



IMF Working Paper

Inflation Dynamics and the Great Recession

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Research Department

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Abstract

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This paper examines inflation dynamics in the United States since 1960, with a particular focus on the Great Recession. A puzzle emerges when Phillips curves estimated over 1960-2007 are used to predict inflation over 2008-2010: inflation should have fallen by more than it did. We resolve this puzzle with two modifications of the Phillips curve, both suggested by theories of costly price adjustment: we measure core inflation with the median CPI inflation rate, and we allow the slope of the Phillips curve to change with the level and variance of inflation. We then examine the hypothesis of anchored inflation expectations. We find that expectations have been fully “shock-anchored” since the 1980s, while “level anchoring” has been gradual and partial, but significant. It is not clear whether expectations are sufficiently anchored to prevent deflation over the next few years. Finally, we show that the Great Recession provides fresh evidence against the New Keynesian Phillips curve with rational expectations.

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1 Introduction

In his Presidential Address, Friedman (1968) presented a theory of the short run behavior of inflation. In Friedman's theory, inflation depends on expected inflation and the gap between unemployment and its natural rate. Friedman also suggested that "unanticipated inflation generally means a rising rate of inflation"—in other words, that expected inflation is well-proxied by past inflation. These assumptions imply an accelerationist Phillips curve that relates the change in inflation to the unemployment gap.

In the decades since Friedman's work, his model has been a workhorse of macroeconomics. Researchers have refined the model extensively; two of the numerous examples are Gordon (1982, 1990)'s introduction of supply shocks and Staiger et al. (1997)'s modeling of a time-varying natural rate. Economists have debated how well the accelerationist Phillips curve fits the data, some declaring the equation's demise and others reporting that "The Phillips Curve Is Alive and Well" (Fuhrer, 1995).

Debate over the Phillips curve has gained momentum during the U.S. economic slump that began in 2007. Some economists see a puzzle: inflation has not fallen as much as a traditional Phillips curve predicts, given the high level of unemployment. For example, in September 2010, John Williams (now president of the San Francisco Fed) said:

"The surprise [about inflation] is that it's fallen so little, given the depth and duration of the recent downturn. Based on the experience of past severe recessions, I would have expected inflation to fall by twice as much as it has."

In addition to analyzing the recent behavior of inflation, economists are debating its likely path in the future. If the accelerationist Phillips curve is accurate, then high unemployment implies a substantial risk that inflation will fall below zero. Yet many economists argue that deflation is unlikely, primarily because the Federal Reserve's commitment to a low but positive inflation rate has "anchored" inflation expectations. According to Bernanke (2010),

“Falling into deflation is not a significant risk for the United States at this time, but that is true in part because the public understands that the Federal Reserve will be vigilant and proactive in addressing significant further disinflation.”

This paper contributes to the debate over past and prospective inflation in several steps. We first show why it is easy to view recent inflation behavior as puzzling. We estimate accelerationist Phillips curves with quarterly data for the period 1960-2007, measuring inflation with either the CPI or the CPI less food and energy (XFE), the standard measure of “core” inflation. We use the estimated equation and the path of unemployment over 2008-2010 to produce dynamic forecasts of inflation. In these forecasts, a four-quarter moving average of core inflation falls to -4.3% in 2010Q4. In reality, four-quarter core inflation was 0.6% in 2010Q4. A simple Phillips curve predicts a deflation that did not occur.

We show, however, that two simple modifications of the Phillips curve eliminate this puzzle. They produce a specification that fits the entire period since 1960, including the Great Recession. Both modifications are suggested by theory, specifically, models of costly nominal price adjustment from the 1980s and 1990s.

First, following Bryan and Cecchetti (1994), we measure core inflation with a weighted median of price changes across industries. This approach is motivated by price-adjustment models in which unusually large relative-price changes cause movements in aggregate inflation. Median inflation fell by more than XFE inflation from 2007 to 2010, reflecting a higher initial level (in 2007, median inflation was about 3% and XFE inflation was 2%). The relatively large fall in median inflation reduces the gap between forecasted and actual inflation.

Second, following Ball, Mankiw, and Romer (1988), we allow the slope of the Phillips curve—the coefficient on unemployment—to vary over time. In the Ball-Mankiw-Romer theory, the Phillips curve steepens if inflation is high and/or variable, because these conditions reduce nominal price stickiness. U.S. time series evidence strongly supports this prediction; in particular, the Phillips curve has been relatively flat in the low-inflation period since the mid-1980s. A flatter Phillips curve reduces the forecasted fall in inflation over 2008-2010. When we account for this effect and measure core inflation with the median price change, forecasted four-quarter

inflation in 2010Q4 is 0.3%, close to the actual level of 0.5%.

After presenting these results, we turn to the idea of anchored expectations. We distinguish between “shock anchoring,” which means that expectations do not respond to supply shocks, and “level anchoring,” which means that expectations stay fixed at a certain level regardless of any movements in actual inflation. We assume this level is 2.5% for core CPI inflation (which corresponds to about 2% for core PCE inflation). Based on the behavior of actual inflation and of expectations (as measured by the Survey of Professional Forecasters), we find that expectations have been fully shock-anchored since the 1980s. Level anchoring has been gradual and partial, but significant. According to our estimates, the fraction of a change in core inflation that is passed into expectations fell from roughly one in 1985 to between 0.4 and 0.7 in 2010.

Following our analysis of recent inflation, we forecast inflation over 2011-2013, using our estimates of the Phillips curve through 2010 and CBO forecasts of unemployment and output over the forecast period. Here, the results depend crucially on whether we incorporate anchored expectations into our equation. Our basic accelerationist specification, while explaining why inflation is currently positive, predicts that deflation is on the way. In contrast, the degree of expectation anchoring estimated for 2010 is high enough to keep inflation positive. We are not confident in this forecast, however, because it assumes that expectations will stay anchored at 2.5% for several years when actual inflation is less than 1%.

Most of this paper examines Phillips curves in which expected inflation depends on past inflation and possibly the Federal Reserve’s target. A large literature since the 1990s studies an alternative, the “New Keynesian” Phillips curve based on rational expectations and the Calvo (1983) model of staggered price adjustment. The last part of this paper asks whether the New Keynesian Phillips curve helps explain recent inflation behavior; the answer is no. Indeed, the last few years provide fresh evidence of the poor empirical performance of the model, especially the Gali and Gertler (1999) version in which marginal cost is measured with labor’s share of income. This specification produces the counterfactual prediction of rising inflation over 2008-2010.

Parts of our analysis overlap with other recent research on the Phillips curve, such as Fuhrer et al. (2009), Fuhrer and Olivei (2010), and Stock and Watson (2008, 2010). We compare our

results to previous work throughout the paper. One difference from Stock and Watson’s work is that they focus on forecasting inflation in real time. In seeking to understand inflation behavior, we freely use information that is not available in real time, such as the 2011 CBO series for the natural rate of unemployment.

2 A Simple Phillips Curve and a Puzzle

We first introduce a conventional Phillips curve, then show that it predicts a large deflation over 2008-2010.

2.1 The Phillips Curve

Milton Friedman’s Phillips curve can be expressed as

$$\pi_t = \pi_t^e + \alpha(u - u^*)_t + \epsilon_t \tag{1}$$

where π is annualized quarterly inflation, π^e is expected inflation, u is unemployment, u^* is the natural rate, and ϵ is an error term that we assume is uncorrelated with $u - u^*$. A common variant of this equation replaces $u - u^*$ with the gap between actual and potential output. Since Friedman wrote, theorists have derived equations that are broadly similar to (1) from models in which price setters have incomplete information (e.g. Lucas, 1973; Mankiw and Reis, 2002) or nominal prices are sticky (e.g. Roberts, 1995).¹

We follow a long tradition in applied work that assumes backward-looking expectations: expected inflation is determined by past inflation. Specifically, we assume that expected inflation

¹The assumption that $u - u^*$ is uncorrelated with the error in the Phillips curve, implying that OLS estimates of the equation are unbiased, is standard in the literature but rarely examined. We interpret the error term as summarizing the effects of relative price changes, which influence inflation when some nominal prices are sticky (see Section 3). We assume that these relative-price effects are uncorrelated with the aggregate variable $u - u^*$. We maintain this assumption when π is a measure of core inflation, which strips away effects of relative price changes but does so imperfectly. In this case, the error summarizes the relative-price effects that are not removed from core inflation.

This approach to identification ignores the problem of measurement error. The variable u is an imperfect measure of the activity variable in the Phillips curve, and u^* is an imperfect measure of the natural rate. These problems bias our estimates of the coefficient α toward zero. Future work should investigate the size of this bias and more generally the identification problem for the Phillips curve.

is the average of inflation in the past four quarters. In this case, equation (1) becomes

$$\pi_t = \frac{1}{4}(\pi_{t-1} + \pi_{t-2} + \pi_{t-3} + \pi_{t-4}) + \alpha(u - u^*)_t + \epsilon_t \quad (2)$$

This equation is a special case of Phillips curves estimated by Gordon and Stock-Watson, which generally include lags of unemployment and lags of inflation with unrestricted coefficients (except for the accelerationist assumption that the coefficients sum to one). We keep our specification parsimonious along this dimension to enrich it more easily along others (for example, by allowing time-variation in the coefficient α). We examine versions of equation (2) with richer lag structures as part of our robustness checks.

The structure of inflation lags in equation (2) implies that a one-percentage-point increase in unemployment for one quarter changes inflation in the long run by 0.4 times the coefficient α . The long run effect of one point of unemployment sustained for a year is 1.6 times α .

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Our empirical work requires a series for the natural rate of unemployment or for potential output. For most of our analysis, we use estimates of these variables from the Congressional Budget Office; as a robustness check, we estimate a path for the natural rate using a technique from Staiger et al. (1997). The CBO natural-rate series is similar to estimates from other sources: the natural rate rises modestly in the 1960s and 1970s, from about 5.5% to 6.3%, then falls to 5.0% in the 1990s. It remains at 5.0% through 2007, then rises slightly to 5.2% in 2010.

Since Gordon (1982), many empirical researchers add “supply shocks” to the Phillips curve. Others seek to filter supply shocks out of the dependent variable with measures of core inflation. The most common supply shocks are changes in the relative prices of food and energy, and the standard core-inflation measure is inflation less food and energy. Most of this paper examines core inflation, but we experiment with alternative measures of this variable.

²The easiest way to derive this result is to numerically calculate the path of inflation following an increase in unemployment.

2.2 The Puzzle

We now take our first pass at estimating the Phillips curve. We want to know whether equation (2) fits inflation behavior since 1960, and especially whether anything has changed during the Great Recession. The starting date of 1960 is based on Barsky (1987), who finds a regime change in the univariate behavior of inflation at that point, from a stationary process to an IMA(1,1) (a process that still captures inflation behavior, albeit with time-varying parameters, according to Stock and Watson, 2010).

We estimate equation (2) for the period 1960-2007, ending the sample at the start of the Great Recession. We examine two measures of inflation, one derived from the CPI (total inflation) and one from the CPI excluding food and energy (XFE inflation). In each case we average monthly data on the price level to create quarterly price levels, then compute annualized percentage changes from quarter to quarter. For each inflation variable, we estimate a Phillips curve that includes the unemployment gap and one that includes the output gap.

Table 1 presents our regression results. For both measures of inflation, the coefficients on unemployment are about -0.5 and are highly significant statistically ($t > 5$). The output coefficients are around 0.25, which accords with the unemployment coefficients and Okun's Law.

Recall that one point-year of unemployment or output changes long-run inflation by 1.6 times the variable's coefficient. For example, in the equation with XFE inflation and output, the estimated coefficient implies an effect of approximately $(1.6)(0.25) = 0.4$ percentage points. Equivalently, the sacrifice ratio for reducing inflation is $\frac{1}{0.4} = 2.5$. This result is in the ballpark of previous estimates of U.S. sacrifice ratios (e.g., Ball, 1994).

Next, we perform dynamic forecasts of inflation over 2008-2010. We start with actual inflation through 2007 and feed the path of unemployment over 2008-2010 into the estimated Phillips curves in Table 1. Figure 1 compares the forecasted and actual levels of total inflation (Panel A) and XFE inflation (Panel B). We present four-quarter moving averages so we can ignore some of the transitory fluctuations in quarterly data.

Figure 1 illustrates why some economists think the Phillips curve has broken down recently. Actual XFE inflation, for example, fell from 2.6% in 2007Q4 to 0.4% in 2010Q4. In the dynamic forecasts, XFE inflation falls to -5.5% for the unemployment equation and -4.1% for the output

equation. The pre-2008 Phillips curve predicts a deflation that didn't occur.

