Has the Behavior of Inflation and Long-Term Inflation Expectations Changed?

By Todd E. Clark and Taisuke Nakata

From 1975 to 1980, inflation in core (nonfood and non-energy) consumer prices rose sharply as crude oil prices more than tripled. Yet, as crude oil prices quadrupled from late 2001 to 2007, core consumer price inflation remained essentially flat. Some observers have attributed the stability of consumer price inflation in the more recent episode to the influence of long-term inflation expectations. While inflation expectations rose significantly in the second half of the 1970s, they remained largely unchanged from 2001 through 2007. The increased stability of inflation and long-term expectations raises the possibility that the behavior of both variables has fundamentally changed.

Recent discussion has focused on two possible forms of change: the *influence* of long-run expectations on inflation and the *anchoring* of inflation and expectations. If influence has risen, a regression model relating inflation to long-run expectations should show an increase in the coefficient on expectations. If inflation and expectations have become better anchored, they will now be less sensitive to news on the state of the economy, probably because the public expects the Federal Reserve to act to keep inflation stable. A model of inflation and expectations

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should then show the effects of an unexpected rise in inflation today to be smaller and shorter-lived than in the past.[1] More specifically, better anchoring should yield a smaller response of expectations to an inflation surprise and a faster return of inflation to baseline.

A third possible source of change is *smaller shocks* to inflation, expectations, and other macroeconomic variables. While some of the enhanced stability of inflation and long-run expectations could be due in part to the influence and anchoring channels, some could also be due to a change in the size of shocks. For example, oil price shocks were generally much smaller in the 1980s and 1990s than in the 1970s. Oil price shocks are captured in the error terms of regression models for inflation and inflation expectations as part of more general shocks to inflation and expectations. Smaller oil price shocks imply smaller error terms in the models.

Any of these changes in the behavior of inflation and long-term inflation expectations could have important implications for monetary policy. For example, if the influence of expectations on inflation has increased, the models used to forecast inflation would need to take account of the change. In addition, an enhanced stability of inflation could affect monetary policy's impact on the economy. However, the specific implications would hinge on the root economic causes of the changes in the dynamics of inflation and long-term inflation expectations.

This article examines the evidence of shifts in the behavior of inflation and long-term inflation expectations, using statistical models that allow for gradual change over time. The analysis focuses on changes in the influence of expectations on inflation, the anchoring of inflation and expectations, and the size of shocks to inflation and expectations. The first section of the article describes the models and methodology. The second section presents the results of the analysis. There is some evidence that the dynamics of inflation and long-term inflation expectations have changed modestly. In particular, compared to 20 or more years ago, inflation and expectations appear to be slightly better anchored: Unexpected increases in inflation die out slightly faster and produce less of an increase in long-term expectations. However, the reduced volatility of inflation and expectations is largely due to smaller shocks.

I. MODELS AND METHODOLOGY

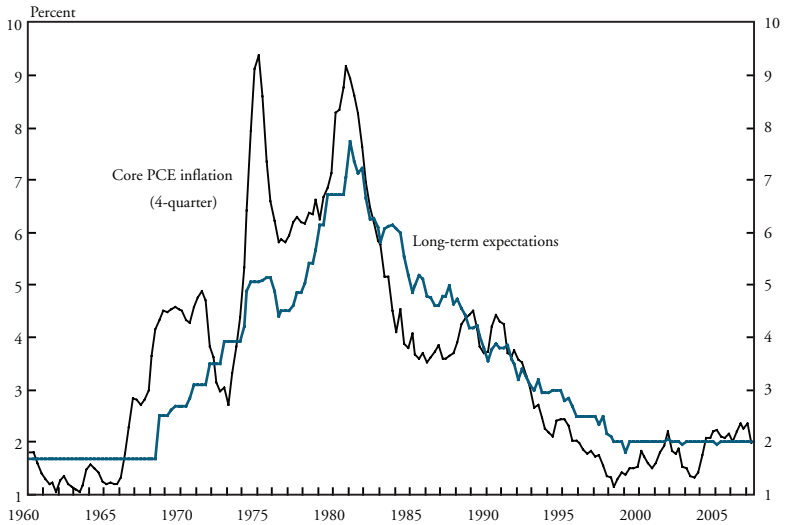
As measured by the chain price index for personal consumption expenditures excluding food and energy (core PCE price index), inflation trended sharply higher from the mid-1960s through the early 1980s and sharply lower from the early 1980s through the mid-1990s (Chart 1).[2] Since the mid-1990s, core PCE inflation has fluctuated in a relatively narrow range. Long-term expectations of PCE inflation—expectations of inflation five to ten years into the future—follow a broadly similar, but smoother, pattern.[3] Expectations trended up from the late 1960s through the early 1980s and down from the early 1980s through the mid-1990s, remaining essentially unchanged since the mid-1990s. This measure of expectations is based primarily on surveys of long-term forecasts and partly on statistical estimates.[4] The series splices 10-year-ahead expectations from the Survey of Professional Forecasters (1990-2007), 5- to 10-year-ahead expectations of financial market participants surveyed by Richard Hoey (1981-89), and econometric estimates from Kozicki and Tinsley (1960-80).[5] The Federal Reserve Board's FRB/US model uses the same measure of long-term PCE inflation expectations.[6]

The relative stability of core inflation and inflation expectations since the mid-1990s has led some observers to suggest the dynamics of inflation and expectations have changed. However, when movements in core inflation and long-term expectations are compared closely, the evidence of a shift in behavior is less clear. Core inflation was persistently above long-term expectations from the late 1960s through the early 1980s and persistently below for much of the last 25 years (Chart 2). Clearly, the sign of the difference between core inflation and long-term expectations shifted over this period. But common to all of this history is some tendency for differences in inflation and expectations to persist for many periods of time. Such seemingly common persistence suggests the dynamics of inflation and long-term expectations may not have changed.

Especially in the light of somewhat mixed evidence from simple charts, assessing whether the behavior of inflation and long-term expectations has changed requires careful statistical analysis. This section describes the models and methodology used in the article. One model relates inflation less the long-term expectation to past values of infla-

Chart 1

CORE PCE INFLATION AND LONG-TERM EXPECTATIONS

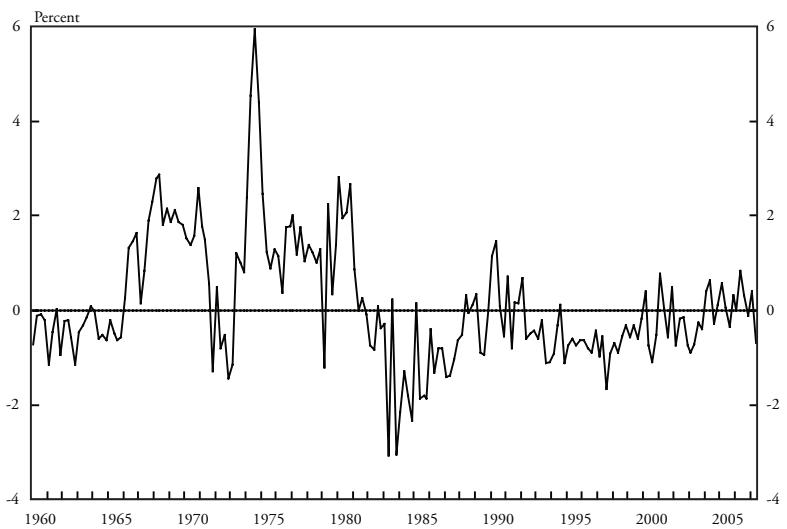


Notes: Inflation is computed as a four-quarter percent change. The long-term (5-10 years ahead) expectations series is a survey-based measure used in the Federal Reserve Board's FRB/US model.

Sources: Bureau of Economic Analysis and Federal Reserve Board of Governors

Chart 2

CORE PCE INFLATION LESS LONG-TERM EXPECTATIONS



Notes: The plotted series is the quarterly rate of core PCE inflation minus long-term expectations of PCE inflation. The long-term (5-10 years ahead) expectations series is a survey-based measure used in the Federal Reserve Board's FRB/US model.

Sources: Bureau of Economic Analysis and Federal Reserve Board of Governors

tion less the long-term expectation. This single-variable model permits assessment of the influence of expectations on inflation and the contributions of shock magnitudes to the reduced volatility of inflation. The other model adds in the change in expectations, a measure of economic activity, and the federal funds rate. This model captures directly the behavior of inflation expectations and the impact of the state of the economy and monetary policy on inflation and inflation expectations. The four-variable model permits assessment, not only of the influence of expectations on inflation and the impact of shock sizes on the volatility of inflation and expectations, but also of the anchoring of inflation and expectations.

