# Deflating Inflation Expectations:
# The Implications of Inflation's Simple Dynamics

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Abstract

This report examines the behavior of inflation in the United States since 1984 (updating Cecchetti et al. (2007)). Over this period, the change in inflation is negatively serially correlated, and the change in inflation is best predicted by a statistical model that includes only information from the two most recent quarters. We find that the level of inflation fluctuates around a slowly changing trend that we call the local mean of inflation. Few variables add extra explanatory power for inflation once the local mean is taken into account. This local mean is itself well characterized by a random walk. Labor market slack has a statistically significant, but quantitatively small, effect on the local mean and inflation expectations have no effect. Some financial conditions that are influenced by monetary policy have larger effects on the local mean. Concretely, this means that one-off moves in labor market slack or inflation expectations that are not mirrored in broader indicators of inflation pressures are unlikely to be predictive of changes in trend inflation.

(JEL: E31, E52)
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## 1. Introduction

Inflation has run below the Federal Reserve's target since 2008. There are many potential reasons for this outcome. In this report, we ask whether labor market slack and inflation expectations (the two most commonly cited factors thought to influence inflation) deserve special attention in explaining recent history, or whether other less prominently mentioned factors are potentially more important.

The starting point for our analysis is the statistical model proposed in the first U.S. Monetary Policy Forum report (Cecchetti et al. 2007). That analysis, conducted before the Global Financial Crisis (GFC), sought to characterize inflation (as measured by the implicit price deflator for gross domestic product) in the G7 economies between 1960 and 2006. We reconsider that model starting from 1984, when inflation has been relatively tame and the monetary policy regime has been stable, and ask whether it has survived the GFC. Our answer is yes. Indeed, an even simpler statistical model works well for this shorter, calmer period.

In the aftermath of the GFC, economic slack rose higher for longer than at any time since the Great Depression. Inflation fell below the central banks' target in the United States, as well as in most other advanced economies. Yet, unlike during the Great Depression of the 1930s, the U.S. price level continued to rise. And, even in those countries where deflation did occur, it was modest. Moreover, while U.S. inflation has been below target, it has been remarkably stable since the GFC. We ask whether our compact statistical model can account for the *stability* of inflation in the presence of severe underutilization of resources.

The central characteristic of our time-series model is that inflation is heavily influenced by a slow-moving trend that we call the *local mean*. This model has no trouble explaining the post-GFC inflation outcomes because it assigns a very limited role to slack in influencing the local mean. Although we do find a reliable statistical connection between slack and this highly-persistent inflation trend, the quantitative impact is relatively small. This is consistent with the growing evidence that the Philips curve has become flatter (IMF, 2013). From a practical perspective, given the range of labor market conditions observed in the last 30 years, this channel is weak enough that it is not likely to be a good predictor of near-term inflation developments. The flattening of the Phillips curve could well be the result of changes in the

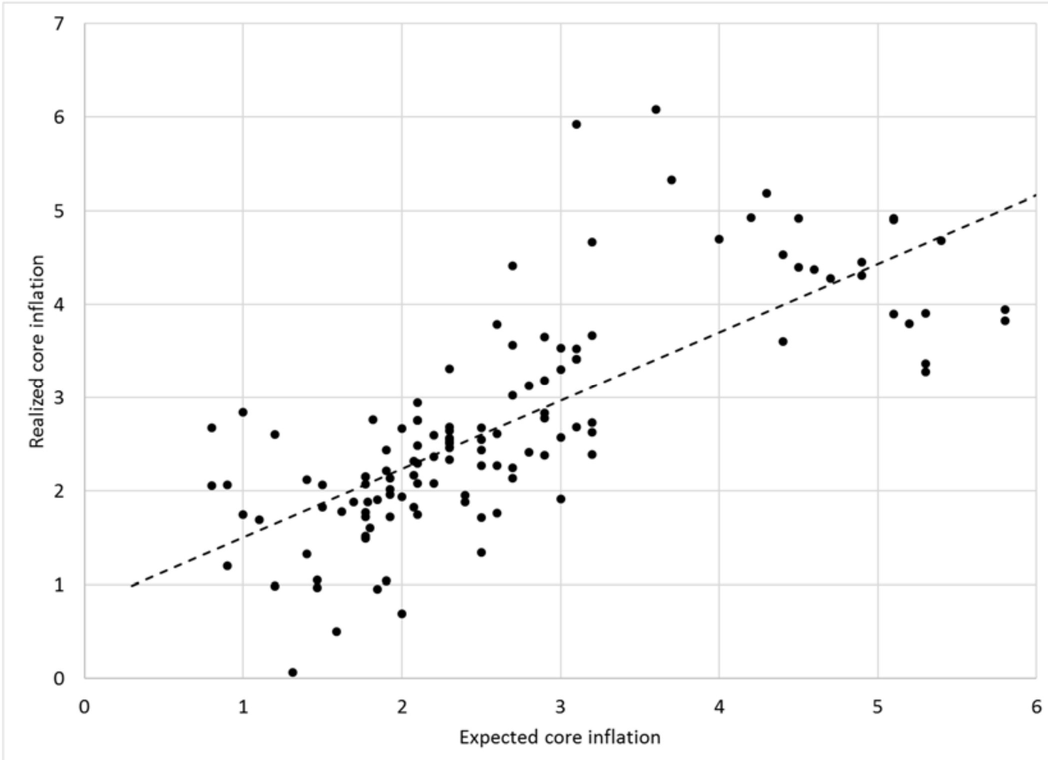
behavior of Fed policy (Roberts, 2006). In this sense, the Fed may be a victim of its own success: the post-1984 stabilization of inflation makes inference about inflation more challenging.

The conventional rejoinder to observations about the slope of the Philips curve is to say that a critical mitigating factor is the role expectations play in determining inflation dynamics. In their extensive review of the recent literature, Faust and Wright (2013) argue that survey measures of inflation expectations can improve the forecasts that come from simple statistical models. Policymakers also have placed significant weight on inflation expectations: for years, the Federal Open Market Committee (FOMC) has included references to measures of inflation expectations in the post-meeting statement that explains the Committee's decisions; and Bernanke (2007) and Yellen (2015) have both described the central role expectations play in the Fed's inflation forecasting framework.

Furthermore, simple statistical evidence suggests an important role for expectations. For example, Figure 1.1 shows a scatter plot of quarterly observations of consumer price inflation excluding food and energy prices (core CPI inflation) measured quarterly and seasonally adjusted at an annualized rate versus expectations for that series from one year earlier, together with a simple regression line. This presentation of the data makes it appear that there is a strong, reliable connection between expectations and inflation outcomes.

To judge how much weight to put on evidence like that in the figure, keep in mind that the chart covers a period in the United States when monetary policy has been conducted well. For an irresponsible central bank, or one that is trying to establish its credibility, movements in expectations could be critical drivers of inflation. However, during the past 30 years in the United States, shifts in various measures of inflation expectations have been somewhat modest. Consequently, the more relevant question for us is the following: given that inflation is low and relatively stable, if inflation expectations shift by an amount that has been routinely observed since the mid-1980s, but the shift is not mirrored in other indicators, should the central bank worry? In other words, what is the *independent* information content of inflation expectations in the *current* environment?

**Figure 1.1. Level of Core CPI Inflation and Expectations of Core CPI Inflation, 1984-2016**



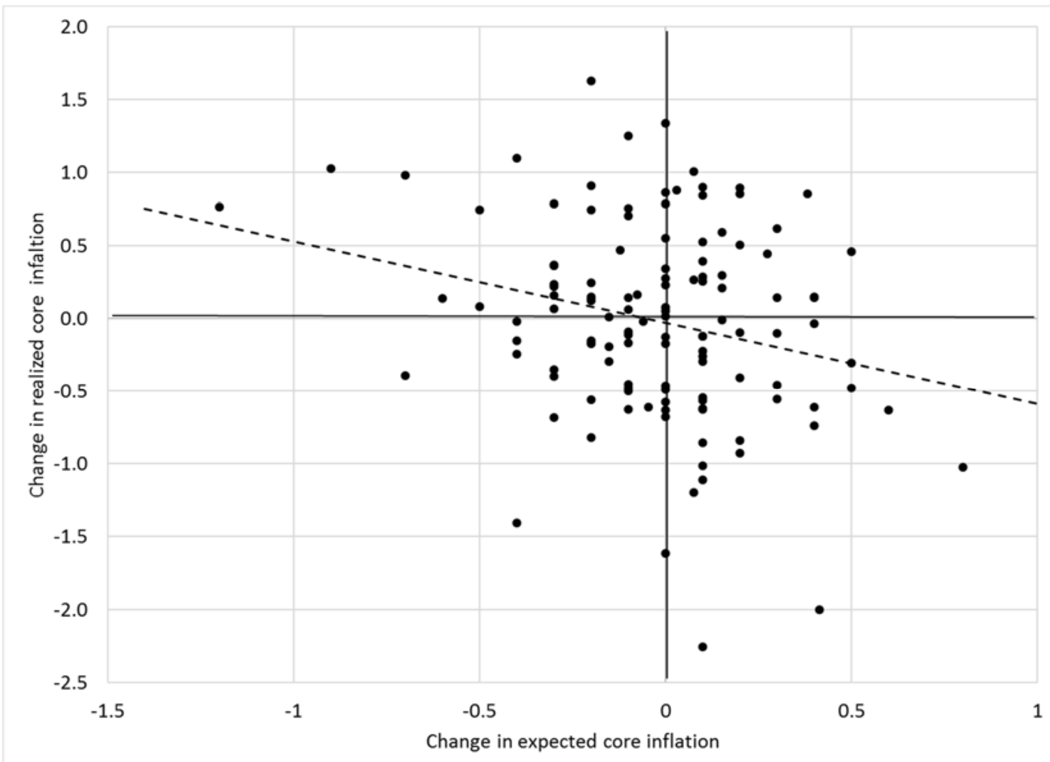

Note: Inflation is measured as the seasonally adjusted annualized rate of change of quarterly observations of the core CPI. Expected core inflation four quarters ahead (and lagged four quarters in the chart) is based on the Fed's Greenbook (1984-2010) and the Survey of Professional Forecasters (2011-2016). The regression line in the figure is $\pi_{t+4} = 0.77 + 0.73\pi^{e}_{t,t+4}$ with an $R^2$=0.57. Source: Board of Governors of the Federal Reserve System, FRED and Haver Analytics.