3 Measuring Core Inflation

Here we compare alternative measures of core inflation. We start by discussing supply shocks, the fluctuations in inflation that core measures are meant to filter out.

3.1 Measuring Supply Shocks

The Phillips curve in much applied work is Gordon's "triangle model." It explains total inflation with three factors: expected inflation, aggregate activity, and supply shocks. The most common measures of supply shocks are changes in the relative prices of food and energy. Since the 1970s, these variables have added greatly to the \bar{R}^2 s of estimated Phillips curves.

Yet, theoretically, it is not obvious why certain relative prices should influence inflation—why it depends on food and energy prices rather than, say, the prices of clothing and home appliances. As Friedman (1975) asked, "Why should the average level of prices be affected significantly by changes in the price of some things relative to others?"

A number of economists answer this question with models of nominal price stickiness. Many, ranging from the Dornbusch and Fischer (1990) text to Blanchard and Gali (2008), assume that food and energy prices are flexible and other prices are sticky. In this setting, a shock that raises the relative prices of food and energy does so by increasing their nominal prices while other prices stay constant. This pattern of adjustment implies an increase in the aggregate price level.

Ball and Mankiw (1995) present a theory of supply shocks based on a different sticky-price model. Rather than assume certain industries have sticky or flexible prices, Ball and Mankiw make price adjustment endogenous. Firms receive shocks to their equilibrium relative prices and choose whether to pay a menu cost and adjust prices. In each period, the firms that receive the largest shocks are most likely to adjust.

The upshot is that inflation depends on the distribution of price changes across industries. If the distribution is skewed to the right, for example, that means many firms have desired

price increases that are large enough to trigger adjustment, and relatively few have large enough negative shocks to adjust. As a result, the aggregate price level rises. Based on this result, Ball and Mankiw measure supply shocks with the skewness of relative price changes and other measures of asymmetry.

In practice, the competing measures of supply shocks—food and energy prices and asymmetries in price distributions—are positively correlated. The reason is that, in many periods, large changes in food and energy prices create large tails in price distributions. Yet there is enough independent variation in supply-shock measures to see which are most closely related to inflation. For the period 1949 to 1989, Ball and Mankiw show that only price-change asymmetries, not changes in food and energy prices, are significant when both are included in a Phillips curve.

3.2 From Supply Shocks to Core Inflation

We define core inflation as the part of inflation not explained by supply shocks, but rather by expected inflation and economic activity—the two other parts of the triangle. With this definition, one can measure core inflation by removing the effects of supply shocks from total inflation. This approach follows common practice. When researchers measure supply shocks with changes in food and energy prices, they measure core inflation with XFE inflation, which strips away the direct effects of food and energy.

If supply shocks are asymmetries in the distribution of price changes, then a measure of core inflation should eliminate the effects of these asymmetries. A simple measure, proposed by Bryan and Cecchetti (1994), is the weighted median of price changes across industries (median inflation).

Researchers sometimes evaluate core inflation measures by their ability to forecast future inflation. In theory, core inflation as we define it might not be a good forecaster. A rise in total inflation caused by a supply shock might raise expected inflation, which in turn raises future inflation; in that case, total inflation would be a better forecaster than core inflation. In practice, however, papers such as Sommer (2004) and Hooker (2002) find that, since the 1980s, supply shocks have not fed strongly into future inflation; thus, core inflation is a good forecaster. We return to this point when we discuss the anchoring of inflation expectations.

Smith (2004) compares median inflation and XFE inflation as forecasters of total inflation over 1984-1997. She finds that forecasts based on median inflation are more accurate.

3.3 Measuring Median Inflation

The Federal Reserve Bank of Cleveland maintains a monthly series for median inflation that begins in 1968. The economy is disaggregated into about forty industries (the number rises from 36 to 45 over time), and core inflation is measured by the weighted median of industry inflation rates, using the industries' weights in the CPI.

The data include an "original" weighted median for 1968-2007 and a "revised" median for 1983 to the present. The main difference is that the original data include owner's equivalent rent (OER) as the price for one large industry, while the revised data include OER for four geographic regions. This revision makes some difference because the change in OER (in the original data) or one of the regional changes (in the revised data) is the median price change for around half of the observations. For the period when the two median series overlap, the differences are modest, although the original series shows somewhat greater monthly volatility. For more documentation of the Cleveland Fed data, see Bryan and Pike (1991) and Bryan et al. (1997).³

We compute quarterly data for median inflation that matches the timing of our quarterly series for total and XFE inflation. We first use the monthly median inflation rates from the Cleveland Fed to construct a monthly series for price levels. Then we average three months to get a quarterly price level, and compute annualized percentage changes in that variable.⁴

The time-aggregation of median inflation is not straightforward. Instead of our approach, one could measure the median of quarterly price changes across industries; in principle, this median

³Some economists (including one of our discussants) question median CPI as an inflation measure because the median price change in the Cleveland Fed data is often one of the regional OERs. It is not clear to us why the validity of the Cleveland Fed's approach depends on which industry is the median. Nonetheless, as a robustness check, we have constructed median non-housing inflation by discarding the regional OERs and computing the median price change for all other industries. A four-quarter average of this series falls by 2.1 percentage points between 2007Q4 and 2010Q4 (from 3.1% to 1.0%); the fall in the Cleveland Fed's median, 2.6 percentage points, is somewhat larger. Yet housing prices have a greater effect on the other leading measure of core inflation, XFE. This variable falls by 1.7 percentage points between 2007Q4 and 2010Q4; if the OERs are removed along with food and energy, the resulting inflation measure falls by only 0.9 percentage points.

⁴The Cleveland Fed website provides a different measure of quarterly inflation: the average of median inflation over the three months of the quarter.

might differ greatly from the quarterly variable that we construct from monthly medians. This non-robustness arises because the median is not a linear function of industry price changes. Future research might compare measures of median inflation based on different frequencies for industry-level data.

3.4 Some New Evidence

We present one new piece of evidence on the measurement of core inflation. Both expected inflation and the activity gap are persistent series, and hence the part of inflation they determine—core inflation—is persistent. One should not expect significant transitory movements in quarterly core inflation. Therefore, one criterion for judging core inflation measures is the extent that their movements are permanent or transitory.

We implement this idea with Stock and Watson (2007)’s procedure for decomposing inflation into permanent and transitory components. Stock and Watson assume that inflation is the sum of a permanent, random-walk component and a transitory, white-noise component. This specification implies that aggregate inflation follows an IMA(1,1) process. Stock and Watson allow the variances of the permanent and transitory shocks to change over time. They estimate series for the permanent component of inflation and the variances of the two shocks.

We apply the Stock-Watson procedure to the two competing measures of core inflation, XFE inflation and median inflation. Figure 2 shows the quarterly series for these two variables and their estimated permanent components. The sample starts in 1983Q2, when the “revised” median data begin. The divergences between total and permanent inflation—the transitory shocks—are smaller when inflation is measured by median inflation. This difference is especially pronounced in the 2000s, when median inflation appears to have almost no transitory component. These results bolster the case for measuring core inflation with the median.

The two core measures behave differently because price changes that are large relative to aggregate inflation—annualized monthly changes of 20% or more—occur frequently in industries besides food and energy. Some of these industries, such as used cars and lodging away from home, may be affected indirectly by energy prices. Women’s apparel is an example of a non-energy-related industry with volatile prices. Large price changes in all these industries cause

transitory movements in XFE inflation, but their effects are filtered out by the Cleveland Fed median.

3.5 Median Inflation During the Great Recession

An important fact for our purposes is that median inflation has fallen somewhat more than XFE inflation during the Great Recession. Over the period from 2007Q4 to 2010Q4, the four-quarter moving average of median inflation fell from 3.1% to 0.5%, while the four-quarter moving average of XFE inflation fell from 2.3% to 0.6%. Median inflation fell by more primarily because it started at a higher level.

Median inflation was relatively high in 2007 because the distribution of price changes was left-skewed during many months of the year. Left-skewness resulted from large price decreases in various industries. In March 2007, for example, the prices of jewelry and watches fell at an annualized rate of 30%, car and truck rental fell 22%, and lodging away from home fell 13%. These price decreases reduced XFE inflation but not median inflation.

The relatively large fall in the median goes in the right direction for reducing the divergence between actual and forecasted inflation over 2008-2010. Yet changing the definition of core inflation is far from enough to resolve the puzzle in Figure 1. We also need another modification of the Phillips curve, which we turn to next.

4 A Phillips Curve With a Time-Varying Slope

As we have discussed, models of costly price adjustment provide a rationale for measuring core inflation with median inflation. These models also imply time variation in the slope of the Phillips curve. As shown by Ball, Mankiw, and Romer (1988), if nominal price adjustment is costly, firms choose to adjust more frequently when the level of inflation is higher and the variance of inflation is higher. More frequent nominal adjustment makes the aggregate price level more flexible, steepening the Phillips curve. That is, the unemployment coefficient α increases in absolute value with the level and variance of inflation.

Ball, Mankiw, and Romer present international evidence supporting their model. In a cross-

country regression for 43 countries, the average level of inflation has a strong effect on the Phillips-curve slope. DeFina (1991) finds a similar effect in U.S. time series data.

Here we document time-variation in the Phillips curve slope from 1960 through 2010. We then show that this variation is tied closely to the level and variance of inflation, as predicted by theory. Finally, we explore the implications for inflation during the Great Recession and in the future.

4.1 Estimates of a Time-Varying Slope

We generalize the basic Phillips curve, equation (2), as follows:

$$\begin{aligned}\pi_t &= \frac{1}{4}(\pi_{t-1} + \pi_{t-2} + \pi_{t-3} + \pi_{t-4}) + \alpha_t(u - u^*)_t + \epsilon_t \\ \alpha_t &= \alpha_{t-1} + \eta_t\end{aligned}\tag{3}$$

where ϵ_t and η_t are white noise errors with variances V and W respectively. This specification allows the coefficient α to vary over time; specifically, it follows a random walk.

Equation (3) is a standard regression equation with a time-varying coefficient. We estimate two versions of this specification. In the first, we assume a value for the ratio of the two shock variances, V and W . With this restriction, we can estimate the path of α_t with the Kalman smoother. We choose V/W to create a degree of smoothness in α_t that appears plausible. Our intuition is that firms' price-setting policies, which determine the Phillips curve slope, do not vary greatly from quarter to quarter. DeVairman (2007) uses a similar approach to estimate a time-varying Phillips curve slope for Japan.

In the second version of our procedure, we estimate the shock variances V and W along with the path of α_t . As suggested by Harvey (1989, Ch. 3) and Wright (2010), we choose the two variances to maximize the likelihood produced by the Kalman smoother. This method is roughly equivalent to choosing the variances to minimize one-step-ahead forecast errors from the model.⁵

We estimate equation (3) for the period 1960-2010. For observations over 1984Q2-2010Q4,

⁵As a robustness check, we also estimate a time-varying α with a simpler technique: rolling regressions with five-year windows. The qualitative results are the same.

we measure inflation with the Cleveland Fed’s revised median. For 1968Q2-1984Q1, we use the original median. For 1960Q1-1968Q1, when the median is not available, we use XFE inflation. We obtain similar results when we use XFE inflation for the entire sample; the measurement of core inflation is not critical for our results about the Phillips curve slope.

Figure 3 presents estimates of the path of α_t , along with two-standard-error bands. Panel A shows the results when the two shock variances are estimated freely, and Panel B imposes the restriction that V/W , the ratio of the variances of ϵ and η , is 100. (Higher values of V/W produce smoother series for α , and lower values produce more variable series.)

The two panels show the same broad trends in α : the estimated parameter falls from near zero in 1960 to around -1 in the early 1970s, fluctuates around this level until 1980, then rises sharply and levels off in the neighborhood of -0.2. In the period since the mid-1980s—the second half of the sample—the estimated α is quite stable. Given the standard errors, there is no evidence against a constant α over 1985-2010.

4.2 Determinants of the Slope

Theory predicts that α is determined by the level and variance of inflation. Figure 4 tests this idea by comparing the estimated path of α (smoothed with $V/W = 100$, and presented on an inverted scale) to two series generated by the Stock-Watson IMA(1,1) model: the level of permanent inflation, and the standard deviation of the sum of permanent and transitory shocks.

The results in Figure 4 are striking: the measures of the level and variability of inflation move together, and the estimated path of α follows them closely. These results strongly confirm the predictions of sticky-price models about time-variation in α . In particular, the high and variable inflation of the 1970s and early 80s created a steep Phillips curve; the curve was flatter before 1973 and after the Volcker disinflation, when inflation was relatively low and stable.

