New Evidence on the Output Cost of Fighting Inflation

By Andrew J. Filardo

The Federal Reserve has made significant progress toward price stability over the last two decades. The annual inflation rate has declined from 13 percent in the early 1980s to roughly 2 percent today. The current environment of low and stable inflation has fostered superior economic performance. Lower inflation has led to lower interest rates, which in turn have helped spur investment, foster more affordable housing, and, arguably, support the current solid expansion and strength of the stock market.

To be sure, the current low-inflation environment has come at a price. One key cost of achieving low inflation is the output loss that generally accompanies a permanent decline in inflation. Particularly stark examples of this output cost were seen in the early 1980s and early 1990s. In the early 1980s, disinflation was associated with one of the largest recessions of the postwar era. A recession, though somewhat milder, also accompanied the disinflation of the early 1990s. Another more subtle output cost of fighting inflation is the cost of preventing inflation from rising. As incipient inflation pressures build, tighter monetary policy can slow the economy and thereby preemptively forestall the rise in actual inflation. The slower output growth is the cost of resisting inflation pressures. Together, these two output costs of fighting inflation play important roles in determining how to seek further disinflation toward price stability and how best to maintain low inflation.[1]

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A significant factor determining the output cost of fighting inflation is the tradeoff between inflation and output, often referred to as the Phillips curve. Traditionally, estimates of this relationship assume the shape of this curve is linear. This implies that the slope of the Phillips curve is constant and, therefore, independent of the stage of the business cycle, the speed of the disinflation, and how aggressively incipient inflation pressures are fought. Recent research, however, has begun to question whether the slope is constant. In other words, assessing the output cost of fighting inflation may be more complicated than traditionally assumed.

This article investigates the shape of the Phillips curve and the associated output cost of fighting inflation. The first section discusses how the output cost of inflation is linked to the shape of the Phillips curve and reviews the current debate about the shape. The second section offers new empirical evidence on the nonlinear shape of the Phillips curve and on the output cost of fighting inflation. The third section draws policy implications from the new evidence. The article concludes that, while the Phillips curve traditionally has been thought of as approximately linear, closer examination of the inflation-output relationship reveals important nonlinearities. This new evidence and its implications for the output cost of fighting inflation may require new policy strategies.

I. RECENT CHALLENGE TO THE TRADITIONAL VIEW OF THE OUTPUT COST OF FIGHTING INFLATION

Strategies for fighting inflation depend on careful consideration of *all* the costs and benefits of achieving and maintaining a low-inflation environment. The potential benefits of low inflation include faster economic growth, higher productivity, a more stable economic environment, and fewer tax distortions. The costs of achieving and maintaining low inflation include lost output, higher unemployment, and related social ills. This article focuses on the output cost of fighting inflation by examining how to accurately measure the output losses. Only with accurate measures can the net benefits of fighting inflation reliably be assessed.[2]

Traditionally, the output cost of fighting inflation has been summarized in a single number using the "sacrifice ratio" concept. The sacrifice ratio is a well-known economic concept that can distill complex economic phenomena into a fairly simple, yet informative, cost measure. Proposed by Okun in 1978, it exploits information about output and inflation in the Phillips curve to measure how much output would be lost by lowering inflation one percentage point.[3]

This section examines one of the key assumptions behind the traditional sacrifice ratio—linearity of the Phillips curve. The discussion points out the limitations of the traditional sacrifice ratio as an accurate measure of the output cost of fighting inflation, and extends the notion behind the sacrifice ratio to include the output cost of preemptively fighting incipient inflation pressures. The accompanying box reviews the traditional linear Phillips curve framework and discusses how it can be used to assess the output cost of fighting inflation.

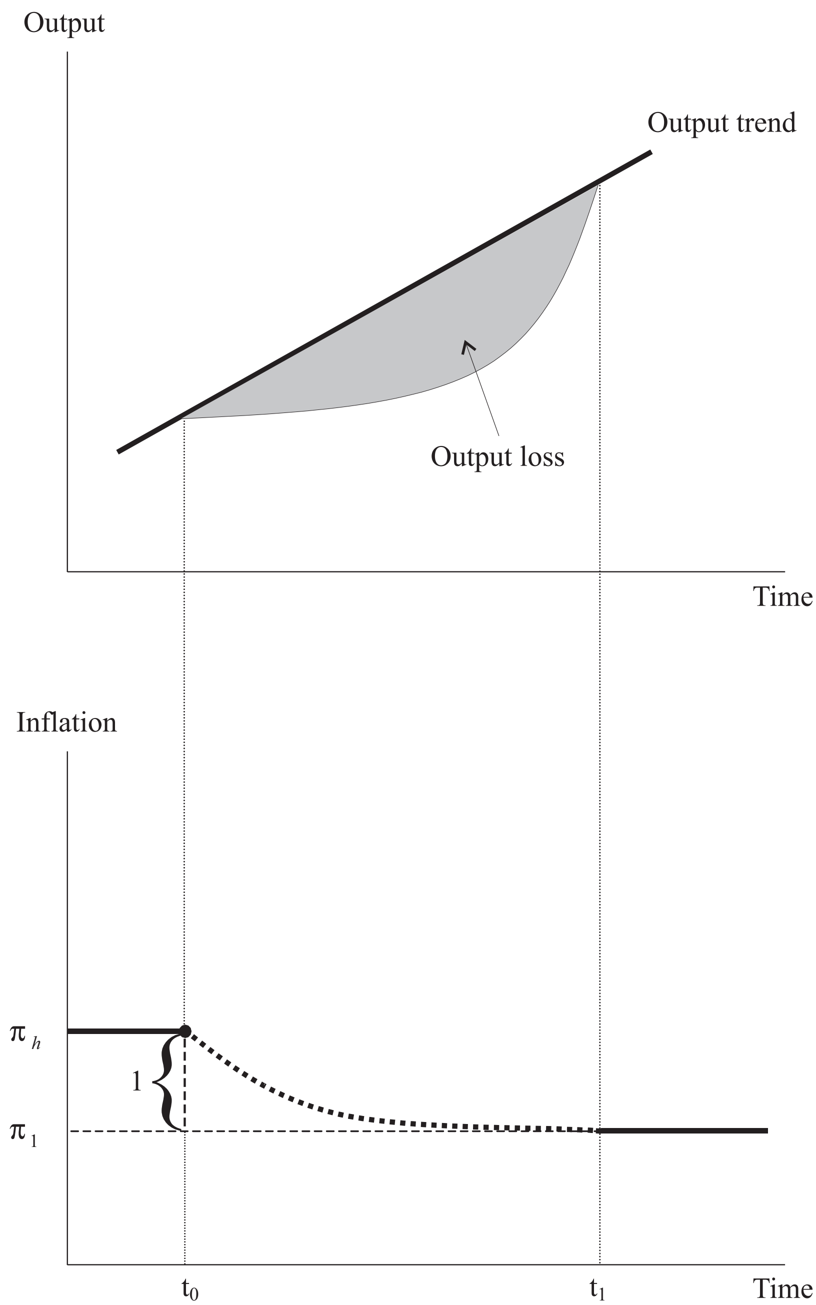
Estimates of the sacrifice ratio

Okun was interested in estimating the output cost of disinflation and offered a simple method to measure the sacrifice ratio.[4] Using a "back-of-the-envelope" approach based on the estimated Phillips curve slopes in the literature at the time, Okun reported a sacrifice ratio of 10.[5] In other words, a permanent one-percentage-point reduction in the inflation rate would, over time, be associated with a 10 percent reduction in real GDP—a huge output cost. To put this number in perspective, the 10 percent loss is equivalent to the typical decline in GDP in a moderate recession.[6] Figure 1 shows one possible time path of output and inflation in response to a tighter monetary policy that ultimately lowers inflation by one percentage point. Okun's notion of the sacrifice ratio corresponds to the output loss in the shaded area expressed as a percent of GDP.

Gordon and King (1982) refined Okun's empirical approach to deliver a more precise estimate of the output cost of disinflation. Using more complex econometric methods, Gordon and King modeled the structure of the economy as a system of equations that captures various factors affecting inflation and output. As in Okun's approach, they used a linear Phillips curve equation to link inflation and output but found a sacrifice ratio that was less than half of Okun's value. After four years, a one-percentage-point decline in inflation was associated with a cumulative 3.0 percent output loss.[7]

Okun's and Gordon and King's assumption of a linear Phillips curve, however, had an important potential limitation. Linearity implies that the output cost of fighting inflation does not vary with the strength of the economy or with

Figure 1
OUTPUT LOSS ASSOCIATED WITH DISINFLATION



the aggressiveness of the fight. In contrast, a nonlinear Phillips curve allows the output cost to depend on these two factors.

Ball (1994) claimed that the limitations of linearity were potentially empirically important. He raised objections to the assumed linearity in the postwar period, arguing that asymmetric wage-price flexibility, credibility, and incomes policies cause the sensitivity of inflation to output to depend on whether output is above or below trend. To avoid the assumption of linearity, Ball estimated the sacrifice ratio using an *atheoretical approach* rather than a Phillips curve relationship. By directly measuring the drop in output during disinflation periods, he estimated a sacrifice ratio of 2.4—smaller than, but fairly close to, Gordon and King's estimate.[8] Using a similar approach, Jordan (1997) examined periods of rising inflation. He estimated the change in output to be roughly 1.0 percent per percentage point of higher inflation.[9] Taken together, these two estimates are inconsistent with the assumption of linearity.

Nonlinear Phillips curve and implications

Recent research on nonlinear Phillips curves is flexible enough to capture output costs that are cyclically sensitive yet precise enough to use in a structural model that incorporates the complex interactions of the macroeconomy.

