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Inflation expectations and core inflation in the United States have been remarkably stable during the past 10 years, a dramatic break from the pattern seen in the prior two decades. Indeed, long-run inflation expectations, as measured by the median response of the Survey of Professional Forecasters (SPF) and shown in Chart 1, have barely budged since 1998. And core measures of CPI and PCE price inflation have fluctuated in relatively narrow ranges during the past decade, a period in which the economy was buffeted by a recession and large changes in energy prices.[1] Economic theory suggests that the reduced-form behavior of inflation may be different in a regime of stable inflation and inflation expectations compared to regimes in which inflation is allowed to drift for a considerable period of time and expectations are poorly anchored. This memo explores whether a standard workhorse reduced-form model of inflation, the so-called "accelerationist" Phillips curve model, provides a reasonable description of U.S. inflation dynamics in the current era of well-anchored inflation expectations.

Has the Observed Behavior of Inflation Changed?

A number of recent research papers have examined whether the observed behavior of inflation in the United States has changed over the past two decades. Inflation appears to have been highly persistent during much of the postwar period, as documented by Fuhrer and Moore (1995) and others. Using a variety of statistical methods, Levin and Piger (2002), Cogley and Sargent (2005), and Nason (2006) find that inflation persistence in the United States declined starting in the early 1980s or early 1990s. For example, Levin and Piger (2002) find that once one adjusts for a shift in the mean inflation rate occurring in the early 1990s, inflation persistence appears to be quite low since the early 1980s. However, the conclusion that inflation persistence has decreased remains controversial. Indeed, Pivetta and Reis (2006) show that one cannot reject the null hypothesis that the

[1] Throughout this memo, the core CPI refers to the consistent-methodology "Research Series" of the core CPI constructed by the Bureau of Labor Statistics, as opposed to the current methods series. The BLS data were seasonally adjusted using the X12 procedure.

observed behavior of inflation has not changed over time and that, in particular, inflation has remained highly persistent. Apparently, the evidence from the past 10-20 years is insufficient to decisively resolve the issue as to whether inflation persistence has fundamentally changed in the current era.

This memo approaches this issue from a slightly different perspective, that of the backward-looking or accelerationist Phillips curve model of inflation that is frequently used for forecasting and policy analysis. In this respect, it is in the tradition of Hooker (2002) and Roberts (2004), who explore the evidence of changes in the coefficients of Phillips curve models. The specification of the accelerationist Phillips curve is given by:

$$(1) \quad \boldsymbol{\pi}_t = \sum a_i \boldsymbol{\pi}_{t-i} + b\,\mathbf{u}_{t-1} + c^*\mathbf{x}_{t-1}, \quad \sum a_i = 1,$$

where $\boldsymbol{\pi}$ is the inflation rate, **u** is the unemployment gap (the unemployment rate less the NAIRU), and **x** are other control variables, such as real import and energy prices. In the following, we use the CBO estimates of the NAIRU in constructing the unemployment gap. The coefficient **b** (presumably negative) measures the slope of the Phillips curve. The restriction that the sum of the coefficients on the lags of inflation equals unity implies that, all else equal, inflation tends to rise (fall) when the unemployment rate is below (above) the NAIRU. When estimated on long samples that include data from the 1960s through the present, the unit sum restriction on lagged inflation is not rejected and the coefficient on the unemployment gap is negative and statistically significant.

To test whether the existence of well-anchored inflation expectations has affected observed inflation dynamics, I estimated using ordinary least squares (OLS) versions of Phillips curve models with different sample starting points (ranging from 1980q1 to 1999q4), but with the sample ending point fixed at 2006q2. In the results reported here, I included four lags of inflation and one lag of the CBO unemployment gap. I estimated equations for core PCE price inflation and for core CPI inflation (using the methodologically-consistent series). The upper panels of Chart 2 show the results for core CPI inflation; those in Chart 3 show the results for core PCE price inflation. In both cases, the unit sum restriction on the coefficients on lagged inflation is imposed. The date on the horizontal axis of the figure corresponds to the beginning date of the sample

used in the regression. The solid lines show the estimated values of the coefficients; the dotted lines show the one-standard-error bands around the estimates.