Single-variable model

Some common models of inflation, such as the expectational Phillips curve, relate movements in inflation to movements in inflation expectations. Often, the horizon of the expectation measure in such models is relatively short, either one quarter or one year. The basic rationale for such a specification is that the inflation rate this quarter or this year will be influenced by what firms and households expect the inflation rate to be over the same period. Under that rationale, there is no good reason to use long-term expectations—as measured in this article, the expectation for average inflation over the next five to ten years—in the model.

Recently, however, a number of studies have developed models relating inflation to trend inflation. Typically, such analysis seeks to address the upward and downward trends in inflation from the mid-1960s through the mid-1990s, sometimes attributed to changes in the Federal Reserve's implicit inflation goal or tolerance.[7] In most of this research, trend inflation is measured indirectly with a simple statistical model that captures the gradual upward drift in inflation from the mid-1960s through the early 1980s and downward drift from the early 1980s through the mid-1990s (Cecchetti and others; Cogley and Sargent 2005, 2007; Primaceri; Stock and Watson 2007).

However, trend inflation could instead be measured with long-term inflation expectations. As Mishkin notes, "When we think about what drives trend inflation, inflation expectations—particularly long-run expectations—come to mind." Several studies have used long-term expectations to capture trend inflation in various models of inflation (Kozicki

and Tinsley; Lehman Brothers; Macroeconomic Advisers). Following such analysis, this article also uses long-term expectations as a direct measure of trend inflation in statistical models of the economy.

Given an approach to measuring trend inflation, a simple model that relates inflation less trend inflation to past values of inflation less trend inflation provides a useful starting point for assessing changes in the behavior of inflation. With π denoting core PCE inflation and π^e denoting trend inflation measured as the long-term expectation, the first model used in this article takes the form:

$$\pi_t - \pi^e{}_t = \beta_1 \left(\pi_{t-1} - \pi^e{}_{t-1} \right) + \beta_2 \left(\pi_{t-2} - \pi^e{}_{t-2} \right) + e_t . \quad (1)$$

This model relates the current differential between quarterly core PCE inflation and the long-term expectation to the differentials observed in the past two quarters.[8] By making the current differential a function of recent differentials, the model can capture the tendency of differences between core inflation and expectations to persist across time. For simplicity, the differential between quarterly core PCE inflation and the long-term expectation is referred to as *detrended inflation*.

Of course, the model cannot fully explain movements in inflation, and therefore includes a regression error or residual. The error term e_t captures unexpected changes in detrended inflation and therefore represents so-called *shocks* to inflation. The shocks captured in the model error will reflect a variety of fundamental shocks to the economy. For example, a sharp rise in oil prices or drop in productivity could lead to a quick rise in inflation that would be captured by the model error.

Changes over time in the relationship between core inflation and long-term expectations will be reflected in changes in the coefficients β_1 and β_2. The variables in model (1) can be rearranged as follows:

$$\pi_t = \beta_1 \pi_{t-1} + \beta_2 \pi_{t-2} + \pi^e{}_t - \beta_1 \pi^e{}_{t-1} - \beta_2 \pi^e{}_{t-2} + e_t . \quad (2)$$

For purposes of illustration, suppose for the moment that inflation expectations move slowly, such that the values of expectations in the past two periods are roughly the same as in the current period. The model (1) used in the analysis can then be approximated by:

$$\pi_t = \beta_1 \pi_{t-1} + \beta_2 \pi_{t-2} + \left(1 - \beta_1 - \beta_2\right) \pi^e{}_t + e_t . \quad (3)$$

As this alternative formulation makes clear, the coefficients β_1 and β_2 bear directly on the importance of past values of inflation and inflation expectations in determining current inflation. A large coefficient on inflation expectations implies expectations exert a significant influence on inflation. A large coefficient on inflation expectations translates into a small value of $\beta_1 + \beta_2$. That is, smaller coefficients β_1 and β_2 imply a greater influence of long-term expectations on inflation and a smaller impact of past inflation.[9] If, over time, inflation has become more influenced by inflation expectations, the sum of coefficients $\beta_1 + \beta_2$ should decline. This applies to not only the approximating model (3) but also the model (1) used in the analysis.

Changes in model coefficients could also explain the reduced volatility of inflation in recent years. Alternatively, reduced volatility could be due to a fall in the size of the shocks to inflation.[10] Lower volatility means the standard deviation of inflation has fallen. The model implies that the standard deviation of detrended inflation depends, in a complicated (but mathematically and statistically precise) way, on the model coefficients β_1 and β_2 and the standard deviation of the error term.[11] Either shifts in coefficients or a fall in the standard deviation of the error term could account for a decline in the standard deviation of inflation. For example, a reduction in the size of oil price shocks would likely yield a reduction in the size of shocks to the inflation model—that is, a smaller standard deviation of the error term e_t. Because model shocks have immediate, one-for-one impacts on inflation, a fall in the size of shocks would lead directly to a decline in the volatility of inflation. The role of the model coefficients is more complicated. In general, a fall in coefficient magnitudes would reduce the influence of past inflation on current inflation, making inflation less sluggish. As a result, following a shock, inflation would more rapidly return to baseline. The shorter-lived departure from baseline results in a lower standard deviation of inflation.

To assess the evidence of changes in coefficients and volatilities, this article uses the statistical methodology of such studies as Cogley and Sargent (2005) and Primaceri.[12] The methodology treats the coefficients β_1 and β_2 and the volatility of shocks to inflation (the regression error e_t) as evolving smoothly over time (from quarter to quarter), estimating coef-

ficient and shock standard deviations for each period. The appendix provides more detail on the statistical model and estimation methodology.

Following Stock and Watson (2002), the roles of changes in coefficients and shock volatility in accounting for the recent decline in inflation volatility are assessed with counterfactual experiments. Specifically, the standard deviation of inflation implied by the model's time-varying coefficients and standard deviation of model shocks at each point in time is compared against the standard deviation of inflation that would have been observed if: (1) the coefficients evolved as estimated, but the standard deviation of the model error were fixed at its 1980:Q1 value; and (2) the standard deviation of the model error evolved as estimated, but the coefficients were fixed at their 1980:Q1 value. The year 1980 provides a useful benchmark because, as shown in the next section, the estimated volatility of shocks fell sharply not long after.[13]

To see the point of such an exercise, suppose the estimated model coefficients are fairly stable over time, but that the standard deviation of the model error trends down sharply. In this case, the model-implied standard deviation of inflation will decline due to the falloff in the volatility of the model error. The counterfactual experiment would show that the time path of the standard deviation of inflation obtained from fixed coefficients and the estimated time-varying standard deviation of model shocks matches up closely with the actual model estimates. However, the path of the standard deviation of inflation obtained from the estimated time-varying coefficients and a fixed standard deviation of model shocks would not match up well with the actual model estimates.

Four-variable macroeconomic model

While the model focused solely on detrended inflation has the advantage of simplicity, it can provide only a partial view of potential changes in the behavior of inflation and long-term inflation expectations. Perhaps most importantly, the single-variable model of detrended inflation does not directly measure changes in the behavior of inflation expectations. Therefore, the model cannot be used to assess whether the responsiveness of inflation expectations to inflation has changed or to identify the sources of the recently increased stability of expectations. In particular, the model cannot be used to assess changes in the anchoring of inflation and expectations. Moreover, the single-variable

model omits some potentially important influences on the dynamics of inflation and inflation expectations: economic activity and monetary policy. For example, some research finds the sensitivity of inflation to economic activity has sharply declined (Roberts).

To provide a more complete assessment of potential changes in the behavior of inflation and inflation expectations, the second model considered in this article includes four variables: detrended inflation, the change in inflation expectations, the output gap, and the federal funds rate less the long-term inflation expectation.[14] The output gap measures the state of the economy by the percentage difference between (real) GDP and potential GDP as measured by the Congressional Budget Office (CBO).[15] A positive value of the gap corresponds to a strong economy, with the level of economic activity exceeding the economy's long-term potential. Subtracting the long-term inflation expectation from the federal funds rate translates the interest rate on federal funds from nominal to real terms. The upward and downward trends in inflation from the mid-1960s through the mid-1990s caused nominal interest rates to follow similar trends. Subtracting the long-term inflation expectation from the nominal federal funds rate also serves to remove the trend from the funds rate. The difference between the federal funds rate and the long-term inflation expectation is referred to as the *detrended federal funds rate.*

The model relates the current value of each variable to the values of all variables over the past two quarters. For example, current detrended inflation is a function of the past two quarters' values of detrended inflation, the change in inflation expectations, the output gap, and the detrended federal funds rate.[16] The current change in inflation expectations is a function of the same list of explanatory variables. Each equation includes an error term that captures shocks. For instance, the error in the detrended inflation equation will capture as shocks sudden movements in inflation due to jumps in oil prices or productivity. The error in the expectations equation will capture forces such as sudden reassessments of long-term inflation prospects by forecasters. Similarly, the error in the detrended federal funds rate will reflect shocks to monetary policy. Models of this form are commonly used in macroeconomic research (for example, Cogley and Sargent 2005, 2007; Kozicki and Tinsley; Primaceri).