By way of analogy, economists all agree that extreme rates of inflation are always accompanied by high rates of money growth. It does not follow, however, that when inflation is low and stable, changes in money growth are central to understanding movements in inflation. Similarly, even if extremely high (or low) levels of slack or severely unhinged inflation expectations are predictive of inflation when it is high and volatile, it does not follow that these variables are useful predictors of inflation when it is low and stable.

Our analysis of inflation suggests the reason why expectations appear relevant is that they can proxy for movements in the local mean of inflation. If there is time variation in the local mean for actual inflation, anyone formulating expectations needs to adjust their forecast to those fluctuations. In our preferred model, as in the original Cecchetti et al. (2007) analysis, the local mean follows a random walk. Failure to account for this feature of the data will lead measured inflation expectations and actual inflation to be spuriously correlated.

A simple way to see how the presence of a local mean creates the illusion that expectations contain information about future inflation over and above that local mean is to compare the *change* in realized inflation to the *change* in inflation expectations. Focusing on the first difference of the series eliminates the local mean. The scatter plot shown in Figure 1.2 mimics the setup in Figure 1.1, with the critical difference that we have plotted the changes in inflation and expectations in place of the levels (again, using core inflation in both cases). As the picture shows, once we account for the presence of the local mean in inflation, little or no meaningful association between the two remains.

**Figure 1.2. Differences in Core CPI Inflation and Expectations of Core CPI Inflation, 1984-2016**




Note: Inflation is measured as the seasonally adjusted annualized rate of change of quarterly observations of the core CPI. Expected core inflation four quarters ahead (and lagged four quarters) is based on the Fed's Greenbook (1984-2010) and the Survey of Professional Forecasters (2011-2016). The regression line in the figure is $\Delta\pi_{t+4} = -0.03 - 0.56\Delta\pi^{e}_{t,t+4}$ with an $R^2$=0.06. Source: Board of Governors of the Federal Reserve System, FRED and Haver Analytics.

In what follows, we provide much more sophisticated and precise tests using multiple proxies to study the role of expectations. The results are consistent with those in Figure 1.2: once we control for the local mean, inflation expectations contribute very little to our ability to

predict movements in inflation. The same is true for labor market slack, and a host of other candidate measures that are thought to help in inflation prediction.

Given the importance of the local mean in understanding inflation dynamics, this raises an obvious question: Even if it is difficult to predict movements of inflation away from the local mean, can we forecast changes in the local mean? Here the answer again is that inflation expectations and labor market slack are of little help. But standard theories of the monetary transmission mechanism suggest that there are numerous channels through which policy influences the economy. These include the exchange rate, borrowing conditions, and risk premia, to name just a few. These other channels could also influence inflation. We see the relative importance of these factors as an empirical question that is relevant for policymaking and communications.

Mechanically, the local mean for inflation can be very closely approximated as a distributed lag of past inflation outcomes. There is a long tradition in economics of approximating inflation expectations as adaptive, based on past data. One way to describe our findings is to say that survey expectations are of limited use, while a form of adaptive expectations appears to be a powerful predictor of inflation. Other recent research has reached similar conclusions, especially regarding inflation in Japan and Europe.[1]

We go beyond that description to ask whether other indicators that the Federal Reserve influences have predictive content for the local mean. We examine several candidates, including the exchange rate, financial conditions, money, and credit.[2] We find that each of these variables, depending on the inflation indicator, contains some useful information about movements in the local mean. This suggests to us that a more eclectic view of inflation forecasting is warranted than might be suggested by the Philips-curve-centric view that has dominated public discussions. To be clear, we are not claiming that slack and expectations are irrelevant; instead we are suggesting that in the current low-inflation environment they do not warrant any special status and should at least be augmented by a wider array of indicators.

[1] For Japan, see Kuroda (2016) and Nishino et al. (2016). Busetti et al. (2017) develop a learning model of inflation expectations in the euro area.

[2] Recent ECB research by Falagiarda and Sousa (2017) has found evidence that money and credit variables significantly enhance the performance of inflation forecasting models in recent years for the euro area.

A potentially important caveat to our entire analysis is that, since we have not experienced extremely tight labor markets since the 1960s, data with those properties are not in our sample. If the Phillips curve is nonlinear, so that inflation is more sensitive to a very tight labor market than to a very loose one, our empirical analysis could not detect this.

The remainder of the report proceeds as follows. In Section 2, we review the literature on inflation dynamics and forecasting. In this review, our focus is on the two broad themes in the literature over the last decade: attempts to explain the missing deflation and further refinements in econometric procedures and specifications for modeling inflation.

In section 3, we present a preliminary statistical analysis. The first part establishes several stylized facts about U.S. inflation. One advantage of shifting our focus more to the U.S. is that we can investigate inflation using multiple price aggregates, not just the price deflator for gross domestic product that was the focus of the 2007 report. Upon considering five different measures, we confirm the widely-held view that *headline* inflation indicators, those that include food and energy prices, behave very differently than *core* measures that omit them (or than the GDP deflator that places less weight on them).

Using this more recent data on multiple inflation proxies, we reconsider the model proposed in the 2007 report. For the core measures, that model remains a reasonable benchmark. Furthermore, we conclude that the model can be simplified, fitting the data equally well, if we shut down the stochastic variances of the trend and the temporary deviations from the trend that were included in the 2007 model. In the appendix to section 3 we report the results of similar analysis for headline and core CPI inflation for other major advanced economies; these findings corroborate our results for core inflation in the U.S. in some but not all cases.

Section 4 takes an in-depth look at the behavior of the core CPI and the core personal consumption expenditure (PCE) price index (the FOMC's preferred price measure).[3] We refine the model from section 3 to allow inflation to follow a simple autoregressive process around the

[3] In what follows, we focus on core measures computed by dropping food and energy from the CPI and the PCE price index. Our conclusions are unaltered when we substituted the trimmed means computed by the Federal Reserve Bank of Cleveland, for the CPI, and the Federal Reserve Bank of Dallas, for the PCE price index.

local mean. By allowing for some persistence in deviations of inflation from its local mean, this specification, which we call the ARUC model, fits the data even better than the 2007 model and we use it to address three questions.

First, we ask which variables help predict inflation, after accounting for the local mean. We find that there is almost no predictive ability to improve upon the local mean. In particular, there is no role for slack, and most measures of inflation expectations do not add much explanatory power. Our other candidate variables—the exchange rate, financial conditions, money growth, and credit—also are either unrelated or quantitatively unimportant after taking the local mean into account.

Next, we investigate the properties of the local mean itself. The statistical procedure we use treats the local mean as a black box; it is assumed to be a random walk. This leads to a natural question of whether expectations or slack influence inflation through the local mean. We find surprisingly weak evidence of a role for measured inflation expectations. Labor market slack, measured by the difference between the unemployment rate and the natural rate of unemployment, is statistically significant but quantitatively unimportant.

This is an area that begs further research. Absent significant impacts on inflation via movements in slack and inflation expectations, it is important to identify the other channels through which the central bank influences the path of inflation. Our initial tests in this direction suggest that in addition to a weak effect via slack, the exchange rate and broader financial conditions both play some role—the latter presumably through changes in aggregate demand and the former via import prices as well as aggregate demand.

Third, we ask what should the Federal Reserve do to hit its target for inflation, given the centrality of the estimates of the local mean? To address this question, we approximate the local mean using past values for actual inflation. We equate achieving the Fed's inflation objective with driving the local mean to the target. Because a large component of the local mean is pinned down by past outcomes, we can then compare how different future paths for inflation will augment the pre-determined part of the local mean to move it to the target level. As of the fourth quarter of 2016, our estimate for the local mean for the core PCE is *below* the Fed's target. We compare different paths for inflation that can return it to target and confirm the intuition that the longer the Fed is willing to take, the smaller the overshoot needed to get

there. While this kind of reduced-form simulation comes with the usual caveats about structural inference, we believe it still provides a useful benchmark. Loosely speaking, because the local mean is not far below target, and it tends to move smoothly, the size of the necessary overshoot is modest.

Finally, section 5 presents our conclusions.

## 2. Review of the Literature

This section reviews developments in the inflation literature since our 2007 report. That literature can be broadly divided into two strands. The first strand continues to push forward the inflation research agenda that was developing prior to the crisis, including refinements of statistical methods for estimating trend inflation. The second strand is explicitly motivated by the challenges to inflation models posed by the behavior of inflation in the wake of the crisis, most notably (but not limited to) the failure of inflation to fall more than it did.

### 2.1 Statistical developments

While much inflation research since the crisis has dealt with new issues raised by the macroeconomic environment, a sizable literature has worked on developing the research agenda that prevailed prior to the crisis. Stock and Watson (2007) developed an unobserved component stochastic volatility (UCSV) model which served as a parsimonious univariate representation of the inflation process. This model inspired an ensuing literature. Clark and Doh (2011) find the UCSV and survey-based measures are the best indicators of trend inflation. In their exhaustive survey of inflation forecasting models, Faust and Wright (2013) reach a similar conclusion. Chan, Clark, and Koop (2016) explore the link between trend inflation and survey-based forecasts of inflation. Mertens (2015) also investigates this link, with an emphasis on the relation between expectations and shocks to the trend. Stock and Watson (2016) employ a multivariate UCSV on disaggregated PCE data to generate a more accurate measure of trend inflation, but note that this estimate is about as accurate as simply using core inflation.

While the UCSV literature grew up as a simple, atheoretical description of the data, the persistence of the estimated inflation process presented challenges to theoretically-grounded inflation modeling. Fuhrer (2009) explores a number of theoretical channels that could generate

the inflation persistence observed in the data. Cogley and Sbordone (2008) link inflation persistence to variations in trend inflation due to shifting monetary policy.