Possible nonlinear shapes. Figure 2 illustrates two possible nonlinear Phillips curves and their implications for the cost of fighting inflation. Both curves share an upward slope that reflects the positive tradeoff between inflation and the economy's strength. In the figure, the economy's strength is measured by the deviation of output from its trend, or the output gap, and inflation is measured relative to inflation expectations. To deliberately disinflate, economic policies must slow the economy. The southwest quadrants in both panels of Figure 2 show that disinflation occurs when output is below trend. In contrast, to prevent inflation from rising, economic policies must preemptively forestall output from rising above trend. The northeast quadrants show that inflation rises when output is above trend.[10]

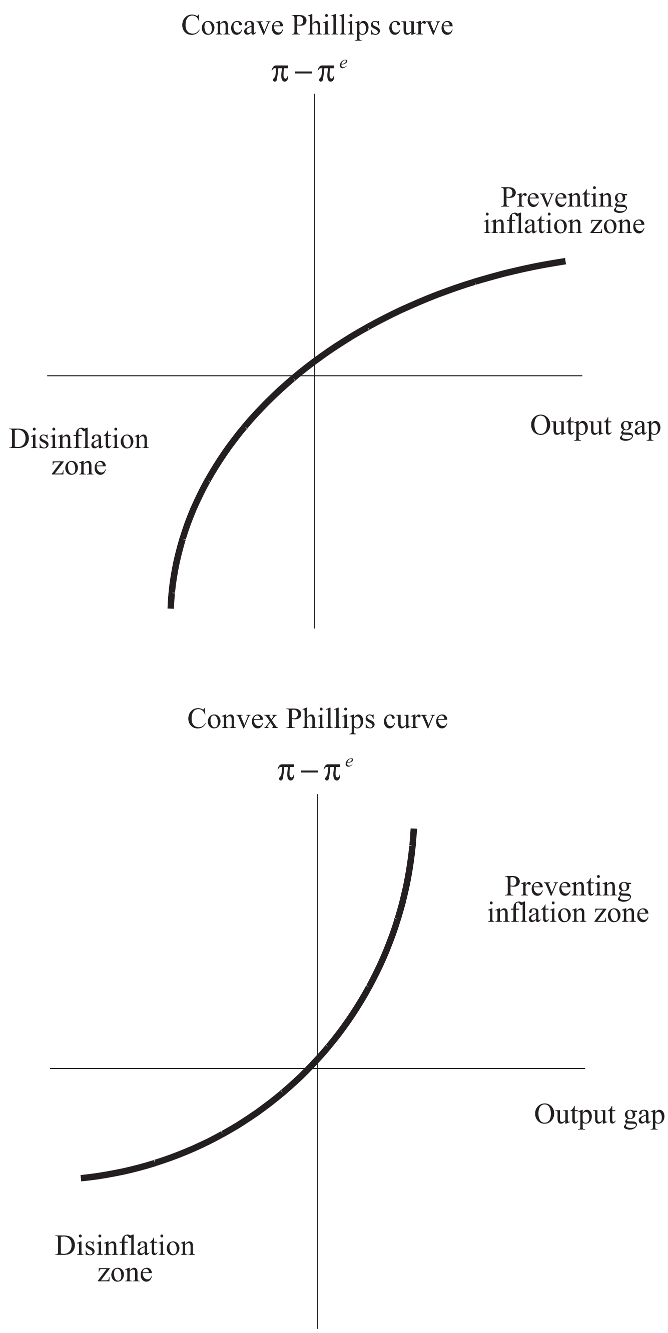
Both nonlinear shapes of the Phillips curve in Figure 2 have intuitive and theoretical appeal. The top panel in Figure 2 shows a concave Phillips curve—which graphically translates into an upward sloping curve that flattens as output rises relative to trend. Intuitively, the concave curve's flattening slope reflects the declining sensitivity of inflation to the strength of the economy. The flattening slope also means that a given change in inflation requires an increasingly bigger adjustment in output.

Theoretically, a concave Phillips curve is consistent with an economy where firms are not purely competitive. If firms have some pricing power and thus the ability and desire to influence their market share, they will be more reluctant to raise prices than to lower them. In this case, firms will respond to an increase in economic activity with more muted price changes and larger output changes than to a similar decrease in economic activity.[11] The reduced sensitivity of inflation as the economy strengthens implies the shape of the Phillips curve is concave.

Another possible shape of the nonlinear Phillips curve is convex. The bottom panel in Figure 2 shows the shape of a convex Phillips curve—which graphically translates into an upward sloping curve that steepens as output rises relative to trend. Intuitively, the steepening slope indicates increased sensitivity of inflation to the economy's strength. As the slope of the convex curve steepens, inflation becomes more sensitive because a given change in inflation requires a progressively smaller output adjustment.

Theoretically, the convex Phillips curve is consistent with an economy subject to capacity constraints. In such an economy, inflation will

Figure 2
TWO THEORETICAL SHAPES OF NONLINEAR PHILLIPS CURVES



Note: The output gap is defined as actual output less its trend.

be increasingly sensitive to changes in output as the economy strengthens. As the economy becomes stronger and capacity constraints increasingly restrict firms' ability to expand output, an increase in demand is more likely to show up as higher inflation than as higher output. In contrast, when the economy is weak and firms face fewer capacity constraints, inflation is likely to be less sensitive to output changes; hence the convex shape of the Phillips curve.

Extant evidence of nonlinearity. Several recent studies have begun to document important nonlinearities in the Phillips curve. Early work on G-7 countries by Turner (1995) and Laxton, Meredith, and Rose (1995) found evidence of nonlinearity in several countries, including the United States. These authors reported that the slope of the U.S. Phillips curve steepens as the economy strengthens—a finding consistent with a convex curve. These authors noted, however, that evidence of nonlinearity depends critically on the specification of the model and careful measurement of the output gap.[12]

Evidence of another form of nonlinearity has also been found. Eisner (1997b) reported results that are consistent with a concave Phillips curve.[13] He argued that inflation's sensitivity falls as the economy strengthens because, at high levels of output and employment, efficiency enhancing efforts hold down increases in unit labor costs, thereby lessening inflationary pressures. In addition, Stiglitz (1997), citing unpublished research from the Council of Economic Advisers, concluded that U.S. data provide some evidence of a concave Phillips curve.

Nonlinear Phillips curves and the output cost of fighting inflation. Different shapes of the nonlinear Phillips curve have different implications for the output cost of fighting inflation. Because the slopes of the concave and convex Phillips curves vary systematically with the strength of the economy, they imply that the output cost of fighting inflation varies with the strength of the economy. The concave Phillips curve implies that the cost of fighting inflation rises with the strength of the economy because as the economy strengthens its slope flattens. In contrast, the convex Phillips curve implies that the cost of fighting inflation falls with the strength of the economy because its slope steepens.

Recognizing such output cost differences between the shapes is important for assessing the output cost of deliberate disinflation and of preemptively resisting rising inflation. The output cost of deliberate disinflation depends on the shape of the Phillips curve when the economy is below trend, and the output cost of preemptively resisting rising inflation depends on the shape of the Phillips curve when the economy is above trend. A concave curve implies that a policy to preemptively resist rising inflation of a given size is more costly than a policy to deliberately disinflate. In contrast, a convex Phillips curve implies that a policy to deliberately disinflate would be more costly than one to preemptively resist a similar rise in inflation. The next two sections discuss new estimates of the shape of the curve and implications for policy.

II. NEW EMPIRICAL EVIDENCE ON THE OUTPUT COST OF FIGHTING INFLATION

This section presents new empirical evidence on the shape of the Phillips curve and the output cost of fighting inflation. The section first estimates a Phillips curve using data through 1997 and allowing for nonlinearity. The particular form of the nonlinearity is quite flexible and may help explain the apparently contradictory extant evidence on the shape of the Phillips curve.

The estimated Phillips curve is then included in a system of equations that describes the macroeconomy. The system is simulated to calculate the output cost of fighting inflation. To help summarize the results, the section introduces a new cost measure called the cost of fighting inflation

TRADITIONAL LINEAR PHILLIPS CURVE

This box describes the linear Phillips curve and draws inferences about the output cost of fighting inflation. The Phillips curve traditionally has been assumed to be linear for two key reasons. First, many analysts have viewed the assumption of linearity as empirically reasonable (Gordon 1997).[14] They have argued that linear models produce good out-of-sample forecasts and provide a reasonable framework to analyze policy issues. Second, linear models are relatively easy to estimate and simulate, thereby simplifying the calculation of the cost of fighting inflation.

The key assumption behind the linear Phillips curve is that inflation depends on three key economic factors: inflation expectations, resource utilization pressures, and supply shocks. While many alternative specifications of the curve have been proposed since the pioneering work by A.W. Phillips in 1958, the basic linear Phillips curve can be described algebraically as follows:

$$\pi_t = \pi_t^e + \beta(y_t - y_{trend}) + \varepsilon_t .$$

In this equation, inflation (π) is the percentage change in the aggregate price level, expected inflation (π^e) is a forecast at t-1 of inflation at time t, the output gap (y_t-y_{trend}) is a measure of the cyclical strength of the economy, and supply shocks (ε) are other factors that have temporary effects on inflation, such as oil shocks and exchange rate changes. The coefficient β measures the sensitivity of inflation to changes in the output gap.

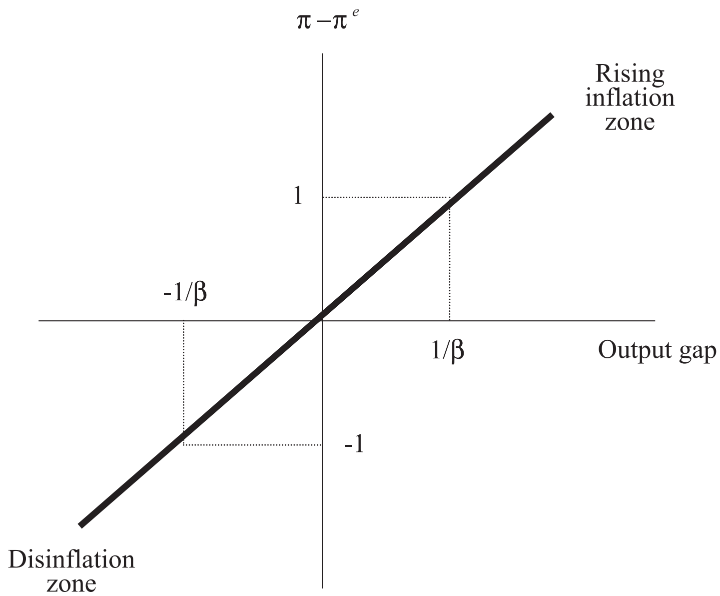
In this framework, deliberate monetary policy actions influence inflation in a fairly limited and indirect way. An easing of monetary policy boosts economic activity relative to trend, while a tightening of monetary policy has the opposite effect. Because β is a positive number, easier monetary policy causes inflation to rise and tighter monetary policy causes inflation to fall. Overall, deliberate policy actions largely affect inflation through the output gap channel in the short run. In the long run, monetary policy works primarily through the expected inflation channel.