The four-variable model is analyzed with the same statistical methodology applied to the single-variable model, detailed in the appendix.[17] All of the regression coefficients are allowed to evolve smoothly over time, taking different values each quarter. To ensure the model captures the increased stability of the economy, the standard deviations of the shocks to the model are also allowed to vary smoothly over time.

With the larger model, changes over time in the dynamics of inflation and inflation expectations can be characterized in several different ways, associated with influence, anchoring, and the size of shocks. First, sums of coefficients on each variable provide a direct measure of changes in the behavior of inflation and expectations. For example, for the detrended inflation equation, the evidence can be summarized by the sum of the two coefficients on past values of detrended inflation, the sum of the two coefficients on the past values of the change in expectations, the sum of coefficients on the output gap terms, and the sum of coefficients on the detrended funds rate. As in the case of the single equation model, a decline in the sum of the coefficients on past values of detrended inflation in the inflation equation would imply (other things held constant) a greater influence of long-run expectations on inflation.[18] The same type of analysis can be applied to the equation for the change in inflation expectations.

Second, the notion of improved anchoring can be assessed with estimates of the responses of inflation and expectations to an unexpected increase (shock) in inflation. If inflation and expectations are better anchored today than in, say, 1970 or 1980, the rise in inflation should be shorter-lived than used to be the case, and long-term inflation expectations should respond less to the inflation shock. The model can be used to trace out, for different points in history, the estimated responses of inflation and expectations to such a shock, taking into account feedback among inflation, expectations, the output gap, and monetary policy.

Finally, the roles of changes in coefficients and shock volatilities in accounting for the recent decline in the volatility of inflation and expectations can be assessed with counterfactual experiments. The four-variable model implies the standard deviations of detrended inflation and inflation expectations to be functions of the model coefficients and standard deviations of the model shocks. Either coefficient

shifts or smaller shocks could reduce the variability of inflation and expectations. As discussed in the last section, a falloff in the size of oil price shocks would likely yield smaller shocks to the inflation equation and, in turn, a decline in the volatility of inflation. Changes in coefficients will affect how rapidly each variable moves in response to other variables and, in turn, the variability of each variable. Accordingly, the time paths of standard deviations of inflation and expectations implied by the model's time-varying coefficients and shock sizes are compared against the standard deviations that would have been observed if shock sizes had been unchanged since 1980:Q1, or if coefficients had been unchanged since 1980:Q1.[19]

Although Stock and Watson (2002) extend such counterfactual analysis to assess the role of monetary policy in the increased stability of the economy, this article does not try to do the same for inflation and inflation expectations. The coefficients and shocks of the statistical models described in this section depend in complicated ways on many different structural economic forces, among them consumer preferences, firms' productivity, and monetary policy. The statistical models lack the economic structure necessary to disentangle such root causes of any changes in the dynamics of inflation and expectations. Similarly, the determinants and impacts of monetary policy decisions are much richer than the four-variable model can capture.[20] Consequently, the model seems inadequate for assessing whether, as Kroszner and Mishkin have suggested, changes in the conduct of monetary policy have made inflation and expectations better anchored.[21] Such analysis would require sophisticated theoretical models of the economy and monetary policy and is left to further research. The next section focuses instead on a statistical assessment of change.

II. EVIDENCE

This section uses estimates of the models described above to assess the evidence of changes in the behavior of core PCE inflation and long-term inflation expectations from late 1970 through mid-2007. Histories of estimates of the time-varying coefficients provide direct evidence

of change, particularly on the influence of expectations on inflation. Estimates of the responses of inflation and long-term expectations to inflation shocks provide further evidence on the anchoring of inflation and expectations. In light of considerable uncertainty surrounding the estimates of coefficients and shock responses, the section reports a simple, direct measure of the evidence of change: the probability that coefficients or shock responses are lower in 2007:Q2 than they were in 1980:Q1.[22] The year 1980 is a useful benchmark because core inflation peaked that year and because most observers believe that, if a change in inflation behavior occurred, it most likely did so in the last 25 or so years. Finally, counterfactual experiments quantify the roles of changes in coefficients and the sizes of shocks in reducing the volatility of inflation and expectations.

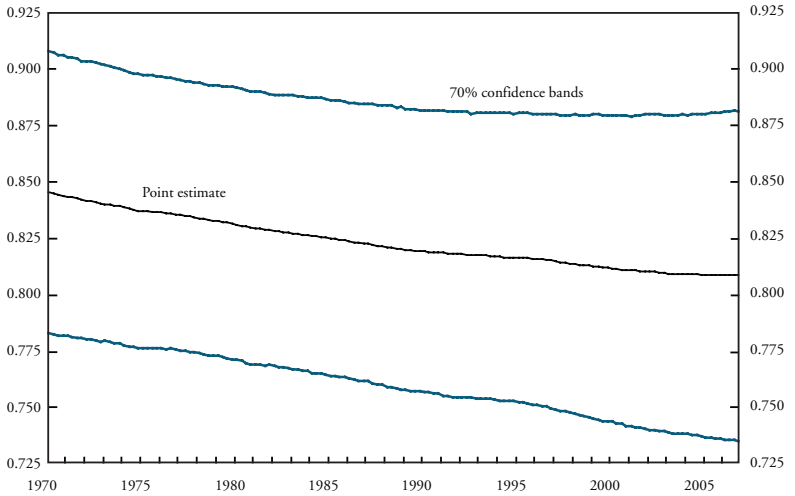
The section proceeds by first presenting evidence from the single-variable model of detrended inflation and then presenting results from the four-variable model.

Single-variable model

The single-variable model of detrended inflation provides only slight evidence of a change in the behavior of inflation, apart from the sharp falloff in volatility due to smaller shocks. For the influence of expectations on inflation to have risen much, the sum of the model coefficients β_1 and β_2 would need to fall significantly. The model estimates, though, yield only a very small decline, from about 0.85 in 1970:Q3 to 0.81 in 2007:Q2 (Chart 3).[23] The uncertainty around the estimate at each point in time, reflected in 70 percent confidence bands, are wide enough that the decline does not appear to be statistically significant.[24] The estimated probability that the sum of coefficients is lower in 2007:Q2 than in 1980:Q1 is 67 percent. Therefore, the sum of coefficients is more likely to have fallen than risen, but not highly likely, and the degree of change is small. In turn, the implied influence of long-term expectations on inflation is only somewhat more likely to have risen than fallen, and the rise appears to be small.

The model estimates indicate the recently increased stability of inflation is due almost entirely to smaller shocks. The standard deviation of shocks to inflation in the model shows a considerable decline over time, with relatively tight confidence bands (Chart 4). The estimated

Chart 3
SUM OF COEFFICIENTS FROM SINGLE-VARIABLE MODEL



Notes: The chart presents the time path of point estimates of the sum of coefficients from the single-variable model in detrended inflation (given in equation (1)), along with a 70 percent confidence band.

Sources: Bureau of Economic Analysis and Federal Reserve Board of Governors

standard deviation of shocks in 2007 is about half the estimated standard deviation for 1974, 1979, and 1983. Accordingly, shocks to inflation have typically been much smaller in the last 20 or so years than from 1970 through the early 1980s.