## 2.2 Inflation expectations

The past 10 years have seen a continuation of the pre-crisis exploration into the importance and development of inflation expectations. In their review article of the role of inflation expectations in the New Keynesian Phillips curve, Mavroeidis, Plagborg-Moller, and Stock (2014) come to a mixed conclusion on the role and usefulness of inflation expectations, and suggest progress is more likely to arise from greater understanding of the micro data.

In that spirit, significant work has been done on the determinants of survey expectations at the individual level. The New York Fed's relatively new Survey of Consumer Expectations has opened a rich vein of research findings in this area (see, for example, Bruine de Bruin, Manski, Topa, and van der Klaauw, 2011). The older University of Michigan Survey of Consumers has also continued to be mined for understanding predictable biases in survey responses, such as in Ehrmann, Plafjar, and Santoro (2015). Similarly, Binder (2015) argues that the inflation expectations of higher-income and more well-educated survey respondents are more important for the inflation process. Dräger and Lamla (2013) also investigate the University of Michigan micro-data to conclude that inflation expectations have gradually become better anchored over time. Mehrotra and Yetman (2014) reach a similar conclusion using professional forecasts from Consensus Economics.

At the time of the 2007 U.S. Monetary Policy Forum, the market for inflation-protected Treasury securities (TIPS) was only beginning to gain the depth and liquidity needed to reasonably infer market participants' expectations for inflation. The ensuing decade has produced a rich body of research looking at the informational content from TIPS and other inflation-indexed markets. D'Amico, Kim, and Wei (2016) reach a conclusion common in the literature: even with the maturation of these markets, liquidity- and inflation risk-premiums can significantly pollute the signal of the market's expected inflation. Bauer and McCarthy (2015) have an even simpler concern: market-based measures underperform survey-based measures in forecast accuracy, echoing earlier findings of Ang, Bekaert, and Wei (2007) and Faust and Wright (2013).

## 2.3 Missing disinflation

While economists continued to advance the pre-crisis inflation research agenda, the turbulent economic environment of the past decade also created new inflation puzzles for the economic community to address. The most notable such impact of the crisis and its aftermath on the modeling of inflation dynamics has been the burgeoning literature on the “missing disinflation” or “missing deflation.” The papers in this tradition generally follow a similar template: first, demonstrate that inflation has not fallen as much as predicted by workhorse accelerationist Phillips curve models; and second, propose some modification or alternative specification to account for the relative stability of inflation in the crisis and post-crisis period.

One of the earliest papers in this literature was Ball and Mazumder (2011). The two modifications to the standard model proposed by these authors were: (1) measuring inflation with a median rather than core measure; and (2) allowing for time variation in the responsiveness of inflation to slack. The inability of these modifications to stand the test of time was demonstrated by the fact that four years later the same authors (Ball and Mazumder 2015) needed to add two additional amendments: (1) replacing accelerationist terms with survey measures of trend inflation; and (2) substituting short-term unemployment for overall unemployment.

The role of inflation expectations in accounting for the missing disinflation is an important theme in this literature. Coibion and Gorodnichenko (2015) argue that the rise in commodity prices in the early years of the current recovery boosted household inflation expectations, and that this helped prevent inflation from falling despite the downward pressure from the severe underutilization of resources.

Blanchard (2016) and Blanchard, Cerutti and Summers (2015) also find that anchored inflation expectations can help explain away the missing disinflation in a Phillips curve model – albeit one with a somewhat flatter slope. In his comment on the first Ball and Mazumder paper, Stock (2011) noted that a firmer anchoring of inflation expectations would be observationally equivalent to an apparently flatter Phillips curve. Clark (2014) both endorses stable survey-based inflation expectations in explaining the missing disinflation, and downplays the usefulness of short-term unemployment as a slack measure. Buono and Formai (2016) confirm that professional forecasters’ inflation expectations were well-anchored in the post-crisis period in

the United States and United Kingdom (though not in the euro area). While the vast majority of the missing disinflation literature that deals with inflation expectations generally finds a stabilizing role, Nautz and Strohsal (2015) reach a less favorable conclusion and find de-anchoring of U.S. inflation expectations in the wake of the crisis.

Accounts of the missing disinflation puzzle in Europe generally rely on global influences that lifted commodity prices. Bobeica and Jarocinski (2017) found no puzzlingly low inflation in the early post-crisis years once global growth, inflation, and commodity prices are considered. Constâncio (2015) also appealed to global factors to explain the path of euro-area inflation in the early post-crisis years. Falaglarda and Sousa (2017) have also incorporated monetary and credit aggregates to improve the fit of euro-area inflation models in the post-recession period.

Certain aspects of the labor market have also been invoked to explain the missing disinflation. One such story emphasizes that *long-term* unemployment—which has been particularly elevated in the wake of the crisis—has less of a disinflationary influence on wage and price pressures. This explanation features in Gordon (2013) and Krueger, Cramer and Cho (2014), though Kiley (2015) finds little evidence of a differential effect of short-term vs. long-term unemployment on inflation outcomes. Watson (2014) allows for time variation in the NAIRU and finds that an estimated one-percentage-point increase in this variable helps explain a part of the missing disinflation.

A separate labor market story appeals to the presence of downward nominal wage rigidities to explain the lack of disinflationary impetus from very high unemployment. Daly and Hobijn (2014) argue that such rigidities "bend" the Phillips curve at very low levels of trend inflation. Fallick, Lettau, and Wascher (2016) document the plausibility of significant nominal wage rigidities using establishment-level data. However, Peneva and Rudd (2015) find little material influence of wage developments on consumer price inflation, a finding which they interpret as casting doubt on labor market explanations for the missing disinflation. Bidder (2015) reaches a similar conclusion as Peneva and Rudd.

Another sort of crisis-era non-linearity was considered in the Jackson Hole paper of Stock and Watson (2010), who essentially argued that it is high *and rising* unemployment that imparts disinflationary pressure, which would be expected to abate shortly after the end of the crisis. While Stock and Watson emphasize the non-linearity that arises in recessions, Nalewaik (2016)

and Kumar and Orrenius (2015) stress the non-linear increase in wage and price pressures at very low levels of unemployment—a finding which has yet to be challenged by post-crisis macroeconomic developments.

## 3. Stylized facts

We now turn to a description of the dynamics of inflation in the United States.[4] Relative to our 2007 report, we make two important changes. First, we begin our sample in 1984 and stop at the end of 2016 (the most recent available data), which means that we are analyzing only the period known as the Great Moderation along with the GFC and its aftermath. Excluding the period prior to 1984 (which drops the Great Inflation) allows us to study a reasonably uniform monetary policy regime. Put differently, our statistical model need not account simultaneously for the instability in the 1970s and for the relative stability that began in the mid-1980s.

Compared with the 2007 report, we also expand the set of price measures that we consider. In our original work, limited data availability combined with the desire for consistency across a number of countries led us to rely exclusively on the GDP deflator. In this report, we focus more specifically on the United States, allowing us to employ five different aggregate price indices: headline and core CPI and PCE, as well as the GDP deflator. Core inflation has generally become the preferred measure for modeling and forecasting, since it nets out the sometimes-distorting influence of volatile movements in food and energy prices. Nevertheless, we include headline measures in part because the ultimate objective of U.S. monetary policy has been defined in terms of headline PCE inflation, while the headline CPI drives many key market indicators and is used in some inflation adjustments by the government. Throughout the analysis, we measure inflation as the quarter-to-quarter percent change in the level of the price index at an annual rate. All data are seasonally adjusted. (See the Data Appendix for information on the data definitions and sources.)

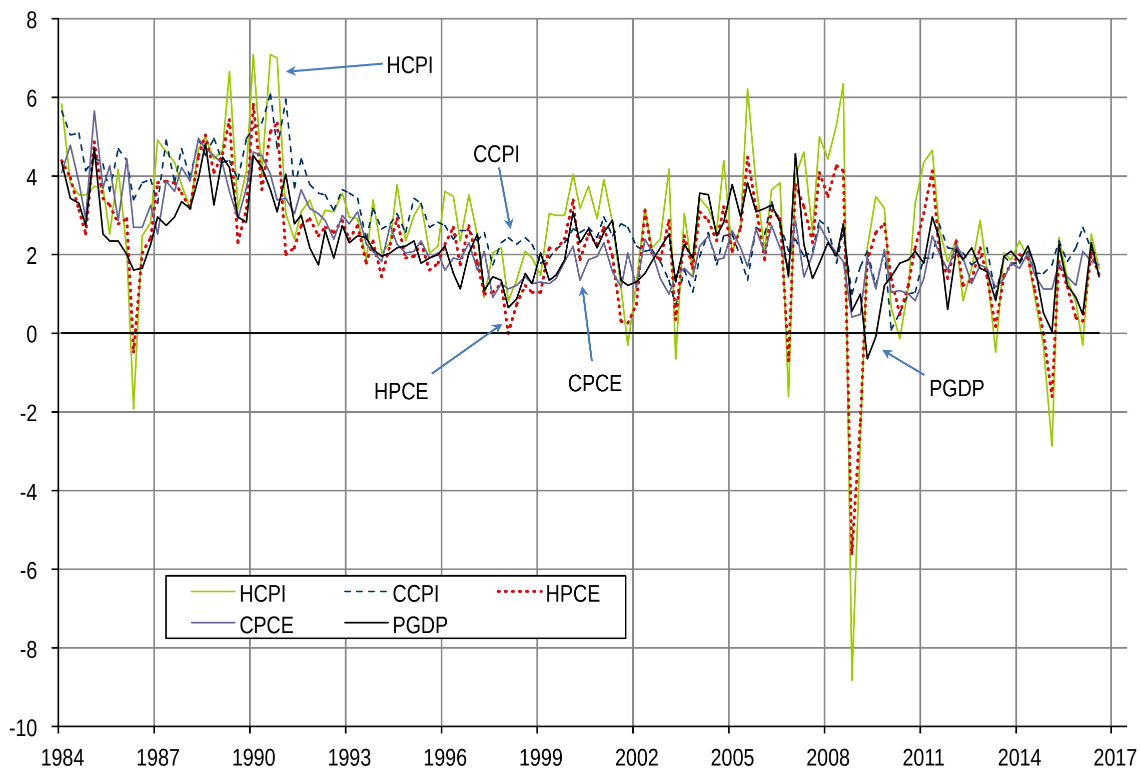
### 3.1 Basic properties

Figure 3.1 shows the level of inflation for the five most frequently studied indicators in the United States: the consumer price index (Headline CPI: HCPI), the consumer price index

[4] Analogous results for other G6 economies are provided in the appendix.

excluding food and energy (Core CPI: CCPI), the personal consumption expenditure price index (Headline PCE: HPCE), the personal consumption expenditure price index excluding food and energy (Core PCE: CPCE) and the GDP deflator (PGDP). The various U.S. indicators exhibit considerable co-movement, although the precipitous drop in inflation as measured by the headline consumer price and personal consumption expenditure price indices in the fourth quarter of 2008 was not present in the other three series. This drop, which coincided with the collapse in oil prices in that quarter, meant that both measures of headline inflation were more than five standard deviations from the period mean. The oil price plunge in the first quarter of 1986 led to a similar, though less pronounced decline. These observations are the first of several confirming that headline price measures can behave quite differently than core measures, or the GDP deflator, which is less sensitive to energy price changes.

