U.S. GNP." The bottom panel of Chart 7 shows the estimates of the UC gaps and HP1600 gaps obtained when these two procedures are used to detrend to U.S. real GDP. 3/ It is evident that the Harvey-Jaeger conclusion is not altered by the change in the output measure; the two methods produce very similar estimates of the U.S. GDP output gap.

Another common procedure for providing trend estimates and gap measures is to fit polynomial, often quadratic, trend lines to the data. For example, Roberts (1994) reports estimates of inflation models that use quadratic time trend approximations to measure potential output.

Table 4 reports estimates of our inflation model based on these alternative estimates of the output gap. Again, to give some indication of the bias associated with using pure measures of central tendency in deriving gap measures for estimating the Phillips curve, we report results with and without the α shift effect.

1/ HP filter estimates ($\bar{y}_t$) are derived by minimizing the sum of squares of the gap $\sum_{1}^{T} (y_t-\bar{y}_t)^{**}2$ and a "smoother" $\lambda \sum_{1}^{T-2} [(\bar{y}_{t+2} - \bar{y}_{t+1}) - (\bar{y}_{t+1} - \bar{y}_t)]^2$. Many users set the smoothness parameter, λ, at 1600 despite the fact that, in principle, the "optimal" value will depend on the properties of the particular series. HP1600 filtered values of U.S. GDP resemble closely those from a two-sided moving average filter with geometrically declining weights. Our simple filter is similar but has equal weights.

2/ For an example of the segmented-trend approach, see Braun (1990), with details in Table A.2, page 302.

3/ We thank Paula De Masi and Michael Funke for supplying us with these estimates.

Table 4. Tests with Alternative Measures of the Output Gap

(t-statistics in parentheses)

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

Where: $\text{gap}^* = y - y^* = y - y + \alpha$, 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 (1993s) Trend Plus Cycle Model

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

Model #4: Hodrick-Prescot Filter with λ=10000

Model #5: Hodrick-Prescot Filter with λ=100000

Model #6: Hodrick-Prescot Filter with λ=500

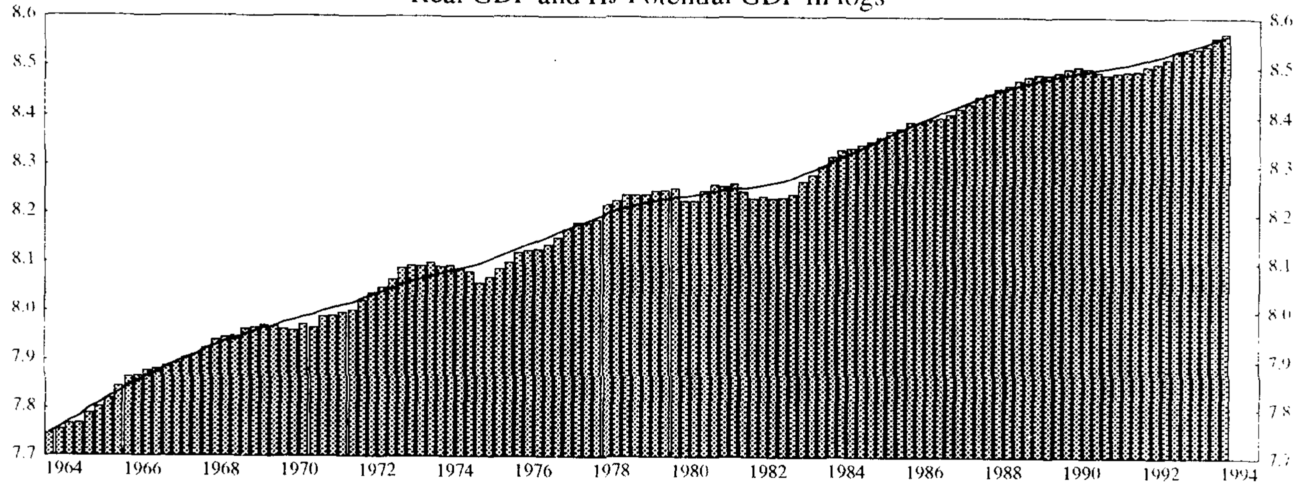
Model #7: Quadratic Time Trend (SMPL 1961Q1-94Q4)