The output gap's relationship to inflation can be simplified by setting supply shocks to zero and abstracting from the determinants of inflation expectations. This leads to a Phillips curve equation that yields a relationship between unexpected inflation changes and the output gap,

$$\pi_t = \pi_t^e + \beta(y_t - y_{trend}).$$

The figure in this box illustrates this linear Phillips curve. The upward slope of the curve signifies the positive tradeoff between inflation and the strength of economic activity. In the southwest quadrant, economic activity is weak (output below trend) and inflation tends to fall. In the northeast quadrant, economic activity is strong (output above trend) and inflation tends to rise.

The Phillips curve determines the output cost of fighting inflation in the southwest quadrant of the figure. In this quadrant, TRADITIONAL LINEAR PHILLIPS CURVE - *continued*



deliberate disinflation is associated with weak economic activity. To deliberately lower inflation, tight monetary policy must lower output below trend. Assuming for simplicity that all adjustments occur in one period, the curve indicates that a one-percentage-point reduction in inflation would require output to fall $1/\beta$ percent below its trend. Thus, the output cost or sacrifice ratio is $1/\beta$.

The output cost of deliberately preventing inflation from rising is more subtle than the cost associated with a deliberate disinflation. The output cost of preventing an increase in inflation is not a direct cost but rather an opportunity cost. To see this, imagine an economy that is at its trend but has considerable underlying strength. In the absence of tighter monetary policy, economic activity would surge above its trend, thereby causing inflation to rise. A tighter monetary policy could prevent the rise in inflation if it forestalls the surge in output. The cost of such a policy is the foregone opportunity of higher output (and its related benefits, such as higher consumption and lower unemployment). The northeast quadrant in the figure illustrates the calculation of the opportunity cost. The curve shows that a $1/\beta$ percent increase in economic activity above trend is associated with a one-

TRADITIONAL LINEAR PHILLIPS CURVE - *continued*

percentage-point rise in inflation. If monetary policy can be tightened to prevent the economy from overheating, the economy would continue to grow along its trend. With the economy growing along its trend, inflation does not rise. However, consumers, workers, and investors would forego the temporary benefits of output being $1/\beta$ percent above trend.

To be sure, the relationships among inflation, output, and monetary policy are not as perfect and exploitable as these examples might suggest. In the real world, there are many factors that need to be considered when determining short-run inflation behavior. The factors include the speed of adjustment of inflation expectations, the size and persistence of supply shocks, and the long and variable lags of monetary policy. To capture these factors in a figure would be difficult and would obscure insights from the Phillips curve into the costs of fighting inflation. Empirical methods used later in this article account for these factors.

(COFI) ratio. This measure summarizes the output cost associated with a deliberate disinflation strategy as well as a strategy to prevent inflationary pressures from causing inflation to rise.

Estimated shape of the nonlinear Phillips curve

This section offers a more flexible Phillips curve specification than in previous studies by extending the specification by Clark, Laxton, and Rose (1995).[15] The specification allows the inflation-output relationship to differ across three rather than two regimes. The three regimes correspond to economic periods when output is well below trend (weak), near trend (balanced), and well above trend (overheated).

Nonlinear specification. The nonlinear Phillips curve captures the statistical relationships among inflation, economic activity, inflation expectations, and supply shocks. Algebraically, the curve can be written as

$$\begin{aligned}\pi_t = \pi_t^e &+ \beta_{weak} * gap(during\ weak\ times)_{t-1}\\ &+ \beta_{balanced} * gap(during\ balanced\ times)_{t-1}\\ &+ \beta_{strong} * gap(during\ overheated\ times)_{t-1}\\ &+ \varepsilon_t . \qquad (1)\end{aligned}$$

In this equation, π_t is consumer price inflation, π_t^e is inflation expectations, the *gap* is output measured by real GDP less its trend, and ε_t is a supply shock.[16] The slope coefficients on the output gap ($\beta_{weak}, \beta_{balanced}, \beta_{overheated}$) measure the sensitivity of inflation to economic activity in the weak, balanced, or overheated regimes. In contrast, a typical linear Phillips curve is regime independent, implying that $\beta_{weak} = \beta_{balanced} = \beta_{overheated}$.

Because there is no official convention to split the data into the three regimes, the regime dates are estimated using a threshold parameter α. Essentially, α classifies economic activity into three regimes. When output is more than α percent below trend, the regime is considered weak. When output is within α percent of trend, the regime is considered balanced. And when output is more than α percent above trend, the regime is considered overheated. Except for allowing three regimes, the specification is the same as described in the box on the linear Phillips curve. Appendix A describes the estimation details of Equation 1.

The specification in this article is sufficiently flexible to allow various nonlinear Phillips curve shapes. Figure 3 illustrates some possible shapes implied by Equation 1. If the estimated slopes, β_i, decline steadily from the weak-economy regime to the overheated-economy regime, the Phillips curve is concave, as in the top panel. In contrast, if the estimated slopes steadily rise from the weak-economy regime to the overheated-economy regime, then the curve is convex. In this figure, the curves—which are composed of linear line segments—can be thought of as approximations to the concave and convex curves in Figure 2.

Unlike in previous research, the nonlinear Phillips curve specification in Equation 1 also allows shapes that are convex in one region and concave in another region. Figure 4 illustrates this possibility. In Figure 4, the slopes of the Phillips curve vary across the three regimes, but the slopes do not steadily increase or decrease. Inflation in the weak-economy regime is more sensitive to economic activity than in the balanced-economy regime but is less sensitive than in the overheated-economy regime. As a result, when the output gap is less than α, the kinked curve is concave; when the output gap is greater than $-\alpha$, the kinked curve is convex.

Estimated shape. The shape of the Phillips curve is determined by estimates of the slopes and the length of the region associated with the balanced regime. The slopes $(\beta_{weak}, \beta_{balanced}, \beta_{overheated})$ measure the regime-dependent sensitivity of inflation to output; the larger the slope coefficient is, the greater the inflation sensitivity will be to the output gap. The size of the balanced regime is determined by α.

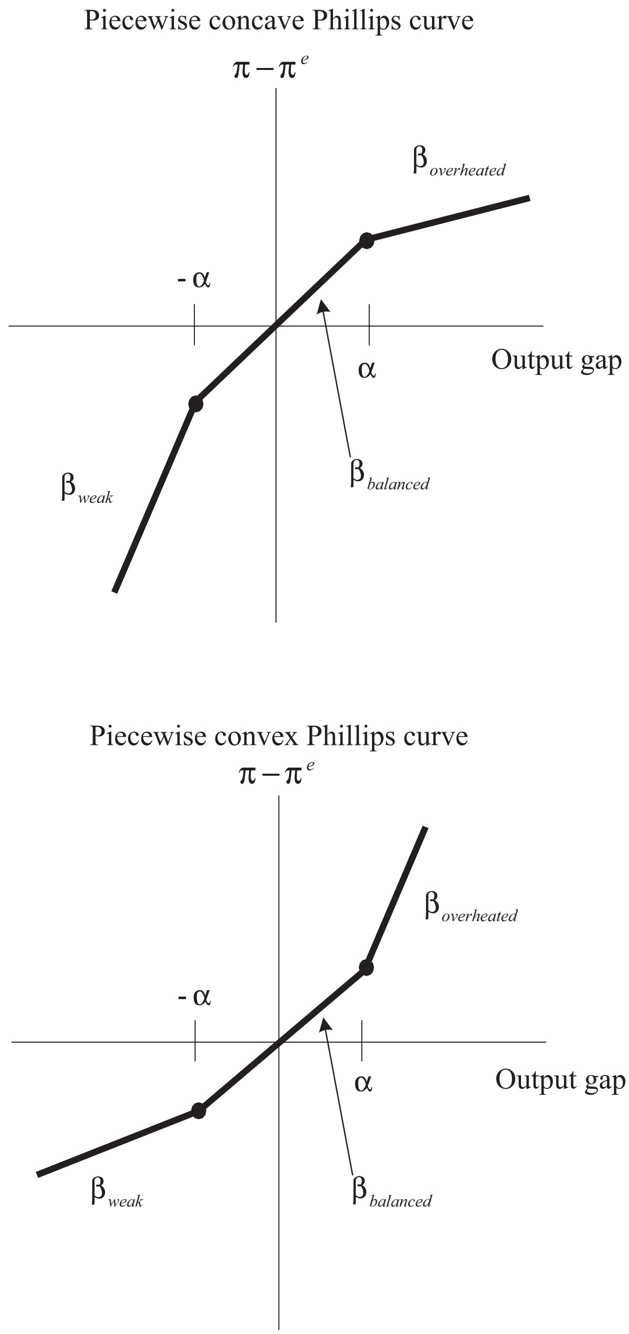
Table 1 summarizes estimation results using data from 1959 to 1997. Slope estimates of the Phillips curve in bold are statistically significant at the 5-percent level. The first three columns report the sensitivity of inflation in the weak, balanced, and overheated regimes, respectively. The R^2 column reports the variation in the inflation data that is explained by the explanatory variables in the estimated equation.