We can also capture these ideas with a regression. We assume that the coefficient α is a linear function of the other two series in Figure 4: $\alpha_t = (a_0 + a_1\bar{\pi}_t + a_2\sigma_t)$, where $\bar{\pi}$ and σ are the level of permanent inflation and the standard deviation of shocks. Substituting this assumption

into equation (3) yields

$$\pi_t = \frac{1}{4}(\pi_{t-1} + \pi_{t-2} + \pi_{t-3} + \pi_{t-4}) + a_0(u - u^*)_t + a_1\bar{\pi}_t(u - u^*)_t + a_2\sigma_t(u - u^*)_t + \epsilon_t \quad (4)$$

Table 2 presents estimates of this equation for 1960-2010 and compares them to an equation with a constant α . We measure $\bar{\pi}_t$ and σ_t in two different ways: with the quarterly series for these parameters and with four-quarter moving averages. In both cases, the joint significance of the $\bar{\pi}$ and σ terms is high ($p < 0.01$). Unfortunately, the collinearity between the two variables makes it difficult to distinguish their individual roles: only $\bar{\pi}$ is significant in one of our specifications, and only σ is significant in the other.

Many other authors present evidence that the Phillips-curve slope has changed over time; examples include Roberts (2006) and Mishkin (2007). These authors focus on the decline in the unemployment coefficient since the 1980s, and generally give a different explanation from ours: they suggest that a flatter Phillips curve reflects an anchoring of inflation expectations. We question this view on two grounds. First, the theory is weak. When the Phillips curve is derived from microeconomic foundations, the unemployment coefficient is determined by the slope of marginal cost and the frequency of price adjustment (Roberts, 1995). Anchoring influences the expected-inflation term in the equation—an effect we examine in Section 5—but not the unemployment coefficient. Second, the common explanation for anchoring is that Fed policy has become more credible since the Volcker disinflation. This story does not explain why the Phillips curve was flat in the 1960s as well as the post-Volcker era, a result that the Ball-Mankiw-Romer model does explain.

4.3 Estimating Constant Slopes for Subsamples

As noted above, the data suggest that α has been close to a constant since the early 1980s, when inflation stabilized at a low level. Assuming a constant α will make it more tractable to enrich the model along other dimensions. Therefore, we assume a constant α starting in 1985Q1, roughly the end of the disinflation and high unemployment of the early 80s. We examine periods

ending in 2007Q4 and 2010Q4 to check for effects of the Great Recession.⁶

For comparison, we also estimate a constant α for the periods 1960-1972 and 1973-1984. Figure 4 suggests some variation in α within these periods, but the statistical significance of this variation is borderline. α is generally low in absolute value during the first period and high during the second.

Table 3 presents estimates of α for each of the periods. We estimate equations with the output gap as well as the unemployment gap, and with XFE inflation as well as median inflation. For the first period, 1960-1972, we only examine XFE inflation, because median inflation is not available for most of the period. We measure median inflation with the original Cleveland Fed series for 1973-84 and with the revised series for the periods beginning in 1985.⁷

For the first three time periods in the table—covering the years from 1960 to the eve of the financial crisis—the estimated coefficients are similar for the two inflation measures. The unemployment coefficient is around -0.2 or -0.25 for both 1960-1972 and 1985-2007. The coefficient is around -0.7 for the 1973-1984 period of high and volatile inflation. The coefficients on output are about -0.5 times the unemployment coefficients, as suggested by Okun’s Law.

As before, multiplying the output coefficient by 1.6 yields the long-run effect on inflation of a one percent output gap for a year. For 1985-2007, with inflation measured by the median, this effect is $(1.6)(0.11) = 1.76$. The sacrifice ratio is $1/(0.176)$, or about 6.

Extending the final sample from 2007 to 2010 has different effects for the different core inflation measures. For XFE inflation, the coefficients decline substantially in absolute value; for median inflation, the coefficients fall by less (when activity is measured by the unemployment gap) or not at all (for the output gap). This difference suggests greater stability in the Phillips curve when inflation is measured by the median, a result we will confirm with dynamic forecasts.

⁶The results do not change significantly if start the sample a year or two later. They are less robust when we move the start date earlier, with observations before 1985 proving influential.

⁷Note that, in these regressions, we use the original median through 1985 even though the revised median is available starting in 1983Q2. This choice ensures that our measure of median inflation is consistent over the 1973-1984 subsample.

4.4 The Great Recession and the Risk of Deflation

We now revisit the puzzle of inflation over 2008-2010. Figures 5 and 6 present dynamic forecasts of quarterly inflation based on the unemployment and output gaps over that period and estimated Phillips curves for 1985-2007. Inflation is measured by the median in Figure 5 and by XFE in Figure 6. Figures 7 and 8 show four-quarter averages of actual and forecasted inflation.

Figures 5 and 7 show that the forecasts for median inflation are close to actual inflation over 2008-2010—in contrast to Figure 2, there is no missing deflation. The most important reason for this change in results is our allowance for time-variation in the Phillips curve slope. The output and unemployment coefficients for 1985-2007 are less than half as large as estimates for the entire 1960-2007 period, which includes the high and unstable inflation of 1973-84. Smaller coefficients mean a smaller predicted fall in inflation.

The measurement of core inflation is also important. The forecasts of XFE inflation in Figures 6 and 8 fall to around -1% at the end of 2010, significantly below actual inflation. Forecasted XFE inflation falls farther than forecasted median inflation because XFE inflation starts at a lower level in 2007. In addition, the estimated coefficients on unemployment and output are somewhat larger for XFE over 1985-2007.

If our Phillips curve for median inflation fits recent history, what does it imply for future inflation? We address this question with new dynamic forecasts based on estimates of the equation from 1985 through 2010. In this exercise, we assume that unemployment and the natural rate follow the paths forecast by the CBO for 2011-2013: unemployment is 9.4% in 2011, 8.4% in 2012, and 7.6% in 2013, and the natural rate is constant at 5.2%. We also compute dynamic forecasts based on CBO forecasts of the output gap over 2011-2013.

Figure 9 shows four-quarter averages of the resulting forecasts. Because unemployment remains above the natural rate and output is below potential, inflation falls steadily. It becomes negative at the end of 2011, and at the end of 2013 it reaches -1.9% (based on unemployment forecasts) or -1.3% (based on output forecasts). Thus our Phillips curve, which explains why deflation hasn't occurred yet, also predicts that deflation will arrive soon.

4.5 Robustness

We have checked the robustness of our results along several dimensions. Specifically, we

- Add lags of unemployment and longer lags of inflation to the Phillips curve, as suggested by Gordon (2011).
- Try Stock and Watson (2010)’s unemployment-gap variable (the difference between current unemployment and minimum unemployment over the current and previous eleven quarters) as an activity measure.
- Try Debelle and Laxton (1997)’s nonlinear transformation of unemployment as our activity variable.
- Add Ball and Moffitt (2001)’s measure of the acceleration of productivity growth to the Phillips curve.
- Estimate a path of the natural rate u^* jointly with the coefficient in the Phillips curve, rather than relying on CBO estimates of u^* .
- Estimate an equation for total inflation that includes a measure of supply shocks (the difference between total inflation and median inflation), rather than estimating an equation for core inflation.

None of these extensions has a significant impact on our conclusions. The Appendix to this paper provides details.

5 Anchored Expectations?

So far we have estimated Phillips curves based on the assumption that expected inflation equals past inflation. A growing number of economists, including Mishkin (2007), Bernanke (2010), and Kohn (2010), argue that this assumption, while once acceptable, has become untenable. In their view, expectations have become “anchored” and therefore do not respond strongly to past inflation. Anchoring has resulted from the public’s growing understanding that the Federal Reserve is committed to low and stable inflation.

Here we review past evidence on the anchoring of expectations and present new evidence. We also examine the importance of anchoring for explaining inflation during the Great Recession and for forecasting future inflation.

We distinguish between two kinds of anchoring, “shock anchoring” and “level anchoring.” The first means that transitory shocks to inflation are not passed into expectations or into future inflation. The second means that expectations are tied to a particular level of inflation, such as two percent. We find strong evidence for shock anchoring since the early 1980s. Level anchoring has occurred gradually and is incomplete, yet it may strongly influence future inflation.

5.1 Shock Anchoring

A consensus holds that the U.S. experienced a shift in monetary regime under Paul Volcker (e.g., Taylor, 1999; Clarida et al., 2000). Before Volcker, the Fed accommodated supply shocks and price setters recognized this behavior. A shock that raised inflation raised expected inflation, which fed into future inflation, and the Fed did not systematically oppose this process. Since Volcker, however, the Fed has been committed to stable inflation. As a result, supply shocks do not strongly affect expectations or future inflation. Expectations have become shock-anchored.⁸

Previous empirical work presents evidence of shock anchoring. Sommer (2004), for example, finds that supply shocks—measured either by changes in food and energy prices or by asymmetries in price distributions—have strong effects on inflation and on survey expectations of inflation before 1979, but little effect afterwards. Authors such as Hooker (2002) and Fuhrer et al. (2009) report similar results.

We confirm these findings with the exercise in Table 4. We estimate Phillips curves in which core inflation depends on the unemployment gap and lagged inflation, but compare two versions of lagged inflation: lagged core inflation and lagged total inflation. We interpret total inflation as the sum of core and supply shocks. We measure core inflation with median inflation for the periods 1973-1984 and 1985-2010, and with XFE inflation for 1960-1972.

The results are stark. For 1960-1972 and 1973-1984, the \overline{R}^2 of the Phillips curve is higher when it includes lagged total inflation. When both lagged total and lagged core are included, the

⁸Christiano and Gust (2000) formalize these ideas with a model of the “high inflation trap.”

weight on lagged core is insignificant. For 1985-2010, these results are reversed. The estimated weight on lagged core is 0.89.

For 1985-2010, we also examine the behavior of expected inflation as measured by one-year forecasts from the Survey of Professional Forecasters (which are not available for earlier periods). We regress expected inflation on an average of lagged core inflation and lagged total inflation, and find a weight on lagged core of 0.86 (with a standard error of 0.06).

Finally, for 1985-2010 we experiment with time-varying weights on lagged core and lagged total inflation. We find little variation: in equations for both actual and expected inflation, the weights on lagged core inflation are consistently close to one. Shock anchoring is a stable feature of the post-Volcker monetary regime.

5.2 Level Anchoring

Many recent discussions of anchoring suggest that expected inflation is tied to a particular level—specifically, 2%. Economists such as Mishkin argue that the Fed is committed to keeping inflation close to 2%, and that the public has come to understand this fact. This anchoring of expectations pushes actual inflation toward 2% as well.

More precisely, Mishkin suggests that expectations of core PCE inflation are anchored at 2%. Since 1980, core CPI inflation has exceeded core PCE by about 0.5% on average (for both the weighted median and XFE measures of core). We should expect, therefore, that expectations of core inflation are anchored at 2.5%.

Using rolling regressions, Williams (2006) and Fuhrer and Olivei (2010) find that the coefficients on inflation lags in the Phillips curve, when not constrained to sum to one, have fallen over time. This finding is consistent with the level anchoring of expectations. We add to this evidence by estimating the degrees of anchoring of both expected and actual inflation and how these parameters have evolved over time. One innovation is that we impose a specific level-2.5%—at which inflation is anchored if it is anchored at all.

While shock anchoring dates back to the Volcker regime shift, level anchoring is more recent. The idea that the Fed has an inflation target around 2% was first discussed in the early 1990s (e.g. Taylor, 1993) and slowly became more prominent. To capture this history, we use data

from 1985 through 2010 to estimate

$$\pi_t^e = \delta_t 2.5 + (1 - \delta_t) \frac{1}{4} (\pi_{t-1} + \pi_{t-2} + \pi_{t-3} + \pi_{t-4}) + \epsilon_t \quad (5)$$

where δ_t follows a random walk. Expected inflation is an average of lagged inflation and 2.5%, with time-varying weights. When $\delta = 0$, expectations are purely backward-looking; when $\delta = 1$, expectations are fully anchored at 2.5%.

To estimate equation (5), we measure π^e with SPF forecasts for inflation over the next four quarters. We measure past inflation with the Cleveland Fed median. We estimate the path of δ_t using the Kalman smoother, assuming that the variance of ϵ is 100 times the variance of innovations in δ .

Figure 10 presents our estimated series for δ_t . We find that δ_t is near zero until the early 1990s and then rises. It is around 0.6 over 2007-2010. Expectations have become largely but not completely anchored.