Inflation equation estimation period: SMPL 1964Q1-90Q4

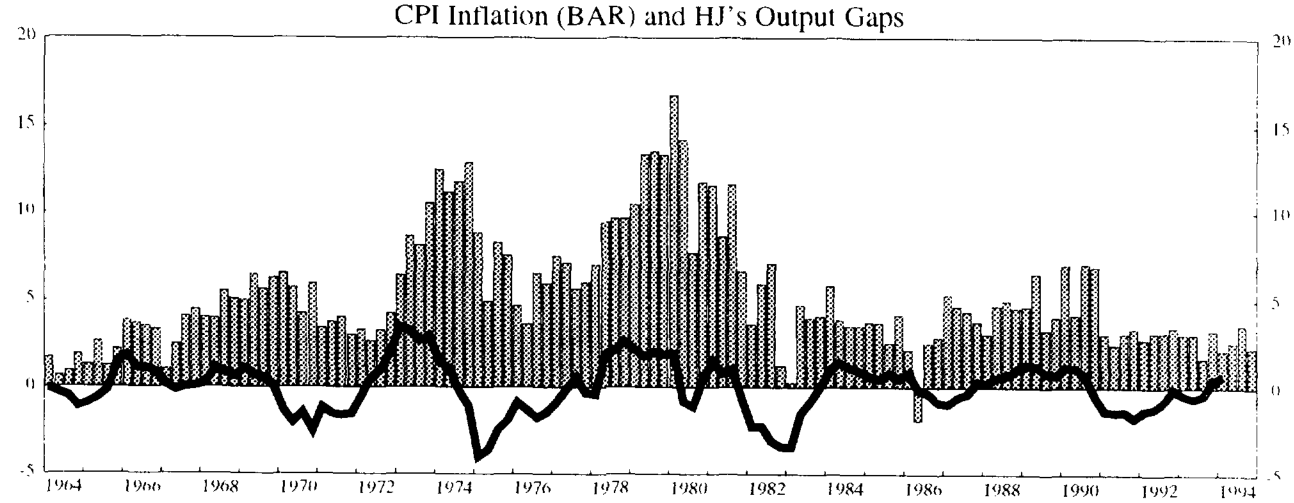
Mod.	α	γ	β	δ	R^2	σ	Wald Test SL(α,γ = 0)
1a	-1.256 (3.66)	0.925 (3.16)	0.202 (2.43)	0.593 (6.13)	.7892	1.6010	0.001
1b	0.000	0.134 (0.79)	0.326 (3.14)	0.557 (5.33)	.7761	1.6421	
2a	-0.791 (2.48)	1.092 (2.80)	0.281 (2.40)	0.611 (6.18)	.7927	1.5877	0.018
2b	0.000	0.331 (1.52)	0.403 (2.75)	0.583 (5.58)	.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	-1.498 (4.28)	1.081 (3.03)	0.175 (2.67)	0.589 (5.25)	.7833	1.6231	0.000
4b	0.000	0.148 (0.88)	0.298 (3.63)	0.558 (5.00)	.7745	1.6477	
5a	-0.506 (0.53)	0.176 (0.70)	0.226 (2.71)	0.530 (4.69)	.7652	1.6895	0.782
5b	0.000	0.046	0.266	0.528	.7649	1.6826	
6a	-0.713 (2.48)	1.066 (2.92)	0.303 (2.53)	0.611 (5.80)	.7920	1.5902	0.013
6b	0.000	0.328 (1.49)	0.424 (2.80)	0.583 (5.47)	.7842	1.6119	
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 7: Harvey and Jaeger's (HJ: 1993) Measure of Potential Ouput