In samples starting in the early 1990s, the slope coefficient in the accelerationist Phillips curve is considerably smaller than in the sample starting in 1980, consistent with Roberts' (2004) finding of a "flattening" of the Phillips curve. As a result, estimates of the sacrifice ratio—the implied cumulative annual unemployment gap needed to permanently lower the inflation rate by one percentage point—are much larger for samples starting in the early-1990s than the full-sample estimates. Interestingly, sacrifice ratio estimates are much lower for core CPI inflation than for core PCE price inflation.

However, in samples that start in the early-1990s or later, the data seem to be at odds with the unit sum restriction on lagged inflation. I estimated using OLS the Philips curve equations, but this time added a constant to the equation and did not impose the unit restriction on the sum of the coefficients on lagged inflation. The lower panels of Charts 2 and 3 show the resulting estimated coefficients on the unemployment gap and the estimated sums of the coefficients on lags of inflation. For samples that start in the 1990s, the estimated unrestricted sum of coefficients on lagged inflation is well below unity for both core PCE and core CPI inflation.[2]

Although the decline in the point estimates of the sum of the coefficients shown in the figures is clear to the eye, standard statistical tests do not reject the hypothesis that the sum of the coefficients is constant over the full sample against alternatives of a break occurring in the early or late 1990s. Thus, from a purely statistical point of view, the low degree of inflation persistence observed over the past decade may just be a random fluke in the data and not represent a true shift in the observed behavior of inflation. This inability to find clear evidence of a break reflects the imprecision of the coefficient estimates.

In the core CPI inflation equation without the unit sum restriction imposed, the magnitude of the coefficient on the unemployment gap is actually larger for samples starting in the 1990s compared to the sample starting in 1980, the opposite pattern

[2] For technical reasons, these OLS estimates of the sum of coefficients are likely biased downward. I re-estimated this model using a "median-unbiased estimator" that corrects for this bias. The resulting estimates of the sum of coefficients are somewhat higher than the OLS estimates reported in the charts, but still show a substantial decline for samples starting in the 1990s relative to the full-sample estimates.

observed when the unit sum restriction is imposed. In the core PCE price inflation equation, the coefficient on the unemployment gap is less negative for samples starting in the 1990s compared to the sample starting in 1980. In fact, it is nearly zero or even positive. These estimates, however, are quite imprecise.

The preceding analysis provides tantalizing evidence that the persistence of inflation may have declined dramatically. I now consider a comparison of the "fit" of three alternative simple inflation forecasting models during the past 10 years, the period roughly corresponding to the attainment of well-anchored inflation expectations. For this exercise, the variable to be forecast is the change in the core price measure, either the core CPI or core PCE price index, over the next four quarters. The three forecasting models are: (1) the prior four-quarter-change in the price index, (2) a constant, and (3) an accelerationist Philips curve model. The first model treats the four-quarter change of inflation as a random walk, a model advocated by Atkeson and Ohanian (2001) for its out-of-sample forecasting properties. The second model treats the four-quarter change in core inflation as a constant plus serially uncorrelated random noise. Over the sample 1996q1-2006q2, the average rate of core CPI inflation is 2.1 percent and for core PCE inflation it is 1.7 percent. The third model is a standard accelerationist Phillips curve model with four lags of inflation where the dependent variable is the inflation rate over the next four quarters estimated on the full sample of data (1980q1-2006q2).

Over the past 10 years, a forecast that core inflation over the next four quarters will equal its sample mean beats a random walk forecast, as indicated by the root-mean-squared forecast errors indicated in Chart 4, which also shows the time series for the forecast errors of the various models. The same result holds for both core CPI and core PCE price inflation. These calculations are based on a comparison of the realized value of inflation to the model prediction for each quarter in the sample from 1996q1 to 2006q2. Note that this comparison is not an out-of-sample forecasting exercise, but rather provides a way of summarizing the behavior of inflation over the past decade.[3] The estimated Phillips curve model fits about as well as the random walk model over the past decade. The relatively small differences between the Phillips curve and random

[3] To construct out-of-sample forecasts of the constant model would require "real-time" estimates of the mean inflation rate.

walk models reflect the fact that the measured unemployment gap was not very large during this period.