We next examine the behavior of actual inflation. We assume that inflation depends on expected inflation and the unemployment gap, equation (1), and substitute in equation (5) for expected inflation. The result is

$$\pi_t = \delta_t 2.5 + (1 - \delta_t) \frac{1}{4} (\pi_{t-1} + \pi_{t-2} + \pi_{t-3} + \pi_{t-4}) + \alpha(u - u_t^*) + \epsilon_t \quad (6)$$

We estimate this equation and a variation with the output gap replacing the unemployment gap.

Figures 11 and 12 shows the estimated path of δ_t for these specifications. Once again, δ is near zero until the early 1990s and then rises. According to these results, as inflation expectations have become anchored, so has actual inflation.

The value of δ in 2010Q4, the end of the sample, is 0.47 when the Phillips curve includes the unemployment gap and 0.30 with the output gap. These δ s are smaller than the degree of anchoring that we estimate for SPF expectations in Figure 10. One possible explanation is that the expectations that enter the Phillips curve are those of typical price setters, who are less sophisticated than professional forecasters. They learn more slowly about the Fed's commitment to 2.5% inflation. But we should not make too much of the differences among Figures 10-12,

because the confidence intervals for the δ s overlap.

Our estimates of the coefficient α in equation (6) is -0.24 (standard error = 0.03) for the unemployment gap and 0.13 (standard error = 0.02) for the output gap. These estimates are somewhat larger in absolute value than the α s for our basic Phillips curve, which includes lagged inflation with a coefficient of one—but again, the confidence intervals overlap.

5.3 Dynamic Forecasts

We now revisit the behavior of inflation in the recent past and the future. Figure 13 parallels Figure 7: it presents dynamic forecasts of four-quarter inflation over 2008-2010, based on estimates of equation (6) for 1985-2007. We assume that, throughout 2008-2010, the anchoring parameter δ remains at the level estimated for 2007Q4; this level is 0.31 when the equation includes the unemployment gap and 0.26 with the output gap.

In Figure 13, forecasted inflation falls less than actual inflation over 2008-2010. The forecasts from our purely backward-looking equation, shown in Figure 7, are closer to actual inflation. This difference in forecast performance, however, is modest in size and statistically insignificant: accounting for anchoring does not sharply change inflation forecasts for the last few years. This finding reflects the fact that the estimated degree of anchoring in 2007Q4 is fairly small. In addition, inflation has been fairly close to 2.5%, so forecasts are not sensitive to the weights on 2.5% and lagged inflation.

Figure 14 parallels Figure 9 for our basic Phillips curve. It shows forecasts of four-quarter inflation over 2011-2013 based on estimates of equation (6) for 1985-2010. Here we assume that δ stays at the level estimated for 2010Q4.

In this exercise, anchoring makes a big difference. Deflation, which is predicted by our basic Phillips curve, does not occur in our forecasts with anchoring. Instead, inflation is steady at about 0.5% and then rises to 1% at the end of 2013. Partial anchoring pulls expected inflation up toward 2.5%, and that causes actual inflation to bottom out rather than fall in response to high unemployment.

Two caveats are in order. First, there is considerable uncertainty about the degree of anchoring in the Phillips curve. With unemployment in the equation, the 95% confidence interval

for δ in 2010Q4 is roughly [0.2, 0.7]. With the output gap, the confidence interval is [0.2, 0.4].

Second, even if expectations were anchored in 2010, they may become less anchored in the near future. The weight on 2.5% rose during a period when actual inflation was near that level. In contrast, Figure 14 tells us that actual inflation will stay below 1% for several years—yet expectations will still be tied to 2.5%. That suggests sub-optimal forecasting. Price setters may learn that inflation is stuck below 2.5%, and expectations will adjust downward.

Believers in anchoring point out that *long run* inflation expectations—as measured, for example, by ten-year SPF forecasts—have been close to 2.5% since 2000. It is plausible that these expectations will remain anchored in the future, because the public believes that the Fed will manage eventually to return inflation to its 2.5% target. However, in most theories of the Phillips curve—both sticky-price and sticky-information models—prices depend on expected inflation over the period when the prices are likely to be in effect. This period is on the order of one year rather than ten years. Recent empirical work also finds that actual inflation depends on one-year rather than ten-year SPF expectations (Fuhrer, 2011).

The forecasts of inflation in Figure 14 are fairly close to the forecasts of others. At the end of 2010, the CBO was forecasting core CPI inflation rates of 0.9%, 1.0%, and 1.4% over 2011–2013. These forecasts are 0.3 to 0.5 percentage points above ours. These differences might be explained by the definitions of core inflation—median for us and XFE for the CBO (although it is not obvious that forecasts of either should be higher than the other). In the SPF, the median forecast for XFE inflation is 1.3% for 2011 and 1.7% for 2012 (and unavailable for 2013). The forecast for 2012 is a full percentage point above ours. One factor here is that only 44 percent of SPF forecasters say they use the concept of the natural rate of unemployment. Evidently, many forecasters use models of inflation that differ greatly from the Phillips curves we estimate.

6 The New Keynesian Phillips Curve

We have followed an empirical tradition that assumes expected inflation is determined by past inflation and possibly the central bank’s inflation target. Another literature studies Phillips curves based on rational expectations. The foundation for much of this work is the “New Keynesian

Phillips Curve” (NKPC) derived from Calvo (1983)’s model of staggered price adjustment. The original version of this equation, presented by Roberts (1995), was:

$$\pi_t = E_t\pi_{t+1} + \lambda(y - y^*)_t \quad (7)$$

where $E_t\pi_{t+1}$ is this quarter’s rational forecast of next quarter’s inflation and $y - y^*$ is the output gap.

A number of authors show that this Phillips curve fits the data poorly (e.g. Gali and Gertler, 1999; Mankiw, 2001). To understand this result, rearrange equation (7) to obtain

$$E_t\pi_{t+1} - \pi_t = -\lambda(y - y^*)_t \quad (8)$$

The theory behind the NKPC implies that the parameter λ is positive. Therefore, equation (8) says that the output gap in quarter t has a negative effect on the expected change in inflation from t to $t + 1$. In the data, output has a positive correlation with the change in inflation—both before the Great Recession and during it, when output was low and inflation fell. As a result, estimates of λ are consistently negative, contradicting the theory.

Motivated by this finding, Gali and Gertler modify the NKPC by replacing the output gap with real marginal cost:

$$\pi_t = E_t\pi_{t+1} + \lambda mc_t \quad (9)$$

Gali and Gertler measure real marginal cost with real unit labor costs, also known as labor’s share of income. They obtain a positive estimate of λ , a result that has led many researchers to adopt their specification.

Rudd and Whelan (2005, 2007) and Mazumder (2010) criticize Gali and Gertler’s work. They argue that labor’s share of income is not a credible measure of real marginal cost. Labor’s share is generally countercyclical, and there is a strong case for procyclical marginal cost based on both theory and evidence, such as the Bils (1987) and Mazumder studies of overtime labor. Mazumder estimates equation (9) with a procyclical measure of marginal cost based on overtime,

and obtains negative estimates of λ —the same result that discredited the original NKPC.⁹

Despite skepticism about the NKPC, we ask whether it helps explain inflation during the Great Recession. It does not; indeed, recent experience provides a new reason to doubt the model. The problem is different from the one stressed in previous work: the Gali-Gertler specification does not fit recent data even if we accept their measure of marginal cost.

Table 5 presents estimates of the parameter λ in the NKPC, with marginal cost measured by labor’s share. We estimate the equation by GMM using the following orthogonality condition:

$$E_t\{(\pi_t - \lambda mc_t - \pi_{t+1})\}z_t = 0 \quad (10)$$

where z_t is a vector of variables dated t and earlier, thus these variables are orthogonal to the inflation surprise in $t + 1$. We use the same instruments as Gali and Gertler: four lags each of inflation, labor’s share, the output gap, a long-short interest rate spread, nominal wage inflation, and commodity price inflation. We use the median CPI inflation rate, but the results are similar for other inflation measures (including Gali and Gertler’s measure, the GDP deflator).¹⁰

As in previous parts of this paper, we find that the coefficient in the Phillips curve varies across time periods. Gali and Gertler report a significantly positive coefficient for 1960-1997, which fits theory, and which we replicate. The noteworthy result in Table 5 is that the coefficient on labor’s share is significantly positive for the period 1985-2007 ($t = 2.04$), but insignificant for 1985-2010 ($t = 0.92$). In other words the model’s fit deteriorates when we add 2008-2010 to the sample.

Figure 15 shows why. For 1985-2010, it plots annual averages of labor’s share of income against the unemployment gap. We see that 2009 and 2010 are big outliers. Before then, labor’s share was positively correlated with the unemployment gap—as noted before, it was countercyclical. This is an unappealing feature for a marginal cost measure, but it produces a positive estimate of λ . The Great Recession, unlike previous recessions, has been accompanied

⁹Rudd and Whelan and Kleibergen and Mavroeidis (2009) also demonstrate technical problems with the studies supporting the Gali-Gertler model, such as weak instruments.

¹⁰More precisely, we use the inflation series we constructed to estimate the accelerationist Phillips curve over 1960-2010: the Cleveland Fed’s revised median for 1983-2010, the original median for 1968-1982, and XFE inflation for 1960-1967.

by a sharp fall in labor’s share—for whatever reason, productivity growth was strong and real wages did not keep up. This change in cyclicalities changes the estimate of the Phillips curve coefficient.

To see the problem a different way, we substitute mc for the output gap in equation (8):

$$E_t\pi_{t+1} - \pi_t = -\lambda mc_t \tag{11}$$

This version of Galí and Gertler’s equation says that the expected change in inflation depends negatively on labor’s share. Throughout 2009 and 2010, when labor’s share was lower than average, the equation says that inflation was expected to rise. In fact, inflation fell, and it seems dubious that price setters repeatedly expected the opposite—that inflation would rise during the Great Recession. In any case, in quarterly data, falling inflation and expectations of rising inflation imply repeated forecast errors in the same direction, a violation of rational expectations.

7 Conclusion

This paper examines U.S. inflation from 1960 through 2010. We find that a simple accelerationist Phillips curve fits the entire period, including the recent Great Recession, under two conditions: we measure core inflation with the weighted median of price changes, and we allow the Phillips curve slope to change with the level and variance of inflation. Both of these ideas are motivated by models of costly price adjustment.

We also find evidence of a change in the Phillips curve since the 1990s: expectations of inflation, and hence actual inflation, have become partially anchored at a level of 2.5%. If this anchoring persists, the United States is likely to avoid deflation in the near future, despite high unemployment. Deflation may occur, however, if low inflation leads to a de-anchoring of expectations.

We conclude with a topic for future research: the effect of unemployment duration on the Phillips curve. For a number of countries, Llaudes (2005) finds that long-term unemployment (the fraction of the labor force unemployed for more than 26 weeks) puts less downward pressure on inflation than short-term unemployment. It is difficult to test this idea with U.S. data because

long-term and short-term unemployment are highly collinear. This collinearity is diminishing, however, because long-term unemployment has risen much more than short-term unemployment since 2008. We may soon have enough data to tell whether long-term unemployment has less effect on inflation. If it does, then inflation will fall by less over the next few years than one would expect based on aggregate unemployment. The shift toward long-term unemployment, along with expectations anchoring, could prevent deflation.

A Appendix

Here we briefly discuss five variations to our basic Phillips curve specification that we also test for robustness.

A.1 Longer Lags

Gordon (2011) argues that the Phillips curve fits history better if it includes lags of unemployment and long lags of inflation. Following Gordon, we modify our basic Phillips curve, equation (1), by including four lags of unemployment and twenty-four lags of inflation (with the sum of coefficients on the inflation lags set to one). We continue to measure inflation with the Cleveland Fed median. When we estimate this specification for the period 1960-2007,¹¹ the sum of unemployment coefficients is -0.26. Paralleling Figure 7, Figure A1 shows dynamic forecasts of four-quarter inflation over 2008-2010. The forecast for 2010Q4 is -5.1%. Thus, our finding that the pre-2008 Phillips curve incorrectly predicts deflation is robust to the equation's lag structure.

