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ABSTRACT

This paper examines the recent behavior of core inflation in the United States. We specify a simple Phillips curve based on the assumptions that inflation expectations are fully anchored at the Federal Reserve's target, and that labor-market slack is captured by the level of short-term unemployment. This equation explains inflation behavior since 2000, including the failure of high total unemployment since 2008 to reduce inflation greatly. The fit of our equation is especially good when we measure core inflation with the Cleveland Fed's series on weighted median inflation. We also propose a more general Phillips curve in which core inflation depends on short-term unemployment and on expected inflation as measured by the Survey of Professional Forecasters. This specification fits U.S. inflation since 1985, including both the anchored-expectations period of the 2000s and the preceding period when expectations were determined by past levels of inflation.

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1 Introduction

How does unemployment affect inflation? This question has been a central topic in macroeconomics since Phillips (1958) and Samuelson and Solow (1960). Since the Great Recession of 2008-2009, economists have entered a new phase of research and debate about the unemployment-inflation relationship.

Recent research has been spurred by a puzzle: the "missing deflation" (Stock, 2011). The accelerationist Phillips curve of textbooks says that a high level of unemployment causes inflation to fall over time. For common calibrations of this relationship, the high unemployment rates during the recession and subsequent weak recovery should have pushed the inflation rate well below zero. Yet by many measures, the current rate of core inflation–inflation excluding the transitory effects of supply shocks–is close to its level before 2008. Many observers conclude that "we don't have a very good story about inflation and unemployment these days" (Krugman, 2014).

Many economists have proposed resolutions of the missing-deflation puzzle, and two basic ideas have become popular. The first idea, emphasized by Fed officials (e.g. Bernanke, 2010) and the IMF (2013), among others, is that inflation expectations have become anchored. According to this story, the Fed's commitment to a 2% inflation target has kept expected inflation near 2%, which in turn has prevented actual inflation from falling very far below that level.

The second explanation, proposed by Stock, Gordon (2013), and Krueger et al. (2014), is that inflation depends not on the aggregate unemployment rate, as in textbook Phillips curves, but rather on the short-term unemployment rate. This variable is defined as the percentage of the labor force unemployed for 26 weeks or less. The story here is that the short-term unemployed put downward pressure on wages but the long-term unemployed do not, because their attachment to the labor force is weak. This idea helps explain why inflation has not fallen by more, because short-term unemployment rose less sharply than total unemployment over 2008-2009, and has since returned to pre-recession levels.

The anchored-expectations and short-term-unemployment stories are sometimes presented as competing explanations for recent inflation behavior. This paper argues that both ideas are on the right track, and that they are complementary. Neither of the ideas can resolve the missing-deflation puzzle by itself, but together they do.

We capture the two ideas in a highly parsimonious Phillips curve. In our specification, the core inflation rate depends only on a constant (which depends on a fixed level of expected inflation) and on the average level of short-term unemployment over the previous four quarters. We fit this equation to data starting in 2000, which is approximately the date, according to the Survey of Professional Forecasters, when long-term inflation expectations became anchored at the Fed's target. Our Phillips curve explains the significant ups and downs in core inflation since 2000, and there is no evidence of a change in inflation behavior during the Great Recession.

We find that our Phillips curve explains core inflation fairly well when that variable is measured in the most common way, with the CPI less food and energy (CPIX). The fit of our equation is especially good, however, when we measure core inflation with the weighted median inflation rate from the Federal Reserve Bank of Cleveland. The reason is that the weighted median filters out short-term noise in inflation more effectively than the CPIX. A by-product of our research, we believe, is new evidence that the weighted median is a good measure of core inflation.

After studying inflation behavior since 2000, we extend our analysis back to 1985, the beginning of the "Great Moderation" era after the Volcker disinflation. For the 1980s and 90s, it is not reasonable to assume a fixed level of expected inflation, because actual inflation was trending downward over time. We find, however, that a generalization of our post-2000 Phillips curve fits the entire period from 1985 to the present. In this specification, core inflation depends on short-term unemployment and on expected inflation as measured by long-run forecasts from the Survey of Professional Forecasters.

For the post-2000 period, the generalized version of our Phillips curve is close to the version with constant expected inflation, because SPF inflation forecasts are almost constant. For 1985 through 1999, our equation is closer to the Phillips curves of textbooks, because SPF expectations are well-explained by past levels of inflation. Overall, the data are consistent with an expectations-augmented Phillips curve with short-term unemployment, and with a change in the behavior of expectations around 2000–a change resulting from the Fed's adoption of a 2% inflation anchor.

2 Measuring Core Inflation

We seek to explain the behavior of core inflation–the underlying level of inflation after the transitory effects of supply shocks are removed. A preliminary issue is how to measure core inflation.

The most popular measure is the growth rate of the CPI excluding food and energy (CPIX). However, as discussed in Ball and Mazumder (2011), we believe that a better measure is the weighted median inflation rate, as constructed by the Federal Reserve Bank of Cleveland. The weighted median filters out movements in headline inflation caused by large relative-price changes in any industry, not just food and energy. Our earlier paper finds that, since 2000, quarterly innovations in median inflation have been almost entirely permanent, whereas CPIX inflation has a substantial transitory component. Median inflation does a better job of capturing the underlying trend in inflation.[1]

Figure 1 illustrates the appeal of the weighted median by plotting this variable and CPIX since 2000. We can see that CPIX is more volatile at the quarterly frequency. The standard deviation of the change in inflation is 0.46 for the median and 0.66 for CPIX.

We hope that researchers will move toward median CPI rather than CPIX as their pri-

[1]As in Ball and Mazumder (2011), we compute a quarterly series for weighted median inflation from the monthly series reported by the Cleveland Fed. We first cumulate the monthly median inflation rates to construct a monthly series for price levels, then average three months to get quarterly price levels. Quarterly median inflation is the annnualized percentage change in the quarterly price level.

mary measure of core inflation. This is not the main point of this paper, however, so throughout our analysis we measure core inflation both ways. The $\overline{R}^2$s for our Phillips curves are considerably higher when we use the weighted median. However, our conclusions about the proper specification and stability of our equations are the same for the two core-inflation measures.

3 Recent Thinking About the Phillips Curve

Here we review the textbook Phillips curve and the puzzle of the missing deflation. We then discuss recent work suggesting that inflation expectations have become anchored, and that labor-market slack should be measured with short-term unemployment. We present informal evidence that these ideas help to explain the missing deflation, evidence that motivates the econometric work in the rest of the paper.

3.1 The Phillips Curve and the Missing Deflation

In his Presidential Address to the American Economic Association, Milton Friedman (1968) posited that the inflation rate depends on expected inflation and the deviation of unemployment from its natural rate. Friedman's theory can be expressed as:

$$\pi_t = \pi_t^e + \alpha(u_t - u_t^*) + \epsilon_t, \qquad \alpha < 0, \tag{1}$$

where π is inflation, π^e is expected inflation, u is unemployment, u^* is the natural rate, and ϵ is an error term. This equation is commonly called the expectations-augmented Phillips curve.