A particularly interesting example of where the Phillips curve and random walk models have recently gone astray occurred in 2003 when core measures of inflation unexpectedly fell. The Phillips curve and random walk models predicted that inflation would remain low in 2004, but, in the event, the shock to inflation proved to be transitory and the inflation rate quickly jumped back up to around its post-1995 mean. Those two models made big forecast errors in 2004, while the constant model did much better.

That said, it is worth emphasizing that the overall differences in forecast performance between the three models is quite small over the past 10 years, reflecting the fact that inflation has been very stable. Put another way, a random walk, an accelerationist Phillips curve, and a constant model can look very similar in samples when the shocks to inflation and the unemployment gaps are relatively small. Therefore, it is not yet possible to draw strong conclusions regarding the relative merits of the different models.

Interpreting the Change in the Observed Behavior of Inflation

One interpretation of the contemporaneous attainment of stable inflation and inflation expectations and low inflation persistence is that the FOMC has systematically acted to stabilize core inflation around a constant long-run "target" and has gained credibility with the public that it will continue to do so in the future. According to a variety of models of inflation dynamics with forward-looking inflation expectations, one would expect the time-series properties of inflation and inflation's correlation with other variables to differ from those seen in the past when inflation expectations were not well anchored. For example, Erceg and Levin (2003) show that inflation will appear to the econometrician to be highly persistent if the central bank changes its inflation objective but the public is uncertain of the change, even in a model where inflation displays very little persistence if the long-run inflation objective is constant. In this view, the very high observed degree of persistence in inflation seen in the past reflects the conduct of monetary policy during this period, which led to the sustained rise in the 1970s and the disinflations of the early 1980s and early 1990s. Similarly, in the model of Orphanides and Williams (2005), if

long-run inflation expectations are well anchored, then inflation will be less persistent than if the public is uncertain about the long-run inflation objective.

In addition, in many such forward-looking models, if the central bank's long-run inflation objective is constant and known by the public, the model predicts that the unit sum restriction of the accelerationist Phillips curve will be violated. Under these conditions, the accelerationist Phillips curve model may be poorly suited for forecasting inflation and monetary policy analysis. Note that the recent evidence on the observed behavior of inflation is consistent with the broad implications of forward-looking models of inflation, but I have not formally tested the performance of any particular theoretical model and compared it to the accelerationist Philips curve model.

An extreme but nonetheless illuminating example of how changes in monetary policy regimes affect the behavior of inflation is found by comparing inflation dynamics in two very different monetary policy regimes. Ball (2000) shows that the variations of the random walk model describe inflation reasonably well over 1960-1999, but these models perform very poorly in the period of 1879-1914 when the monetary regime was very different and inflation displayed very little persistence. In the pre-World War I period, a reasonable model is one where inflation returns to a sample mean with only a modest degree of persistence.

Conclusion

This analysis provides some suggestive evidence that the standard accelerationist Phillips curve may no longer provide a reasonable description of the behavior of inflation in an era where inflation expectations are well anchored. Inflation appears to have become far less persistent in the past decade than it was in the preceding decades. This finding is consistent with the prediction of theoretical models when monetary policy systematically acts to stabilize inflation around a constant long-run target and has credibility with the public. If true, then one should expect inflation to display low persistence in years to come as long as policy continues to act in the pattern of the past decade and inflation expectations remain well anchored. This conclusion is admittedly quite tentative. Because inflation has been very stable over the past decade, it is simply not possible to unequivocally determine whether the observed shift in estimated coefficients in the

Phillips curve model represents a sustained change in the observed behavior of inflation or instead is due to random causes.

Importantly, even taken at face value, this evidence regarding possible shifts in the coefficients of the Phillips curve may only reflect changes in the correlations in the data, possible induced by changes in the behavior of monetary policy, and not correspond to any change in the true structure of the economy. Therefore, the recent low level of inflation persistence *cannot* be taken as given in designing monetary policy: if policy acts in ways to create a high degree of inflation persistence, then the public's expectations would eventually shift to reflect that reality.