A.2 The Stock-Watson Unemployment Gap

Stock and Watson (2010) compute a new unemployment gap variable defined as the difference between the unemployment rate in quarter t and the minimum unemployment rate from quarters t to $t - 11$:

$$u_t^{SW} = u_t - \min(u_t, \dots, u_{t-11}) \quad (\text{A-1})$$

Computing the gap variable in this way focuses on recessions by producing only non-negative values for the unemployment gap. Tables A1(a) and A1(b) compare the results of our basic Phillips curve specification for the CBO unemployment gap and the Stock-Watson unemployment gap. These results show a very similar Phillips curve is produced when either $(u - u^*)$ or u^{SW} are used in turn in the model. We then estimate a version of the Phillips curve that

¹¹Data on core inflation starts in 1957, therefore this regression actually starts in 1964.

incorporates both unemployment gap variables simultaneously:

$$\pi_t = \frac{1}{4}(\pi_{t-1} + \pi_{t-2} + \pi_{t-3} + \pi_{t-4}) + (\beta_0 + \beta_1 D1_t + \beta_2 D2_t)((u - u^*)_t + \lambda u_t^{SW}) \quad (\text{A-2})$$

where $D1_t$ is a dummy variable equal to 1 for 1973:1-2010:4 (0 otherwise), and $D2_t$ is a dummy variable equal to 1 for 1985:1-2010:4 (0 otherwise). This model is estimated from 1960:1 to 2010:4, and allows us to compare the statistical significance of the two unemployment gap variables at the same time. Specifically we estimate the model jointly while also imposing the restriction that the ratio of the coefficients on the two variables is the same for every period. We are able to do this since there is no obvious reason to believe that the relative importance of $(u - u^*)$ and u^{SW} changes, even though the coefficient on the activity variable itself should change over different time periods.

The results (Table A1(c)) suggest that the Stock-Watson unemployment gap does not add much to the explanatory power of our equation. The weight on the Stock-Watson unemployment gap is not statistically significant, leading us to believe that the Stock-Watson variable is not useful for our purposes (but might be better suited to real-time forecasting as Stock and Watson (2010) originally intended it for).

A.3 A Nonlinear Phillips Curve

Debelle and Laxton (1997) estimate both linear and nonlinear Phillips curves for Canada, the United Kingdom, and the United States, and argue that a nonlinear specification fits the data better. The equation that Debelle and Laxton estimate essentially replaces the unemployment gap $(u - u^*)$ with the unemployment gap relative to the level of unemployment:

$$\pi_t = \frac{1}{4}(\pi_{t-1} + \pi_{t-2} + \pi_{t-3} + \pi_{t-4}) + \alpha \frac{(u - u^*)_t}{u_t} + \epsilon_t \quad (\text{A-3})$$

Table A1(d) presents estimates of equation (A-3) for our three main sample periods. The fit of the equation, as measured by the \overline{R}^2 s, is very close to the fit of our linear Phillips curve, equation (2). We have also estimated a Phillips curve that includes both $(u - u^*)$ and $(u - u^*)/u$. In this case, high collinearity between the two variables causes both to be statistically insignificant.

Thus, the data do not suggest that making the Phillips curve nonlinear improves the model.

When we estimate the Debelle-Laxton version of the Phillips curve from 1985-2007 and compute dynamic forecasts of inflation for 2008-2010, the model performs less well than our linear specification. The four-quarter average of median inflation fell from 3.1% to 0.5% from 2007Q4 to 2010Q4, whereas the Debelle-Laxton model predicts four-quarter inflation of 1.3% in 2010Q4. The forecast from the linear model, 0.3%, is closer to actual inflation.

A.4 Productivity Growth

Ball and Moffitt (2001) argue that the fit of the Phillips curve can be improved by adding the change in productivity growth, $g - \hat{g}$. They explain this effect with a model in which workers' real wage aspirations adjust slowly to shifts in productivity growth. As a result, an acceleration of productivity growth means that productivity growth is high relative to wage demands, thereby reducing the natural rate of unemployment. Likewise a productivity slowdown does the reverse.

Therefore we also estimate a version of the Philips curve which adds $g - \hat{g}$ to our basic specification, where g is labor productivity in the business sector (output divided by total hours of work) and \hat{g} is a weighted average of past productivity growth defined recursively by a partial adjustment equation, $\hat{g}_t = \mu\hat{g}_{t-1} + (1 - \mu)g_{t-1}$. Ball and Moffitt suggest a value of μ of 0.95 yields a good fit to annual data. We therefore use the quarterly analog of 0.9875.

The results in Table A1(e) suggest that the productivity growth variable is insignificant for 1960-1972 and 1973-1984. It is however significant for 1985-2010 and adds modestly to the \overline{R}^2 . However it does not substantially change our interpretation of the period 2008-2010. Computing dynamic forecast based on estimates for 1985 to 2007 with $g - \hat{g}$ included are very similar to those that ignore $g - \hat{g}$: median inflation is forecast to fall to -0.32% by the fourth quarter of 2010, which is close to the predicted fall to -0.24% in our basic specification.

A.5 Estimating A Time-Varying NAIRU

The way in which the NAIRU is computed is often a contentious issue in the literature, though for the purposes of this paper we view the CBO estimate of the NAIRU as close as we can get to a measure that captures a pattern common in other estimates. That being said, for robustness we

also check what happens to our results when we alter the way in which the NAIRU is estimated.

Specifically we compute the NAIRU in a similar manner as in Staiger et al. (1997). We estimate the Phillips curve model with median CPI inflation and lagged median CPI inflation, where the NAIRU is modeled as a random walk. Just as in Section 4 of the paper, we derive maximum likelihood estimates of the path of the NAIRU using the Kalman filter with the restriction that V/W is equal to 400.

This produces a series for the NAIRU that is very close to the CBO estimate of the NAIRU. For instance in 1985:1, the CBO estimate of the NAIRU is 6.03% and it falls to 5.20% by the end of 2010. Over the exact same time period our estimate of the time-varying NAIRU goes from 6.04% at the start of 1985 to 5.44% by the end of 2010. In fact comparing all quarters from 1985 to 2010, the deviation between the CBO estimate of the NAIRU and our time-varying NAIRU never exceeds 0.32%. Finally, we also estimate our basic specification of median inflation on lagged median inflation and the unemployment gap using the new NAIRU estimate. We obtain a coefficient of the unemployment gap of -0.178, which is extremely close to the coefficient obtained under the CBO unemployment gap of -0.168. Therefore we conclude that our results are robust to alternative measures of the NAIRU.

A.6 Supply Shocks

An alternative to estimating the Phillips curve with core inflation is to use total CPI inflation and incorporate measures of supply shocks. We follow Ball and Mankiw (1995) by defining a supply shock as the difference of current inflation from current core inflation which captures asymmetries in the distribution of price changes. Thus our supply shock becomes total CPI inflation less median inflation for 1972 to 2010. Hence the model we estimate is:

$$\pi_t^T = \frac{1}{4}(\pi_{t-1} + \pi_{t-2} + \pi_{t-3} + \pi_{t-4}) + \alpha(u - u^*)_t + \beta Shock_t + \epsilon_t \quad (\text{A-4})$$

where *Shock* is equal to total inflation minus core inflation, π^T denotes total CPI inflation, and π denotes median CPI inflation. Table A1(f) shows the results for the periods 1973-1984, 1985-2007, and 1985-2010. The interesting result to note here is that the coefficient on the

supply shock variable is approximately equal to one in all periods, particularly for 1985-2007 and 1985-2010. Assuming $\beta = 1$ means that (A-4) becomes:

$$\pi_t^T = \frac{1}{4}(\pi_{t-1} + \pi_{t-2} + \pi_{t-3} + \pi_{t-4}) + \alpha(u - u^*)_t + (\pi_t^T - \pi_t) \quad (\text{A-5})$$

which further reduces into:

$$\pi_t = \frac{1}{4}(\pi_{t-1} + \pi_{t-2} + \pi_{t-3} + \pi_{t-4}) + \alpha(u - u^*)_t \quad (\text{A-6})$$

which is exactly our basic specification for the Phillips curve. In other words, the behavior of total inflation in the presence of supply shocks is consistent with the behavior of core inflation that we assumed previously. Since the estimated equations for total inflation reduce approximately to our equations for core inflation, our estimates for the coefficient α are similar for the two types of equations for a given time period and activity gap.

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Table 1: Phillips Curve Estimated from 1960:1 to 2007:4

(a) $\pi_t = \frac{1}{4}(\pi_{t-1} + \pi_{t-2} + \pi_{t-3} + \pi_{t-4}) + \alpha(u_t - u_t^*)$ (b) $\pi_t = \frac{1}{4}(\pi_{t-1} + \pi_{t-2} + \pi_{t-3} + \pi_{t-4}) + \alpha(y_t - y_t^*)$				
	(a) Unemployment Gap		(b) Output Gap	
π_t measure:	TOTAL CPI	XFE CPI	TOTAL CPI	XFE CPI
Coefficient for α	-0.507	-0.474	0.308	0.257
S.E.	(0.091)	(0.077)	(0.049)	(0.042)
\overline{R}^2	0.703	0.746	0.713	0.744

Note: π_t is the inflation rate, u_t is the national unemployment rate, u_t^* is the CBO measure of the NAIRU, y_t is log of real GDP, and y_t^* is the CBO's estimate of potential (log) real GDP. Estimation is conducted by OLS.

Table 2: Phillips Curve with Level and Variance of Inflation

(a) $\pi_t = \frac{1}{4}(\pi_{t-1} + \pi_{t-2} + \pi_{t-3} + \pi_{t-4}) + a_0(u - u^*)_t + \epsilon_t$			
	a_0		
Coefficient	-0.355		
S.E.	(0.058)		
\bar{R}^2	0.773		
(b) $\pi_t = \frac{1}{4}(\pi_{t-1} + \pi_{t-2} + \pi_{t-3} + \pi_{t-4}) + a_0(u - u^*)_t + a_1\bar{\pi}_t(u - u^*)_t + a_2\sigma_t(u - u^*)_t + \epsilon_t$			
<i>Quarterly Data for $\bar{\pi}_t, \sigma_t$</i>			
	a_0	a_1	a_2
Coefficient	0.194	-0.008	-0.645
S.E.	(0.115)	(0.036)	(0.187)
\bar{R}^2	0.800		
p -value for $H_0 : a_1 = a_2 = 0$	0.000		
<i>4-Quarter Moving Averages for $\bar{\pi}_t, \sigma_t$</i>			
	a_0	a_1	a_2
Coefficient	0.132	-0.134	-0.008
S.E.	(0.110)	(0.036)	(0.191)
\bar{R}^2	0.807		
p -value for $H_0 : a_1 = a_2 = 0$	0.000		

Note: Time period for results in this table is 1960:1-2010:4. $\bar{\pi}$ and σ are the level of permanent inflation and the standard deviation of shocks.

Table 3: Phillips Curves for Core Inflation

(a) $\pi_t = \frac{1}{4}(\pi_{t-1} + \pi_{t-2} + \pi_{t-3} + \pi_{t-4}) + \alpha(u_t - u_t^*)$ (b) $\pi_t = \frac{1}{4}(\pi_{t-1} + \pi_{t-2} + \pi_{t-3} + \pi_{t-4}) + \alpha(y_t - y_t^*)$				
	(a) Unemployment Gap		(b) Output Gap	
π_t measure:	MEDIAN CPI	XFE CPI	MEDIAN CPI	XFE CPI
1960:1-1972:4				
Coefficient for α S.E.		-0.231 (0.103)		0.135 (0.056)
\overline{R}^2 S.E. of Regression		0.729 0.992		0.733 0.985
1973:1-1984:4				
Coefficient for α S.E.	-0.650 (0.172)	-0.688 (0.184)	0.365 (0.095)	0.371 (0.103)
\overline{R}^2 S.E. of Regression	0.513 2.254	0.402 2.408	0.516 2.247	0.391 2.429
1985:1-2007:4				
Coefficient for α S.E.	-0.202 (0.054)	-0.246 (0.067)	0.114 (0.029)	0.136 (0.037)
\overline{R}^2 S.E. of Regression	0.700 0.425	0.761 0.529	0.703 0.423	0.763 0.528
1985:1-2010:4				
Coefficient for α S.E.	-0.168 (0.031)	-0.136 (0.039)	0.114 (0.019)	0.092 (0.024)
\overline{R}^2 S.E. of Regression	0.781 0.448	0.764 0.570	0.792 0.437	0.769 0.563

Note: Median CPI inflation data begins in 1967:2.