Friedman went a step farther by specifying the behavior of expectations. He said that "unanticipated inflation generally means a rising rate of inflation," or in other words, that expected inflation is well-proxied by past inflation. With this assumption, equation (1) becomes

$$\pi_t = \pi_{t-1} + \alpha(u_t - u_t^*) + \epsilon_t, \tag{2}$$

where π_{t-1} is past inflation. This equation is the accelerationist Phillips curve, a staple of undergraduate textbooks. It is often written with past inflation moved to the left:

$$\pi_t - \pi_{t-1} = \alpha(u_t - u_t^*) + \epsilon_t. \tag{3}$$

As we see here, the textbook Phillips curve is a negative relationship between the level of unemployment and the *change* in inflation.

Equation (2) has guided much empirical research on U.S. inflation, including the work of Gordon (1982, 2013), Stock and Watson (1999, 2009), Ball and Mazumder (2011), and many others. Typically these researchers seek to explain quarterly data on core inflation, capturing past core inflation with four or more lags. Their equations often include lags of unemployment as well, and allow the natural rate u^* to vary over time.

As Stock and Watson (2010) discuss, the accelerationist Phillips curve has had enduring appeal because it captures "a broad historical regularity": since 1960, U.S. recessions have led to decreases in the inflation rate. The most salient example is the recession of the early 1980s, which pushed the unemployment rate above ten percent. In this episode, core inflation fell by about six percentage points.

This history explains why recent inflation behavior has puzzled economists. During the Great Recession of 2008-09, the unemployment rate again exceeded ten percent, and in 2014 it is still above pre-recession levels. Therefore, as shown formally below, an accelerationist Phillips curve estimated with pre-2008 data predicts that inflation falls below zero in late 2010 and then continues to fall. In reality, the current level of core inflation is close to its level in 2007. From 2007Q4 to 2014Q2, the four-quarter rate of CPIX inflation fell only from 2.3% to 1.9%, and median inflation from 3.0% to 2.2%. The disinflationary effect of recessions–"the essential empirical content of the Phillips curve," according to Stock and

Watson–seems to have disappeared.[2]

3.2 Anchored Expectations

Why hasn't inflation fallen by more? Many policymakers and economists cite the anchoring of inflation expectations. For example, according to Janet Yellen (2013):

> Well-anchored inflation expectations have proven to be an immense asset in conducting monetary policy. They've helped keep inflation low and stable while monetary policy has been used to help promote a healthy economy. After the onset of the financial crisis, these stable expectations also helped the United States avoid excessive disinflation or even deflation.

According to this story, the expectations-augmented Phillips curve, equation (1), still holds, but the behavior of expectations has changed. In the past, expected inflation, π^e, may have depended on lagged inflation, but today it is close to a constant–specifically, the Fed's 2% inflation target. With a constant π^e, the Phillips curve becomes a relationship between unemployment and the level of inflation, not the change in inflation.

This idea goes in the right direction for explaining the missing deflation. According to the accelerationist Phillips curve, a recession causes inflation to fall lower and lower as long as unemployment exceeds the natural rate. With anchored expectations, a period of high unemployment implies a low level of inflation but not an ever-falling level.

The idea of anchored expectations pre-dates the Great Recession. The Fed announced a formal inflation goal of 2% only in 2012, but research as far back as Taylor (1993) finds that the Fed was implicitly targeting 2%. In the 2000s, Fed officials began to suggest that their commitment to stable inflation "in both words and actions" had produced "a strong anchoring of long-run inflation expectations" (Mishkin, 2007).

An important detail: The Fed's target of 2% applies to inflation as measured by the

[2] As the reader probably knows, much academic research has analyzed the "New Keynesian" Phillips curve (NKPC), in which inflation depends on expected future inflation and real marginal cost (e.g. Gali, 2008). The empirical validity of the NKPC is disputed, and we are on the side that believes it does not fit inflation behavior in general or recent U.S. inflation in particular. We discuss this issue in our 2011 paper (Section 5), and have nothing to add here.

core PCE (personal consumption expenditure) deflator. Since 1980, core CPI inflation has exceeded core PCE inflation by about 0.5% on average (for both the weighted-median and CPIX measures of core). We should expect, therefore, that expectations of core CPI inflation are anchored at 2.5%.

As many researchers have pointed out, the idea of anchored expectations receives striking support from long-term inflation forecasts in the Survey of Professional Forecasters (SPF). For the period from 1985 to the present, Figure 2 shows the median SPF forecast of CPI inflation over the next ten years, along with a four-quarter moving average of weighted median inflation. From 1985 to about 2000, SPF forecasts drift down along with the realized levels of median inflation. In the 2000s, by contrast, SPF forecasts are almost constant at 2.5%, despite significant fluctuations in median inflation.

3.3 Short-Term Unemployment

The traditional Phillips curve includes the aggregate unemployment rate. A growing number of researchers replace this variable with the short-term unemployment rate–usually defined as the percentage of the labor force unemployed for less than 27 weeks–and argue that this modification helps explain the missing deflation.

The rationale for this specification is that the long-term unemployed "are on the margins of the labor force" (Krueger et al., 2014). These workers are unlikely to find jobs because they are unattractive to employers and because they do not search intensively for work. As a result, only the short-term unemployed create an excess supply of labor and put downward pressure on wage growth and inflation.

Figure 3 shows how this reasoning helps explain the missing deflation. Long-term unemployment rose sharply over 2008-09, so the rise in total unemployment was unusually large compared to the rise in short-term unemployment. Long-term unemployment has remained high into 2014, so total unemployment is still high even though short-term unemployment has almost returned to its 2007 level. Overall, labor-market slack since 2008 is less severe if it is measured by short-term rather than total unemployment, so the Phillips curve predicts a smaller fall in inflation in this case.

Phillips curves with short-term unemployment were introduced in the 1980s to explain experiences in Europe, where inflation rates were stable despite high long-term unemployment (e.g. Nickell, 1987). Llaudes (2005) shows that this Phillips-curve specification fits the data for a number of countries.

Before the Great Recession, students of the U.S. Phillips curve rarely considered specifications with short-term unemployment. The reason is that short-term and total unemployment were highly collinear in U.S. data, making it difficult to separate their effects. This collinearity problem has diminished substantially since 2008 because of the disproportionate rise in total unemployment.