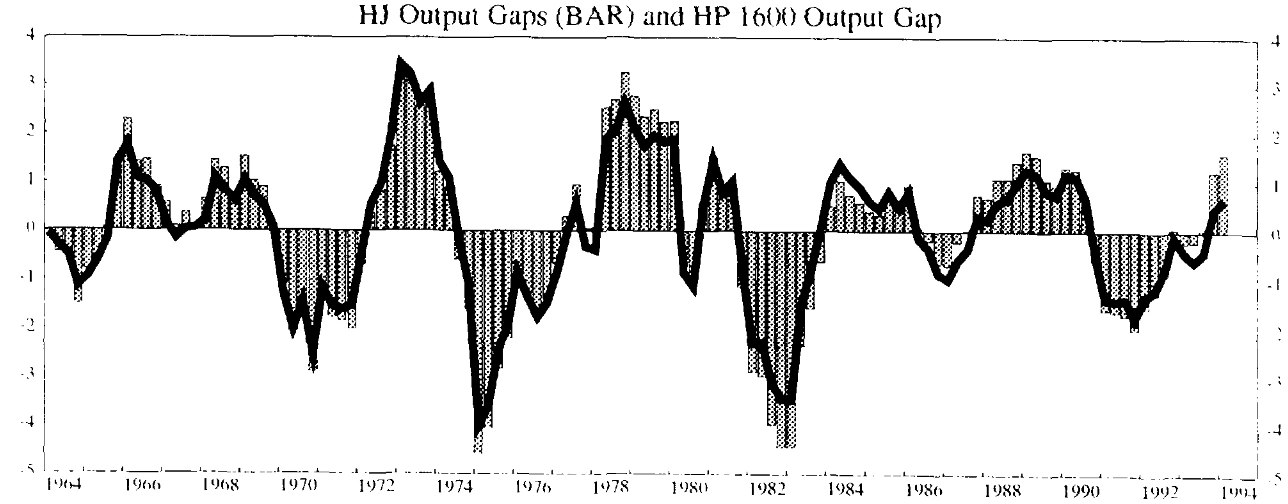
Real GDP and HJ Potential GDP in logs



CPI Inflation (BAR) and HJ's Output Gaps



HJ Output Gaps (BAR) and HP 1600 Output Gap



Equation (1a) in Table 4 reports the estimates for our model with the Harvey-Jaeger output gaps. Note that the fit of the model is slightly better with the Harvey-Jaeger gaps than in our best result. In this estimation, both γ and β are slightly larger than in Table 1. Moreover, all the parameters are statistically significantly different from zero, and a Wald test indicates that we can reject the joint restriction that α, $\beta = 0$ with considerable confidence. Equation 1b 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 the restricted model. In addition, the coefficient on the output gap (β) rises from 0.281 in the unrestricted model to 0.403 in the restricted model. This confirms the direction of bias from the Monte Carlo evidence reviewed above. Moreover, as in our exercise using the simple filter, an econometrician would not be able to reject the hypothesis $\gamma = 0$ at the traditional high levels of confidence, although with these results an objective researcher might think long and hard about the risks of assuming that this gave license to throw the gappos* variable out of the model.

Equation 2a 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 Harvey-Jaeger gaps from the unobserved components model. Indeed, the parameter estimates are almost identical to those from Equation 1a. And, again, the case for asymmetry weakens when we impose $\alpha = 0$.

In general, 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 is implied by the HP1600 filter or the unobserved components model. To test the sensitivity of our results to this assumption we re-estimated our model with larger weights on the smoothness parameter of the HP filter. In the limit, an extremely high weight on smoothness implies that potential output is treated as a linear time trend. Equations (3a) and (4a) provide additional estimates when λ, the HP smoothing parameter, is set equal to 10,000 and 100,000, respectively. Note that the fit of the inflation equation deteriorates 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.

For completeness, we also offer a result with a smaller value, $\lambda = 500$, which gives the supply component of shocks more weight such that the trend estimate follows the data somewhat more closely. The fit is not quite as good as with $\lambda = 1600$ or the Harvey-Jaeger gaps, but the results look very much like those from these two estimations.

Our final alternative is a gap measure based on a simple quadratic time trend to measure potential output, as in Roberts (1994), for example. These estimates are reported in Equation (6a) and (6b) of Table 4. Note that when we estimate our model with these gaps we obtain a positive estimate of α and a negative estimate of γ, although neither is significantly different from zero. This result is very similar to the finding of Eisner (1994) and has the exact opposite policy implications of short-run capacity constraints. Note, however, that this particular model has the worst fit of the models considered here.

The conclusion that emerges from these supplementary regressions is that, while the particular choice of a gap measure does matter to the details of the estimates, the overall case that there is an important asymmetry in the U.S. Phillips curve is quite robust. In particular, our conclusions are robust to testing with the Harvey and Jaeger (1993) measure of output gaps, which those authors have subjected to careful scrutiny and for which they claim some important optimality properties. What emerges very clearly from the results is that it is not so much the gap measure that matters, but how it is used in estimating the Phillips curve. Consistently, we see evidence that tests for asymmetry are seriously biased if the logical implications of the asymmetric model are not taken into account in the estimation.