Table 4: Shock Anchoring in the Phillips Curve

(a) $\pi_t = \frac{1}{4}(\pi_{t-1} + \pi_{t-2} + \pi_{t-3} + \pi_{t-4}) + \alpha(u_t - u_t^*)$			
	1960:1-1972:4	1973:1-1984:4	1985:1-2010:4
Coefficient for α	-0.231	-0.650	-0.168
SE	(0.103)	(0.172)	(0.031)
$\overline{R^2}$	0.729	0.513	0.781
(b) $\pi_t = \frac{1}{4}(\pi_{t-1}^T + \pi_{t-2}^T + \pi_{t-3}^T + \pi_{t-4}^T) + \alpha(u_t - u_t^*)$			
	1960:1-1972:4	1973:1-1984:4	1985:1-2010:4
Coefficient for α	-0.319	-0.620	-0.003
SE	(0.091)	(0.165)	(0.064)
$\overline{R^2}$	0.789	0.551	0.042
(c) $\pi_t = \gamma \frac{1}{4}(\pi_{t-1} + \pi_{t-2} + \pi_{t-3} + \pi_{t-4}) + (1 - \gamma) \frac{1}{4}(\pi_{t-1}^T + \pi_{t-2}^T + \pi_{t-3}^T + \pi_{t-4}^T) + \alpha(u_t - u_t^*)$			
	1960:1-1972:4	1973:1-1984:4	1985:1-2010:4
Coefficient for α	-0.329	-0.630	-0.150
SE	(0.095)	(0.165)	(0.031)
Coefficient for γ	-0.117	0.326	0.886
SE	(0.295)	(0.294)	(0.046)
$\overline{R^2}$	0.785	0.553	0.791

Note: π_t is core inflation (XFE inflation for 1960:1-1972:4, and median inflation for 1973:1-2010:4), and π_t^T is the total CPI inflation rate.

Table 5: New Keynesian Phillips Curve Results

$\pi_t = E_t \pi_{t+1} + \lambda s_t$			
	1960:1-1997:4	1960:1-2010:4	1960:1-1972:4
Coefficient for λ	0.060	0.040	0.110
SE	(0.012)	(0.045)	(0.020)
$\overline{R^2}$	0.710	0.740	0.733
	1973:1-1984:4	1985:1-2007:4	1985:1-2010:4
Coefficient for λ	0.129	0.044	0.012
SE	(0.053)	(0.022)	(0.013)
$\overline{R^2}$	0.398	0.665	0.760

Note: In this table we again use the combined median inflation rate that uses the revised median series from 1983-2010, the original median series for 1967-1982, and XFE for 1960-1967. s_t is the log of the labor income share. For the rational expectations Phillips curve we use GMM with instruments of: four lags of inflation, the labor share, the output gap, a long-short interest rate spread, nominal wage inflation, and commodity price inflation.

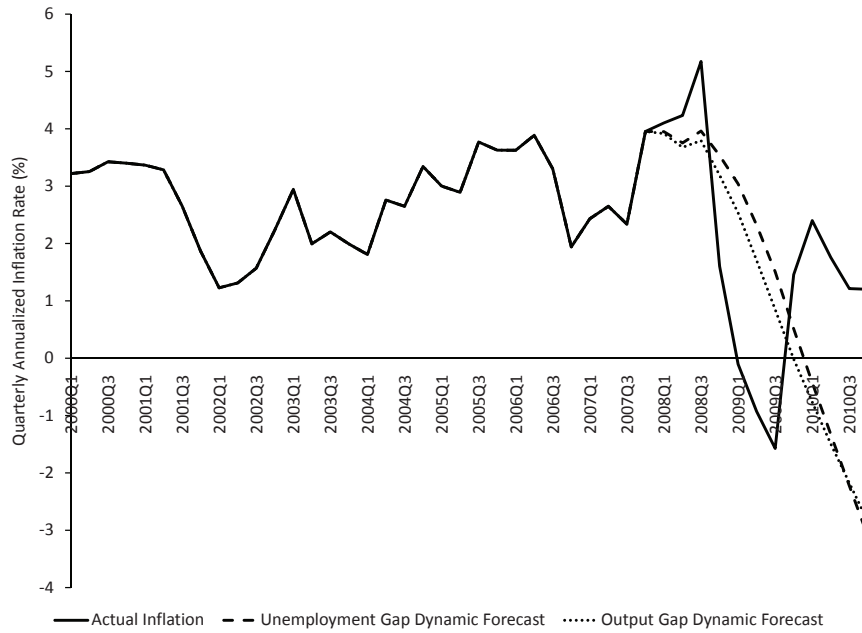
A1. Variations on Basic Phillips Curves

(a) $\pi_t = \frac{1}{4}(\pi_{t-1} + \pi_{t-2} + \pi_{t-3} + \pi_{t-4}) + \alpha(u_t - u_t^*)$				
	1960:1-1972:4	1973:1-1984:4	1985:1-2010:4	
Coefficient for α	-0.231	-0.650	-0.168	
SE	(0.103)	(0.172)	(0.031)	
$\overline{R^2}$	0.729	0.513	0.781	
(b) $\pi_t = \frac{1}{4}(\pi_{t-1} + \pi_{t-2} + \pi_{t-3} + \pi_{t-4}) + \alpha u_t^{SW}$				
	1960:1-1972:4	1973:1-1984:4	1985:1-2010:4	
Coefficient for α	-0.296	-0.521	-0.157	
SE	(0.118)	(0.164)	(0.027)	
$\overline{R^2}$	0.735	0.477	0.788	
(c) $\pi_t = \frac{1}{4}(\pi_{t-1} + \pi_{t-2} + \pi_{t-3} + \pi_{t-4}) + (\beta_0 + \beta_1 D1_t + \beta_2 D2_t)((u - u^*)_t + \lambda u_t^{SW})$				
	1960:1-2010:4			
	β_0	β_1	β_2	λ
Coefficient	-0.259	-0.258	0.381	0.269
SE	(0.125)	(0.189)	(0.141)	(0.340)
$\overline{R^2}$	0.788			
(d) $\pi_t = \frac{1}{4}(\pi_{t-1} + \pi_{t-2} + \pi_{t-3} + \pi_{t-4}) + \alpha \frac{(u - u^*)_t}{u_t}$				
	1960:1-1972:4	1973:1-1984:4	1985:1-2010:4	
Coefficient for α	-0.965	-5.836	-1.312	
SE	(0.390)	(1.441)	(0.241)	
$\overline{R^2}$	0.734	0.529	0.780	
(e) $\pi_t = \frac{1}{4}(\pi_{t-1} + \pi_{t-2} + \pi_{t-3} + \pi_{t-4}) + \alpha(u_t - u_t^*) + \beta(g_t - \hat{g}_t)$				
	1960:1-1972:4	1973:1-1984:4	1985:1-2010:4	
Coefficient for α	-0.224	-0.636	-0.158	
SE	(0.105)	(0.172)	(0.030)	
Coefficient for β	-0.014	-0.096	-0.049	
SE	(0.033)	(0.085)	(0.016)	
$\overline{R^2}$	0.724	0.515	0.798	
(f) $\pi_t^T = \frac{1}{4}(\pi_{t-1} + \pi_{t-2} + \pi_{t-3} + \pi_{t-4}) + \alpha(u_t - u_t^*) + \beta Shock_t$				
	1973:1-1984:4	1985:1-2007:4	1985:1-2010:4	
Coefficient for α	-0.667	-0.194	-0.167	
SE	(0.175)	(0.055)	(0.030)	
Coefficient for β	0.852	1.031	1.038	
SE	(0.221)	(0.034)	(0.024)	
$\overline{R^2}$	0.566	0.922	0.953	

Note: u_t is the national unemployment rate, u_t^* is the CBO measure of the NAIRU, and u_t^{SW} is the difference from unemployment in quarter t from the minimum unemployment rate from quarter t to $t - 11$. $D1$ is a dummy variable equal to 1 for 1973:1 to 2010:4 (0 otherwise), and $D2$ is a dummy variable equal to 1 for 1985:1 to 2010:4 (0 otherwise). For Tables (a), (b), (d), and (e) π_t is XFE inflation for 1960:1-1972:4, and is median CPI inflation for subsequent periods. For Table (c), we use a combined median inflation rate that uses the ‘revised’ median series from 1983-2010, the ‘original’ median series for 1967-1982, and XFE for 1960-1967. For Table (f), total CPI inflation is used as dependent variable with median inflation for the lagged inflation term on the right-hand side, and $Shock_t$ is total CPI inflation minus median CPI inflation.

Figure 1: 4-Quarter Moving Averages of Dynamic Forecasts of Inflation for 2008 to 2010 Based on 1960:1-2007:4 Regression