**Figure 3.1 United States: Measures of Inflation (quarter-to-quarter percent change, seasonally adjusted at an annual rate), 1984-2016**




Sources: Bureau of Economic Analysis and Bureau of Labor Statistics.

To further examine the extent of co-movement, we compute estimates of the principal components of the five series. Principal component analysis is a statistical procedure designed to summarize the commonality amongst the behavior of different data series. Each component

is selected to recombine the underlying data to explain as much of the variance as possible, while forcing the components to be uncorrelated with each other. Hence, the first principal component is constructed to find the weights to place on each series so that it explains as much of the total variation in the group of series as is possible. By construction, if a sample consists of five series, then collectively the five principal components will explain all the variation in the sample.

Panel A of Table 3.1 reports the fraction of the variance for the series in Figure 3.1 associated with each component. The first principal component for these five measures of inflation accounts for nearly three quarters of the variance, while the second one explains an additional 16 percent. Panel B shows the linear combinations of the inflation measures that form each of the components. The first component puts nearly equal weights on each of the indices. Interestingly, the second component puts almost no weight on the GDP deflator and roughly equal and opposite weights on core and headline series. Our interpretation of this component is that it is picking out the difference between the headline and core series. We read these results as suggesting our first stylized fact: *there is a high degree of commonality in inflation variation across measures, especially after accounting for the idiosyncratic movements in food and energy prices*.[5]

**Table 3.1. Principal Component Analysis of Various Inflation Series**

| A. Incremental fraction of the variance accounted for by each component | | | | | |
|---|---|---|---|---|---|
| | **Comp1** | **Comp2** | **Comp3** | **Comp4** | **Comp5** |
| **Five Series** | 0.743 | 0.159 | 0.071 | 0.028 | 0.001 |
| B. Weights on the underlying series used to form each component | | | | | |
| **HCPI** | 0.437 | -0.560 | 0.288 | 0.291 | 0.573 |
| **CCPI** | 0.425 | 0.550 | 0.341 | 0.580 | -0.253 |
| **HPCE** | 0.474 | -0.419 | 0.158 | -0.340 | -0.678 |
| **CPCE** | 0.456 | 0.457 | 0.090 | -0.653 | 0.385 |
| **PGDP** | 0.442 | 0.002 | -0.876 | 0.193 | 0.007 |

[5]We note that, because GDP is based on PCE, and to a large extent PCE is based on the CPI, this result is in part a mechanical outcome of how the indices are constructed.

As shown in Figure 3.1, and emphasized in our 2007 report, inflation is very persistent. Statistically this creates challenges for inferring cyclical properties. Unless we properly account for the slow-moving trend, low-frequency relationships between these trends can be spuriously mistaken for cyclical connections. To avoid this pitfall, in the remainder of this section we work with differences of inflation to eliminate the lower-frequency movements.

Table 3.2 provides further evidence on the dynamic properties of the different measures by tabulating the first three autocorrelations of the change in inflation for each of the indicators. The table suggests two additional stylized facts. One is that *the first difference of inflation is negatively serially correlated*. This observation was discussed extensively in the 2007 report, where we noted that this pattern presented a challenge for the workhorse New Keynesian models of the time. This basic property of the data has not changed and, as the table shows, applies for each of the five series we are investigating. Indeed, as laid out in the Appendix, it also applies to the headline and core consumer price indexes that we considered for each of five other major advanced economies.

**Table 3.2. Autocorrelations of the Change of Inflation**

| | **Lag 1** | | **Lag 2** | | **Lag 3** | |
|---|---|---|---|---|---|---|
| | Estimate | t-stat | Estimate | t-stat | Estimate | t-stat |
| **HCPI** | -0.320 | -3.603 | -0.210 | -2.159 | 0.095 | 0.941 |
| **CCPI** | -0.548 | -6.180 | 0.228 | 2.034 | 0.005 | 0.047 |
| **HPCE** | -0.278 | -3.132 | -0.242 | -2.534 | 0.109 | 1.090 |
| **CPCE** | -0.474 | -5.344 | 0.068 | 0.634 | -0.065 | -0.603 |
| **PGDP** | -0.411 | -4.629 | -0.042 | -0.404 | -0.017 | -0.161 |

Our third stylized fact is that *the third autocorrelation of the change in inflation is indistinguishable from zero* for all the inflation measures. This is important because the autocorrelations summarize the dynamic properties of the series. Loosely speaking, the fact that these correlations are zero tells us that all the dynamics for the change in inflation are short-lived. This observation puts further constraints on the type of economic model that might fit these data.

### 3.2 Statistical models for inflation

With these three facts in hand, we now estimate some parsimonious statistical models to describe the different inflation series. We begin by updating the estimates of the UCSV model that played a central role in our 2007 report.[6]

That model takes the following form:

(3.1) $\pi_t = \tau_t + \eta_t$, where $\eta_t = \sigma_{\eta,t}\zeta_{\eta,t}$

(3.2) $\tau_t = \tau_{t-1} + \varepsilon_t$, where $\varepsilon_t = \sigma_{\varepsilon,t}\zeta_{\varepsilon,t}$ ,

where $\pi_t$ is the inflation rate, and $\zeta_{\eta,t}$ and $\zeta_{\varepsilon,t}$ are mutually-independent i.i.d. *N*(0,1) stochastic processes. In this model, inflation is represented as the sum of a random walk component, $\tau$ (which we will call the local mean for inflation), and a random disturbance $\eta_t$. The relative importance of the trend and random disturbances depends on the variances $\sigma^2_{\eta,t}$ and $\sigma^2_{\varepsilon,t}$ , which follow the processes:

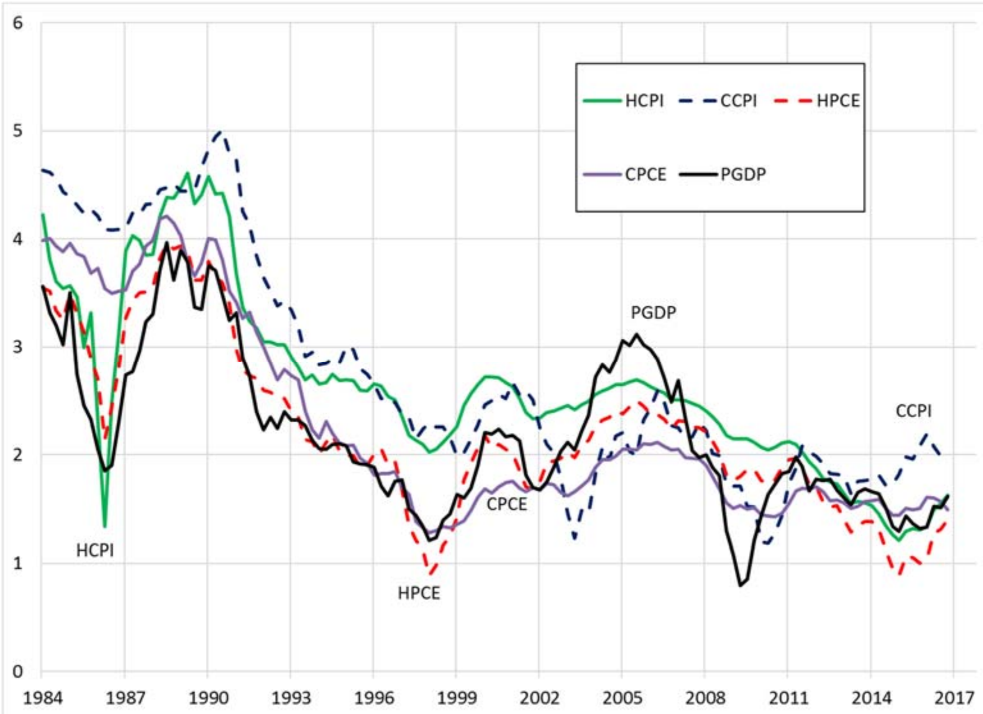
(3.3) $\ln(\sigma^2_{\eta,t}) = \ln(\sigma^2_{\eta,t-1}) + \nu_{\eta,t}$

(3.4) $\ln(\sigma^2_{\varepsilon,t}) = \ln(\sigma^2_{\varepsilon,t-1}) + \nu_{\varepsilon,t}$ ,

where $\nu_{\eta,t}$ and $\nu_{\varepsilon,t}$ are mutually independent, mean zero, and serially uncorrelated random variables. The magnitude of the time variation in $\sigma^2_{\eta,t}$ and $\sigma^2_{\varepsilon,t}$ is governed by the variances of $\nu_{\eta,t}$ and $\nu_{\varepsilon,t}$. For example, when var($\nu_{\eta,t}$) = 0, then $\ln(\sigma^2_{\eta,t}) = \ln(\sigma^2_{\eta,t-1})$, so $\sigma^2_{\eta,t}$ is constant and there is no stochastic volatility in $\eta_t$. On the other hand, when var($\nu_{\eta,t}$) is large, $\sigma^2_{\eta,t}$ can undergo large period-by-period proportional changes. To allow for the possibility of infrequent large changes in the variances, $\nu_{\eta,t}$ is modeled as a mixture of two normal distributions: $\nu_{\eta,t} \sim N(0,\gamma_1)$ with probability *p* and $\nu_{\eta,t} \sim N(0,\gamma_2)$ with probability 1–*p*. Thus, with *p* large and $\gamma_1 < \gamma_2$, most draws of $\nu_{\eta,t}$ are from a low-variance distribution, with occasional draws from the large-variance distribution. Typically, the changes in $\ln(\sigma^2_{\eta,t})$ are relatively small (with variance $\gamma_1$), but there are occasional large changes in $\ln(\sigma^2_{\eta,t})$ (with variance $\gamma_2$). The same model is used for $\nu_{\varepsilon,t}$. As in the 2007 report, we set $p$=0.98, $\gamma_1=0.2^2$ and $\gamma_2= 0.8^2$.