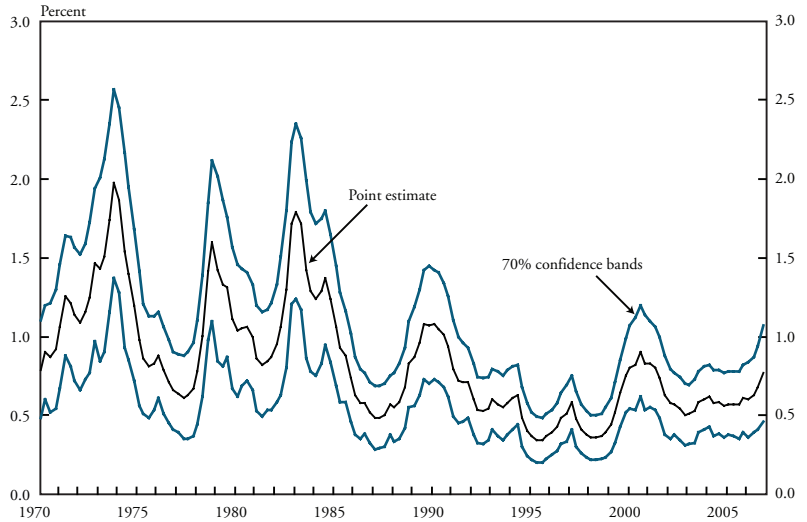
The standard deviation of inflation implied by the model shows a very similar decline over time (Chart 5). The falloff in the overall variability of inflation is almost entirely attributable to the decline in the standard deviation of shocks to inflation, with little contribution from changes in model coefficients. Had the coefficients stayed at their 1980:Q1 values for the entire 1970-2007 period, the volatility of inflation would have fallen just as much as it did according to the model estimates that allow the coefficients to vary. In contrast, had the shock standard deviation been fixed at its 1980:Q1 value, the volatility of inflation would have only edged down.

Four-variable macroeconomic model

Extending the model to include equations for long-term inflation expectations, the output gap, and the federal funds rate provides mod-

Chart 4

STANDARD DEVIATION OF SHOCK IN SINGLE-VARIABLE MODEL

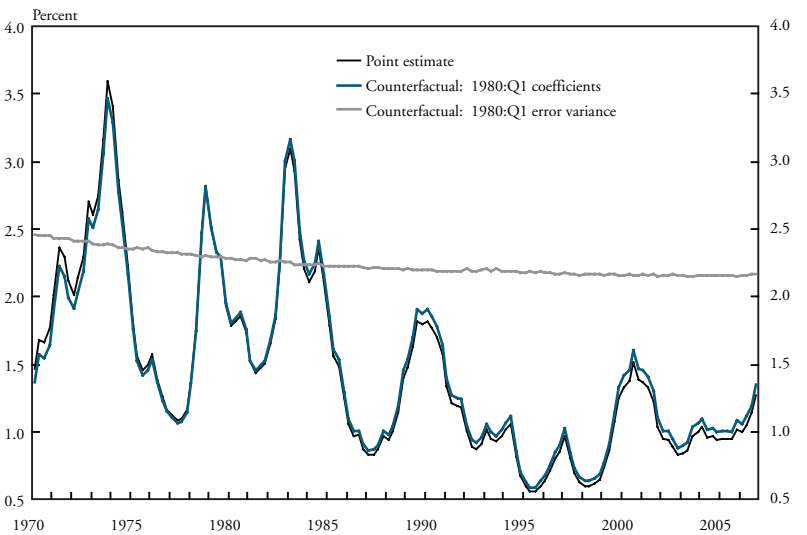


Notes: The chart presents the time path of point estimates of the standard deviation of the error or shock in the single-variable model in detrended inflation (given in equation (1)), along with a 70 percent confidence band.

Sources: Bureau of Economic Analysis and Federal Reserve Board of Governors

Chart 5

FITTED STANDARD DEVIATION OF DETRENDED INFLATION IMPLIED BY SINGLE-VARIABLE MODEL



Notes: The chart presents alternative time paths of the standard deviation of detrended inflation implied by estimates of the single-variable model (given in equation (1)). The model implies the standard deviation of detrended inflation to be a specific function of the model coefficients and shock standard deviation. The point estimate is based on the model-estimated time-varying coefficients and shock standard deviation. One counterfactual reports the path of inflation standard deviations that results from holding the coefficients at their 1980:Q1 values for the whole sample (but using the model estimates of time-varying shock standard deviations). The other counterfactual reports the path of inflation standard deviations that results from holding the shock standard deviation at its 1980:Q1 value (but using the model estimates of the time-varying coefficients).

Sources: Bureau of Economic Analysis and Federal Reserve Board of Governors

estly stronger evidence of changes in the behavior of inflation and inflation expectations.[25] As with the single variable model, though, the sharper evidence is that smaller shocks, not coefficient changes, account for nearly all of the recent improvement in the stability of inflation.

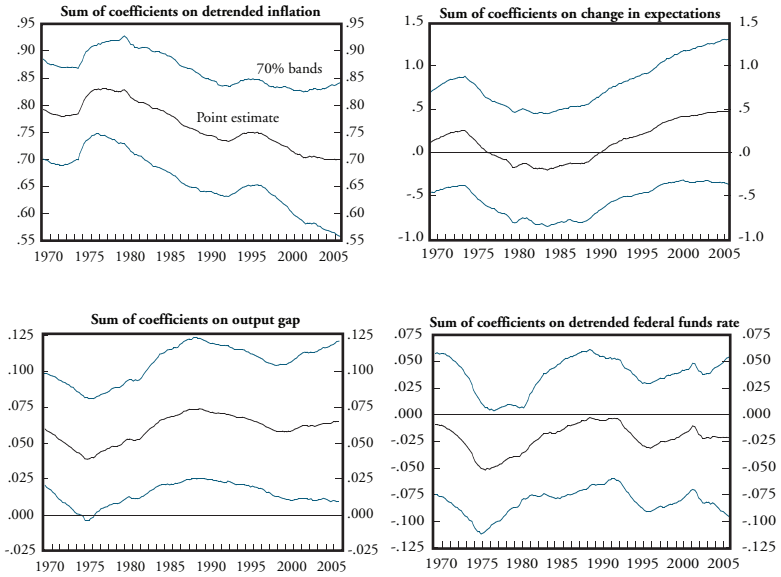
In the case of the equation for detrended inflation, estimates of the four-variable model show a measurable, although not dramatic, decline in the coefficients on past values of detrended inflation (Chart 6, top left panel). The sum of the coefficients falls from about 0.83 in 1980 to 0.70 in 2007. However, the uncertainty captured by the 70 percent confidence bands is great enough that the decline does not appear to be statistically significant by conventional standards. The estimated probability that the sum of coefficients on detrended inflation is lower in 2007 than in 1980 is 79 percent. Therefore, the sum of coefficients is much more likely to have fallen than risen, but not certain, and the degree of change is modest. In turn, the influence of long-term expectations on inflation is more likely to have risen than fallen, but the rise appears to be modest.

For the coefficients on the other variables of the detrended inflation equation, there is little evidence of change over time. The estimated sum of coefficients on the change in long-term expectations has drifted up, but the confidence bands are very wide and always include the value of zero (Chart 6, upper right panel). Consequently, at no point in time is the estimated sum of coefficients statistically different from zero. Similarly, the estimated coefficients on the detrended federal funds rate are very small and not statistically different from zero. In the case of the coefficients on the output gap, the estimated sum of coefficients is essentially steady, fluctuating in a relatively narrow range.[26]

There seems to be less evidence of important shifts in the coefficients of the equation for the change in long-term inflation expectations. The sum of the coefficients on past values of the change in expectations has been roughly flat since 1970 (Chart 7, upper left panel). The sum of coefficients on detrended inflation drifted up from the mid-1970s through the mid-1980s, peaking at 0.07, and then drifted down to a current value of 0.03 (Chart 7, upper right panel). Such a pattern indicates that, as actual inflation rose in the 1970s, the responsiveness of expectations to inflation increased. Then, after inflation fell sharply in the early 1980s, the responsiveness of expectations to infla-

Chart 6

SUMS OF COEFFICIENTS FROM FOUR-VARIABLE MODEL, EQUATION FOR DETRENDED INFLATION

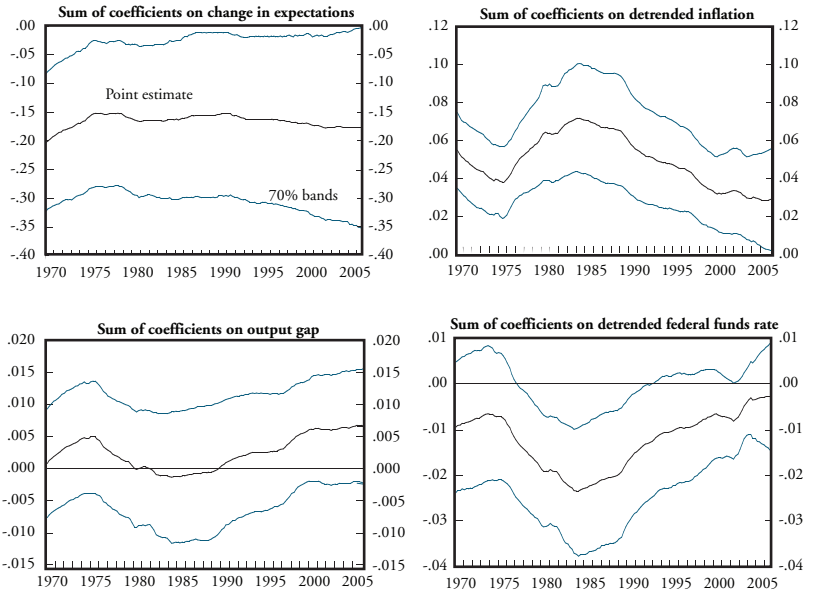


Notes: The chart presents the time path of point estimates of sums of coefficients from the detrended inflation equation of the four-variable model, along with 70 percent confidence bands. The model variables include detrended inflation, the change in long-term expectations, the output gap, and the detrended federal funds rate.