4. Some additional robustness tests

Two common criticisms of the work presented in Laxton, Meredith, and Rose (1994) and earlier drafts of this paper were that our α was merely capturing omitted influences that would normally be picked up in a free constant and that our asymmetry was likely largely a reflection of special effects associated with the major oil-price shocks. We now show that neither of these arguments stands up to scrutiny. The results we cite are reported in Table 5.

a. Is α simply capturing omitted variables?

No. When we add a free constant to the preferred model using our filter, or to the Harvey-Jaeger estimation from Table 4, it is small and insignificantly different from zero. For example, the significance level of the restriction of this constant to zero is about 86 percent in the extension based on our simple filter. Moreover, none of our other conclusions is affected.

What this tells us, and quite clearly, is that the estimation strongly prefers our interpretation and use of α to alter the form of the curvature in the Phillips curve over the competing hypothesis that it is capturing the influence of omitted variables. Moreover, as a bonus, the theoretically preferred specification with no exogenous component to inflation is entirely consistent with the data.

b. Is the asymmetry capturing the particular influence of oil-price shocks?

No. When we add the rate of change of the relative price of crude oil to our preferred model or to the model with Harvey-Jaeger gaps, there are no

Table 5. Tests with Constant Term and Oil Prices

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

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

π ≡ Percent change in the CPI at annual rates

π^e_{t+4} ≡ Michigan Survey measure of inflation expectations

Model #1: Add a constant (λ) term to the Model

a: Case of k = 12 from Table 1 with a constant (α estimated)

b: Harvey and Jaeger (1993s) Trend Plus Cycle Model

Model #2: Add Relative Oil Prices to the Model (see λ)

a: Case of k = 12 from Table 1 with a constant (α estimated)

b: Harvey and Jaeger (1993s) Trend Plus Cycle Model

Inflation equation estimation period: SMPL 1964Q1-90Q4.

Mod.	α	γ	β	δ	λ	R^2	σ	Wald Test SL(α,γ = 0)
1a	-1.281 (-2.52)	0.876 (3.04)	0.222 (1.641)	0.592 (6.20)	0.070 (0.17)	.7893	1.6083	0.003
1b	-0.798 (-2.13)	0.972 (2.73)	0.318 (1.97)	0.610 (6.08)	0.099 (0.30)	.7929	1.5944	0.014
2a	-1.391 (-4.47)	1.019 (3.99)	0.196 (2.47)	0.620 (7.77)	0.000 (6.25)	.7990	1.5708	0.000
2b	-.798 (-2.95)	1.068 (3.37)	0.284 (2.30)	0.632 (7.46)	0.000 (6.98)	.8006	1.5644	0.002

changes in any of the conclusions. In fact, the case for asymmetry is strengthened. The new variable enters significantly and improves the fit of the equations. All the other coefficients all become a touch better determined, and there are no important changes in any of the point estimates. 1/

5. Inflation expectations and the Phillips curve

a. The role of the survey measure

Recent work by Roberts (1994) has suggested that the Michigan Survey measure of CPI inflation expectations has considerable predictive content for explaining actual movements in inflation. If such measures prove reliable, this could alleviate a major problem that has plagued reduced-form empirical work on the Phillips curve. Without a measure of expectations, researchers are forced to use some proxy in estimation.

In recent years, many researchers have argued that a forward-looking interpretation of expectations (or at least some weight on model-consistent expectations) is a necessary part of estimation as well as simulation of models of inflation. 2/ Consistent implementation of this view forces researchers into difficult econometric techniques, such as using forecasts from auxiliary equations as instruments for the forward-looking components to avoid the severe simultaneity bias that arises if actual future values are used. This instrumental variables approach was followed, for example, by Laxton, Meredith, and Rose (1994). While such techniques are well understood, there are always questions about whether good instruments have been chosen, and so on.

Some researchers still rely on purely backward-looking proxies for expectations, despite the considerable evidence that such models cannot capture the historical experience adequately. For example, applications of Markov switching models to U.S. inflation data, as in Evans and Wachtel (1992) and Ricketts and Rose (1995), show plausible patterns of regime shifts and give results that are consistent with the observation that survey measures of expectations exhibit periods of persistent bias that cannot be reconciled easily with ex post estimates of distributed lag reduced forms. Moreover, the reduced-form approach does not permit the separate

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1/ This conclusion also holds if we add further lags of the relative price of oil.