4 Explaining Core Inflation Since 2000

This section presents our central econometric results. For the period from 2000 to 2014Q2, we find that the behavior of core inflation is well-explained by a Phillips curve with anchored expectations and short-term unemployment. There is no evidence of a shift in this relationship during the Great Recession. We also find that the fit of the Phillips Curve deteriorates markedly if we measure expected inflation with past inflation rates, or if we include total rather than short-term unemployment.

4.1 Our Preferred Specification

We consider a version of the expectations-augmented Phillips curve, equation (1), in which expected inflation is constant and labor-market slack is measured by the deviation of short-term unemployment from its natural rate. Following Staiger et al. (1997) and Gordon (2013), we specify an equation for quarterly data, with four lags of the unemployment term:

$$\pi_t = \pi^e + \sum_{j=1}^{4} \alpha_j (u^s_{t-j} - u^{s*}_{t-j}) + \epsilon_t, \tag{4}$$

where π^e is the constant level of expected inflation, u^s is the short-term unemployment rate, and u^{s*} is the natural rate of short-term unemployment.

For parsimony, we impose two restrictions on equation (4). First, we assume that the natural rate u^{s*} is constant over time. Later in the paper we estimate a specification that allows u^{s*} to vary, and find that it has been fairly stable since 2000. As a result, imposing a constant u^{s*} does not materially affect the fit of the Phillips curve.

Second, we assume that the coefficients on the four unemployment lags are equal. When we test this restriction, it is not rejected (p-value for Wald test=0.54).

With our two restrictions, equation (4) becomes

$$\pi_t = \phi + \alpha \overline{u}^s_{t-1} + \epsilon_t, \tag{5}$$

where $\overline{u}^s_{t-1}$ is the average level of short-term unemployment from $t-4$ through $t-1$, and $\phi = \pi^e - \alpha u^{s*}$. In this Phillips curve, inflation depends on a constant and a single variable capturing labor-market slack.

Notice that the parameters π^e and u^{s*} are not separately identified. However, if we assume $\pi^e = 2.5$, as suggested by the SPF, we can measure u^{s*} using estimates of equation (5) and the formula $u^{s*} = (2.5 - \phi)/\alpha$.

4.2 Results for our Preferred Specification

Table 1 presents estimates of equation (5). We report results for each of our measures of core inflation, weighted median inflation and CPIX inflation, for the period 2000Q1-2014Q2. We also break our sample into periods before the onset of the Great Recession (2000Q1-2007Q4) and after (2008Q1-2014Q2).

When we measure core inflation with the weighted median, the fit of our Phillips curve is excellent. The $\overline{R}^2$ for the full sample is 0.81, and there is no evidence that the coefficients change between the first and second sub-samples (p-value for stability=0.59).

The coefficient on short-term unemployment is approximately -1.0, which means that a one percentage point rise in average short-term unemployment over the previous four quarters reduces core inflation by one percentage point. If we assume $\pi^e = 2.5\%$, then the full-sample coefficient estimates imply a natural rate of short-term unemployment, u^{s*}, of 4.4%.

When we measure core inflation with CPIX, the fit of our Phillips curve declines markedly: for the full sample, the $\overline{R}^2$ falls from 0.81 to 0.41. We still cannot reject stability of the coefficients across the two sub-samples (p=0.31), but the point estimate of the coefficient on short-term-unemployment falls from -0.89 in the pre-2008 period to -0.52 in the post-2008 period.

On the other hand, with core inflation measured by either median inflation or CPIX, equation (5) fits better than Phillips curves based on more traditional assumptions about expected inflation and/or labor-market slack. We demonstrate this point below.

Figure 4 illustrates the fit of equation (5) by comparing the path of core inflation to fitted values based on our full-sample estimates. In Panels A and B of the Figure, we examine median and CPIX inflation at the quarterly frequency. In Panels C and D, we smooth both the actual and fitted series by taking four-quarter moving averages.

The Figure confirms that our Phillips curve explains median inflation well throughout the 2000s. Median inflation has gone through two cycles of decline and recovery, with troughs during the "deflation scare" of 2003 and in 2010. These two inflation cycles correspond closely to movements in short-term unemployment in the opposite direction.

The Figure also confirms that our equation fits less well for CPIX inflation than for median inflation, because of volatility in the quarterly CPIX series. The fit for CPIX improves, however, when we examine four-quarter moving averages.

4.3 More Conventional Specifications

Our preferred specification departs from the textbook Phillips curve in two ways: by assuming that expected inflation equals a constant rather than past inflation, and by including short-term rather than total unemployment. Undoing either of these changes worsens the fit of the Phillips curve to data since 2000.

Table 2 makes this point, with core inflation measured by the weighted median. Row (1) of the Table repeats our preferred specification from Table 1. Row (2) reports estimates of the same equation, except with total unemployment replacing short-term unemployment (the unemployment rate is again averaged over the previous four quarters). For our full sample, this change reduces the $\overline{R}^2$ from 0.81 to 0.55. In addition, the coefficient on total unemployment is almost twice as large in the first subsample as in the second, although we cannot statistically reject stability of the equation.[3]

Rows (3) and (4) examine specifications in which expected inflation equals past inflation. Specifically, following Ball and Mazumder (2011), we assume that expected inflation is the average of core inflation over the previous four quarters. Labor market slack is measured with short-term unemployment in row (3) and with total unemployment in row (4). In both cases, the $\overline{R}^2$ is below 0.50, and the point estimates of the unemployment coefficient differ markedly between the two subsamples.

As we have discussed, recent debates about the Phillips curve are motivated by the missing-deflation puzzle. To see how this puzzle arises and how it can be resolved, we examine forecasts of inflation over 2008-2014, the missing deflation period, based on Phillips curves estimated over 2000-2007.

Figure 5 presents forecasts based on the four Phillips curves in Table 2. Panel A shows the results for our preferred specification with anchored expectations and short-term unem-

[3]Kiley (2014) estimates Phillips curves with geographically-disaggregated data for 24 metropolitan areas in the United States. He finds that short-term and long-term unemployment have equal effects on inflation, which implies that a Phillips curve with total unemployment fits better than one with short-term unemployment. We do not know why regional and aggregate data appear to produce different results, and leave this question for future research.

ployment. In this case, the pre-2008 Phillips curve produces accurate forecasts of post-2008 inflation. This result reflects the good fit of our specification over the entire period since 2000.

Panel B shows the results when we assume anchored expectations but replace short-term unemployment with total unemployment. In this case, inflation forecasts based on the pre-2008 Phillips curve are accurate until 2010, but then under-predict actual inflation. Forecasted inflation is 2.1 percentage points below actual inflation in 2011Q3, and 1.3 points at the end of the sample. These results reflect the fact that the Great Recession raised total unemployment more sharply and persistently than short-term unemployment. As a consequence, a Phillips curve with total unemployment predicts lower levels of inflation.