Sources: Bureau of Economic Analysis, Bureau of Labor Statistics, Congressional Budget Office, and Federal Reserve Board of Governors

Chart 7

SUMS OF COEFFICIENTS FROM FOUR-VARIABLE MODEL, EQUATION FOR CHANGE IN INFLATION EXPECTATIONS



Notes: The chart presents the time path of point estimates of the sums of coefficients from the expectations equation of the four-variable model, along with 70 percent confidence bands. The model variables include detrended inflation, the change in long-term expectations, the output gap, and the detrended federal funds rate.

Sources: Bureau of Economic Analysis, Bureau of Labor Statistics, Congressional Budget Office, and Federal Reserve Board of Governors

tion diminished. The estimated probability that the sum of coefficients on detrended inflation is lower in 2007 than in 1980 is 82 percent. Therefore, the sum of coefficients is much more likely to have fallen than risen, but not certain, and the degree of change is small.

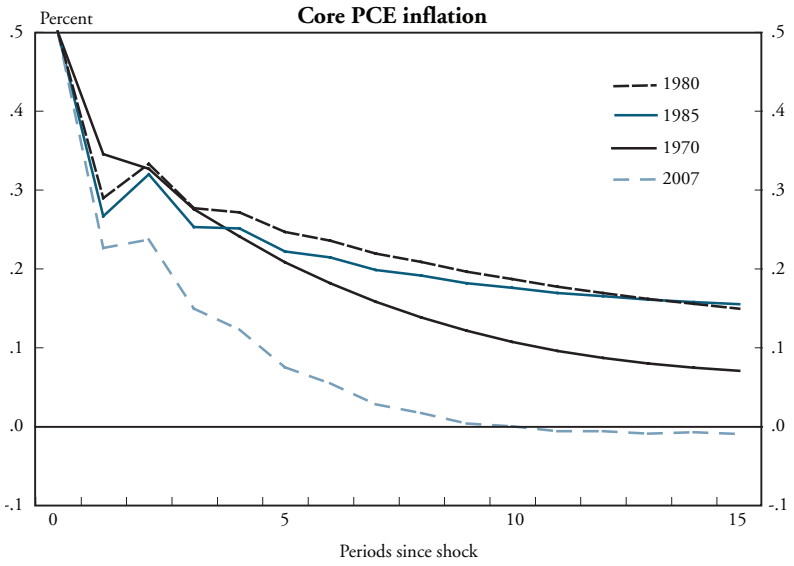
The sum of coefficients on the detrended federal funds rate shows a similar, but inverted, pattern—drifting down from the mid-1970s through the mid-1980s and then drifting up to essentially zero. This path suggests increases in the federal funds rate reduced long-term inflation expectations more in the mid-1980s than they do today.[27] Finally, the estimated sum of coefficients on the output gap is very small, with confidence bands wide enough that the sum is not statistically different from zero.

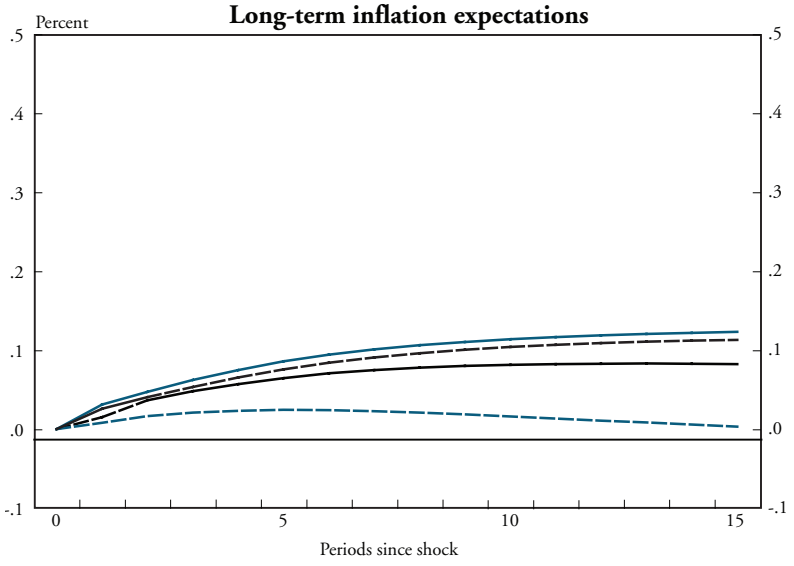
Although the coefficient estimates suggest the behavior of inflation and long-term expectations may have changed, the coefficients offer only a partial view of the responsiveness of inflation and expectations to various influences. Focusing on particular coefficients abstracts from the potential impact of feedback among variables, such as interactions among monetary policy and inflation. Therefore, to assess whether inflation and expectations have become better anchored, Chart 8 compares, across time, the responses of core inflation and long-term expectations to a 0.5 percentage point shock to inflation.[28] Responses are traced out over a four-year period, from the initial period of the shock through the next 15 quarters. Each of four lines show the shock response implied by coefficient estimates from different points in time: 1970:Q4, 1980:Q1, 1985:Q1, and 2007:Q2.

In all estimates, after a shock to inflation, inflation gradually declines, while expectations gradually rise. Consistent with the notion that inflation and expectations have become slightly better anchored, inflation falls faster in 2007 than in prior years, while expectations rise less in 2007 than in prior years (Chart 8). To isolate the key changes, Chart 9 reports the differences between the shock responses implied by the 1980:Q1 coefficient estimates and the responses implied by the 2007:Q2 coefficient estimates. With inflation returning to baseline faster in 2007 than in 1980, the estimated difference in inflation responses in Chart 9 is negative. Similarly, with the shock to inflation having less impact on expectations in 2007 than in 1980, the estimated difference in the response of inflation expectations is negative.