2/ We consider it self-evident that the Lucas critique is important for monetary policy analysis, that is, in counterfactual simulations where monetary policy is presumed to change. Representations of expectations with fixed-parameter, backward-looking dynamics can be dangerously misleading in such cases. We offer some examples later in this section. However, for estimation of the rest of the parameters of the Phillips curve, such representations may inefficient but still admissible.

identification of intrinsic elements of dynamics from those associated with expectations formation.

Use of survey measures of expectations could prove helpful in clarifying debates about issues in this area. There is no perfect substitute for data. Nevertheless, one cannot know how good a measure of the inflation expectations of economic agents the Michigan survey measure provides. Therefore, one might ask whether our test results with respect to asymmetry depend critically on our use of this measure of expectations. To answer this question, we repeat the estimation with our gaps and with the Harvey-Jaeger gaps, replacing the Michigan survey measure of inflation expectations with a four-quarter distributed lag on past inflation. The results are shown in Table 6. Our conclusions are not altered; the evidence for asymmetry is still clear as long as the effect of the α shift is taken into account.

b. Interpretation of the linear model in empirical work and policy analysis

The natural rate hypothesis imposes on the basic linear model in equation (2), repeated here for convenience, the condition that the coefficients in A(L) and B(L) sum to one. With this restriction, there will be no long-run tradeoff between the output gap and inflation.

$$\pi_t = A(L)\pi_{t-1} + B(L)\pi^e_{t+1} + \beta \; gap_t + \epsilon^{\pi}{}_t \tag{2}$$

In empirical work, however, inflation expectations are often proxied by a fixed-parameter autoregressive model--in other words B(L) is not estimated separately but is combined with A(L) in some mongrel function that mixes expectations and the intrinsic elements of inflation dynamics. This is unfortunate because some researchers appear to (mis)interpret the natural rate hypothesis as implying that the sum of the coefficients on the lagged inflation terms in this mongrel function must sum to one. This is not correct. There is no logical link between the natural rate hypothesis and this sum of coefficients. In fact, the natural rate hypothesis implies that the sum of the coefficients on the lagged inflation terms in reduced-form inflation equations should sum to less than one as long the monetary authorities are setting instruments in a way that ensures that inflation is stationary. Even if this property is not evident in the data for a particular sample, the unit-sum restriction has some very undesirable properties in models designed for policy analysis.

Consider first the issue of reduced forms, per se. In his recent paper, for example, Robert Gordon (1994) estimates this type of reduced-form model and then proceeds to ask what the implications would be (p. 14) "if the Fed "let her rip" ... and allowed unemployment to fall" and stay below the natural rate by one percentage point, forever. In modern formulations of the natural rate hypothesis with forward-looking expectations, the monetary authority simply cannot set instruments to obtain such a goal.

Table 6. Tests with Autoregressive Process for Expectations

(t-statistics in parentheses)

Estimated equation: $\pi_t = A_o\, A(L)\pi_{t-1} + \beta\ gap_t^* + \gamma\ gappos_t^* + \epsilon_t^\pi$

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

$A(L)\pi_{t-1} = a_1\pi_{t-1} + a_2\pi_{t-2} + a_3\pi_{t-3} + a_4\pi_{t-4}$

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

Model #1: K = 12 from Table 1

a: α estimated

b: $\alpha \equiv 0$

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

a: α estimated

b: $\alpha \equiv 0$

Inflation equation estimation period: SMPL 1964Q1-90Q4.

Mod.	α	γ	β	Σa	A_o	R^2	σ	Wald Test SL(α,γ = 0)
1a	-0.817 (1.42)	0.878 (2.04)	0.404 (2.36)	0.856	0.978 (1.93)	.8022	1.5812	0.000
1b	0.000	0.503 (1.35)	0.375 (1.79)	0.860	0.527 (1.58)	.7967	1.5954	
2a	-1.509 (2.48)	0.933 (2.14)	0.305 (2.59)	0.871	0.960 (2.15)	.8028	1.5791	0.000
2b	0.000	0.311 (1.08)	0.312 (1.88)	0.884	0.350 (0.99)	.7920	1.6135	

Indeed, any attempt to do so would result in rapid escalation of inflation; and models with forward-looking expectations would generate a rapid collapse into hyperinflation and eventually simply fail to solve because of the absence of any nominal anchor. 1/ By contrast, because Gordon assumes that agents' expectations are tied down by long distributed lags, he predicts that the inflation rate would only rise gradually to 5.5 percent by 2004. Although it may be reasonable to argue that inflation expectations are partly tied down by initial conditions, it is quite another matter to assume that agents would be fooled systematically and would not eventually react to such a dramatic and persistent change in Fed policy.