Panels C and D present results when we assume expected inflation equals past inflation, implying an accelerationist Phillips curve. The slack variable is short-term unemployment in Panel C and total unemployment in Panel D. The forecasts here are dynamic, not static: we measure past inflation with inflation forecasts for previous quarters. (The distinction between static and dynamic forecasts does not arise for our other specifications, which do not include past inflation.)

The accelerationist specifications in Panels C and D produce the missing-deflation puzzle. Based on the pre-2008 Phillips curve, high levels of unemployment should eventually have pushed inflation below zero. The forecasted inflation rate at the end of the sample is -0.6% with slack measured by short-term unemployment, and -2.1% with total unemployment. Actual median inflation, by contrast, averaged 2.2% over the last four quarters of the sample.

Ball and Mazumder (2011) argue that an accelerationist Phillips curve fits inflation behavior during the Great Recession. The data in that paper end in 2010Q4, which happens to be near the trough for inflation in its most recent cycle. As shown in Figure 5, accelerationist equations predict inflation declines from 2007 to 2010 that are not far from actual experience. However, these equations predict that inflation keeps falling after 2010, whereas actual inflation has risen. This recent experience has persuaded us that inflation expectations are strongly anchored, a view that we doubted in 2011.[4]

Table 3 presents estimates of the same Phillips curves as Table 2, but with core inflation measured by CPIX. Once again, the specification with anchored expectations and short-term unemployment fits best. The $\overline{R}^2$ is 0.41 for that equation, and it ranges from 0.02 to 0.25 for the others.

Notice that the $\overline{R}^2$ of 0.02 arises when we measure core inflation with CPIX, measure expected inflation with past inflation, and measure slack with total unemployment. This version of the Phillips curve is the most traditional of any we consider, and it fails miserably to capture inflation behavior since 2000. The fit improves if we switch to median inflation, or anchored expectations, or short-term unemployment. With all three changes, the $\overline{R}^2$ is 0.81.

5 Explaining Core Inflation Since 1985

We have found a simple Phillips curve that explains core inflation in the U.S. since 2000. We now examine the robustness of our story by extending the sample period back to 1985. In this part of the paper, the weighted median is our sole measure of core inflation.

5.1 Motivation

We start the extended sample in 1985 because the level and volatility of inflation have been low since then, in contrast to the 1970s and early 80s. In Ball and Mazumder (2011), we argue that these facts make it plausible that the Phillips curve has been stable since 1985.

[4]Stock's comment on our 2011 paper is prescient. He writes, "The real test for the level anchoring theory is just around the corner. Currently, all the unemployment gaps considered here [estimated deviations of total and short-term unemployment from their natural rates] remain positive... Depending on the gap used, an accelerationist Phillips curve would predict inflation to stabilize at a low rate or decline further. In contrast, if expectations are anchored at, say, 2 percent, and if these expectations influence price setting, then inflation should begin to climb back to its long-term target value.... [T]here was a return from very low inflation in 2004 despite positive gaps. Whether there will be a second such return will be a test of the expectations anchoring theory in a way that the decline of inflation so far during this episode is not." Inflation *did* rise toward its target over 2011-2014, so the results of Stock's test favor anchored expectations over the accelerationist Phillips curve.

We do not, however, expect the extremely simple Phillips curve that fits the post-2000 period, equation (5), to fit our extended sample. We derived (5) by positing an expectations-augmented Phillips curve, equation (1), and then assuming that expectations are anchored at the Fed's inflation target. We interpret (1) as a structural relationship that always holds, but anchored expectations is not a credible assumption for the entire period since 1985.

This point is clear from long-term inflation expectations in the Survey of Professional Forecasters, shown above in Figure 2. In these data, expected inflation is anchored at 2.5% starting around 2000, but not before then. Expected inflation is 4.5% in 1985 and drifts down during the late 1980s and 1990s, apparently following the downward trend in actual inflation.

Later we will study the pre-2000 behavior of expectations more closely. But first, we examine the fit of the expectations-augmented Phillips curve without modeling the behavior of expectations. To do so, we treat long-term expectations from the SPF as a direct measure of expected inflation, following past work such as Fuhrer et al. (2009). We seek a stable specification of the Phillips curve taking as given the path of expected inflation in the data.

Once again, we measure labor-market slack with the deviation of short-term unemployment from its natural rate, averaged over the previous four quarters. In this part of the paper, we relax our earlier assumption that the natural rate is constant. As shown in Figure 6, short-term unemployment followed a downward trend during the late 1980s and 1990s, mirroring a decline in total unemployment. A time-varying natural rate allows us to capture this trend, and significantly improves the fit of the Phillips curve for our extended sample.

With our present assumptions, the Phillips curve is

$$\pi_t = \pi_t^F + \alpha(\overline{u}_{t-1}^s - \overline{u}_{t-1}^{s*}) + \epsilon_t, \qquad (6)$$

where π^F is the SPF's consensus forecast of CPI inflation over the next ten years, and $\overline{u}_{t-1}^{s*}$ is the average of the natural rate of short-term unemployment from $t-4$ through $t-1$. We measure the natural rate by smoothing the series for short-term unemployment, using the Hodrick-Prescott filter with a smoothing parameter of 16,000. Figure 6 shows the path of the natural rate.[5]

5.2 Phillips Curve Estimates

Table 4 presents estimates of equation (6), the Phillips curve with SPF expectations. We present results for 1985-2014Q2, and for the subsamples of 1985-1999 and 2000-2014Q2. The second subsample is the anchored-expectations period that we have examined previously.

For the full sample, the estimated coefficient on short-term unemployment is -0.91. This estimate is close to -0.98, the coefficient in our preferred specification for the post-2000 period (Table 1, row 1). The $\overline{R}^2$ for equation (6) is 0.76 for the full sample. The top panel of Figure 7 illustrates this good fit by plotting the actual and fitted values of median inflation.

The fit of equation (6) partly reflects the fact that actual inflation and SPF forecasts decline together from 1985 to 2000. However, short-term unemployment also explains a substantial part of inflation behavior. To see this point, we move π_t^F to the left side of (6) and compute the $\overline{R}^2$ for this version of the equation. This statistic–the fraction of the variation in $\pi - \pi^F$ explained by short-term unemployment–is 0.47. The bottom panel of Figure 7 plots the actual and fitted values of $\pi - \pi^F$.

For the post-2000 subsample, the estimated coefficient on short-term unemployment is -1.11, which again is close to the estimate of -0.98 from our preferred specification for that period. We have relaxed our earlier assumptions that π^e and u^{s*} are constant, but that makes little difference after 2000 because our measures of π^e and u^{s*} do not change much.