Chart 8

RESPONSES TO 0.5 PERCENTAGE POINT INFLATION STOCK



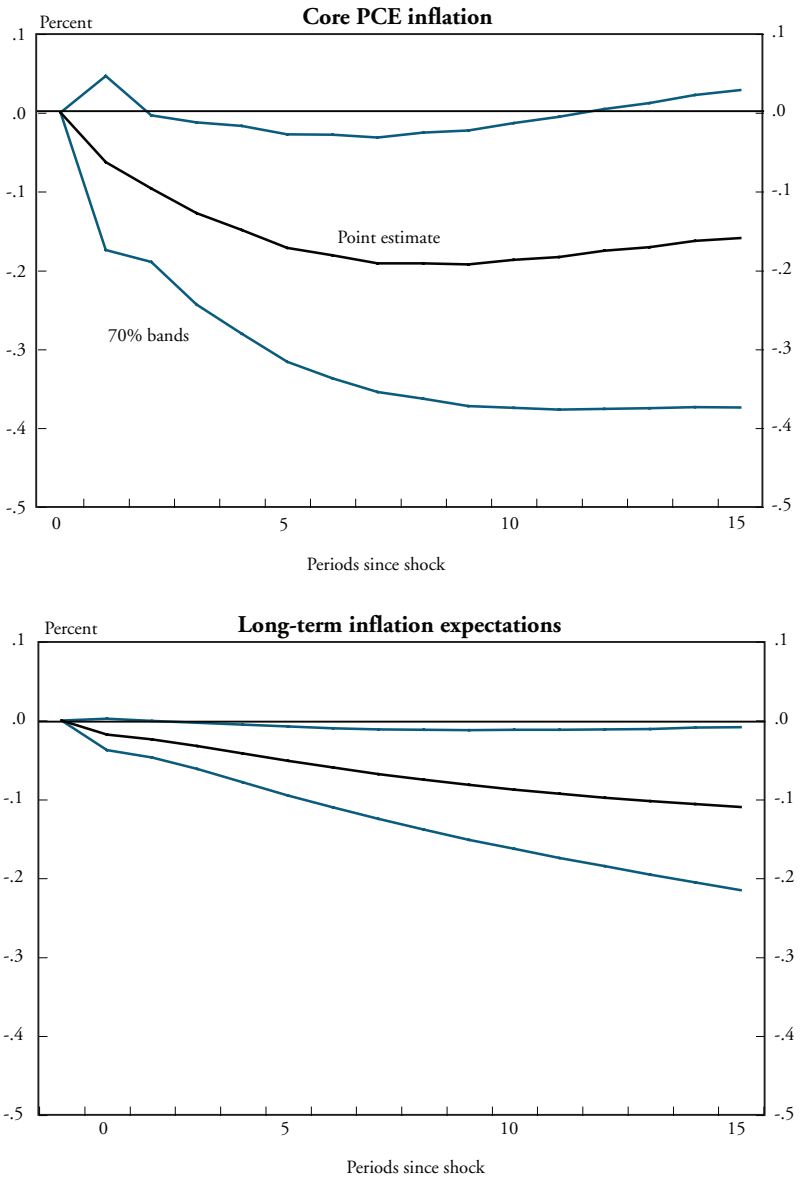


Notes: The chart presents the paths of responses of core PCE inflation and long-term inflation expectations to a 0.5 percentage point temporary shock to inflation, obtained from estimates of the four-variable model. Responses are reported for the values of coefficient estimates in selected periods: 1970:Q4, 1980:Q1, 1985:Q1, and 2007:Q2.

Sources: Bureau of Economic Analysis, Bureau of Labor Statistics, Congressional Budget Office, and Federal Reserve Board of Governors

Chart 9

DIFFERENCE IN 1980 AND 2007 RESPONSES TO INFLATION SHOCK



Notes: The chart presents the difference between the 1980:Q1 and 2007:Q2 paths of responses of core PCE inflation and long-term inflation expectations to a 0.5 percentage point temporary shock to inflation. The paths are determined by the model coefficient values for 1980:Q1 and 2007:Q2. The point estimates are the 2007 estimate less the 1980 estimate. A negative value means an unexpected increase in inflation has a smaller impact in 2007 than in 1980. The chart includes 70 percent confidence bands.

Sources: Bureau of Economic Analysis, Bureau of Labor Statistics, Congressional Budget Office, and Federal Reserve Board of Governors

Quantitatively, though, the changes in shock responses are small, typically amounting to 0.2 percentage point or less for inflation and 0.1 percentage point or less for expectations. And, the estimated changes are somewhat imprecise. The decline in the responsiveness of inflation and expectations is significant at the 70 percent confidence level provided in Chart 9, but not at a more conventional 90 percent level. However, the evidence of small declines in the responses—and therefore slightly better anchoring of inflation and expectations—seems solid. The estimated probability of a decline in the response of inflation is 89 percent; the probability of a decline in the response of expectations is 90 percent.[29]

The quantitatively more important change has been in volatility, with the model attributing the sharp reduction in the volatility of inflation and expectations entirely to smaller shocks. The model estimates of the standard deviations of shocks to each variable show a considerable falloff over time, with relatively tight confidence intervals (Chart 10).[30] The estimated standard deviation of inflation shocks in 2007 is about half the estimated standard deviation for 1974, 1979, and 1983. The estimated standard deviation of shocks to long-term inflation expectations trended down in the 1980s and 1990s, until hitting the very low level at which it has remained since 1999.

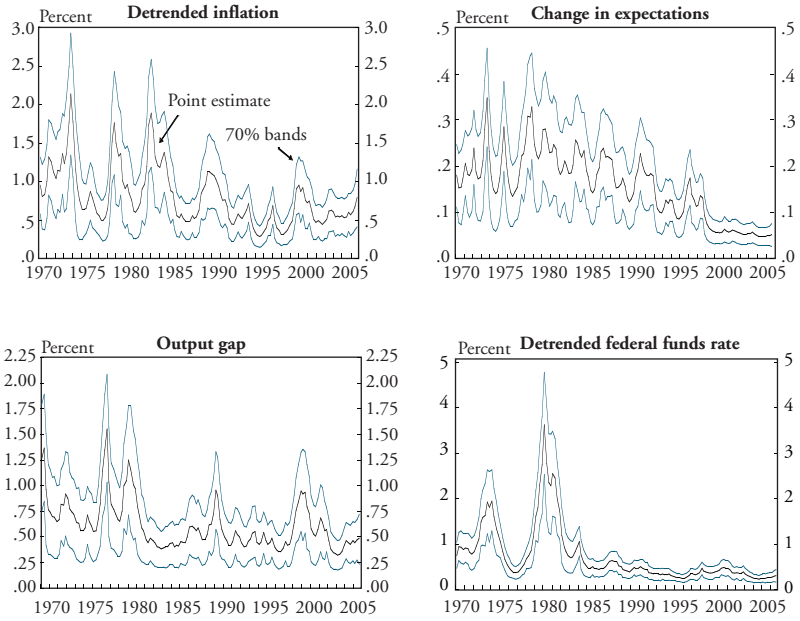
Reflecting the reduced variability of shocks, the model-based estimates of the standard deviations of inflation and inflation expectations have plummeted (Chart 11). Had the model coefficients stayed at their 1980:Q1 value for the entire 1970-2007 period, the volatilities of inflation and expectations would have fallen as much as they did according to the model estimates that allow the coefficients to vary. In contrast, had the shock standard deviations been fixed at their 1980:Q1 values, the volatilities of inflation and expectations would have changed very little or, in the case of inflation, moved even higher.

III. CONCLUSIONS

Because core inflation and long-term inflation expectations have varied less in the past decade than in prior years, some observers have suggested the behavior of inflation and expectations has fundamentally shifted. This article uses statistical models that allow for gradual change over time to assess the evidence of changes in the behavior of inflation

Chart 10

STANDARD DEVIATIONS OF SHOCKS IN FOUR–VARIABLE MODEL

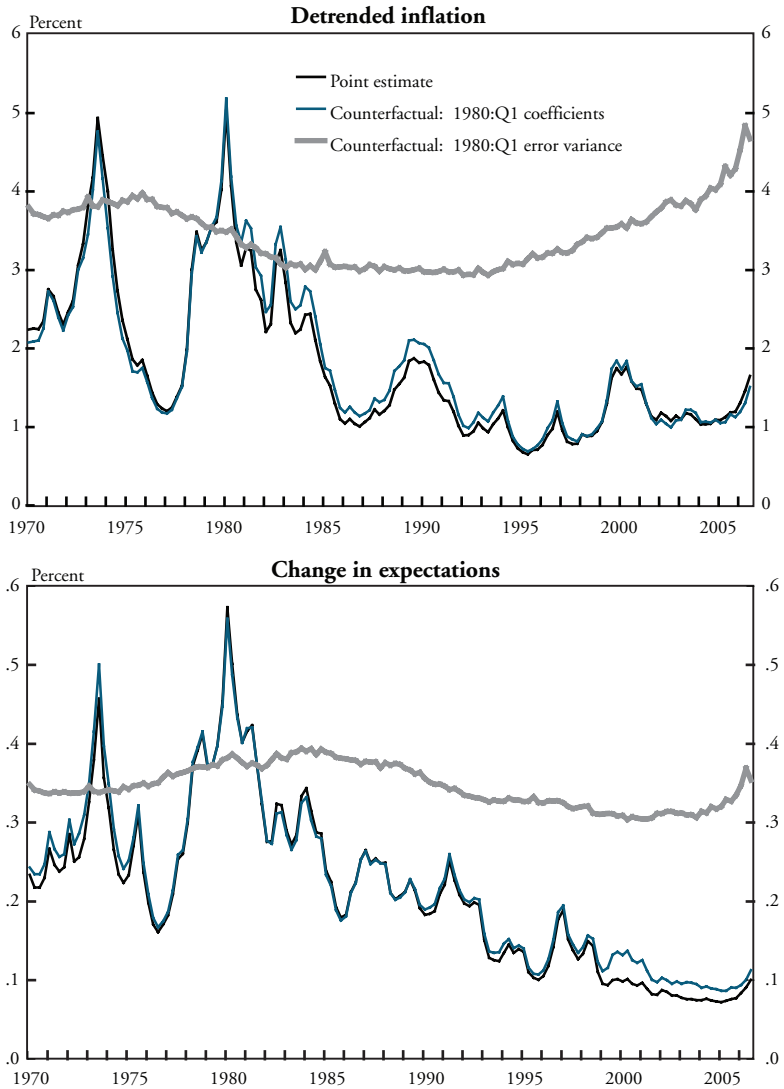


Notes: The chart presents the time paths of point estimates of the standard deviations of the shocks in the four-variable model, along with 70 percent confidence bands for each point estimate.