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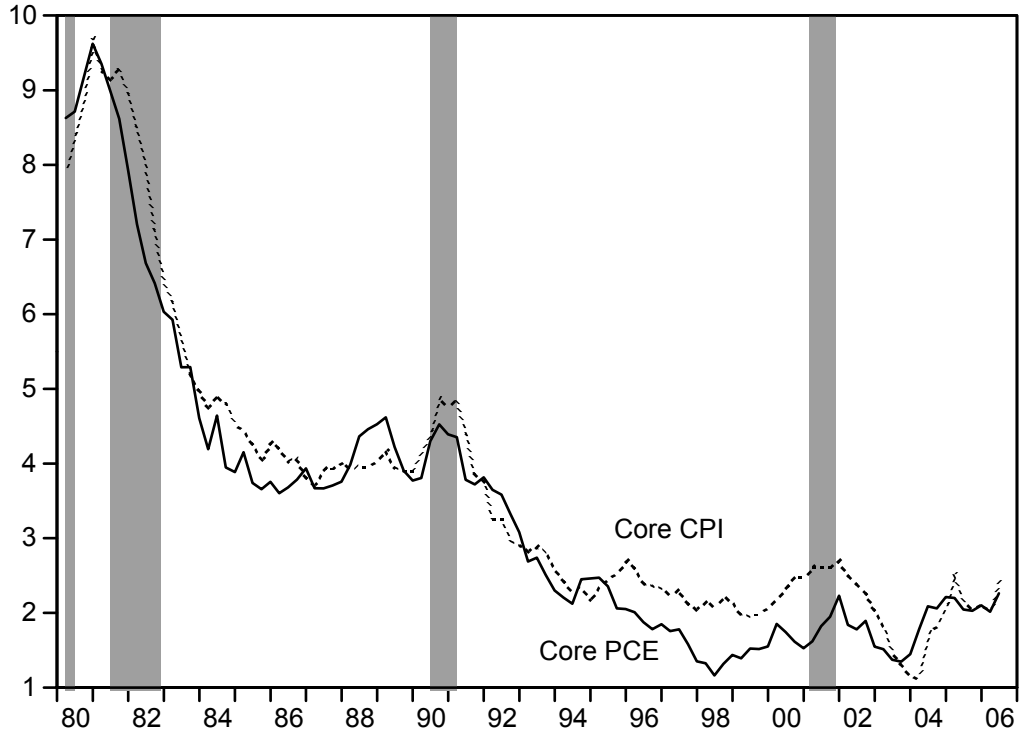
Chart 1

Inflation

Q4/Q4 percent change



Note: Gray bars denote NBER recessions.