For the 1985-1999 subsample, the estimated coefficient on short-term unemployment is -0.61, with a relatively large standard error of 0.22. When we test the hypothesis that the coefficient is equal in the two subsamples, the result is borderline: the p-value is 0.062. For

[5]We compute our series for u^{s*} with data starting in 1975 to minimize the end-point problem with the HP filter.

the entire sample, an equation with different coefficients before and after 2000 produces an $\overline{R}^2$ of 0.78, only marginally higher than the 0.76 when we assume a constant coefficient.

All in all, we conclude that inflation over the last 30 years is explained fairly well by a stable Phillips curve with long-term SPF expectations and short-term unemployment.

5.3 The Changing Behavior of Expectations

Expected inflation was clearly not anchored at a constant level in the 1980s and 1990s. How then were expectations formed? Based on previous Phillips-curve research, a natural hypothesis is that expectations were backward-looking–they were determined by past inflation rates. This idea receives visual support from Figure 2, in which SPF inflation forecasts follow the downward trend in actual inflation over 1985-1999.

To investigate this idea more formally, we estimate an equation in which SPF inflation forecasts depend on past levels of core inflation, as measured by the weighted median. Following Gordon (2013), we include a large number of lags, which allows expectations to adjust slowly to changes in actual inflation. We assume that the coefficients on the lags sum to one.

For parsimony, we also assume that the coefficients decline exponentially as the lag length rises. This assumption yields a single parameter to be estimated, and we find that it fits the data well. In principle the exponential specification includes infinite lags, but we truncate them at 40 quarters. Our equation is:

$$\pi_t^F = \frac{1}{1-\gamma^{40}} \left[(1-\gamma)\pi_{t-1} + \gamma(1-\gamma)\pi_{t-2} + \ldots + \gamma^{39}(1-\gamma)\pi_{t-40} \right] + \epsilon_t, \qquad (7)$$

where γ determines the rate of decay of the lag coefficients. (The term outside the brackets makes the coefficients sum to one.)

Table 5 presents estimates of (7) for 1985-1999, the pre-anchored-expectations period. We use non-linear least squares. The estimated gamma is 0.86, and the $\overline{R}^2$ is 0.85. The high value of γ supports Gordon's view that long lags of inflation influence expectations.

With $\gamma = 0.86$, the sum of coefficients on the first four lags is only 0.45 and the sum of the remaining lags is 0.55.

So far we have examined the behavior of expectations separately for 1985-1999 and for 2000-2014Q2, because this behavior appears to shift around 2000. As a final exercise, we test for a shift by estimating an equation that nests anchored and backward-looking expectations:

$$\pi_t^F = \beta 2.5 + (1-\beta)\frac{1}{1-\gamma^{40}}\left[(1-\gamma)\pi_{t-1} + \gamma(1-\gamma)\pi_{t-2} + \ldots + \gamma^{39}(1-\gamma)\pi_{t-40}\right] + \epsilon_t. \quad (8)$$

Here, expected inflation from the SPF is a weighted average of two terms, the 2.5% anchor and our backward-looking specification with exponential weights on past inflation. We ask whether the coefficients β and $1-\beta$ on the two terms have changed over time.

We do two versions of our test, which are reported in Table 6. In the first version, we estimate equation (8) for 1985-1999 and for 2000-2014Q2 (first two columns of Table 6). In the first of these periods, the coefficient on 2.5% is 0.06, which is statistically indistinguishable from zero; in the second, the coefficient is 0.81. The data strongly reject stability of the coefficient across the two periods. These results suggest a sharp regime shift in 2000, from backward-looking expectations to strongly anchored expectations.

In the second version of our exercise, we use the Andrews (1993) sup-Wald test for a break in equation (8) at an unknown break date. Once again, stability is strongly rejected. The break date that produces the highest Wald statistic is 1997Q4, not too far from the break in 2000 that we have previously imposed. When we split the sample at 1997Q4 (last two columns of Table 6), the estimates of β are 0.06 for the first subsample and 0.83 for the second, which again suggests a sharp regime shift.

6 Conclusion

One of Mankiw's (2014) ten principles of economics is, "Society faces a short-run tradeoff between inflation and unemployment." This tradeoff, the Phillips curve, is critically important for monetary policy and for forecasting inflation. It would be extraordinarily useful to discover a specification of the Phillips curve that fits the data reliably.

Unfortunately, researchers have repeatedly needed to modify the Phillips curve to fit new data. Friedman added expected inflation to the Samuelson-Solow specification. Subsequent authors have added supply shocks (Gordon, 1982), time-variation in the Phillips-curve slope (Ball et al., 1988), and time-variation in the natural rate of unemployment (Staiger et al., 1997). Each modification helped explain past data, but, as Stock and Watson (2010) observe, the history of the Phillips curve "is one of apparently stable relationships falling apart upon publication." Ball and Mazumder (2011) is a poignant example.

Nonetheless, because of the practical importance of the Phillips curve, researchers must continue to search for better specifications. This paper proposes a simple Phillips curve that fits the recent behavior of core inflation, especially when core inflation is measured by median inflation. Our key assumptions are that labor-market slack is measured by short-term unemployment, and that expected inflation is anchored at a constant level.

Expectations became anchored around 2000, when it became apparent that the Fed was targeting 2% inflation in the PCE deflator. In the future, expectations could become unmoored from their anchor if the Fed changes its target, or if actual inflation deviates greatly from the target. If that happens, future Phillips curves will need to incorporate the new behavior of expectations.

We have drawn on previous research for both of the key features of our Phillips curve, short-term unemployment and anchored expectations. On the other hand, we have ignored a third idea that is prominent in recent work on inflation: downward nominal wage rigidity. We neglect downward rigidity primarily because our Phillips curve fits the data without it. Research will surely continue on the roles of short-term unemployment, anchored expectations, and downward wage rigidity in explaining recent inflation behavior.[6]

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[6]Recent analyses of downward wage rigidity include Dickens (2010); Schmitt-Grohe and Uribe (2012); Daly and Hobijn (2013); and numerous blog posts by Paul Krugman. Recent research on inflation has also explored the roles of oil prices and consumer expectations (Coibion and Gorodnichenko, 2013); weak balance sheets of firms (Sim et al., 2013); and uncertainty about regional economic conditions (Murphy, 2014).