Sources: Bureau of Economic Analysis, Bureau of Labor Statistics, Congressional Budget Office, and Federal Reserve Board of Governors

Chart 11

FITTED STANDARD DEVIATIONS OF DETRENDED INFLATION AND THE CHANGE IN INFLATION EXPECTATIONS IMPLIED BY FOUR–VARIABLE MODEL



Notes: The chart presents alternative time paths of the standard deviations of detrended inflation and the change in long-term expectations implied by estimates of the four-variable model. The model implies the standard deviations of inflation and expectations to be specific functions of the model coefficients and shock standard deviations. The point estimates are based on the model-estimated time-varying coefficients and shock standard deviations. One counterfactual reports the paths of standard deviations for inflation and expectations that result from holding the coefficients at their 1980:Q1 values for the whole sample (but using the model estimates of time-varying shock standard deviations). The other counterfactual reports the paths of of standard deviations for inflation and expectations that result from holding the shock standard deviations at their 1980:Q1 values (but using the model estimates of the time-varying coefficients).

Sources: Bureau of Economic Analysis, Bureau of Labor Statistics, Congressional Budget Office, and Federal Reserve Board of Governors

and expectations. The analysis yields modest evidence that, compared to 20 or so years ago, expectations have a slightly larger influence on inflation, and inflation and expectations are slightly better anchored. However, the greatly increased stability of inflation and expectations in recent years is largely due to smaller shocks to the economy.

APPENDIX

This appendix details, in technical terms, the statistical models and estimation methodology used in the article. For brevity, the appendix focuses on describing the four-variable model. The single variable-model takes the same basic form and is estimated with the same methodology, with only modest differences noted below. Many additional details are covered by Primaceri.

Model

The model is a vector autoregression (VAR) with time-varying coefficients and stochastic volatility, as in Primaceri. Let y_t denote the vector of variables measured in quarter t: the change in long-term inflation expectations, core PCE inflation less long-term expectations, the output gap, and the federal funds rate less long-term inflation expectations.[31] The model takes the form:

$$y_t = B_{1,t} y_{t-1} + B_{2,t} y_{t-2} + A_t^{-1} H_t^{.5} e_t, \text{var}(e_t) = I$$

$$A_t = \begin{pmatrix} 1 & 0 & 0 & 0 \\ a_{21,t} & 1 & 0 & 0 \\ a_{31,t} & a_{32,t} & 1 & 0 \\ a_{41,t} & a_{42,t} & a_{43,t} & 1 \end{pmatrix}$$

$$H_t = \begin{pmatrix} h_{1,t} & 0 & 0 & 0 \\ 0 & h_{2,t} & 0 & 0 \\ 0 & 0 & h_{3,t} & 0 \\ 0 & 0 & 0 & h_{4,t} \end{pmatrix}.$$

The errors e_t are independent structural shocks, identified from the common recursive, or Choleski, ordering. The reduced-form residuals are $A_t^{-1} H_t^{.5} e_t$. Under the ordering of variables in y_t, a shock to expectations can have an immediate impact on inflation, but a shock to inflation (above and beyond expectations) can only affect expectations with a one-period delay. In the case of the single-variable model, the matrix A_t simplifies to just a constant of 1. The estimation of the single-

variable model does not involve the terms associated with A_t described below (such as the variance of shocks to the elements of A_t).

The first three variables of the model have means of roughly zero over the full sample. For simplicity, the federal funds rate less long-term inflation expectations is de-meaned prior to estimation.[32] With all variables having means of roughly zero, no intercepts are necessary in the model.

With all the coefficients of $B_{1,t}$ and $B_{2,t}$ stacked in a vector B_t, the model can be rewritten as

$$y_t = X_t' B_t + A_t^{-1} H_t^{.5} e_t,$$

where X_t is a stacked vector containing all of the right-hand-side variables (lags of detrended inflation, the change in expectations, the output gap, and the detrended federal funds rate) for all equations.

All of the time variation in coefficients and variances is modeled with random walk processes, which relate current values to last period's value plus a shock. For notational convenience, let a_t denote a vector containing all of the coefficients $a_{ij,t}$ of A_t, and let h_t denote a vector containing all of the variances $h_{i,t}$ of H_t. The time variation of the model parameters is governed by the following equations:

$$B_t = B_{t-1} + u_t$$
$$a_t = a_{t-1} + v_t$$
$$\log h_t = \log h_{t-1} + n_t$$

All of the innovations in the model are assumed to follow joint normal distributions, with independence among e_t, u_t, v_t, and n_t. In addition, the blocks of v_t associated with each different equation are assumed to be independent.

Estimation methodology

The model is estimated with the Bayesian methodology detailed in Primaceri, for the period 1970:Q4 (1970:Q3 for the single variable model) through 2007:Q2. Bayesian estimation combines prior distributions for all coefficients with the likelihood, to obtain posterior distributions. Markov chain Monte Carlo methods are used to simulate the posterior distributions, from prior distributions that are normal or inverted Wishart, as spelled out by Primaceri. The estimates are based

on 20,000 draws, with the first 5,000 discarded. In all cases, the reported point estimates are posterior means from the 15,000 net draws.

The priors use estimates for the first ten years of data—an estimation sample of 1960:Q4 through 1970:Q3 (1960:Q3 through 1970:Q2 for the single variable model)—to set initial values of the time-varying coefficients and variances. The prior mean and variance of the initial value of VAR coefficients, B_0, are set to OLS estimates of the coefficients and their variance, for the 1960-70 pre-sample.[33] Similarly, the prior mean and variance of the coefficients of the Choleski matrix, stored in a_0, are set to OLS estimates of the coefficients and their variance from the 1960-70 pre-sample.[34] The prior mean of the initial value of the log variances, h_0 , is set to the log of OLS estimates of residual variances from the 1960-70 pre-sample; the prior variance is set to an identity matrix.

Somewhat more informative priors are imposed on the amount of time variation in the coefficients and variances, reflecting a prior view that some time variation is likely, especially in the variances. The (inverted Wishart) prior for the variance of u_t , the shocks to the VAR coefficients, uses a mean of 0.005 times the variance of the OLS estimates from the 1960-70 initialization sample, with 40 degrees of freedom.[35] The (inverted Wishart) prior for the variance of v_t, the shocks to the Choleski coefficients, uses a mean of 0.01 times the variance of the OLS estimates from the 1960-70 initialization sample, with 10 degrees of freedom. Finally, the (inverted Wishart) prior for the variance of n_t, the vector of shocks to the log variances, uses as mean a matrix with 0.5 for all diagonal elements and 0 elsewhere, with 40 degrees of freedom.

ENDNOTES

[1]This definition fits within the somewhat more general definition of Bernanke.

[2]The article focuses on core PCE inflation because many FOMC members have indicated they prefer it over alternatives. In addition, compared to the CPI, the PCE price index is less affected by historical changes in measurement methodology. For example, a shift in the treatment of housing creates a break in published CPI dynamics in 1983 (Clark and McCracken).

[3]Chart 1 suggests that, for at least most of the sample, changes in inflation often lead to subsequent adjustment of inflation expectations–that is, that inflation Granger-causes long-run expectations. Model estimates confirm this pattern. Whether expectations Granger-cause inflation might be less clear from the chart. However, various model estimates confirm that movements in expectations lead to movements in inflation.

[4]Some aspects of the measure of long-term inflation expectations–in particular, the CPI rather than PCE basis of the source data and splicing of different data sources–may be seen as effectively increasing the uncertainty around the overall evidence in the article. To assess the importance of the CPI-PCE distinction, estimates were generated using a housing-consistent core CPI series in place of core PCE inflation. To assess the impact of splicing the econometric measure of expectations to the survey measures (Kozicki and Tinsley note that different survey estimates are generally similar), model estimates were generated using data starting in 1980 instead of 1970. Estimates for housing-consistent CPI inflation are broadly similar to those for PCE inflation but generally less suggestive of change. With CPI inflation, the single-variable model yields weaker evidence of an increase in the influence of expectations, while the four-variable model yields somewhat stronger evidence. However, for CPI inflation, there is less evidence of improved anchoring. Estimates (based on core PCE inflation) for 1980-2007 are qualitatively similar to those for the 1970-2007 sample, but the overall evidence of change is weaker, particularly for anchoring (however, shortening the sample should be expected to weaken the strength of the statistical evidence, by increasing the uncertainty around point estimates in the early 1980s).

[5]Kozicki and Tinsley use time series models of bond yields and inflation to obtain estimates of long-run inflation expectations, corresponding to so-called end points.