Survey of Professional Forecasters:
Median Expected Inflation over next 10 Years

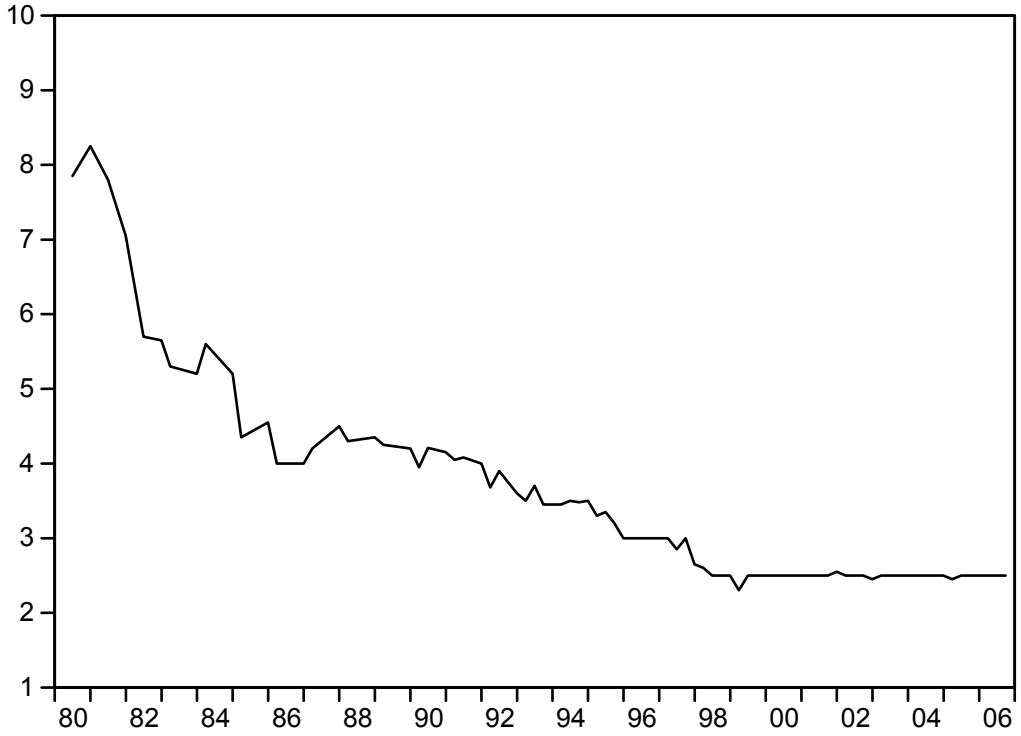
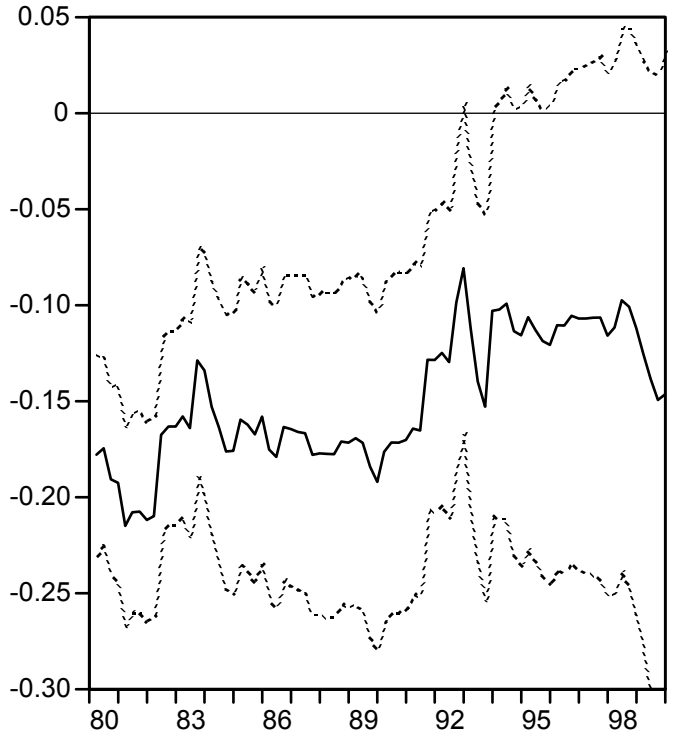
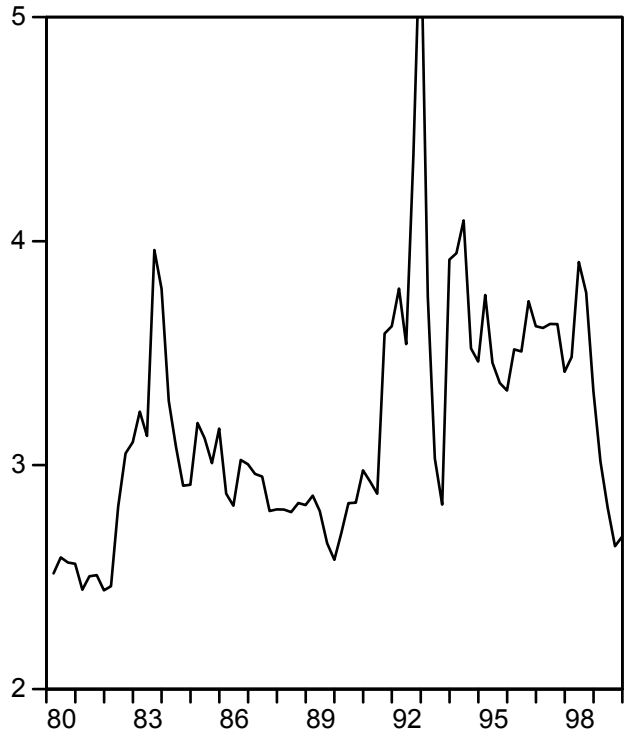