The slope estimates in each of the three regimes illustrate the nonlinear nature of the estimated Phillips curve. In the weak-economy regime, the slope is 0.20. In the balanced-economy regime, the slope is essentially flat. The slight negative coefficient estimate (-0.02) suggests, counterintuitively, that inflation tends to fall in this regime when the economy strengthens; however, the coefficient estimate is statistically indistinguishable from zero. A more intuitive interpretation of this coefficient is that there is not enough systematic evidence in the balanced-economy regime to give a reliable slope estimate.[17] In the overheated-economy regime, the slope is 0.49, more than twice as steep as in the weak-economy regime. In sum, the estimated slopes are neither steadily increasing nor steadily decreasing across the three regimes.

In addition to the slope estimates, the shape of the Phillips curve depends on the size of the weak, balanced, and overheated regimes. The estimate $\hat{\alpha} = 0.9$ implies the size of the balanced-economy regime is fairly wide. The balanced-economy regime occurs when output is roughly a percentage point above or below trend; the weak-economy regime occurs when output is less than a percentage point below trend; and the overheated-regime occurs when output is more than a percentage point above trend. By way of comparison, in recessions output typically falls from 2 to 4 percent below trend, and in exceptionally robust expansions output typically rises from 2 to 4 percent above trend.[18]

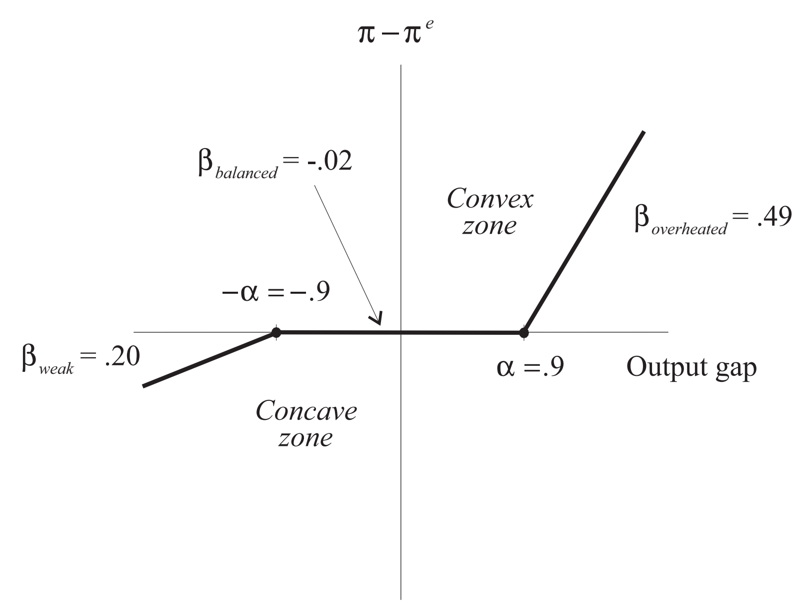
The estimated nonlinear Phillips curve has a

Figure 3
TWO POSSIBLE EMPIRICAL SHAPES OF NONLINEAR PHILLIPS CURVES



Note: In the top panel, $\beta_{weak} > \beta_{balanced} > \beta_{overheated}$. In the lower panel, $\beta_{weak} < \beta_{balanced} < \beta_{overheated}$.

Figure 4
ANOTHER POSSIBLE EMPIRICAL SHAPE OF A NONLINEAR PHILLIPS CURVE



convex region and a concave region. Its shape is therefore consistent with the curve found in Figure 4. When the output is below trend, the curve tends to be concave because the slope falls from 0.20 to -0.02. When the output is above trend, the curve is convex because the slope steepens from -0.02 to 0.49.

Because it has both concave and convex regions, the estimated shape of the three-regime Phillips curve helps reconcile the results of earlier studies on the nonlinear Phillips curve shape. Previous studies used a restrictive two-regime specification that implied either a convex or a concave curve, but not a curve with convex and concave regions. Given the shape of the estimated three-regime Phillips curve, it is not surprising that some earlier studies based on the two regimes found evidence of convexity (Clark, Laxton, and Rose 1995) and some other studies found evidence of concavity (Stiglitz 1997, Eisner 1997a). The evidence of convexity could have arisen in specifications that emphasize inflation and output behavior in the balanced and overheated regimes or the weak and overheated regimes; the evidence of concavity could have arisen in specifications that emphasize inflation and output behavior in the weak and balanced regimes.

Estimated COFI ratios

The output cost of fighting inflation measures the average output loss associated with fighting a given-sized inflation. In the case of disinflation, the COFI ratio is equivalent to the traditional sacrifice ratio. In the case of incipient inflation pressures, the COFI ratio measures the opportunity cost of forgone output associated with preemptively fighting the pressure. In both

Table 1

ESTIMATES OF NONLINEAR PHILLIPS CURVE: 1959-97

Sensitivity of inflation to the output gap

Dependent variable	Three regimes: Weak economy	Balanced economy	Overheated economy	
	$\hat{\beta}_{weak}$	$\hat{\beta}_{balanced}$	$\hat{\beta}_{overheated}$	R^2
CPI inflation	**.20**	-.02	**.49**	.96
	(3.98)	(-.23)	(5.95)	

Notes: The estimates in bold indicate statistical significance at the 5-percent level. The t-statistics are in parentheses. Output gap is the deviation of real GDP from its Hodrick-Prescott trend. The other parameters in the model are $\hat{\pi}_0 = -.14\,(-1.82), \hat{\alpha} = .9$ and $\hat{\delta} = 0.16\,(2.15)$. A test of the hypothesis that $\hat{\beta}_{weak} = \hat{\beta}_{overheated}$ is rejected at the 5-percent level. A linear specification of the Phillips curve yields coefficient estimates of $\hat{\pi}_{0,linear} = -.04\,(-.69)$, $\hat{\beta}_{linear} = .18\,(7.07)$, and $\hat{\delta}_{linear} = .10\,(1.56)$.

cases, the estimated COFI ratio depends on the shape of the Phillips curve. As might be expected, COFI ratios based on the nonlinear model are much more complicated to estimate and describe than the COFI ratio based on the linear model. A linear model produces a single COFI ratio that is independent of the economy's strength and of the size of the disinflation or the strength of the incipient inflation pressures being fought. In contrast, nonlinear models produce COFI ratios that depend on these factors. To account for these factors, this article simulates a simple, yet conventional, model of the macroeconomy that includes the estimated regime-dependent Phillips curve. COFI ratios are directly measured by the responses of output and inflation to different simulated changes in monetary policy.[19] Appendix A outlines technical details of the model and simulations. To simplify the presentation of the simulation results, the section first describes the COFI ratios for simulations where the economy does not switch regimes, and then describes the COFI ratios for more complicated, but more realistic simulations, where the economy switches regimes.

Within-regime COFI ratios. The within-regime COFI ratios can be thought of as the cost of fighting inflation if the economy were to remain in one regime and not switch to another. Table 2 reports the regime-dependent COFI ratios associated with the response of output and inflation to tighter monetary policy. The first and third columns show that the COFI ratios vary systematically. The output cost of disinflation in the weak regime (5.0 percent of GDP) is higher than the cost of preemptively forestalling the economy from operating in the overheated regime and thus preventing rising inflation (2.1 percent of GDP). The qualitative difference can be traced back to the different slopes of the nonlinear Phillips curve in each regime.[20] The flatter slope in the weak regime implies a larger output cost of fighting inflation than in the overheated regime. The quantitative difference between the estimated within-regime COFI ratios is plausible. The COFI ratio for the weak economy is higher than Ball's and King and Gordon's estimates but lower than Okun's for disinflations, and the ratio for the overheated regime is somewhat higher than Jordan's estimate.

The second column in the table indicates a difficulty in measuring the output cost associated

Table 2

COFI RATIO ESTIMATES FOR THREE REGIMES

Output cost of fighting inflation within each regime

Nonlinear model — three regimes			Linear model
Weak economy	Balanced economy	Overheated economy	
$COFI_{weak}$	$COFI_{balanced}$	$COFI_{overheated}$	$COFI_{linear}$
5.0	*	2.1	5.7

* The slope of the Phillips curve in the balanced economy is essentially flat. If the point estimate were exactly zero, the COFI ratio would be infinite because a small change in inflation is associated with a big change in real activity.

Notes: Each column reports the COFI ratio in each of the three regimes. $COFI_{weak}$ is equivalent to the more commonly known sacrifice ratio; $COFI_{overheated}$ is equivalent to the cost of fighting incipient inflation ratio; $COFI_{linear}$ in the linear model constrains the sacrifice ratio and cost of fighting incipient inflation ratio to be the same. In each row, the COFI ratio is measured as the accumulated output loss divided by the cumulative decline in inflation at each horizon. The linearity of the Phillips curve in each regime implies that the within-regime COFI ratio is the equivalent of the reciprocal of the Phillips curve slope coefficient in each regime. The variance-covariance matrix was estimated using maximum likelihood methods for the nonlinear system of equations described in Appendix A.

with the balanced regime. If the economy stays in the balanced regime and the slope were truly zero, the within-regime $COFI_{balanced}$ ratio by definition would approach infinity. Such a result is inevitable because the COFI ratio measures the output loss per percentage point of inflation change.[21] Since the inflation change in the balanced regime is zero for any given change in output, the ratio is infinity. It is more intuitive to think about the flat portion of the Phillips curve as indicating the cost of initiating a disinflation. For example, if the economy were growing along its trend so that the output gap were zero, output could fall α percent below trend and remain up to α percent below trend indefinitely without any change in the inflation rate. It takes output losses greater than α percent to initiate a disinflation.[22]

The last column in Table 2 reports the COFI ratio from a linear Phillips curve model. There are two key differences between linear and nonlinear models. First, the single $COFI_{linear}$ ratio from the linear Phillips curve model does not vary with the business cycle as does the within-regime COFI ratios from the nonlinear model. Second, the $COFI_{linear}$ ratio (5.7 percent of GDP) is greater than COFI ratios in both the weak and overheated regimes. The difference reflects the flatter slope of the linear Phillips curve than the slope of the nonlinear Phillips curve in the weak and overheated regimes.