(a) Total CPI Inflation



(b) XFE CPI Inflation

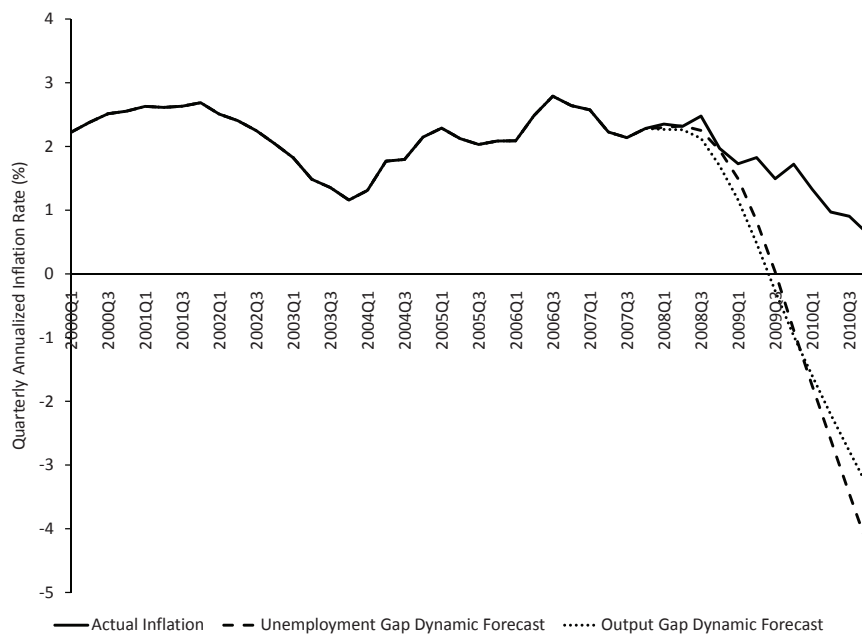


Figure 2: Median CPI and XFE CPI Inflation Rates, 1983:2-2010:4

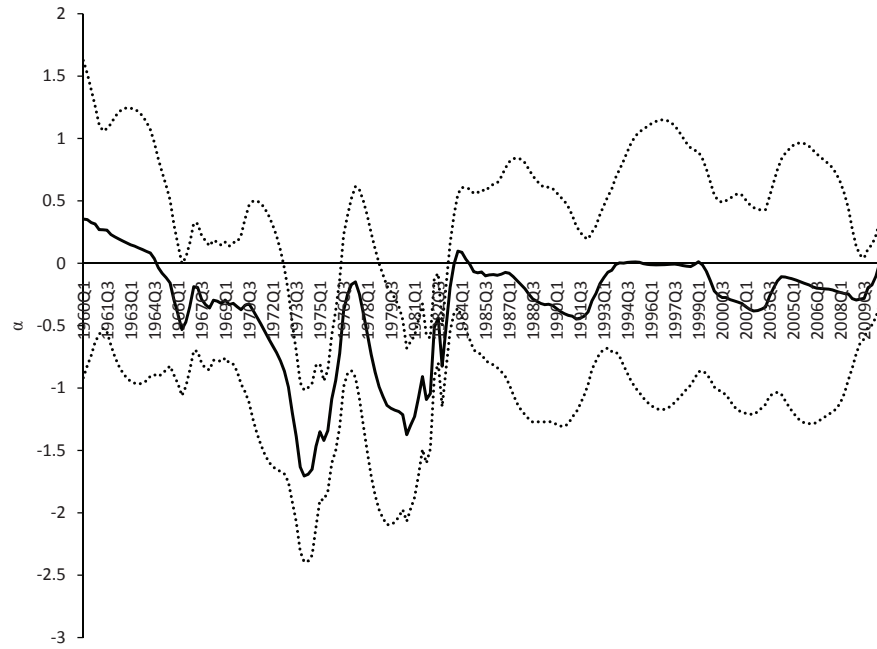
(a) Median CPI Inflation



(b) XFE CPI Inflation



Figure 3: Time-Varying α_t from Phillips Curve, 1960:1-2010:4
(a) No Restriction



(b) $V = 100Q$

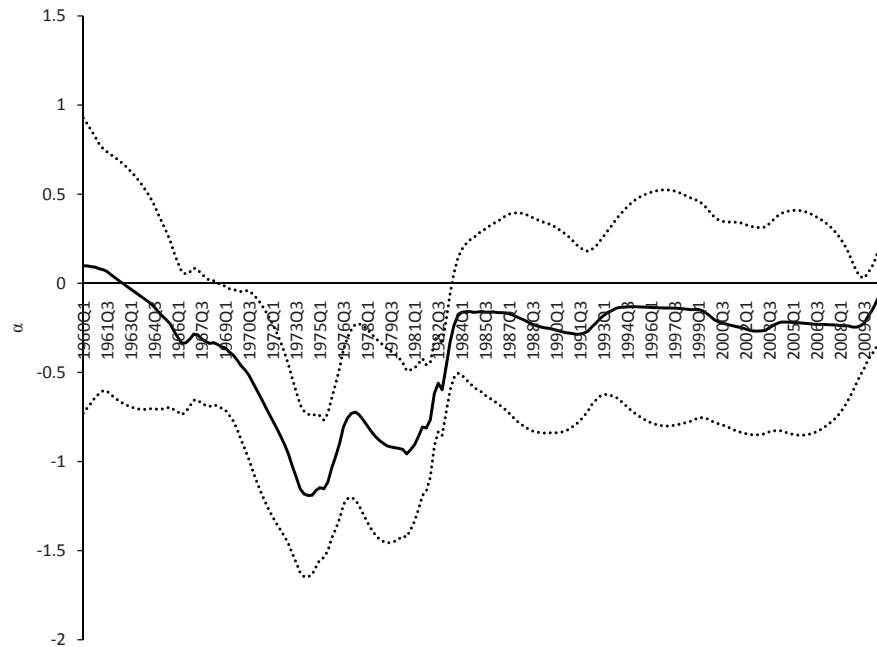


Figure 4: Permanent Component of Median CPI Inflation vs. Time-Varying α

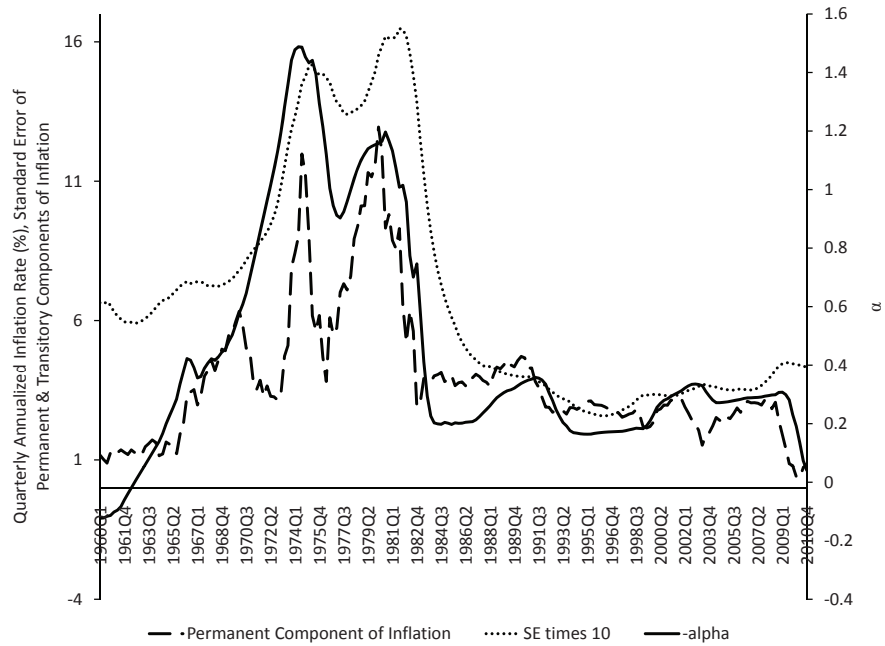
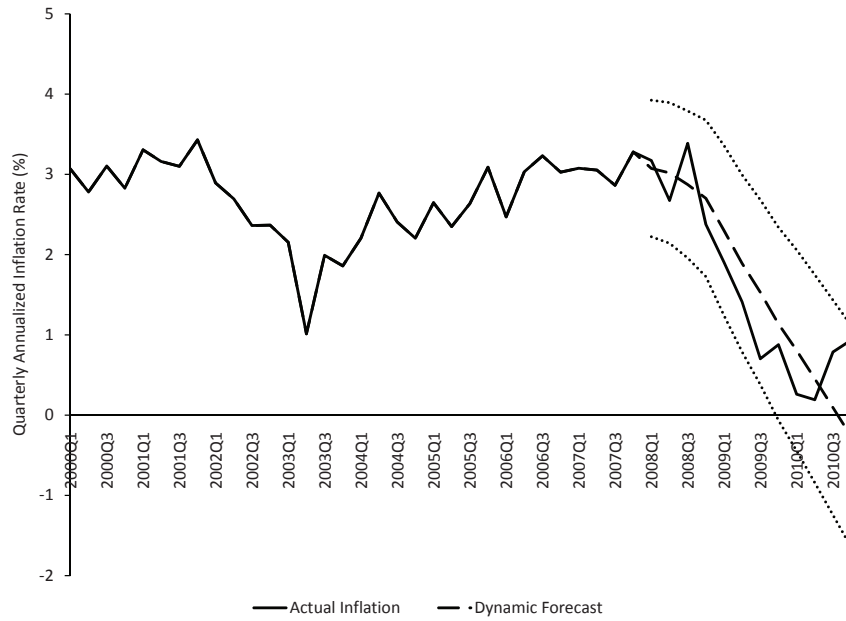


Figure 5: Dynamic Forecasts of Median CPI Inflation Based for 2008 to 2010 on 1985:1-2007:4 Regression

(a) Unemployment Gap



(b) Output Gap

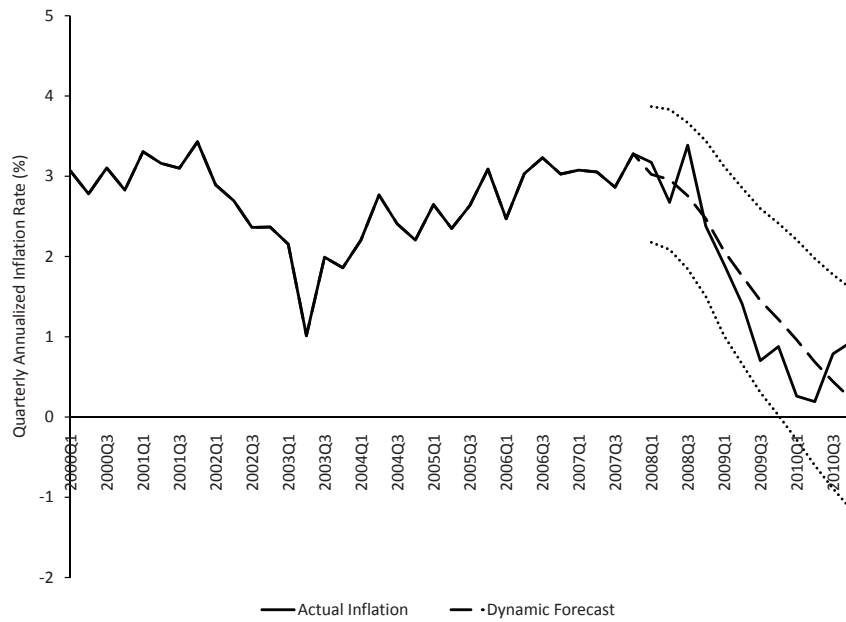
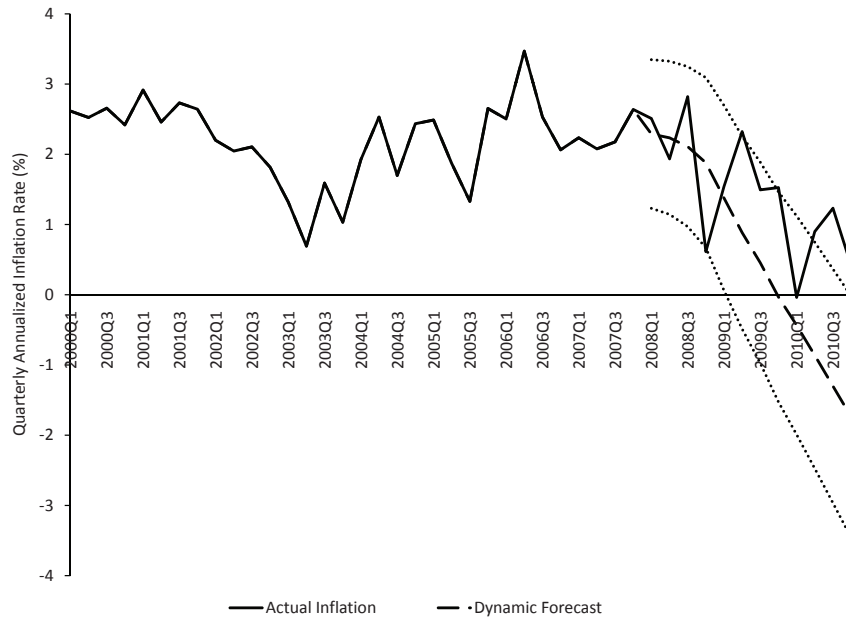


Figure 6: Dynamic Forecasts of XFE CPI Inflation Based for 2008 to 2010 on 1985:1-2007:4 Regression

(a) Unemployment Gap



(b) Output Gap

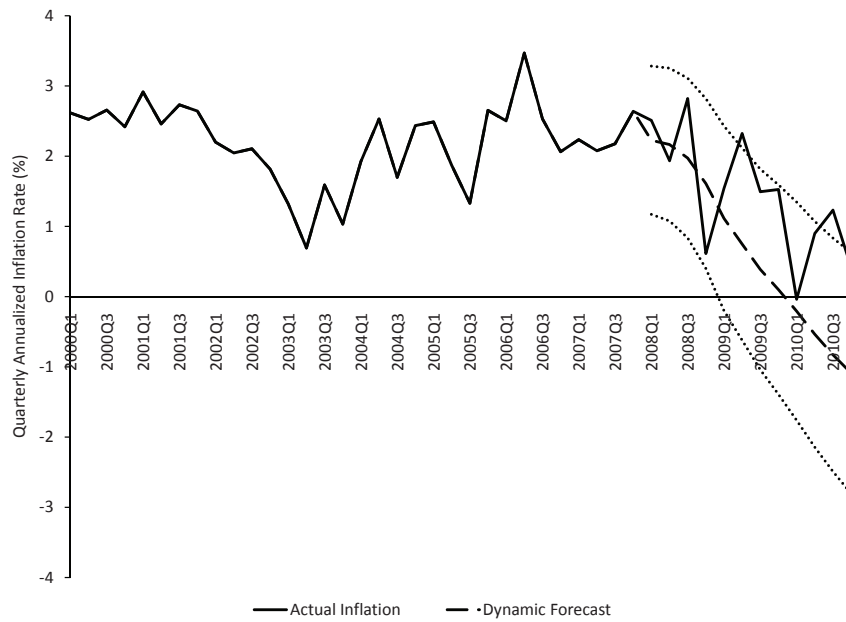


Figure 7: 4-Quarter Moving Averages of Dynamic Forecasts of Median CPI Inflation for 2008 to 2010

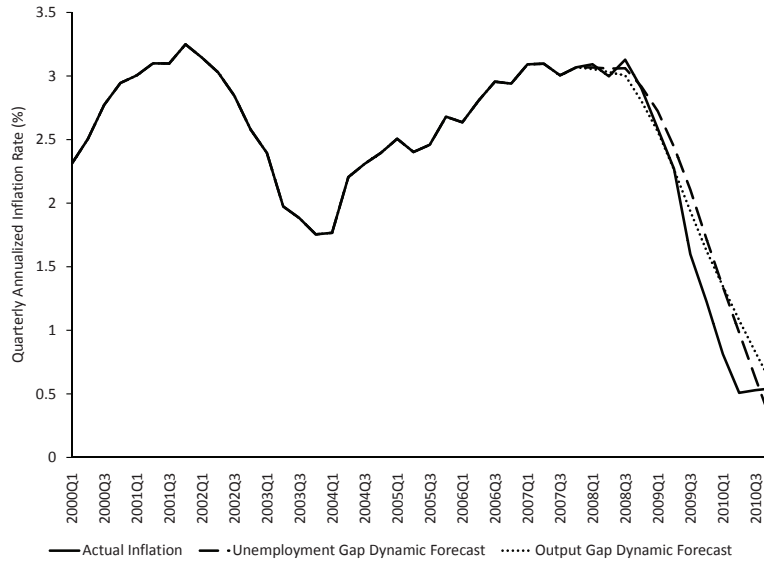


Figure 8: 4-Quarter Moving Averages of Dynamic Forecasts of XFE CPI Inflation for 2008 to 2010