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Figure 1: Weighted Median Inflation vs. CPIX Inflation, 2000-2014

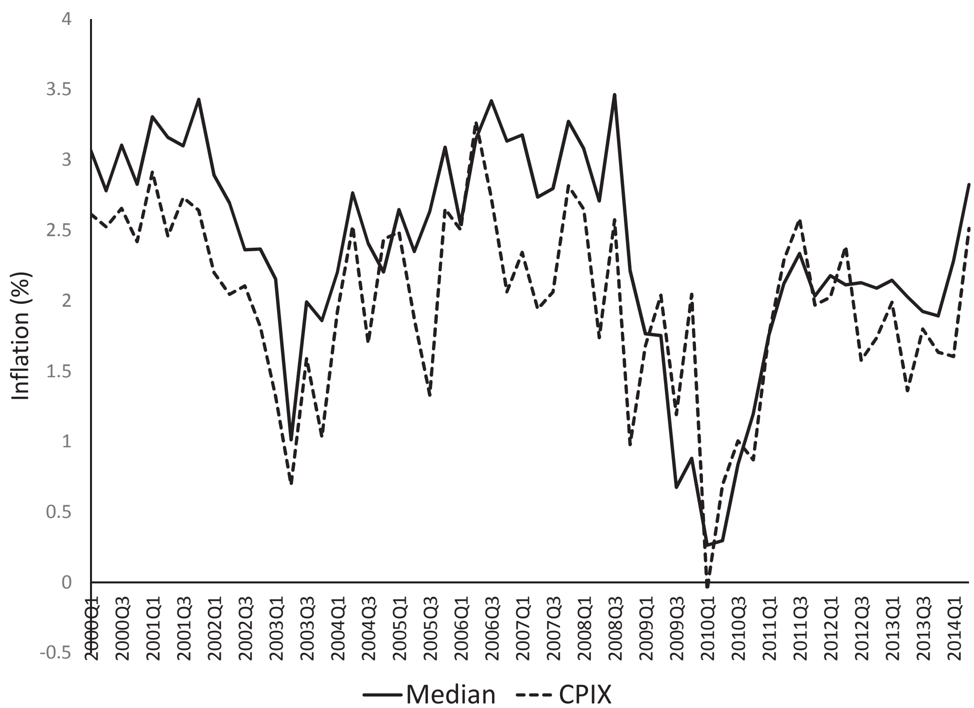


Figure 2: Long-Term SPF Inflation Expectations vs. 4-Quarter Moving Average of Median Inflation, 1985-2014

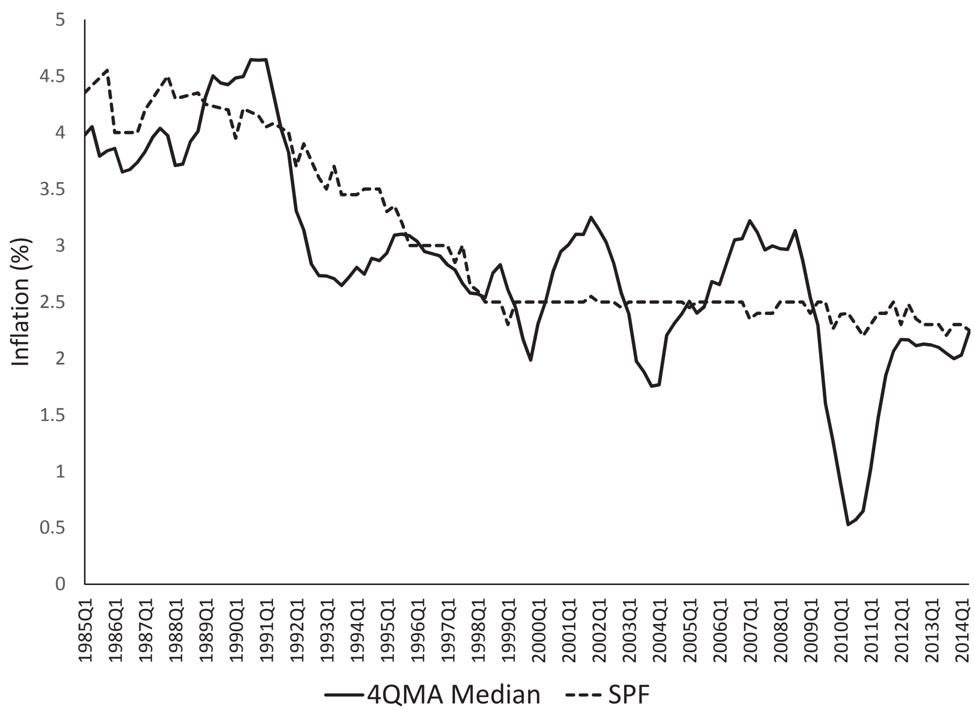


Figure 3: Short-Term Unemployment vs. Total Unemployment, 1985-2014

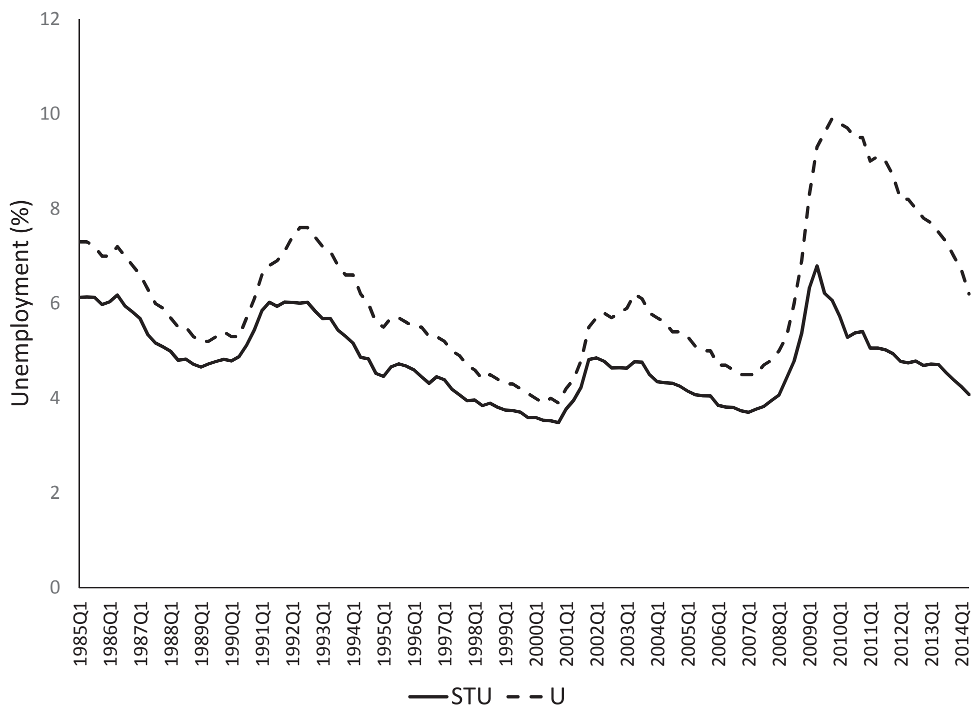
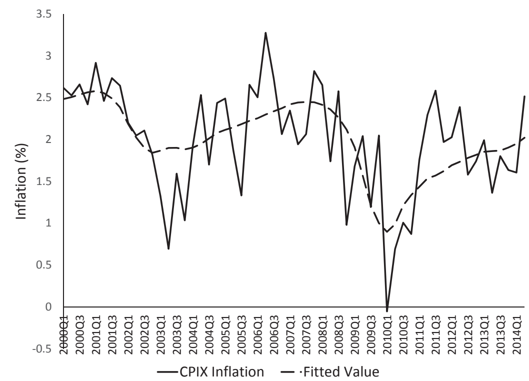