Across-regime COFI ratios. Because most inflation fighting strategies are likely to cause the economy to switch regimes, it is useful to calculate across-regime COFI ratios. One particularly interesting output cost calculation is one associated with deliberate disinflation policies initiated when the economy is growing along its trend. Such an output cost calculation, however, is quite complicated because of regime switching. Complications arise because the output cost depends on the exact path of the economy and on the number of regime switches as the economy returns to its trend. Simulations can account for these computational complications and provide insights into the output cost of fighting inflation.

Table 3

EXAMPLES OF ACROSS-REGIME COFI RATIOS

COFI ratios based on initial strength of business cycle and on size and type of inflation change

	Average output cost of fighting inflation*		
	Initial strength of the economy (percent)		
	$\frac{1}{2}\alpha$ Below trend	At trend	$\frac{1}{2}\alpha$ Above trend
Size of disinflation			
1 percent	7.0	9.8	12.6
2 percent	5.6	7.0	8.1
Strength of incipient inflation pressure			
1 percent	15.0	7.3	4.8
2 percent	5.4	4.8	3.2

* The average cost is defined as the cost per percentage point of inflation reduction, or COFI ratio.

Notes: This table is based on the estimated nonlinear Phillips curve similar to Figure 4. With such a Phillips curve, the cost of fighting inflation depends on the stage of the business cycle, the size of the disinflation, and the size of the potential inflation change. The output gaps indicate the initial condition for the simulations. Output gaps of $\alpha/2$, 0, and $\alpha/2$ represent three possible starting points in the balanced regime; the estimated $\alpha = 0.9$.

If the Phillips curve is linear, the average cost of fighting inflation is independent of the strength of the economy and the size and type of inflation change. The $COFI_{linear}$ is 5.7.

Appendix B explains why the across-regime COFI ratios are conceptually more complicated than the within-regime COFI ratios.

Simulations show that $COFI_{across\text{-}regime}$ ratios for deliberate disinflations and preemptive fights against incipient inflation pressures depend on the initial strength of the economy and the size of the potential inflation change. Table 3 reports across-regime COFI ratios from these simulations. Reading across Table 3, the cost of fighting inflation systematically varies with the initial strength of the economy. To illustrate this point, the table reports COFI ratios that correspond to three different starting points for the economy. The benchmark case is when the economy starts at trend (output gap is zero). One alternative corresponds to a relatively weak economy which starts out -0.45 percent below trend (i.e., output gap equals $-\alpha/2$) and to a relatively strong economy starting 0.45 percent above trend.

In the case of disinflation, the output cost increases as the initial strength of the economy increases. A 1-percent disinflation costs 7.0 percent of output if initiated when the economy is slightly below trend (output gap = $-\alpha/2$), 9.8 percent when the economy is at trend (output gap = 0), and 12.6 percent when the economy is slightly above trend (output gap = $\alpha/2$). Intuitively, the stronger is the economy, the greater is the output loss necessary to achieve a given disinflation.[23]

In contrast, the output cost of preemptively fighting incipient inflation decreases as the initial strength of the economy increases. Table 3 indicates that preventing a one-percentage-point increase in inflation costs 15 percent of output when the economy is initially below trend, 7.3 percent when the economy is initially at trend, and 4.8 percent when the economy is initially above trend. The simulation results reflect the sizes of the implicit economic forces that monetary policy must offset to avert a rise in inflation. Intuitively, the strength of economic forces associated with a weak economy must exceed those associated with a stronger economy if both would produce a given rise in inflation. Moreover, the stronger the economic forces that would propel the economy into the overheated regime, the stronger the preemptive monetary policy response must be to prevent rising inflation; and thus, the larger will be the foregone output.

The simulations in the table (reading down the columns) also indicate that the cost of fighting inflation decreases as the size of the desired inflation change increases. In the case of disinflation, when the economy starts at trend, the output cost per percentage point reduction in inflation is 7.0 percent for a two-percentage-point disinflation and 9.8 percent for a one-percentage-point disinflation. Thus, the cost for each percentage point reduction of inflation of a two-percentage-point disinflation is lower than for a one-percentage-point disinflation. In the case of a preemptive fight against incipient inflation, the same result applies. Fighting a potential two-percentage-point rise in inflation, on average, costs less per percentage point of incipient inflation than a one-percentage-point rise.

In sum, Table 3 shows that the across-regime COFI ratios are fairly complicated but help describe how the output cost of fighting inflation changes with the economy's strength, size of potential inflation change, and type of anti-inflation policy. Though more complicated, the COFI ratios for the nonlinear model provide a richer picture of the output cost than a standard linear Phillips curve.

III. POLICY IMPLICATIONS OF THE NEW EVIDENCE

The reported COFI ratios provide new evidence on the output cost of fighting inflation. Taken at face value, they may shed new light on how best to achieve and maintain low inflation. In particular, the evidence has implications for traditional views on the output cost of fighting inflation, the timing and speed of deliberate disinflations, the benefits of preemptive monetary policy, and the merits of monetary policy experimentation.

New view on the aggressiveness of fighting inflation

The flat portion of the nonlinear Phillips curve has important implications for policies on fighting inflation. For example, the output cost implied by the traditional linear model overestimates output loss when the economy is in either the weak or overheated regimes. When the economy is well below trend, the COFI ratio is 5.0, and when the economy is well above trend, the COFI ratio is 2.1. However, the linear model produces a COFI ratio estimate of 5.7 for both regimes. Thus, if the economy were in one of these two regimes, the nonlinear model's lower cost of fighting inflation would suggest a more aggressive stance of policy against inflation than would be implied by a linear Phillips curve model. Moreover, the COFI ratio for the balanced regime is much greater for the nonlinear model than for the linear model. In general, the results of this article show that the linear Phillips curve may provide misleading signals about the cost of fighting inflation and, thus, the appropriate stance of policy.

In addition, changes in regime complicate the comparison of the nonlinear and linear models. Despite the result that the COFI ratio for the weak regime is 5.0, Table 3 shows that when output starts at its trend (in equilibrium), a one-percentage-point disinflation involves an output cost of 9.8 percentage points of output, but only 5.7 percentage points if the curve is linear. Moreover, Table 3 shows that the COFI ratios from the nonlinear model depend on the strength of the economy and on the size of the potential inflation change.

In some cases, the nonlinear model indicates higher costs of fighting inflation than the costs implied by the linear model. In other cases, the opposite is true. Thus, in terms of inflation fighting policy, the nonlinear model will at times imply a more aggressive fight against inflation and at other times a less aggressive fight than implied by the linear model. The lesson for monetary policy is that the output cost and stance of policy have to be evaluated on a case-by-case basis.

Implications for timing of deliberate disinflation

The flat portion of the Phillips curve also has implications for the timing of deliberate disinflations. The linear Phillips curve indicates that once output is below trend, inflation pressures fall. Since it is generally thought that the costs of disinflation not directly related to output grow as the economy weakens (for example, economic dislocations such as bankruptcies and unemployment), the overall costs of deliberate disinflation might be minimized by keeping the economy below, but near, trend.

The nonlinear curve offers a quite different prescription. The flat portion of the curve indicates that pursuing disinflation by pushing the economy slightly below trend is unwise. Such a policy would generate output losses but no progress toward price stability because the economy has to operate well below its trend before any benefits of disinflation can be achieved.[24]

The nonlinear Phillips curve suggests two relatively unpleasant options for the timing of deliberate disinflation: a large tightening when the economy is near (or above) trend or a small tightening when the economy is weak. The large, and possibly severe, tightening implies a large output loss and raises the possibility of uncontrollably sharp adjustments in economic activity. In the past, severe tightenings have at times been associated with recessions. The small tightening, while more controllable, offers the prospect of driving a weak economy even weaker. Ultimately, the desirability of pursuing either option has to be compared with other costs related to weak economic activity and with the benefits of disinflation.[25]

Gradualism versus "cold turkey"

The output cost of disinflation may vary with the speed of a given disinflation. Despite many studies of disinflation, no consensus has formed among economists about whether a gradual reduction in inflation is less costly than a rapid decline (often called a cold turkey strategy). Sargent (1983) and Ball (1994), for example, report evidence in favor of the cold turkey strategy. In their studies, a monetary authority's inflation fighting credibility plays an important role in determining the costs of disinflation. A rapid disinflation enhances a monetary authority's credibility, thereby lowering the average cost of disinflation.[26]

King (1996), however, raises the point that the credibility dividend may not be available to nations such as the United States. He argues pragmatically that a monetary authority in a low-inflation environment does not have the opportunity to enhance its credibility with a large, rapid disinflation. Without the possibility of such a disinflation, the shape of the Phillips curve largely determines the output cost of disinflation. King notes that gradualism is the low-cost strategy if the Phillips curve is convex. If the Phillips curve is concave, cold turkey is the low-cost strategy.

Because the estimated Phillips curve in this article is concave when output is below trend, the cold turkey strategy is the low-cost strategy for a deliberate disinflation. Table 3 corroborates the cost advantage of the cold turkey approach. The table shows that the average cost of a two-percentage-point disinflation is generally less costly per percentage point of disinflation than a one-percentage-point disinflation.[27]

Benefits of preemptive monetary policy

The estimated nonlinear Phillips curve in this article illustrates the benefit of preemptive policies. If the economy were to temporarily grow well above its trend, output would be temporarily high but inflation would rise. Deliberately disinflating to lower the inflation rate to its previous rate would then require a temporary reduction of output below trend. In fact, the estimated shape of the nonlinear Phillips curve indicates that the reduction in output would have to more than offset the temporary rise in output to return inflation to its previous rate. Thus, there is an output cost of permitting inflation to drift upward.

Policymakers may be able to avoid such costs if they are able to foster conditions that would keep the economy balanced.[28] Policies that foster balanced growth along the economy's trend are most likely to maintain stable inflation and eliminate the need to engage in costly inflation fighting. However, fostering conditions for near-trend growth is easier said than done. It is generally accepted that monetary policy affects the economy with long and variable lags. Thus, preemptive policies are needed to respond to the early signs of rising inflationary pressures. Of course, the effectiveness of these policies depends on the accuracy with which incipient inflationary pressures are measured.