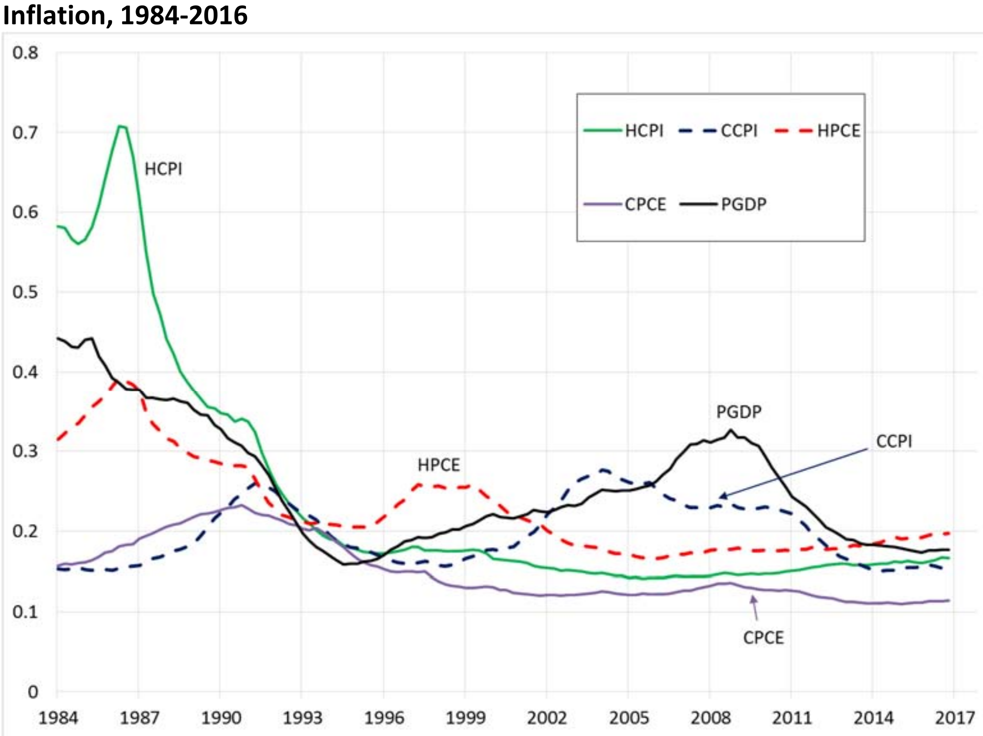
[6] The next two paragraphs are reproduced from the 2007 report.

**Figure 3.2 Estimated Time-varying Local Means for Various Measures of U.S. Inflation, 1984-2016**



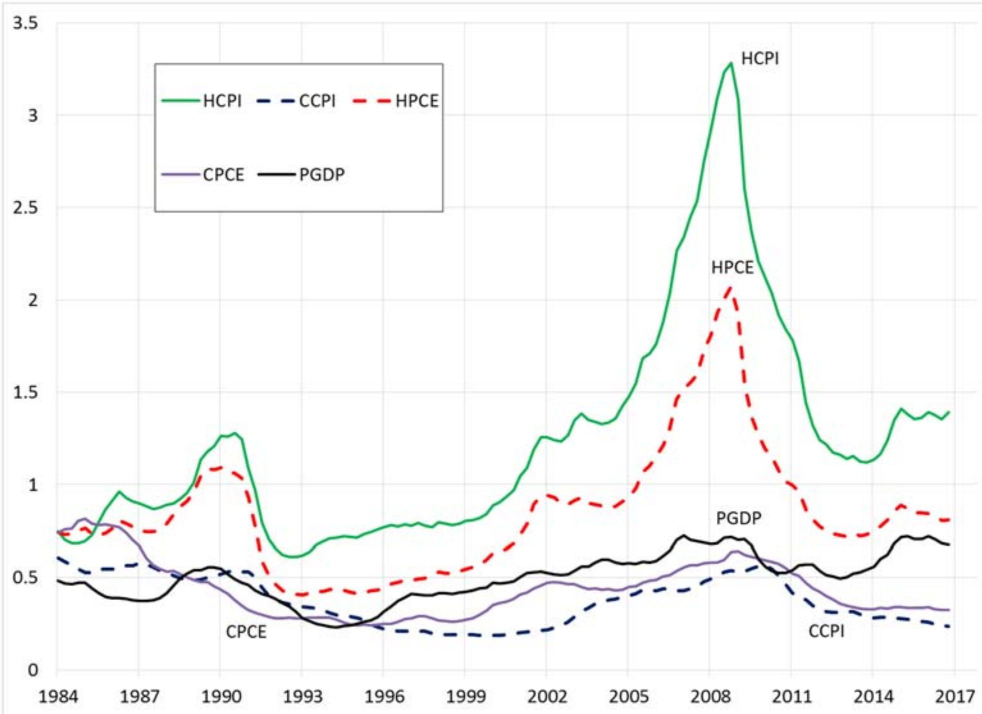

Source: Authors' estimates.

**Figure 3.3 Time-varying Standard Deviation of the Local Mean for Various Measures of U.S. Inflation, 1984-2016**




Source: Authors' estimates.

**Figure 3.4 Time-varying Standard Deviation of the Innovations for Various Measures of U.S. Inflation, 1984-2016**




Source: Authors' estimates.

**Table 3.3. Principal Component Analysis of the Estimated Local Means of Inflation**

| A. Incremental fraction of the variance accounted for by each component | | | | | |
|---|---|---|---|---|---|
| | Comp1 | Comp2 | Comp3 | Comp4 | Comp5 |
| Five Local Means | 0.8950 | 0.0639 | 0.0252 | 0.0142 | 0.0018 |
| B. Weights on the underlying series used to form each component | | | | | |
| HCPI | 0.4502 | 0.233 | -0.7507 | 0.2211 | 0.3614 |
| CCPI | 0.4378 | -0.6213 | 0.0123 | 0.4943 | -0.4217 |
| HPCE | 0.4614 | 0.2102 | -0.1204 | -0.6314 | -0.5742 |
| CPCE | 0.4532 | -0.4088 | 0.313 | -0.4108 | 0.6006 |
| PGDP | 0.4328 | 0.5902 | 0.5691 | 0.3734 | 0.034 |

Our estimation results for the time variation in τ, $\sigma_{\varepsilon,t}$ and $\sigma_{\eta,t}$ for the five U.S. inflation measures are shown in Figures 3.2, 3.3 and 3.4. We draw four important conclusions from these estimates. First, by removing much of the transitory noise, *the local means show a very high degree of co-movement*. This pattern is confirmed by a principal component analysis of the local

means (shown in Table 3.3, which is analogous to Table 3.1, but substitutes the local mean estimates in place of the actual inflation data). The first principal component for the local means accounts for 90 percent of the variance across all five measures.

Second, *the local means show a series of slow-moving waves*, drifting down through much of the 1990s, before stabilizing at the start of the century. There is also some decline after the GFC that gives way to a rise in the most recent period. Third, for each of the series, *the standard deviation of the local mean stabilizes in the mid-1990s at a level between 0.2 and 0.3* percentage points (see Figure 3.3). Complete success for inflation targeting would be to lower this dispersion to zero, while moving the local mean $\tau$ to the level of the inflation target. Although these goals have not been fully achieved, the progress is impressive and there has been no back-tracking since the GFC. Fourth, *the standard deviation of inflation innovations shows different patterns for the core and headline measures of inflation* (see Figure 3.4). The core series have relatively stable levels of volatility (again around 20 to 25 basis points). In contrast, the levels of volatility for the headline series are much higher on average, and exhibit much more time variation. Overall, the UCSV models suggest that a constant variance assumption should be a reasonable approximation for the core inflation series.

In summary, the stylized facts and estimated statistical models' results we have reviewed in this section collectively confirm that inflation is well-characterized by an unobserved components model with a local mean that exhibits substantial persistence. Furthermore, core inflation and headline inflation have very different properties. The core measures are broadly consistent with a *constant variance* unobserved components model. The evidence further suggests that the variance of the innovations to headline inflation is not constant and direct estimates of the model show a poor fit. Based on this evidence we focus our analysis in the next section on the core measures of inflation, CCPI and CPCE.

## 4. The dynamics of core inflation

We separate our more detailed analysis of core inflation into four parts. We begin by estimating a better-fitting time-series model than the UCSV model from Section 3. We then show that once we account for the local mean, neither inflation expectations nor labor market slack provide much additional information about the pattern of inflation that we observe. This leads us to study the determinants of the local mean itself. Can we explain these highly persistent moves in inflation? The answer is that alternative measures, like the exchange rate and financial conditions, do help; labor market slack less so; and inflation expectations not at all. We close by asking the following question: Given the dynamics of inflation that we observe and document, what are the implications for policymakers intent on hitting their inflation objective? Specifically, in subsection 4.4, we start by showing that the local mean is well-characterized by a long moving average of past inflation. This moving average can then be used to estimate the extent to which inflation would need to overshoot the target if the goal is to bring the local mean up to the target one, two or three years into the future.