The basic problem is that the parameters in reduced-form Phillips curves will be subject to the Lucas (1973) critique. 2/ This severely limits the usefulness of such models for monetary policy analysis because it is impossible to incorporate what we see as the fundamental prediction of the natural rate hypothesis, namely, that it is potentially very costly to allow the economy to overheat. Policymakers who lose sight of this point and place too much weight on empirical reduced-form equations risk repeating the policy errors of the 1970s and putting in place the seeds of another major recession.

The argument against reduced-form specifications that impose a unit root should not be based purely on econometric criteria. In fact, such unit root tests are as uninformative as the tests that Gordon and others have conducted to test the predictions of the natural rate model. For example, in his recent paper, Gordon tests if the sum of coefficients on the lags in his Phillips curve are equal to one. Since this is equivalent to asking if the inflation process is nonstationary, this restriction is equivalent to testing for a unit root in the inflation process. Gordon and others have confused this restriction as being a necessary and sufficient restriction for the natural rate hypothesis to hold. This is obviously incorrect. 3/

1/ This argument is also clear in the seminal exposition of these ideas in Friedman (1968).

2/ Ericson and Irons (1995) have recently provided an assessment of the quantitative significance of the Lucas critique. These authors argue that despite the fact that most economists presume that the Lucas critique is valid, direct empirical evidence to support this presumption is rarely offered. They go on to claim that, in fact, "virtually no evidence exists that empirically substantiates the Lucas Critique." We think that there is plenty of evidence, but that debate must await a separate paper.

3/ In Gordon's model inflation expectations always lag behind actual inflation. In this model, the integral of the output gaps or unemployment gaps must always sum to zero as long as the terminal inflation rate is equal to the initial value of inflation. For this reason we follow Summers (1988) and refer to this model as the integral gap model so that it will not be confused with the natural rate model.

If there is no tradeoff between output and inflation in the long run, and if the monetary authorities are successful at providing an anchor for inflation, then both the output gap and the inflation rate will be stationary processes. Of course, the degree of persistence in the inflation process will depend, in part, on the reaction of the monetary authorities and how successful they are in providing an anchor for inflation expectations. But the natural rate hypothesis is an entirely different question and can hold regardless of the manner in which expectations are formed and can certainly hold in a world where inflation is stationary. Moreover, imposing the unit-sum restriction in an estimation if policymakers are providing a nominal anchor could be quite misleading. This point does not seem to be widely understood, despite the fact that it has been available to the profession at least since Sargent (1971) and was revisited in Summers (1988).

This does not deny that there is important inertia in both U.S. inflation and inflation expectations. Indeed, given the historical experience it may be perfectly rational for agents to discount current actions by the Fed to contain inflationary pressures and to continue to place some weight on the possibility that the policies of the 1970s may be repeated. In fact, given that there is little to prevent future policymakers from allowing the economy to inflate--beyond the reputation of today's policymakers who promise not to do it--it would be irrational for agents to discount completely the evidence that it has happened before. Indeed, both survey measures of inflation expectations and the evidence from Markov switching models (see Ricketts and Rose 1995) seem to confirm that there is a degree of skepticism about the Fed's commitment to low inflation. 1/

IV. Conclusions

In this paper, we present estimates of a simple asymmetric Phillips curve for the United States. We find that a restriction to a linear version of the model is strongly rejected. This confirms recent evidence presented by Laxton, Meredith, and Rose (1994) using the pooled G-7 data and by Turner (1995) using the U.S. data.