Policy "experimentation"

The issue of policy experimentation has taken on special importance recently. Some economists have argued that the economy in the 1990s experienced a structural change which has altered the traditional relationship between output and inflation. In particular, the labor productivity trend has perhaps become steeper because of increased investment in computers, strong business fixed investment, and widespread downsizing (Filardo 1995). If the productivity trend were stronger, the Federal Reserve could accommodate output above its historical trend without sparking inflation. Since the structural change is not known with certainty, this policy would be somewhat speculative.

Stiglitz (1997) raises the possibility that such policy experimentation can enhance economic welfare. On the one hand, by avoiding preemptive policies that deliberately seek to slow output toward its historical trend, the Federal Reserve could make people better off by allowing the average level of output to exceed its historical trend. If a structural change had occurred, average output would rise and inflation would remain subdued. If there had not been structural change, average output may still rise without a permanent increase in the inflation rate.

The effect of the accommodative policy on the average level of output depends on the shape of the Phillips curve. If the Phillips curve is concave, the increase in output that generates higher inflation would be greater than the subsequent decline in output that would return inflation to its previous rate. As a result, the average level of output would rise. If the Phillips curve is convex, however, this fortuitous relationship does not exist. In this case, to return inflation to its previous level, the initial rise in output would be smaller than the subsequent decline in output. Thus, to deliver output benefits, the Phillips curve must be concave.

On the other hand, such policy experimentation can also reduce economic welfare by increasing uncertainty about short-run inflation because the structural change is not known with certainty. Overall, the net benefit of policy experimentation depends, as Stiglitz points out, on the Phillips curve being sufficiently concave to more than offset the costs of the increased inflation risk.

While Stiglitz's argument is theoretically sound, its practical importance rests on empirical evidence of concavity. At the time, Stiglitz noted that the evidence supporting concavity was simply "mild" and suggestive. This led him to conclude tentatively that "even risk-averse policymakers may want to engage in moderate experiments."[29] However, does Stiglitz's conclusion still hold when only a portion of the Phillips curve is concave as reported in this article? In general, the answer is no. Stiglitz's conclusion depends on the Phillips curve being concave when the economy is above trend. The estimated shape of the Phillips curve in this article exhibits convexity when the economy is above trend and concavity only when the economy is operating below trend. Thus, the evidence presented in this article suggests that experimentation is undesirable.

In summary, the new evidence on the cost of fighting inflation has several implications for monetary policy. Policies should be more proactive than those implied by the traditional models, but the more proactive policies should not include policy experimentation.

IV. CONCLUSION

Accurately assessing the output cost of fighting inflation plays an important role in determining the appropriate policy to achieve and ultimately maintain price stability. The estimated Phillips curve in this article offers a new perspective on the output cost. The estimated shape of the curve suggests that inflation and output are related in a complicated, nonlinear way. In particular, the curve is found to be concave when the economy is operating below trend and convex when above trend.

Such a shape implies that the output cost of fighting inflation is more complex than previously thought. The output cost is found to depend critically on the strength of the economy, the size of the inflation change, and whether policymakers seek to disinflate or prevent inflation from rising. This new evidence may help policymakers assess more precisely the output cost of fighting inflation than in the past. When devising future strategies, however, policymakers must still weigh this new evidence against the other costs and benefits of fighting inflation.

APPENDIX A
MODEL DESCRIPTION AND ESTIMATION

This appendix describes the multivariate system of equations, model estimation, and simulation methods used to calculate the COFI ratios.

Nonlinear system of equations

A six-equation-system derivative of that in Christiano, Eichenbaum, and Evans (1994) is used to describe macroeconomic activity. The dependent variables of the system are the contemporaneous values of real GDP relative to trend, inflation, commodity prices, inflationary expectations, the federal funds rate, and the ratio of nonborrowed reserves to total reserves. The explanatory variables for all these equations (except for the inflation equation) include the lags of these variables. The key difference between Christiano, Eichenbaum, and Evans's system (CEE) and the system in this article is that the article's inflation equation is specified to be the nonlinear Phillips curve relationship used in the second section.[30]

The article assumes that inflation is a piecewise linear function of the output gap, and that expectations slowly adjust. In particular, inflation expectations are assumed to have the following form:

$$\pi_t^e = \pi_0 + \pi_{t-1} + \delta(\pi_{t-1}^e - \pi_{t-1}).$$

The inflation expectation specification has an intuitive interpretation. The π_0 term is a constant inflation premium, reflecting the average empirical deviation of survey inflation expectations from actual inflation.[31] Some theories predict that survey inflation expectations may be biased measures of inflation if the public is skeptical of the Federal Reserve's commitment to fight inflation.[32] The $\pi_{t-1} + \delta(\pi_{t-1}^e - \pi_{t-1})$ term captures the empirical observation that changes in inflation are sluggish. Expectations sluggishly adjust to a new equilibrium inflation rate because π^e depends on last period's inflation rate and the realized error in last period's expectation from the actual inflation rate.

Substituting this expectation formation equation into the general nonlinear Phillips curve relationship and rearranging terms yield the following three-regime Phillips curve:

$$\begin{aligned}\pi_t - \pi_{t-1} = \pi_0 &+ \delta(\textit{last period's inflation forecast error}) \\ &+ \beta_{neg}(\textit{lagged output gap} \times I_{neg}) \\ &+ \beta_{balanced}(\textit{lagged output gap}) \\ &+ \beta_{pos}(\textit{lagged output gap} \times I_{pos}) + \varepsilon_t\end{aligned}$$

$$\begin{aligned}= \pi_0 &+ \delta(\pi_{t-1}^e - \pi_{t-1}) \\ &+ \beta_{weak}\, gap(\textit{weak times})_{t-1} \\ &+ \beta_{balanced}\, gap(\textit{balanced times})_{t-1} \\ &+ \beta_{overheated}\, gap(\textit{overheated times})_{t-1} \\ &+ \varepsilon_t\end{aligned}$$

$$\begin{aligned}\text{where } & gap(\textit{weak times})_{t-1} \\ &\quad = gap_{t-1}, \textit{ if } gap_{t-1} \le -\alpha \\ &\quad \textit{otherwise} = 0 \\ & gap(\textit{balanced times})_{t-1} \\ &\quad = gap_{t-1}, \textit{ if } -\alpha < gap_{t-1} \le \alpha \\ &\quad \textit{otherwise} = 0 \\ & gap(\textit{overheated times})_{t-1} \\ &\quad = gap_{t-1}, \textit{ if } gap_{t-1} > \alpha, \\ &\quad \textit{otherwise} = 0\end{aligned}$$

APPENDIX A - *continued*

In this equation, the indicator functions I_{neg} and I_{pos} take on a value of 1 if the output gap data come from the regime associated with the weak and overheated regimes, respectively.[33] Otherwise the indicator functions are zero. Econometrically, the use of the indicator functions forces the three line segments to be joined at common knot-point (rather than being disjointed). The difference between the actual regression equation and the form of the equation in the second section is a minor redefinition. The coefficient estimates for each regime are defined as $\beta_{weak} = \beta_{neg} + \beta_{balanced}$ and $\beta_{overheated} + \beta_{pos} + \beta_{balanced}$.[34]

Nonlinear system estimation, impulse responses, and calculating COFI ratios

The estimation strategy is also somewhat more involved than the usual VAR structure of CEE. This model is a nonlinear system of equations which requires more than equation-by-equation ordinary least square methods. The parameters of the system of equations are jointly estimated with nonlinear least squares. Despite the nonlinearity estimation of the parameters, the model in each regime is essentially linear in the explanatory variables. Thus, the impulse responses for each regime are generated in a manner similar to a standard VAR. In addition, innovations in this system are assumed to be recursive (allowing the Choleski decomposition of the estimated variance-covariance matrix to be used).

The COFI ratios are measures of the output cost of fighting inflation. In this model, inflation will be affected by innovations in any of the equations. Of particular interest are changes in the inflation rate caused by innovations to the federal funds rate equation. As is standard in the CEE-type model of monetary policy, innovations to the federal funds rate equation are taken as measures of the change in monetary policy. Positive innovations are thought to represent unexpectedly tighter monetary policy and negative innovations represent unexpectedly easier policy.[35]

In this framework, the COFI ratios are measured as a ratio of the response of output relative to the response of inflation following an innovation to the federal funds rate.[36] Following Gordon and King (1982) and Cecchetti (1994), the ratio is defined relative to the following moving average representations of the estimation model:

$$y_t = A(L)\nu_t$$

where $A(L)_{i,j} = \sum_{j=1}^{J} a_{i,j} L^j$, for $i = \{gap, \pi, com, \pi^e, ff, m\}$. This equation provides enough structure to calculate the COFI ratio in each regime. There are several steps in the calculation. First, the cumulative impact of a federal funds equation shock on output after τ periods is measured by $\frac{\Delta y_{gap}}{\Delta \nu_{ff}} = \sum_{i=1}^{\tau} a_{gap,ff}$. Second, the cumulative impact of a federal funds equation shock on inflation is $\frac{\Delta y_{\pi}}{\Delta \nu_{ff}} = \sum_{i=1}^{\tau} a_{\pi,ff}$. The COFI ratio can then be calculated as

APPENDIX A - *continued*

$$COFI(\tau) = \frac{\Delta y_{gap}}{\Delta y_{\pi}} = \frac{\sum_{i=0}^{\tau} a_{gap,ff}}{\sum_{i=0}^{\tau} a_{\pi,ff}}.$$

These measures of the cost of fighting inflation are somewhat more complicated than in the traditional structural model because of the regime dependence. This article takes a two-step approach to characterize the basic results. First, COFI ratios for each regime are calculated assuming the economy remains in the regime that it starts in. Table 2 reports the within-regime COFI ratios. Second, COFI ratios for policy simulations are reported for monetary policy shocks that cause the economy to switch regimes. The two types of simulations help provide insights into how the output cost can vary with the business cycle and with the type of inflation fighting strategy.