### 4.1 The autoregressive unobserved components model of core inflation

Given the results in Section 3, we would like to allow for the possibility that inflation has somewhat more complex dynamics than those implied by the UCSV model. With that in mind, we model core inflation using a simplified version of the model in Chan, Clark, and Potter (2013) in which the deviations of inflation from its time-varying local mean are an AR(1) process. We can write the model as follows:

(4.1) $(\pi_t - \tau_t) = \phi(\pi_{t-1} - \tau_{t-1}) + \eta_t$

(4.2) $\tau_t = \tau_{t-1} + \varepsilon_t$,

where the innovations, $\varepsilon$ and $\eta$ are independent, identically distributed and uncorrelated with constant variances, $\sigma_\eta^2$ and $\sigma_\varepsilon^2$. The local mean $\tau$ is still assumed to be a random walk. We label this the "autoregressive-unobserved-components model" (ARUC). When $\sigma_{\eta,t}^2$ and $\sigma_{\varepsilon,t}^2$ are constant, this becomes the constant-variance version of the model from Section 3. In addition to

holding the variances constant, the ARUC model allows for persistence in deviations of inflation from the local mean.[7]

Employing state-space methods, we proceed to estimate the model (4.1) and (4.2) using quarterly data for the seasonally adjusted annualized percent changes of core CPI and core PCE data over the period 1984 to 2016.[8] The full-sample results are reported in Table 4.1.

**Table 4.1. Full-sample Parameter Estimates of the ARUC Model**

| | Core CPI | Core PCE |
|---|---|---|
| AR(1) parameter $\phi$ | 0.149 | 0.157 |
| Variance of changes in $\tau$, $\sigma_\varepsilon^2$ | 0.029 | 0.023 |
| Variance of deviations ($\pi - \tau$), $\sigma_\eta^2$ | 0.231 | 0.259 |
| Pseudo-$R^2$ | 0.21 | 0.38 |
| Note: The pseudo-$R^2$ is computed as one minus $2\sigma_\eta^2 / \sigma_{\Delta\pi}^2$.[9] | | |

As was the case in the UCSV model, here the bulk of the variation in core inflation is attributable to noise in the deviations of inflation from the stochastic trend. In fact, the variance of $\eta$ is roughly 10 times larger than the variance of $\varepsilon$. This can also be viewed as telling us that the variance of the local mean is modest, which is to be expected.

The model estimates include values for the local mean itself. These estimates are constructed using the entire sample. This implies that estimates at any intermediate date, say the third quarter of 1995, should be interpreted as reflecting the perspective based on all the information that is available through the end of 2016. To eliminate the influence of future data on current estimates, we have also generated recursive, out-of-sample estimates of the $\tau$'s. We do this by estimating the model over a short, initial, six-year sample from the first quarter of 1984 to the end of 1989. We use this model to estimate a value for the local mean for the first

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[7]We thank Davide Pettenuzzo for his indispensable help in formulating, understanding, and estimating this model.

[8] See Hamilton (1994).

[9] There are a variety of ways to compute a goodness of fit statistic for state-space models. We have chosen to do it in a manner that treats the local mean – the state in equation (4.2) – as if it were data. Then, taking the first difference of the observation equation, (4.1), we get that the unexplained portion of the change in inflation is twice the variance of the error, $\eta$.

quarter of 1990. Next, we add an additional data point, re-estimate the model, estimate a value of τ for the next quarter, and so on. We refer to these recursive estimates as $\tilde{\tau}_R$'s.

The two panels of Figure 4.1 plot the $\tilde{\tau}_R$'s, along with the raw inflation data for the core CPI and core PCE. We also include the 10th and 90th percentiles of the estimated $\tilde{\tau}_R$'s constructed from 1,000 simulations.[10] Both panels show very similar patterns: estimates of the local mean start relatively high (CPI at 5 percent and PCE at 4 percent), and then drop steadily through the 1990s, with the CPI reaching 2.1 percent and the PCE 1.4 percent in 1999. During the 2000s, the local mean estimates fluctuate in a range between roughly 1 and 3 percent. The estimated fourth-quarter 2016 levels are 2.04 percent for core CPI and 1.53 percent for core PCE.

The precision of the estimates of the local mean, as measured by the average distance from the 10th to the 90th percentile (and plotted as the dotted lines in Figure 4.1), is roughly three-quarters of a percentage point for both the core CPI and core PCE. In other words, we can say with 80 percent confidence that the current trend for the core CPI is between 1.7 and 2.4 percent, and for the core PCE it is between 1.2 and 1.9 percent.

### 4.2 Incremental explanatory power

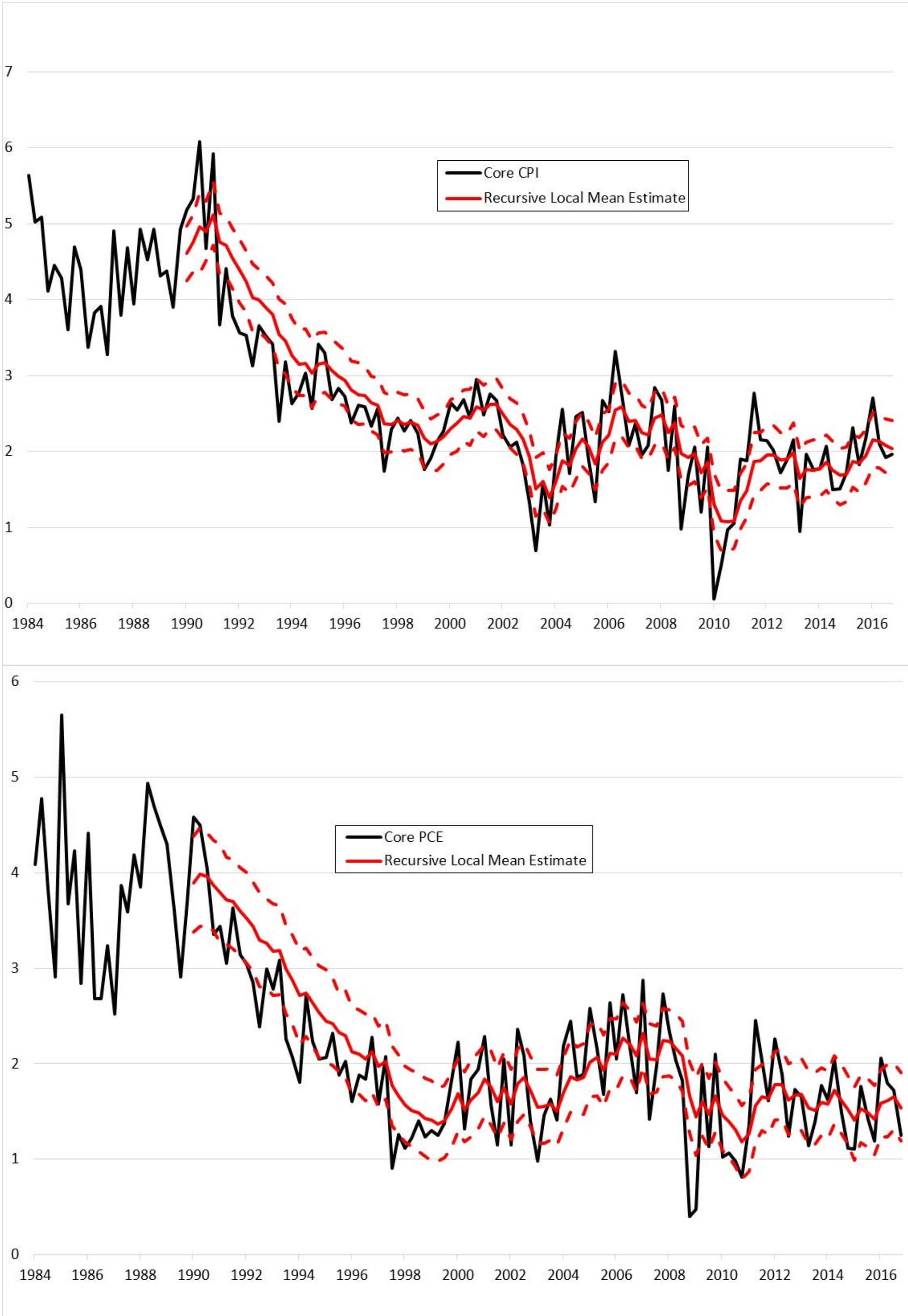
We now investigate the explanatory power of the local mean. Put slightly differently, we ask whether, once we account for the local mean, indicators such as inflation expectations and the unemployment gap further improve our understanding of the dynamics of inflation. To assess that hypothesis, we run a series of regressions of the following form:

(4.3) $\pi_t = \alpha + \beta\tilde{\tau}_{R,t} + \gamma X_t + e_t$,

where $\tilde{\tau}_{R,t}$ is the local mean (the solid red lines in Figure 4.1), and the *X*'s are a set of twelve possible determinants, entered individually. The first six *X*'s are measures of inflation expectations. First, using the history of the Federal Reserve's Greenbook forecasts, spliced in 2011 to the Survey of Professional Forecasters (SPF) projections, we construct a series for the projected quarter-to-quarter annualized rates of core CPI and core PCE inflation four quarters

[10] Constructing 10,000 (rather than 1,000) simulations does not change any of the results reported below.