Figure 4: Core Inflation vs. Fitted Values from Preferred Phillips Curve, 2000Q1-2014Q2

(a) Weighted Median Inflation-Quarterly

(b) CPIX Inflation-Quarterly



(c) Weighted Median Inflation-4-Quarter Moving Average

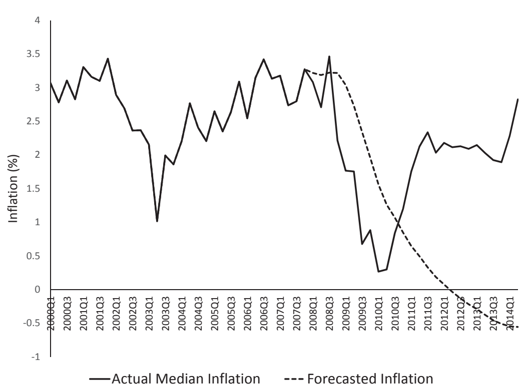
(d) CPIX Inflation-4 Quarter Moving Average

Figure 5: Forecasts for Median Inflation for 2008Q1-2014Q2

(a) Constant Expectations, Short-Term Unemployment

(b) Constant Expectations, Total Unemployment

(c) Lagged Expectations, Short-Term Unemployment



(d) Lagged Expectations, Total Unemployment

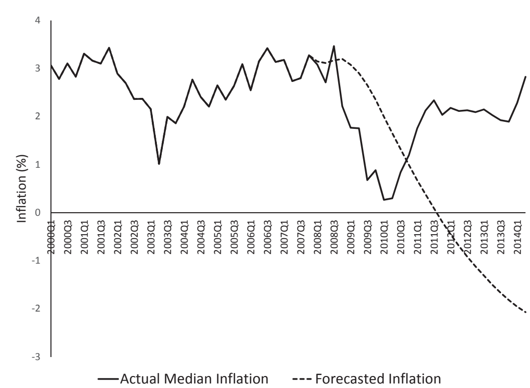
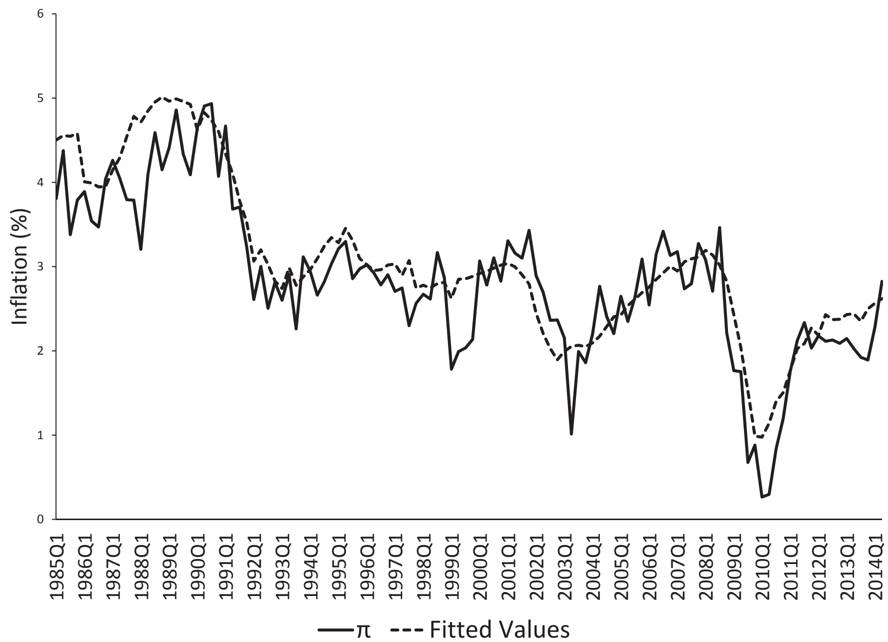


Figure 6: Short-Term Unemployment and its Trend, 1985-2014

Figure 7: Actual and Fitted Values from Phillips Curve with Long-Term Expectations

(a) π



(b) $\pi - \pi^F$

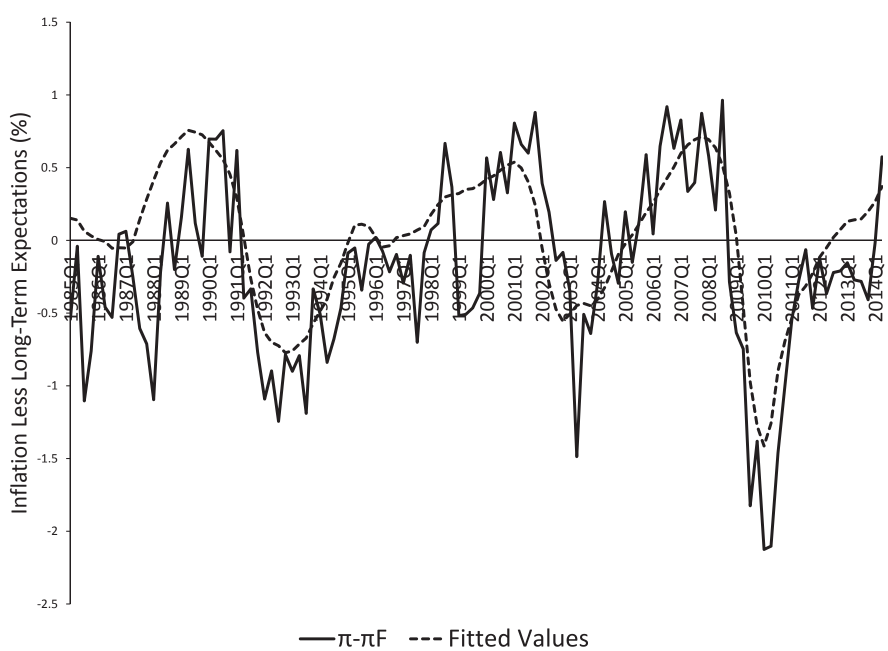


Table 1: Preferred Phillips Curve Specification

$\pi_t = \phi + \alpha \overline{u}^s_{t-1} + \epsilon_t$			
(1) Median Inflation			
	2000Q1-2007Q4	2008Q1-2014Q2	2000Q1-2014Q2
ϕ	6.670	7.177	6.781
	(0.704)	(0.401)	(0.332)
α	-0.960	-1.053	-0.981
	(0.175)	(0.083)	(0.076)
$\overline{R}^2$	0.568	0.823	0.809
Stability Test	—	—	0.594
(2) CPIX Inflation			
	2000Q1-2007Q4	2008Q1-2014Q2	2000Q1-2014Q2
ϕ	5.879	4.325	4.690
	(0.798)	(0.841)	(0.417)
α	-0.891	-0.519	-0.597
	(0.201)	(0.174)	(0.098)
$\overline{R}^2$	0.401	0.266	0.412
Stability Test	—	—	0.314

Note: OLS with robust (HAC) standard errors is used throughout this paper (standard errors in parentheses). The stability test reports the p-value for the Wald test of structural stability around 2008Q1.