APPENDIX B

COST COMPONENTS OF THE ACROSS-REGIME COFI RATIO

The nonlinear Phillips curve suggests that the total cost of fighting inflation can be thought of as including fixed, marginal, and transitional costs. To simplify the discussion in this appendix, the case of disinflation is highlighted. The arguments also apply to the case of fighting incipient inflation.

A simple framework

The fixed cost corresponds to the flat portion of the estimated Phillips curve and can be thought of as the cost the economy must pay each period to initiate a disinflation. It is independent of the size of the disinflation sought.

The marginal cost of a disinflation corresponds to the slope of the Phillips curve in the weak regime. Once the fixed cost is paid, any additional output loss in a period is a marginal cost because there is an inflation-output tradeoff. The marginal cost of disinflation is within-regime $COFI_{weak}$.

Finally, the transitional cost corresponds to output losses that do not generate inflation reductions. Such costs are incurred as the economy returns to trend and passes through the balanced regime. When in this regime, the economy experiences output losses that do not generate changes in inflation. In theory, an inflation fighting strategy would try to eliminate these costs. In practice, these costs are impossible to eliminate and can be large. These costs arise because monetary policy is not a precise instrument. Monetary policy can alter output conditions to lower inflation but cannot perfectly control output adjustments. In other words, monetary policy cannot engineer a disinflation with an exact one-period output adjustment.

In sum, the three key cost components associated with across-regime COFI ratios can be described in the simple equation at the bottom of the page.

The main difference between the across-regime ratios and the within-regime ratios is that the across-regime ratios include both the fixed and transitional costs. If the fixed and transition costs are zero, the $COFI_{across\text{-}regime} = COFI_{within\text{-}regime}$.

An example

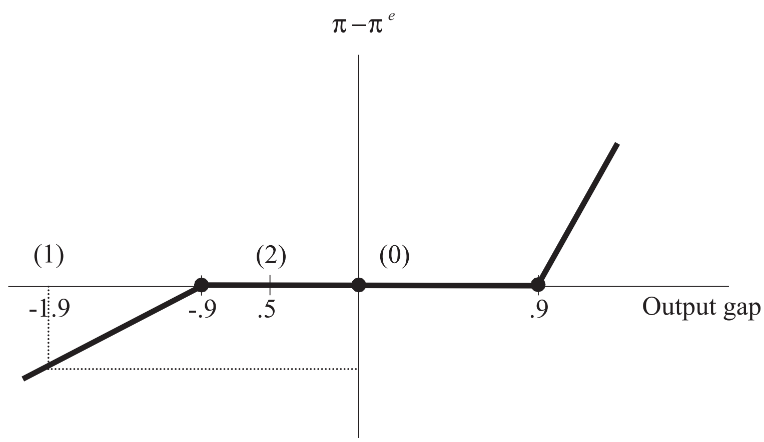
To illustrate the various costs, suppose monetary policy is tightened to deliberately disinflate. Suppose also that the economy is initially growing along its trend—the output gap is zero. The starting point of the

$$COFI_{across-regime} = \frac{\text{fixed output cost} + COFI_{within-regime} * (\text{change in } \pi) + \text{transition output cost}}{\text{change in } \pi}$$

APPENDIX B - *continued*

Figure B1

A HYPOTHETICAL EXAMPLE OF THE OUTPUT COST OF DISINFLATION



Notes: The slopes of the nonlinear Phillips curve are estimated to be $\beta_{weak} = .2, \beta_{balanced} = -.2$, and $\beta_{overheated = 0.49}$. The within-regime COFI ratio associated with β_{weak} is 5. The kink points occur at $-\alpha = -.9$ and $\alpha = .9$.

economy is denoted by (0) in Figure B1. Assume for simplicity that the tighter policy causes output to deviate from trend for three periods. In the first period, the tighter monetary policy causes output to fall 1.9 percent below trend, denoted by the (1) in the figure. The 1.9 percent output loss is attributed to two component costs: 0.9 percent is fixed cost and 1 percent is marginal cost. At this level of the output gap, the Phillips curve indicates that inflation will fall by 0.2 percentage point. In the second period, output is 0.5 percent below trend. Because the output loss is not associated with a further drop in inflation, the 0.5 percent output gap is a transition output cost. In the third period, output returns to trend. In sum, the cost of fighting inflation ratio is

$$\frac{.9 + 5*(.2) + .5}{.2} = 12.$$

ENDNOTES

[1] Even though some economists and policymakers believe that inflation is currently sufficiently close to price stability, conventional indicators of inflation such as the CPI (adjusted for measurement biases) are above zero.

[2] To assess the desirability of disinflation, the costs of disinflation have to be weighed against the benefits of lower inflation. The benefits may be particularly favorable because the temporary output losses are offset by the benefits of the permanently lower inflation rate. See Neely and Waller (1997) for a description on the cost-benefit analysis of disinflation.

[3] The output cost of disinflation, however, is only one cost out of many which policymakers must consider. In addition to the output cost, disinflation may also cause other costs that are missed by measuring the costs by output alone. For example, large disinflations are associated with recessions. Recessions not only lower output but also lead to other difficult-to-measure intangible costs related to such developments as lost jobs, failed businesses, greater social unrest, higher crime, and a widening of the income distribution. In a sense, the sacrifice ratio does not take into account the economic welfare costs of those in society who are making the sacrifice.

[4] Okun certainly was not the first economist to consider the costs of disinflation. Predecessors include Milton Friedman and Friedrich Hayek. See Ball (1994) for a short overview of more recent history of the sacrifice ratio, and Friedman's (1994) comment on Ball's research for further historical antecedents.

[5] Okun actually reported a wide range of sacrifice ratios corresponding to the range of estimates of the Phillips curve slope in the literature. The estimate of 10 reported in the text has a range of 6 to 18. Note the range is not a conventional standard error of the estimate.

[6] For example, the cumulative output loss (measured as deviation of actual output from trend) in the early 1990s recession was roughly 13 percent.

[7] This article uses the approach of Gordon and King (1982) to measure the cost of fighting inflation. See also King and Watson (1994) on how to extend these models to deal with different identification restrictions and their effects on sacrifice ratio measures. Another small-scale modeling method that may offer a different perspective on measuring sacrifice ratios has been recently offered by Huh and Lansing (1997).

In principle, sacrifice ratio measurement is not limited to small-scale macroeconomic models but can be generated in any model that incorporates inflation and real activity. See, for example, Bonfim and Rudebusch (1997), and Bonfim, Tetlow, von zur Muehlen, and Williams (1997). These models generate sacrifice ratios in the range of 1 to 3 under different assumptions about credibility and expectation formation.

[8] Ball (1994) outlines a procedure in his paper to estimate the trends in inflation and output. With these trends and the starting points and ending points of disinflationary episodes, he can directly calculate sacrifice ratios. Ball finds that the average sacrifice ratio across many countries has a range of .75 to 2.92 when using quarterly data. Using annual data, the measures are somewhat smaller. The smaller estimates may be due to measurement error because the annual data smooth the quarterly peaks and troughs. Andersen uses a slightly different variant on the atheoretical approach and reports cross-country sacrifice ratios mainly between .25 and 2.25. See Cecchetti (1994), Friedman (1994), Jordan (1997), Mayes and Chapple (1994), and Neely and Waller (1997) for comments on this approach.

[9] Jordan (1997) extends Ball's approach to periods of rising inflation. In periods of rising inflation, output is typically above trend, indicating a temporary output gain, not a loss. Thus, the term sacrifice ratio is a misnomer. In contrast, Jordan's output measure is called a benefice ratio.

The cost of fighting incipient inflation is closely related to the notion of the benefice ratio. A benefice ratio measures the temporary output gain above trend associated with higher inflation. Thus, it is related to the slope of the Phillips curve when output is above trend. In the linear Phillips curve model, the benefice ratio is equal in absolute value to the sacrifice ratio because the slope of the Phillips curve is the same for both disinflation and rising inflation.

More important, the cost of fighting incipient inflation is related to the benefice ratio because both are linked to the shape of the Phillips curve when output is above trend. The cost of fighting incipient inflation is equal to the negative of the benefice ratio. However, the interpretation is different. The cost of fighting incipient inflation can be thought of as the forgone loss of output that would have accompanied the rise in inflation.

[10] Taken literally, the Phillips curve indicates that inflation should exceed inflation expectations when output is above trend. Thus, it is a theoretical possibility that if inflation expectations were falling rapidly, inflation could fall when output exceeds trend. However, because expectations are assumed to adjust sluggishly, inflation will rise generally when output is above trend.

[11] Firms that exhibit this pricing power are referred to as monopolistic competitors. Another theoretical

justification for the convex shape is wage rigidity. If wages are downwardly rigid and aggregate demand falls, firms will have to adjust employment (and therefore output) rather than wages to lower costs. Wage rigidity causes the slope of the Phillips curve to flatten as output rises above trend. See Dupasquier and Ricketts (1997a & b) for a catalog of Phillips curve nonlinearities and for a discussion of specification and testing issues.

12 Turner (1995) and Clark, Laxton, and Rose (1995) sparked a series of studies into the robustness of the findings as well as refinements of the estimation model. Laxton, Meredith, and Rose (1995), Clark and Laxton (1997), Debelle and Laxton (1996), Duspasquier and Ricketts (1997a & b), and Laxton, Rose, and Tambakis (1997) use similar nonlinear Phillips curve specifications. In their specifications, inflation sensitivity to the output gap varies with the state of the economy in a particular way. The sensitivity does not continuously vary with the state of the economy but depends on whether the economy is in a weak-economy regime or overheated-economy regime. Within each regime the sensitivity is constant. Technically, the Phillips curve slope is constant in each of two regimes, but the slopes differ across the two regimes. In other words, the curve has a piecewise linear shape. The authors note the importance of accounting for a possible measurement bias in the output gap. The exact functional form is discussed later in the article.

All these studies corroborate evidence of nonlinearity. Using nonparametric rank correlation tests, Duspasquier and Ricketts find "weak" evidence of nonlinearity. Using standard F-tests, Turner rejects linearity in the U.S. data at the 1 percent significance level. And the other authors generally find robust statistical significance of parameters that capture nonlinearity.