We also show why other researchers may have been misled in reaching the opposite conclusion. Following arguments advanced in Laxton, Meredith, and Rose (1994), we demonstrate that in a stochastic economy the presence of an asymmetry in the Phillips curve has an important implication as to how output gaps should appear in the function to be estimated. In particular, we show that it is inconsistent to use mean-zero gaps in the estimation, as

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1/ This observation is also consistent with measures of inflation expectations from countries that have conventional and indexed bonds and similar inflation experiences. For example, in Canada despite the fact that monetary policy has delivered 2 percent inflation for three years now, long-term inflation expectations are still around 4.5 percent by this measure.

this vitiates the implementation of the asymmetric alternative hypothesis. We cite Monte Carlo evidence that the use of such gaps will bias standard statistical tests of the restriction to linearity, and we show that this is confirmed by the results with U.S. data.

We also provide a number of tests of the robustness of our conclusions. Our conclusions come initially from results based on output gaps obtained using a simple, two-sided moving average filter to measure potential output. However, we show that if the above implication of asymmetry is taken into account in the estimation and testing, then the precise method used to provide the measure of potential output and the mean-zero output gap does not matter as much. In particular, we show that if we use the Harvey-Jaeger (1993) approach to derive gap measures or a variety of measures based on the Hodrick-Prescott filter, our conclusions are not affected.

We also show that our results stand up to a number of other tests for robustness. These include adding a free constant to the estimation, testing for the influence of changes in the relative price of crude oil and replacing our survey measure of expectations with a distributed lag proxy.

The paper also discusses some issues in policy modeling. We are concerned that with the small samples of business cycle variation available to researchers, there will be significant limitations on one's ability to measure important variables, such as potential output and expectations, and to discriminate among competing hypotheses. We argue that policy analysis should not be conducted by the rules of classical econometrics and Occam's razor. We note that most researchers who opt for a linear null hypothesis because it cannot be clearly rejected in their results, could just as easily have argued that the same results are consistent at the same confidence levels with the presence of important asymmetry. But our main point is that policy modeling should be concerned with the costs of policy errors, regardless of the precise strengths of one empirical case or another. We show here in a simple form, citing the more complete discussion in Laxton, Rose, and Tetlow (1993c), that policy errors arising from an incorrect assumption that the world is linear will be much more costly than the errors arising from making an error the other way round.

Another important point concerns the manner in which policy simulations are conducted. Some researchers, such as Robert Gordon (1994), appear to be willing to ignore completely the possibility that expectations have a forward-looking component. In our view, this is dangerous and can produce misleading policy advice. It is one thing to deal with the problem of representing expectations for historical estimation by using long distributed lags; it is quite another to assume that this procedure captures stable parameters that will be invariant to a policy shock. While we do not think that using distributed lags is an efficient estimation strategy, we might grudgingly accept it as part of an empirical strategy if survey measures were not available. However, we would reject completely the notion that simulations of the resulting models have anything useful to say about the implications of alternative policies. Indeed, such simulations are likely to be quite misleading. We describe an example of such a simulation in Section IV.5, citing a recent paper by Robert Gordon (1994). Gordon uses an estimated reduced-form model to ask what would happen if the Fed "let her rip" and allowed the unemployment rate to stay below the natural rate by one percentage point forever. Because Gordon assumes that agents' expectations are tied down by long distributed lags, he predicts that the inflation rate would only rise gradually to 5.5 percent by 2004. Although it may be reasonable to argue that inflation expectations are partly tied down by initial conditions, it is quite another matter to assume that agents would be fooled systematically and would never react to such a dramatic and persistent change in Fed policy.

The limited policy experiments we present in this paper are designed to illustrate the power of the asymmetry hypothesis to provide a logic for monetary policy. 1/ We show that if the world is linear, then delaying the response to a positive demand shock may be beneficial, if the metric is simply cumulative output, if the world is linear. In such a world, a fast response is essential only for negative shocks. Thus the linear world produces asymmetric policy advice--take risks with inflation but not with disinflation. If this view of the world is wrong, however, as our evidence suggests, the consequences of such a policy will be higher volatility in the real economy and a lower average level of output. In the presence of asymmetry, it is critical to respond as quickly as possible to signs of excess demand because failure to do so results in much greater volatility in output and a lower average level of output over time. In this case, moreover, the policy advice is roughly symmetric with respect to negative shocks. While delay is not as costly when there is excess supply, it is still preferable to act sooner rather than later.

1/ The policy implications of asymmetry are discussed in greater detail in a companion paper--Clark, Laxton and Rose (1995).

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