Chart 2

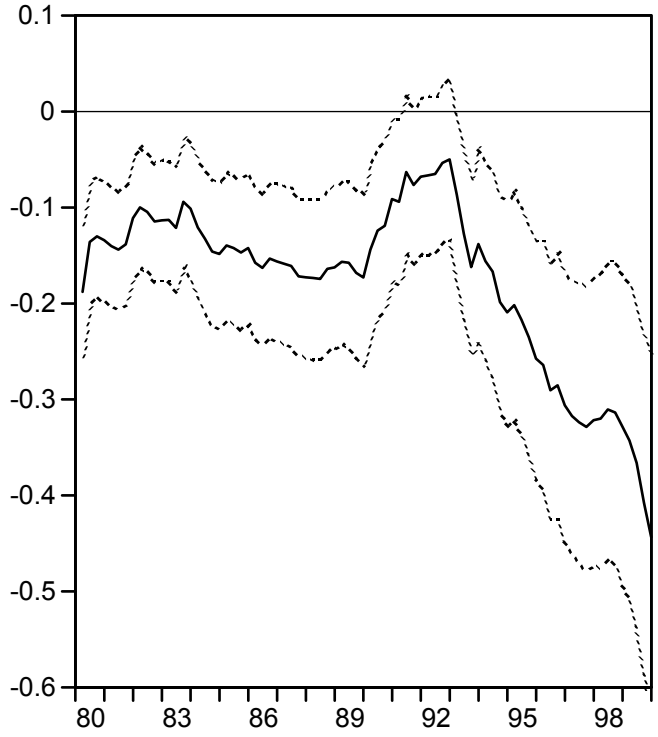
Coefficient on UGAP, restricted, core CPI



Sacrifice ratio, restricted, core CPI



Coefficient on UGAP, unrestricted, core CPI



Sum of coefficients on lags of core CPI, unrestricted, core CPI

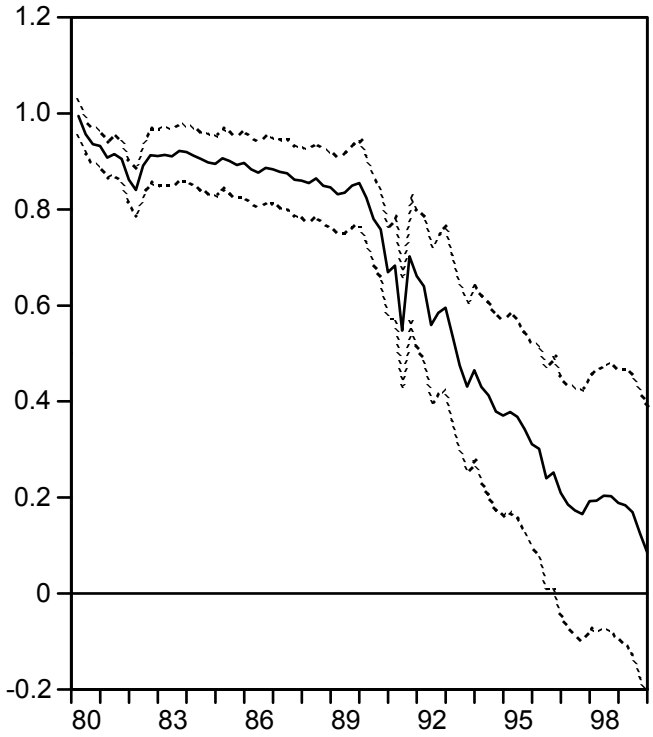
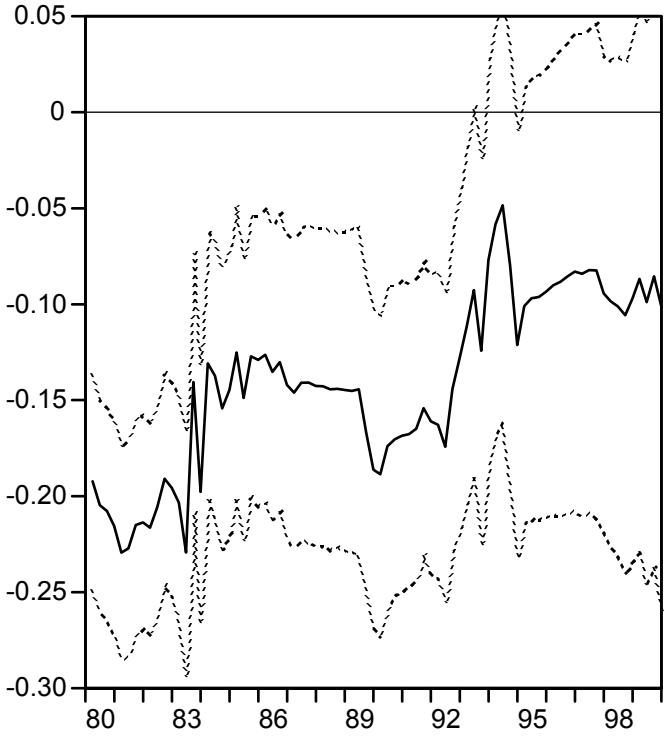
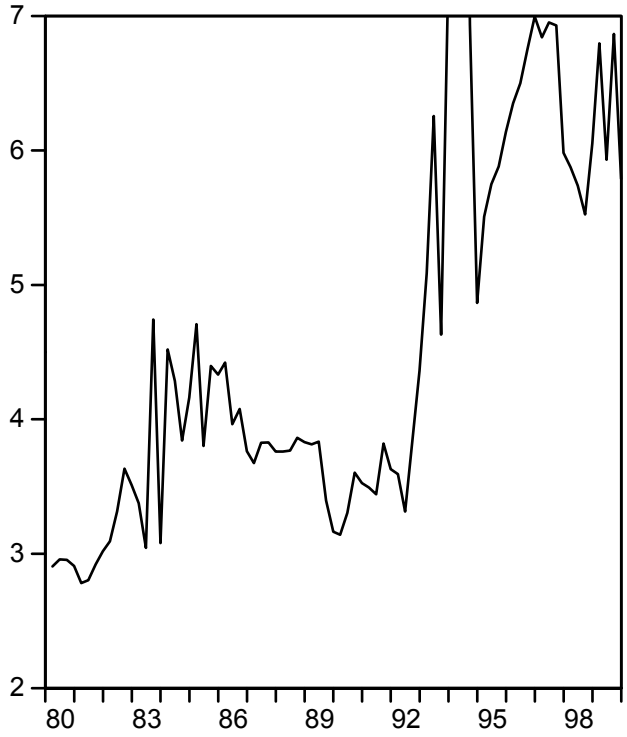