[6]Effectively, this series is the only (mostly) survey-based measure available for any length of time. Mishkin explains the construction of the expectations series, denoted PTR in the FRB/US model documentation. The source data on CPI inflation expectations are translated into PCE by subtracting 0.5 percentage point from the original CPI-based source data, reflecting the average differential between CPI and PCE inflation.

[7]The cause of the upward and downward trends in inflation is the subject of debate. Studies such as Ireland and Kozicki and Tinsley suggest the implicit inflation target of the Federal Reserve rose and then fell. Orphanides argues that the broad failure of economists to detect the trend productivity slowdown of the early 1970s and the associated slowdown in trend GDP growth can explain much of the rise in inflation over the 1970s. Still others, such as Clarida, Gali, and Gertler, suggest the Federal Reserve didn't respond aggressively enough in the 1970s to increases in inflation (in a Taylor Rule context, the coefficient on inflation was too small in the 1970s).

[8]Two lags are sufficient for capturing serial correlation in detrended inflation. Using four lags yields very similar results. Adding a constant to the model (and then allowing the coefficient to be time-varying in the estimation) also yields very similar results.

[9]In this model, if inflation expectations become more important, shocks to inflation die out more quickly, making inflation less persistent.

[10]In light of prior evidence from such studies as Kim and Nelson, McConnell and Perez-Quiros, and Stock and Watson (2002), the article treats a decline in volatility as given and focuses on examining the roles of coefficients versus shock variances in accounting for the decline in volatility.

[11]Specifically, letting σ denote the standard deviation of the model error e_t, the model implies the standard deviation of detrended inflation to be:

$$\left[\frac{1-\beta_2}{(1+\beta_2)\left[(1-\beta_2)^2-\beta_1^2\right]}\right]^{.5}\sigma.$$

In the four-variable model, the mathematical expressions for model-implied volatilities are more complicated, but qualitatively similar.

[12]More formally, the model allows random walk variation in slope coefficients and the log of the residual variance. The model is estimated with the Bayesian method of Primaceri.

[13]Using other reasonable benchmark periods yields very similar findings.

[14]The specification of the expectations variable as the change in expectations is intended to remove the long-term trend.

[15]Model estimates using the unemployment gap (based on the CBO's estimate of the natural rate of unemployment) instead of the output gap are very similar.

[16]More specifically, the equation for detrended inflation is:

$$\pi_t-\pi_t^e=\beta_1(\pi_{t-1}-\pi_{t-1}^e)+\beta_2(\pi_{t-2}-\pi_{t-2}^e)+\beta_3(\pi_{t-1}^e-\pi_{t-2}^e)+\beta_4(\pi_{t-2}^e-\pi_{t-3}^e)+\beta_5 gap_{t-1}+\beta_6 gap_{t-2}+$$
$$\beta_7(ffr_{t-1}-\pi_{t-1}^e)+\beta_8(ffr_{t-2}-\pi_{t-2}^e)+e_t,$$

where *gap* denotes the output gap and *ffr* denotes the federal funds rate. The equations for the three other variables of the model take the same basic form.

[17]More formally, the model allows random walk variation in all slope coefficients and stochastic volatility as in Primaceri. The residual variances are modeled with a recursive (Choleski) structure. The log variances of the structural shocks and Choleski coefficients all follow random walk processes. The model is estimated with the Bayesian method of Primaceri.

[18]However, such a decline would not ensure a greater impact of expectations, because feedback among other variables could offset the impact suggested by the inflation coefficients alone. Moreover, a decline in the coefficients on detrended inflation implies an increase in the relative influence of the output gap and the detrended federal funds rate.

[19]Using other reasonable benchmark periods yields very similar findings.

[20]See, for example, former Chairman Greenspan's comments in Federal Reserve Bank of Kansas City (pp. 74-75).

[21]Because the model does identify the structural behavior of monetary policy under the conventional recursive ordering used in studies ranging from Bernanke and Blinder to Christiano, Eichenbaum, and Evans to Primaceri, the model could be used to try to assess the role of monetary policy in any changes in inflation dynamics. Indeed, Primaceri conducts a conceptually similar exercise, examining the response of monetary policy to inflation and unemployment shocks. However, because the other shocks in the model—including the inflation shock for which the article reports results—are not structurally identified, it would not be possible to draw strong conclusions. Moreover, the great predictability of monetary policy in recent years raises econometric issues in the identification of structural shocks to monetary policy versus other variables.

[22]The Bayesian statistical methodology used to estimate the models makes such probabilities natural and easy to compute (Cogley and Sargent 2007).

[23]All point estimates in the article are posterior means.

[24]The proper Bayesian term for "confidence intervals" or "confidence bands" is "credible sets." The article uses the more familiar classical econometrics language of "confidence bands" and "statistical significance" to simplify the text presentation.

[25]While coefficients are only reported for the inflation and expectations equations, the coefficients in the equations for the output gap and funds rate are also time-varying. For the model as a whole, the sharpest evidence of coefficient change is for the coefficients on the federal funds rate in the output gap equation. The estimated sum of coefficients rises from a peak of -0.27 in 1974 to -0.02 in 2007.

[26]This result contrasts with some other research (for example, Roberts) that has found a decline in the slope of the Phillips curve. The contrast in part reflects differences in the treatment of statistical uncertainty. If the date of a potential shift in coefficients is treated as known to fall in the early or mid-1980s, the resulting split-sample regression estimates suggest a significant break. However, such estimates abstract from the uncertainty surrounding the date of any change, and

therefore understate the true uncertainty surrounding the coefficient estimates. Consistent with this argument, applying an Andrews (1993) test to a Phillips curve in detrended inflation fails to uncover a statistically significant break in the coefficients of the model. The point estimates of a change in the mid-1980s are large, but the break is not statistically significant. Similarly, the methodology used in this article treats the extent and timing of change as unknown. Specifically, the Bayesian methodology assigns a loose initial value to the slope of the Phillips curve, based on data prior to the estimation sample, a prior on the variance of changes over time, and then obtains point estimates of the initial value and time path based on information in the data and the prior.

[27]Nominal appearances aside, such a finding could mean monetary policy is actually more effective at stabilizing inflation expectations now than in the early or mid-1980s. In the mid-1980s, in the absence of much communication of the Federal Reserve's long-term inflation goals, private-sector economists drew inferences on those goals from adjustments in the federal funds rate. Today, in contrast, private-sector economists perceive the Federal Reserve's long-term inflation goals to be relatively clear, from various Federal Reserve communication efforts. Consequently, adjustments in the federal funds rate for economic stabilization purposes tend to have little impact on long-term inflation expectations. As noted above, while the statistical models used in this article are useful for assessing how the behavior of inflation and expectations have changed, more sophisticated economic models would be necessary to assess why change has occurred, and monetary policy's possible role.

[28]The shock is identified from a recursive or Choleski ordering, with the variables ordered as follows: change in expectations, detrended inflation, the output gap, and the detrended federal funds rate. The responses of the change in expectations are accumulated such that the reported responses show the level of expectations relative to baseline. Similarly, the response of the level of expectations is added to the response of detrended inflation such that the reported responses show the level of inflation relative to baseline.

[29]These probabilities are computed for the responses at a horizon of eight periods (seven periods after the shock).

[30]The reported results are for the reduced form standard deviations, which are dependent on both the Choleski factors and the structural shocks. Results for the structural shocks are qualitatively identical.

[31]Following Primaceri, the variables are scaled prior to estimation in order to make the estimation method of Kim, et al. accurate (specifically, the usual annualized rates for detrended inflation, the output gap, and the detrended federal funds rate are multiplied by 0.25 prior to estimation). After estimation, the scaling is un-done, such that the reported units for the coefficients and variances are the usual annualized percentages.

[32]Implicitly, the analysis assumes the real funds rate defined as the nominal rate less long-term inflation expectations has a constant mean or steady state value over the sample.

[33]Because long-term inflation expectations vary little over the initialization sample, the OLS variance matrix used in the priors is adjusted in order to prevent excessive variation in the coefficients associated with the change in expectations. More specifically, with little variation in expectations, the OLS variance terms associated with expectations are very large. To more reasonably limit the amount of variation in coefficients, the OLS variance matrix is recomputed as KVK' where K is a matrix with 0.5 on the diagonal for all expectations coefficients, 1 on the diagonal for all other coefficients, and 0 elsewhere.

[34]These estimates are obtained from regressions using the OLS-estimated VAR residuals, as described by Primaceri.

[35]The scaling by 0.005 implies that, under the prior, the coefficients at the end of the sample should (with 90 percent probability) lay within about two standard errors of the initial value.

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