**Figure 4.1: Estimates of the Local Mean of Inflation: Core CPI and Core PCE, 1984-2016**




Notes: Recursive estimates of the ARUC model. Solid red lines are the mean and dotted red lines are the 10th and 90th percentiles of the distribution.

ahead.[11] From the Blue Chip and SPF, we also collect the four-quarter-ahead expectations of the quarter-to-quarter annualized rate of *headline CPI* inflation. For the monthly Michigan one-year inflation expectations survey, we use quarterly averages of the median expected change in prices over the next 12 months. Finally, we also have quarterly averages of median five-year inflation expectations from the Michigan survey and of the 10-year headline CPI forecast from the SPF.[12]

We also include five other potential drivers of the underlying trend in inflation: the gap between the unemployment rate and the natural rate of unemployment (both contemporaneous and lagged one quarter)[13], the Federal Reserve Bank of Chicago's National Financial Conditions Index (NFCI), and the percentage changes in M2, in private non-financial debt, and in the nominal, broad trade-weighted U.S. dollar index. Summary statistics for all the variables in the regressions are in Appendix Table A4.1.[14]

The results of this exercise are in Table 4.2. The left three columns show the findings for the core CPI and the right three columns show the results for the core PCE. Each column in the table shows the estimates of β and $\gamma$ for different *X*'s. We draw three main conclusions from the table. First, in all twenty-four regressions the estimates of β are positive with t-ratios well above 4, so the local means have very strong predictive power. Second, few of the $\gamma$'s are of the anticipated sign with high t-ratios. Only for the Michigan one-year inflation expectations and the dollar index are the coefficients significant with the anticipated sign (positive for the Michigan survey and negative for the dollar) for both core PCE and core CPI. Even in these cases, the implied effects are small.[15] For example, a one-standard-deviation change in the Michigan

[11] In doing so, we take observations from the middle of each quarter (such as the January-February and April-May Greenbooks, and the February, May, August, and November SPF forecasts). The Greenbook forecasts for core inflation themselves are only publicly available through 2010. To extend the series to 2016, we splice it to the Survey of Professional Forecasters (SPF) core CPI expectation forecasts. We start by taking the overlap from 2007 to 2010 and regressing the Greenbook forecasts on the Survey of Professional Forecasters (SPF) core CPI expectation forecasts. Then, using the regression, along with the SPF data, we impute estimates over the 2011 to 2016 period.

[12] These longer-term expectations measure the average expected rate of inflation over the next five or ten years, not the expected rate of inflation five or ten years hence. We use these same longer-term expectations in analyzing both core series; longer-term expectations for PCE inflation are not available.

[13] The natural rate of unemployment is taken from the Greenbook estimates collected by the Philadelphia Fed's Real-Time Data Research Center. From 2011 onwards we use the longer-run unemployment rate estimates in the FOMC's Summary of Economic Projections. Using instead the CBO estimate of the natural rate of unemployment yields similar findings.

[14] Several other candidate variables also displayed little explanatory power. We do not report the details.

[15] We measure the effect using the coefficients reported in Table 4.2 together with the standard deviations for the different variables that reported in Table A4.1.

survey implies about one-seventh of a standard deviation change in core PCE. For the dollar index, the equivalent calculation yields one-fifth of the standard deviation change. Third, for the other inflation expectations measures, the estimated effects frequently have the wrong sign (sometimes with statistical significance), implying that higher expected inflation is associated with lower realized inflation.

**Table 4.2: Modeling Inflation**

| | Core CPI | | | Core PCE | | |
|---|---|---|---|---|---|---|
| **X Variable** | $\tilde{\tau}_{R,t}$ | $\hat{\gamma}$ | $R^2$ | $\tilde{\tau}_{R,t}$ | $\hat{\gamma}$ | $R^2$ |
| $\pi^e$ Greenbook<br>4-quarters ahead | 0.793<br>(5.23) | 0.220<br>(1.10) | 0.807 | 0.924<br>(7.56) | -0.005<br>(-0.05) | 0.721 |
| $\pi^e$ SPF<br>4-quarters ahead | 0.950<br>(5.36) | -0.172<br>(-1.01) | 0.687 | 1.007<br>(5.63) | -0.239<br>(-1.45) | 0.548 |
| $\pi^e$ SPF<br>10-year | 1.259<br>(11.17) | -0.751<br>(-4.89) | 0.735 | 1.425<br>(15.54) | -0.827<br>(-8.96) | 0.625 |
| $\pi^e$ Blue Chip<br>4-quarters ahead | 1.072<br>(5.46) | -0.167<br>(-0.61) | 0.800 | 1.238<br>(8.73) | -0.393<br>(-2.93) | 0.739 |
| $\pi^e$ Michigan<br>1-year | 0.925<br>(12.40) | 0.271<br>(2.27) | 0.819 | 0.859<br>(11.44) | 0.207<br>(2.29) | 0.738 |
| $\pi^e$ Michigan<br>5-year | 0.846<br>(4.58) | 0.233<br>(0.62) | 0.791 | 1.056<br>(5.00) | -0.299<br>(-1.01) | 0.707 |
| Unemployment<br>Gap | 0.942<br>(11.59) | -0.048<br>(-1.35) | 0.804 | 0.915<br>(11.62) | -0.015<br>(-0.50) | 0.721 |
| Unemployment<br>Gap Lagged | 0.937<br>(11.49) | -0.054<br>(-1.31) | 0.805 | 0.915<br>(11.47) | -0.013<br>(-0.46) | 0.721 |
| Chicago Fed Financial<br>Conditions Index | 0.964<br>(11.82) | 0.019<br>(0.12) | 0.799 | 0.917<br>(10.61) | -0.102<br>(-0.81) | 0.726 |
| Percentage<br>change in M2 | 1.016<br>(14.84) | 0.042<br>(2.10) | 0.814 | 0.945<br>(13.50) | 0.012<br>(0.53) | 0.723 |
| Percentage change in<br>Private Nonfin. Debt | 0.962<br>(11.57) | 0.012<br>(1.57) | 0.800 | 0.915<br>(11.19) | 0.012<br>(1.39) | 0.723 |
| Percentage change in<br>Trade-Weighted<br>Dollar Index | 0.980<br>(11.70) | -0.008<br>(-1.93) | 0.806 | 0.940<br>(12.20) | -0.15<br>(-4.25) | 0.760 |

Results are for the estimation of equation (4.3) using quarterly data for 1990 to 2016. The t-ratios are in parentheses. We highlight in yellow the values of $\gamma$ that are significantly different from zero at the 10% level or less, and of the anticipated sign.

In assessing the incremental power of these variables in several other ways, we reach similar conclusions. For instance, for unemployment, the NFCI, M2, private debt, and the trade-weighted dollar index, we have added lags to allow for additional dynamics. We also added

dummy variables for the fourth quarter of 2008 and first quarter of 2009. These alternative specifications yield similar results.

We also examined a specification of the following form:

(4.4) $$(\pi_t - \tilde{\tau}_{R,t}) = \alpha + \phi(\pi_{t-1} - \tilde{\tau}_{R,t-1}) + \omega(\pi_t^e - \tilde{\tau}_{R,t}) + \beta(U_{t-1} - U_{t-1}^*) + e_t.$$

In this formulation, we assume that both actual and expected inflation are centered around the same local mean. We then ask if the deviation of inflation from the recursive estimate of the local mean is related to either the deviation of inflation expectations from that same mean, or to the unemployment gap (once we control for the lagged deviation of inflation from the local mean that our model tells us is present). When we estimate (4.4), we find neither inflation expectations nor labor market slack help us to explain quarter-to-quarter deviations of inflation from its local mean.[16]

These results convince us that the key to understanding inflation dynamics is to understand the local mean itself.

### 4.3 Modeling the local mean

As written, the simple statistical model is agnostic about the reasons for movements in the local mean. We explore the drivers of these movements in two steps. In the first, we examine the hypothesis that labor market slack or inflation expectations influence the dynamics of the local mean. In the second, we look to the set of alternatives we used in the previous section: indicators of financial conditions, money, credit, and the trade-weighted exchange rate.

We start with the following simple regression:

(4.5) $$\Delta\tilde{\tau}_{R,t} = \alpha + \delta\Delta\pi_t^e + \beta\Delta(U_{t-1} - U_{t-1}^*) + e_t.$$

These regressions allow us to test whether the change in the local mean is related to changes in expected inflation, to changes in the unemployment gap, or to both.[17]

[16] Appendix Table A4.3 reports the results of this exercise.

[17] We run this regression in first-difference form for consistency with our assumption that the local mean of inflation is a random walk, and hence the level of inflation is nonstationary. We also assume that inflation expectations will inherit the time-series properties of inflation itself, so they too, will be

The results of these regressions are shown in Table 4.3. Starting with inflation expectations, where only one of 14 estimated coefficients displays statistical significance, we read these results as saying that movements in the local mean of core inflation are not well explained by changes in inflation expectations.

**Table 4.3 Modeling the Local Mean Using Inflation Expectations and Labor Market Slack**

| | Core CPI | | | | | | Core PCE | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | | (6) | (7) | (8) | (9) | (10) |
| Greenbook 4-quarters ahead | 0.066 (1.16) | 0.051 (0.69) | | | | | 0.078 (0.99) | 0.089 (0.98) | | | |
| SPF 4-quarters ahead | | | | | 0.029 (0.41) | | | | | | 0.159 (1.23) |
| SPF 10-year | | -0.074 (-0.65) | | | -0.080 (-0.65) | | | 0.022 (0.21) | | | -0.051 (-0.35) |
| Blue Chip 4-quarters ahead | | | 0.165 (1.76) | | | | | | 0.125 (2.44) | | |
| Michigan 1-year | | | | 0.029 (0.97) | | | | | | 0.060 (1.35) | |
| Unemployment Gap, lagged | -0.066 (-2.79) | -0.067 (-2.87) | -0.072 (-3.24) | -0.074 (-3.18) | -0.073 (-2.76) | | -0.045 (-1.72) | -0.045 (-1.72) | -0.057 (-2.07) | -0.049 (-1.81) | -0.044 (-1.54) |
| Constant | -0.022 (-1.41) | -0.025 (-1.54) | -0.020 (-1.33) | -0.023 (-1.47) | -0.025 (-1.57) | | -0.020 (-1.36) | -0.019 (-1.32) | -0.019 (-1.39) | -0.021 (-1.48) | -0.020 (-1.38) |
| $R^2$ | 0.035 | 0.030 | 0.047 | 0.032 | 0.026 | | 0.048 | 0.049 | 0.048 | 0.070 | 0.070 |

Notes: All right-hand side variables are in first differences. Asymptotic t-ratios, computed with using robust standard errors, are in parentheses. Highlighted estimates are those for which the t-ratio is greater than 1.96, the 5% critical value for a two-sided test.