Chart 3

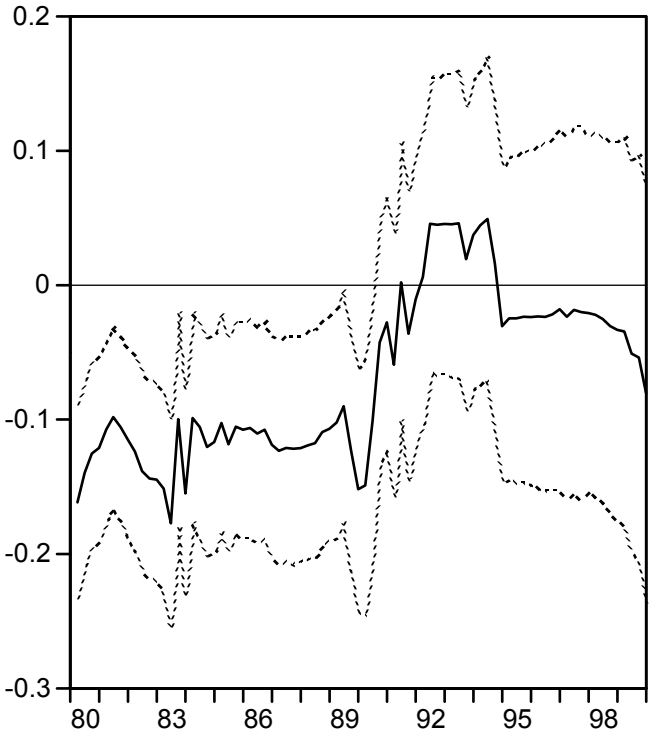
Coefficient on UGAP, restricted, core PCE prices