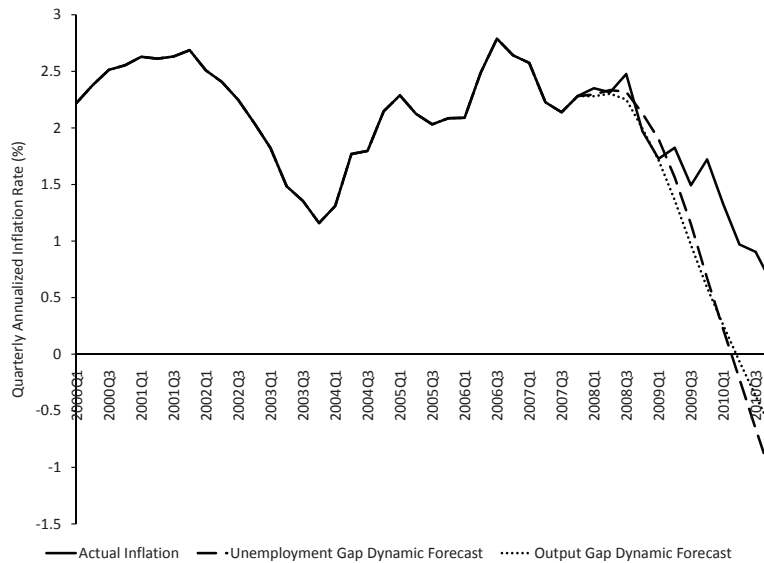


Figure 9: 4-Quarter Moving Averages of Dynamic Forecast of Median CPI Inflation for 2011 to 2013 Based on 1985:1-2010:4 Regression

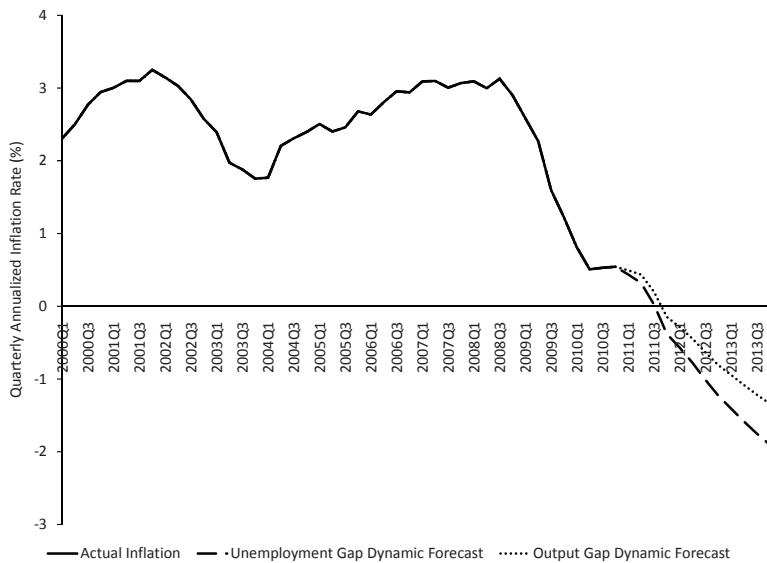


Figure 10: Level Anchoring based on $SPF4Q = \delta_t 2.5 + (1 - \delta_t) \frac{1}{4}(\pi_{t-1} + \pi_{t-2} + \pi_{t-3} + \pi_{t-4})$, 1985:1-2010:4

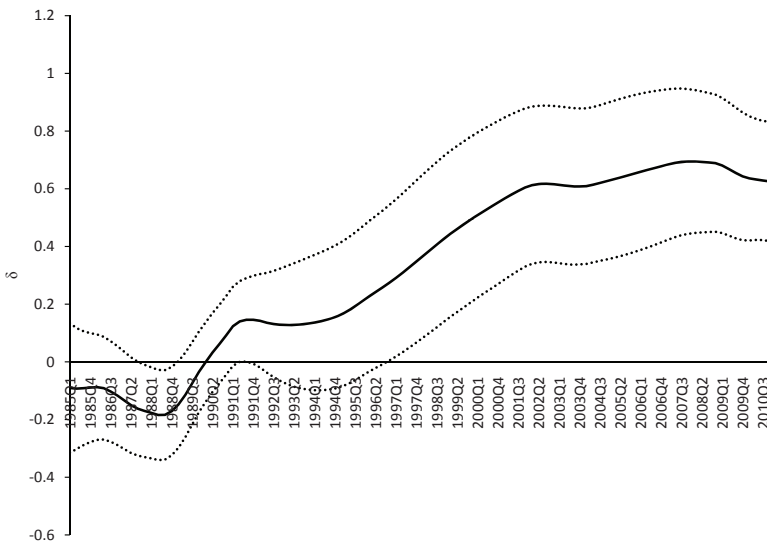


Figure 11: Level Anchoring based on $\pi_t = \delta_t 2.5 + (1 - \delta_t) \frac{1}{4} (\pi_{t-1} + \pi_{t-2} + \pi_{t-3} + \pi_{t-4}) + \alpha (u - u_t^*)$, 1985:1-2010:4

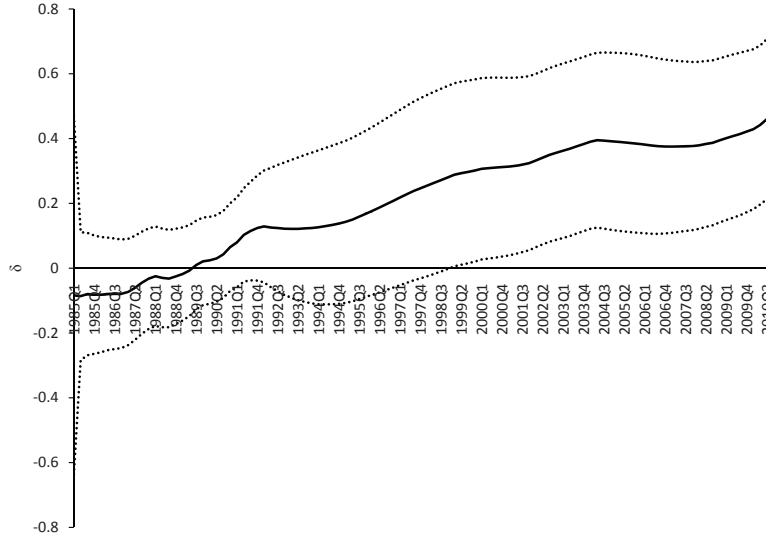


Figure 12: Level Anchoring based on $\pi_t = \delta_t 2.5 + (1 - \delta_t) \frac{1}{4} (\pi_{t-1} + \pi_{t-2} + \pi_{t-3} + \pi_{t-4}) + \alpha (y - y_t^*)$, 1985:1-2010:4

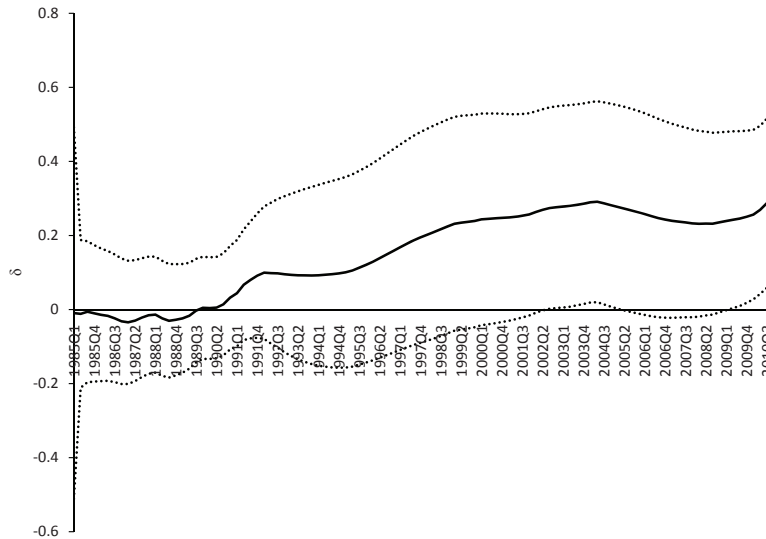


Figure 13: 4-Quarter Moving Averages of Dynamic Forecasts of Median CPI Inflation for 2008 to 2010 Based on Phillips Curve with Anchoring, 1985:1-2007:4

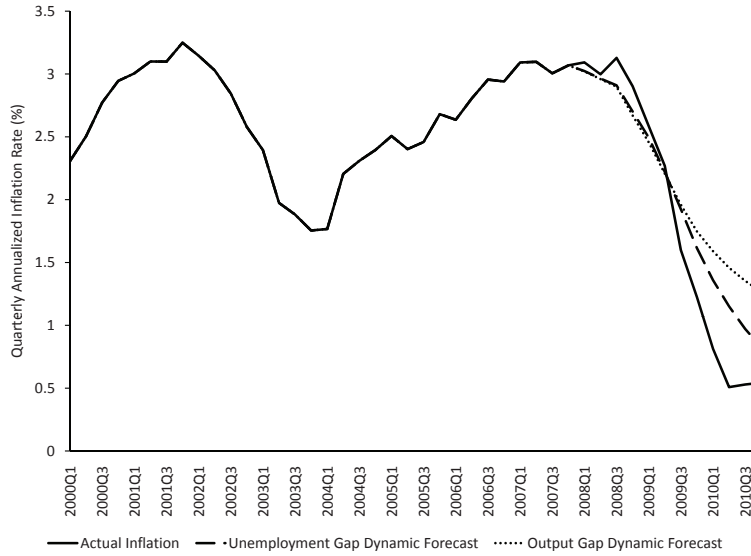


Figure 14: 4-Quarter Moving Averages of Dynamic Forecasts of Median CPI Inflation for 2011 to 2013 Based on Phillips Curve with Anchoring, 1985:1-2010:4

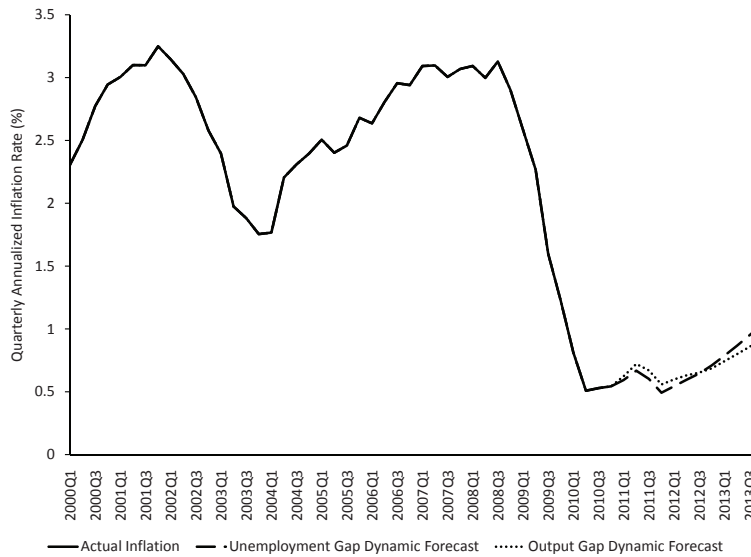


Figure 15: Labor Income Share vs. Unemployment Gap (Annual Averages), 1985-2010

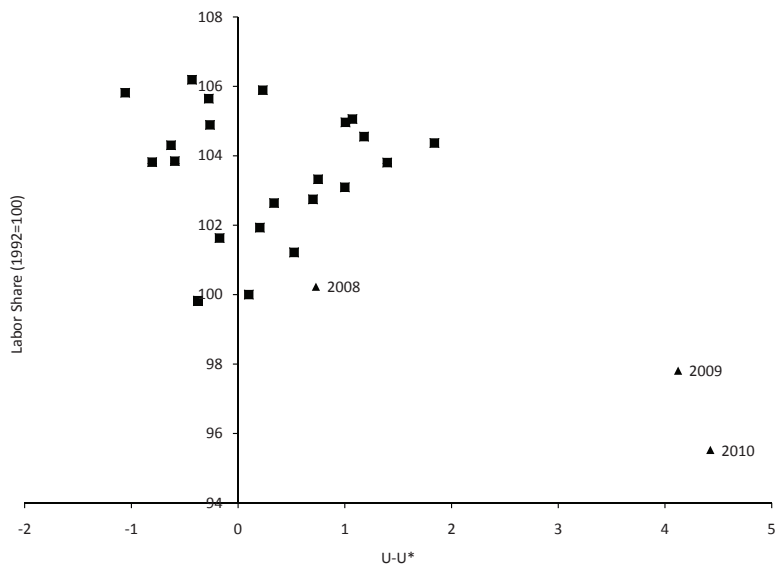


Figure A1: 4-Quarter Moving Averages of Dynamic Forecasts of Median CPI Inflation for 2008 to 2010 Based on Gordon (2011)