13 Eisner (1997a & b) uses the unemployment rate as his measure of real activity. Using Okun's law relating unemployment and output, Eisner's results can be translated into implications for inflation and output. The translation is not likely to change the conclusions of concavity. Debelle and Laxton (1997) use unemployment rates to define the Phillips curve and find evidence of convexity. The evidence of nonlinearity depends on careful measurement of the natural rate of unemployment.

14 Gordon (1997, p. 26) states, "None of these differences is statistically significant, indicating that the short-run Phillips curve is resolutely linear, at least within the range of inflation and unemployment values observed over the 1955-1996 period."

15 Clark, Laxton, and Rose (1995) proposed a simple asymmetric model of the Phillips curve. Their inflation equation is a function of inflationary expectations, the output gap, and lagged inflation: $\pi_t = \delta\pi^{\varepsilon}_{\tau+4} + (1-\delta)\pi_{t-1} + \beta\, gap^*_t + \gamma\, gappos^*_t + \varepsilon^{\pi}_t$, where $gap^*_t = y_t - y_{trend} + \lambda$. Inflationary expectations are measured as the five-quarter average of the four-quarter-ahead expectation of inflation from the University of Michigan survey; the output trend is measured by a 12-quarter centered-moving average of actual output.

The key features of the model are the use of the positive values of the normalized output gap, and the definition of the normalized output gap to include a λ term. They point out that the evidence of nonlinearity is much weaker in the two-regime model without the adjustment. They argue that in models where inflationary expectations are unbiased estimates of actual inflation, λ naturally arises to guarantee bounded inflation when the model is subject to stochastic demand. Note that the specification in this article does not rely on their controversial adjustment to find nonlinearity. However, a constant is included in the Phillips curve equation that is discussed in Appendix A.

16 Inflation is measured by the consumer price index with the adjustment for rental equivalent corrections in the pre-1983 period (CPI-U-X1). Inflation expectations are estimated to be a function of the quarterly average of the University of Michigan survey's 12-month mean expected change in prices; details are given in Appendix A. The output gap is calculated as the difference between log GDP and its Hodrick-Prescott trend with a standard smoothing parameter of 1,600.

17 In specifications with the core consumer price index inflation (without food and energy prices) and PCE inflation, the slope coefficient for the balanced regime is negative but statistically insignificant at the 10 percent level. This suggests that the inflation-output tradeoff model in this article is too simple to adequately provide guidance about inflation when the economy is near its trend.

18 In 1997:Q4, the estimated output gap was .9.

19 The nonlinear Phillips curve complicates the calculation of the cost of fighting inflation because the costs depend on the particular path of the economy. Since there are myriad ways that monetary policy can be designed to fight inflation, no simple measure can be developed. Technically, the costs are calculated from nonlinear impulse responses that are path dependent. This article summarizes some of the qualitative features of the results with examples.

20 The within-regime COFI ratios are simply the inverse of the Phillips curve slope estimate, $1/\beta_i$, where the index i corresponds to the weak, balanced, and overheated regimes. However, the simple relationship between the slope of the Phillips curve in each regime and the COFI ratio breaks down when the economy switches regimes.

21 For example, if the output were at trend (output gap = 0) and a small disinflation of size π^- was sought in one period, the average cost ratio can be algebraically described as $\frac{\alpha + (5.0 \times \pi^-)}{\pi^-}$. When π^- is tiny, the average cost ratio is large.

22 The flat portion of the estimated Phillips curve can also be interpreted as an indication that Equation 1 does not include all relevant factors that determine inflation. Factors other than the output gap may play a more important role in determining the inflation rate when the economy is close to its trend. Some of these factors may be special to particular disinflationary or inflationary episodes. For example, commodity prices may fall because of discoveries of new supplies. The resulting disinflation may therefore be independent of whether the economy is above or below trend. However, if the output gap is sufficiently large or small, the output gap largely dominates other factors that determine the inflation rate.

23 Another way to interpret this result is to focus on the two components of the output cost. The output cost component associated with the weak regime is the same for both starting points. However, the output cost component associated with initiating a disinflation differs. If output is initially at or above trend, policy must significantly slow the economy in order to initiate a disinflation. In contrast, if the economy is operating below trend but above $-\alpha$, policy needs to slow the economy by a smaller amount, thus making the output cost due to policy smaller in this case.

24 In other words, the flat portion of the nonlinear Phillips curve indicates that subpar economic activity (sometimes associated with what economists call a growth recesssion) would not necessarily cause a disinflation.

25 Moreover, even if both options are proven to be undesirable, that does not mean that no progress toward price stability will ever be made by the economy operating below trend. There is always the chance that a significant and unexpected reduction in aggregate demand—such as a recession—would slow the economy sufficiently to reduce inflation. Such developments entail an output cost but one usually unavoidable by monetary policy; Blinder (1997), for example, has commented in the past that "the United States is 'one recession away' from price stability." Note that this discussion ignores the regime design issues of Orphanides and Wilcox (1996).

26 In contrast, Gordon (1982) examines how inflation responds to nominal spending changes. He looks at 14 international historical episodes and concludes that the benefits of cold turkey may be small.

27 To illustrate this finding with the framework outlined in Appendix B, consider the following two strategies to disinflate by two percentage points: disinflate by $\pi^d = 2$ in one period or by $\pi^d/2 = 1$ in each of two periods. Assuming the economy is initially growing at trend and that the adjustments all occur in one period, the cost of the first strategy is $\alpha + 5.0 \times 2 = 10.9$ percentage points of output (ignoring transitional costs for simplicity). The cost of the two-period strategy is $(\alpha + 5.0) + (\alpha + 5.0) = 2\alpha + 10.0 = 11.8$ percentage points of output. With a large disinflation, the fixed cost (per period) of disinflation is "paid" for fewer periods than if the disinflation is gradual. The marginal cost for each strategy is the same. Thus, in general, more rapid disinflation is less costly. The lower output cost of rapid disinflation indicates that the cold turkey strategy is a lower output cost strategy than gradualism.

28 Given the output cost advantage of keeping the economy well balanced, is there a cost advantage to being close to a zero output gap? If the curve is flat, the answer is no. If flat, a small positive output gap would be beneficial without an apparent cost in terms of inflation. Even though the point estimates are consistent with a flat slope, they are also consistent with a slightly increasing slope. If the slope is somewhat upward sloping, then there are benefits of fostering conditions conducive for balanced output growth centered around a zero output gap.

29 It should be noted that if policymakers think that the Phillips curve is linear, then the costs of the higher inflation are the same as the costs of disinflation to wring the inflation out of the system. Thus, a risk-averse policymaker would shun the experimentation.

30 The dates from 1959 to 1997 of the weak, balanced, and overheated economic periods of at least two quarters are: weak-economy regime, 1960:Q4-1961:Q3, 1962:Q4-1963:Q2, 1970:Q1-1972:Q1, 1974:Q4-1977:Q1, 1982:Q1-1983:Q3, 1991:Q1-1992:Q2; balanced-economy regime, 1960:Q2-1960:Q3, 1964: Q1-1964:Q3, 1965:Q1-1965:Q3, 1967:Q2-1968:Q1, 1969:Q3-1969:Q4, 1972:Q2-1972:Q3, 1977:Q4-1978: Q1, 1983:Q4-1984:Q1, 1986:Q2-1988:Q3, 1990: Q3-1990:Q4, 1992:Q3-1997:Q3; overheated-economy regime, 1959:Q2-1960:Q1, 1965:Q4-1967:Q1, 1968:Q2-1969:Q3, 1972:Q4-1974:Q2, 1978:Q2-1980:Q1, 1984:Q2-1984:Q3, 1988:4-1990:2.

31 In the nonlinear Phillips curve estimation, the π_0 parameter is statistically significant. The estimate indicates that when the output gap is zero, inflationary expectations tend to be higher than the actual inflation rate.

32 In textbook Phillips curve models, π_0 would be constrained to be zero. This would reflect the economic intuition that when the economy is in its steady state with a zero output gap, the inflation rate should be steady. This empirical model allows the possibility that when the real economy is in equilibrium, inflationary expectations may not necessarily be set to the steady rate. This parameter is

assumed to measure the inflation premium and can be explained in a standard political economy model of monetary policy. The inflation premium can be thought of as a function of the credibility of the monetary authority. Barro and Gordon (1983) and many others have argued that monetary policy in the postwar period has been subject to this time inconsistency. They point out that an inflation bias arises naturally because well-intentioned monetary authorities may be predisposed to exploit the inflation-output tradeoff. McCallum (1995), however, raises doubts about the arguments supporting the inflation bias hypothesis.

[33] It should be noted that adding commodity prices to this equation to capture supply shocks did not statistically affect the coefficient estimates on the output gap terms. Because the output cost of fighting inflation largely depends on the β coefficients, this article did not pursue a more elaborate specification of supply shocks.

[34] The model is estimated using a slightly modified nonlinear least squares (NLS) routine. All parameters in the model except α are estimated with standard NLS methods. Because of data discreteness, the parameter α is estimated by searching over a grid (similar to threshold autoregressive estimation) to solve the following problem: $\underset{\alpha}{\text{argmax}}\, g(\alpha;\text{other parameters})$ subject to the side constraint that the slope coefficients are not statistically negative. The g function is the sum of squared errors. Standard errors of the α parameter are difficult to calculate. Various starting values in the parameter space were used to verify the robustness of the results.

[35] The interpretation of the federal funds rate innovations as monetary policy shocks is somewhat standard. See, for example, the research of Christiano, Eichenbaum, and Evans (1994) and Leeper, Sims, and Zha (1996). This view, however, is not without its critics. See Rudebusch (1996) for a critique of the monetary policy interpretation.

[36] The shocks used in the simulation are the orthogonalized innovations from a Choleski decomposition of the variance-covariance matrices. The ordering of the decomposition is: GDP, inflation, commodity prices, inflation expectations, federal funds rate, and ratio of nonborrowed reserves to total reserves.

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