Sacrifice ratio, restricted, core PCE prices



Coefficient on UGAP, unrestricted, core PCE prices



Sum of coefficients on lags of core PCE prices, unrestricted, core PCE prices

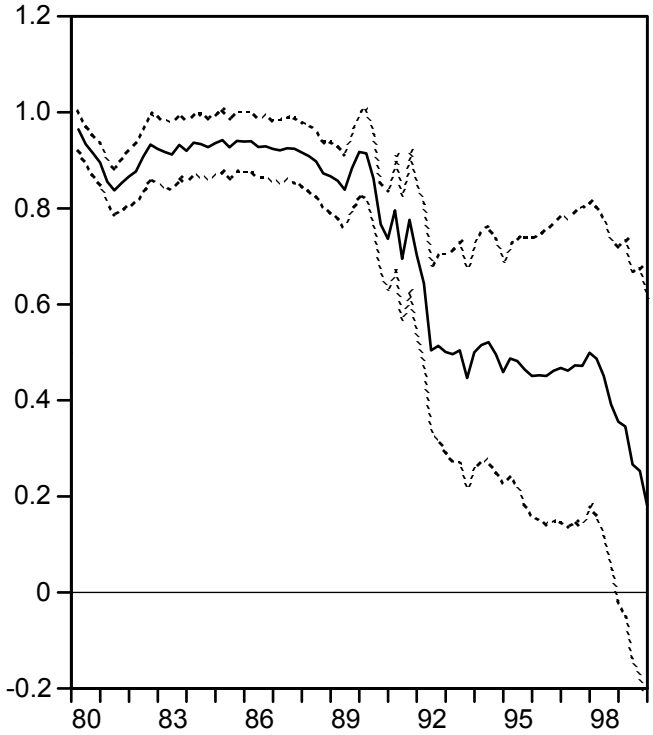
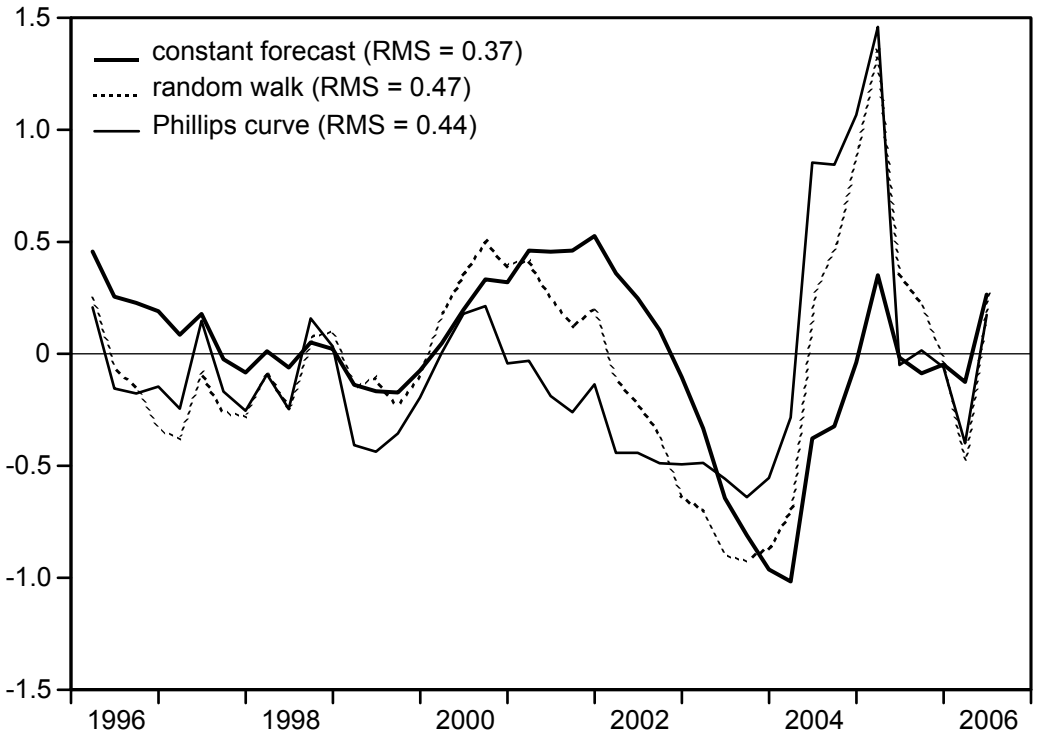


Chart 4

Forecast Errors: Core CPI Inflation



Forecast Errors: Core PCE Inflation