Table 2: More Conventional Phillips Curve Specifications, Weighted Median Inflation

(1) $\pi_t = \phi + \alpha \overline{u}^s_{t-1} + \epsilon_t$

	2000Q1-2007Q4	2008Q1-2014Q2	2000Q1-2014Q2
ϕ	6.670	7.177	6.781
	(0.704)	(0.401)	(0.332)
α	-0.960	-1.053	-0.981
	(0.175)	(0.083)	(0.076)
$\overline{R}^2$	0.568	0.823	0.809
Stability Test	—	—	0.594

(2) $\pi_t = \phi + \alpha \overline{u}_{t-1} + \epsilon_t$

	2000Q1-2007Q4	2008Q1-2014Q2	2000Q1-2014Q2
ϕ	5.542	4.168	4.282
	(0.584)	(0.668)	(0.366)
α	-0.567	-0.291	-0.309
	(0.121)	(0.095)	(0.069)
$\overline{R}^2$	0.536	0.334	0.553
Stability Test	—	—	0.206

(3) $\pi_t = \phi + \frac{1}{4}(\pi_{t-1} + \pi_{t-2} + \pi_{t-3} + \pi_{t-4}) + \alpha \overline{u}^s_{t-1} + \epsilon_t$

	2000Q1-2007Q4	2008Q1-2014Q2	2000Q1-2014Q2
ϕ	1.994	0.972	1.070
	(1.143)	(1.130)	(0.743)
α	-0.465	-0.206	-0.233
	(0.289)	(0.245)	(0.180)
$\overline{R}^2$	0.206	0.238	0.448
Stability Test	—	—	0.710

(4) $\pi_t = \phi + \frac{1}{4}(\pi_{t-1} + \pi_{t-2} + \pi_{t-3} + \pi_{t-4}) + \alpha \overline{u}_{t-1} + \epsilon_t$

	2000Q1-2007Q4	2008Q1-2014Q2	2000Q1-2014Q2
ϕ	1.042	-1.049	0.017
	(0.833)	(0.805)	(0.393)
α	-0.193	0.126	-0.0003
	(0.178)	(0.104)	(0.068)
$\overline{R}^2$	0.131	0.275	0.401
Stability Test	—	—	0.021

Table 3: More Conventional Phillips Curve Specifications, CPIX Inflation

(1) $\pi_t = \phi + \alpha \overline{u}^s_{t-1} + \epsilon_t$			
	2000Q1-2007Q4	2008Q1-2014Q2	2000Q1-2014Q2
ϕ	5.879	4.325	4.690
	(0.798)	(0.841)	(0.417)
α	-0.891	-0.519	-0.597
	(0.201)	(0.174)	(0.098)
$\overline{R}^2$	0.401	0.266	0.412
Stability Test	—	—	0.314

(2) $\pi_t = \phi + \alpha \overline{u}_{t-1} + \epsilon_t$			
	2000Q1-2007Q4	2008Q1-2014Q2	2000Q1-2014Q2
ϕ	4.763	2.666	3.104
	(0.616)	(0.658)	(0.360)
α	-0.513	-0.121	-0.178
	(0.135)	(0.095)	(0.062)
$\overline{R}^2$	0.357	0.054	0.248
Stability Test	—	—	0.024

(3) $\pi_t = \phi + \frac{1}{4}(\pi_{t-1} + \pi_{t-2} + \pi_{t-3} + \pi_{t-4}) + \alpha \overline{u}^s_{t-1} + \epsilon_t$			
	2000Q1-2007Q4	2008Q1-2014Q2	2000Q1-2014Q2
ϕ	1.013	0.332	0.454
	(1.198)	(1.213)	(0.633)
α	-0.240	-0.073	-0.101
	(0.305)	(0.251)	(0.148)
$\overline{R}^2$	-0.020	-0.259	0.030
Stability Test	—	—	0.864

(4) $\pi_t = \phi + \frac{1}{4}(\pi_{t-1} + \pi_{t-2} + \pi_{t-3} + \pi_{t-4}) + \alpha \overline{u}_{t-1} + \epsilon_t$			
	2000Q1-2007Q4	2008Q1-2014Q2	2000Q1-2014Q2
ϕ	0.289	-0.668	-0.074
	(0.855)	(0.697)	(0.375)
α	-0.054	0.080	0.011
	(0.185)	(0.099)	(0.064)
$\overline{R}^2$	-0.047	-0.223	0.019
Stability Test	—	—	0.391

Table 4: Phillips Curve with Long-Term Inflation Expectations

$\pi_t = \pi_t^F + \alpha(\overline{u}_{t-1}^s - \overline{u}_{t-1}^{s*}) + \epsilon_t$			
	1985Q1-1999Q4	2000Q1-2014Q2	1985Q1-2014Q2
α	-0.606	-1.112	-0.909
	(0.222)	(0.116)	(0.150)
$\overline{R}^2$	0.619	0.762	0.759
Stability Test	—	—	0.062

Table 5: Long-Term Inflation Expectations Regressed on Exponential Lags of Median Inflation, 1985Q1-1999Q4

$\pi_t^F = \frac{1}{1-\gamma^{40}}\left[(1-\gamma)\pi_{t-1} + \gamma(1-\gamma)\pi_{t-2} + \ldots + \gamma^{39}(1-\gamma)\pi_{t-40}\right] + \epsilon_t$	
γ	0.860
	(0.015)
$\overline{R}^2$	0.846

Table 6: Long-Term Inflation Expectations Regressed on 2.5% and Exponential Lags of Median Inflation

$\pi_t^F = \beta 2.5 + (1-\beta)\frac{1}{1-\gamma^{40}}\left[(1-\gamma)\pi_{t-1} + \gamma(1-\gamma)\pi_{t-2} + \ldots + \gamma^{39}(1-\gamma)\pi_{t-40}\right] + \epsilon_t$				
	1985Q1-1999Q4	2000Q1-2014Q2	1985Q1-1997Q3	1997Q4-2014Q2
β	0.061	0.809	0.064	0.834
	(0.044)	(0.082)	(0.043)	(0.062)
γ	0.874	0.895	0.877	0.876
	(0.016)	(0.060)	(0.017)	(0.058)
$\overline{R}^2$	0.850	0.128	0.741	0.145