There is evidence of a relationship to the unemployment gap: the estimated coefficients on the unemployment gap are negative and significantly different from zero at normal levels of statistical significance. However, they are quite small in magnitude. To see this, note first the standard deviations of the change in the estimated local mean, $\Delta\tilde{\tau}_{R,t}$, is 0.160 percentage points for the core CPI and 0.123 percentage points for the core PCE.[18] Since the standard deviation of the change in the unemployment gap, $\Delta(U_{t-1} - U^*_{t-1})$, is 0.318 over the 1990 to 2016

nonstationary. Finally, we suppose that the level of inflation is dependent on expected inflation and the level of the unemployment gap. Taking the first difference of that specification results in including the change in the unemployment gap.

[18] Summary statistics for all the variables used in the regressions reported in this section are in appendix Table A4.2.

estimation period, a one-standard-deviation (i.e. a typical) move in the unemployment gap will result in a change in the local mean that is equal to a 0.07×0.318=0.022 percentage-point change in the core CPI trend and a 0.05×0.312=0.016 percentage-point change in the core PCE trend. These changes are on the order of one-eighth of one standard deviation of the local mean series. That is, consistent with the recent literature on inflation dynamics, the impact of changes in labor market slack on changes in inflation is measurable, but weak.

This result leads us to examine alternative drivers of the local mean. To do this, we estimate the following regression:

(4.6) $$\Delta\tilde{\tau}_{R,t} = \alpha + \sum_{j=0}^{8} \gamma_j \Delta X_{t-k} + e_t,$$

where the *X*'s are the same variables we examined in the previous section: the Chicago Fed Financial Conditions Index (NFCI),the percentage changes in M2, in private non-financial debt, and in the trade-weighted U.S. dollar index, and the unemployment gap defined above. Given that these indicators are likely to influence inflation only with a relatively long lag, we choose to estimate the impact of the past 8 quarters.

**Table 4.4: Modeling the Local Mean of Inflation: Alternative Measures**

| | Core CPI | | Core PCE | |
|---|---|---|---|---|
| | Sum lags 0 to 4 | Sum lags 5 to 8 | Sum lags 0 to 4 | Sum lags 5 to 8 |
| Chicago Fed Financial Conditions Index | 0.151<br>(1.229) | -0.376<br>(-2.704) | -0.121<br>(-1.453) | -0.248<br>(-3.100) |
| Percentage change in M2 | 0.049<br>(1.559) | -0.013<br>(-0.756) | -0.010<br>(0.429) | -0.022<br>(-1.993) |
| Percentage change in Nonfinancial Debt | 0.043<br>(1.919) | 0.019<br>(0.820) | 0.015<br>(1.187) | 0.015<br>(1.165) |
| Percentage change in Trade-weighted Dollar Index | -0.001<br>(-0.152) | -0.007<br>(-0.965) | -0.012<br>(-2.054) | -0.004<br>(-1.068) |
| Unemployment gap | -0.122<br>(-2.04) | -0.017<br>(-0.21) | -0.011<br>(-0.25) | -0.031<br>(-0.87) |

Notes: Estimates of equation (4.5). All right-hand side variables are in first differences. Numbers in parentheses are t-ratios for the test that the sum of the subset of coefficients are zero. Dark yellow indicates statistical significance at the 5% level and lighter yellow at the 10% level, with the anticipated sign.

We start by noting that the results for the unemployment gap do change somewhat from those in Table 4.3. When we include lags of the change $\Delta(U_{t-1} - U^*_{t-1})$ on their own, the

estimated impact on the core CPI nearly doubles, while the coefficient on the core PCE disappears.

Turning to the other possible determinants, the results of the exercise reported in Table 4.4 suggest that the local mean, as measured by CPI inflation, is generally sensitive to financial conditions; as measured by core PCE inflation, the local mean is influenced by the dollar index. To get a sense of the empirical magnitudes of these effects, we can multiply the sum of the coefficients in the table by the standard deviation of the variable (as reported in Appendix Table A4.2) and compare this to the standard deviation of the change in the local mean, $\Delta\tilde{\tau}_R$. This calculation suggests a large impact: a one-standard-deviation move in either the change in the growth rate of M2 or the change in the growth rate of debt is associated with a roughly one-standard-deviation move in the local mean of core CPI inflation over the next year. For the PCE, the estimated effects are smaller, with the notable exception of the trade-weighted dollar. The estimates imply that a one-standard deviation move in the trade-weighted dollar moves the local mean as measured by core PCE inflation by roughly one standard deviation. That is, there appears to be an important mechanism by which external developments influence the U.S. local mean.

## 4.4 Hitting the inflation objective

Our view of inflation as a highly persistent process with a slow-moving local mean has implications for the current debate about whether the Federal Reserve should wait until inflation is at or above target before adjusting monetary policy. To see the connection, we note that the time-series model we use to estimate $\tau$ implies that the local mean is a function of past inflation. That, in turn, means that if the local mean is below the central bank's target, then the level of inflation as a matter of course *must* overshoot the target to get it there. However, the size of the overshoot is a quantitative issue and our model also provides some guidance on this question.

To assess magnitudes, we start by approximating the recursive estimates, those plotted as the solid red lines in Figure 4.1, by a 16-quarter distributed lag on actual inflation. That is, we

run the following regression:

$$(4.7)\ \tilde{\tau}_{R,t} = \sum_{j=0}^{16} \psi_j \pi_{t-j} + \xi_t .$$

We restrict the lags to sum to one. That is, $\sum_{j=0}^{16} \psi_i = 1$. The restriction guarantees that if the level of inflation is constant for sixteen quarters the local mean will wind up at that value.

This regression fits quite well: the $R^2$ is 0.97 for both the core CPI and the core PCE. Furthermore, the weights (the $\psi$'s) die out gradually, suggesting a rough equivalence to an adaptive expectations formulation.[19]

The coefficient estimates from (4.7) can then be used to translate a variety of potential paths for inflation into estimates for the local mean. Because of the lag structure, much of the local mean is pre-determined at any given time. For instance, given that the fourth-quarter 2016 value of the local mean for PCE inflation is 1.53 percent, the coefficient estimates imply that if core PCE inflation in the first quarter of 2017 happened to be equal to 3.53 percent, the local mean would be exactly 2 percent.[20] However, if core inflation were to remain at 3.53 percent thereafter, the local mean would quickly rise substantially above 2 percent.

There are countless paths that we could investigate, but an easy way to summarize them is to simply compute the average value for inflation over some interval and ask what it would have to average so that the local mean would average 2 percent. Accordingly, we conduct simulations to answer the following question: If policymakers wish to return the local mean of inflation to the target over the next N quarters, what does inflation have to average between now and N quarters from now?

One critical input into the calculation is how much inertia should we assume is present in inflation? Our estimates above suggest that the local mean is not very volatile, so it would be at odds with the past data to assume an abrupt large one-time jump. We account for this feature of the data by showing two scenarios. In the first, we assume that inflation over the next

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[19] Plots of the $\tilde{\tau}_R$ with the fitted values from equation (4.7), as well as the estimated coefficients, are shown in Appendix figures A4.1 to A4.4. The coefficients are well-approximated by a 3rd order polynomial.
[20] This can be seen because the $\psi_1$ =0.225, the weighted average of past inflation for lags 1 to 15 is 1.22. So, 0.225*3.53 + 1.22 = 2.

4 quarters is pre-determined and that it equals the level that is expected by the SPF, 2.20 percent for core CPI and 1.86 percent for core PCE. We call this the "4-quarter lag" scenario. In the second, the "no lag" scenario, we allow the central bank to immediately move inflation and hold it constant at the new level. The resulting estimates are shown in Table 4.5.

### Table 4.5 Average Inflation Required to Hit Target in *N* Quarters

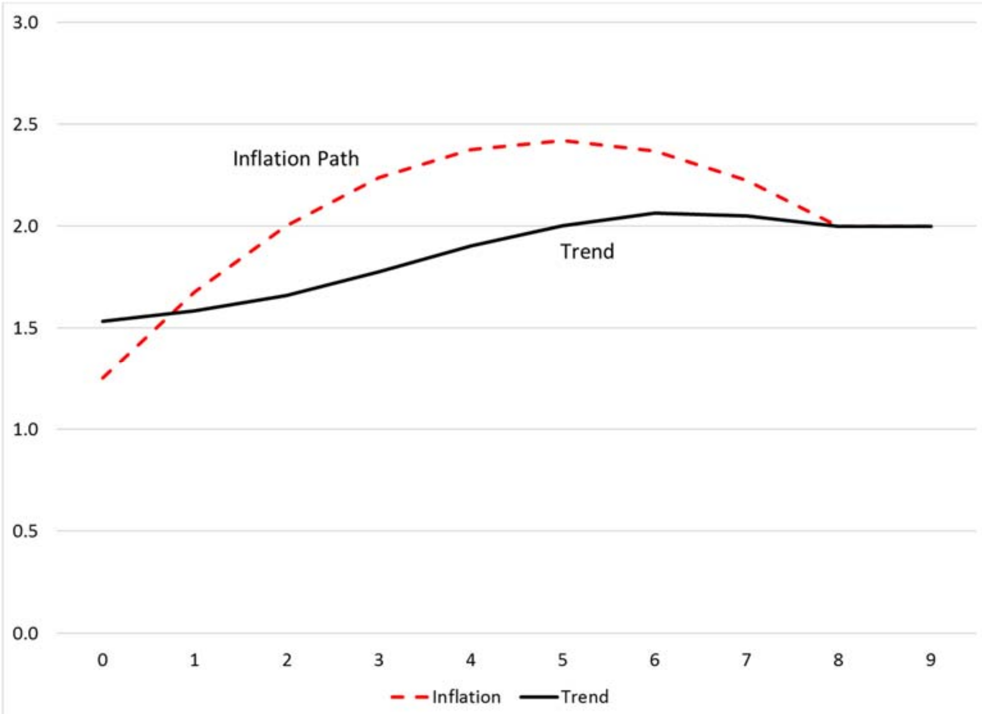
| | **Core CPI** | | **Core PCE** | |
|---|---|---|---|---|
| Time to hit target (N) | No lag | 4-quarter lag | No lag | 4-quarter lag |
| 4 quarters | 2.42% | | 2.23% | |
| 8 quarters | 2.33% | 2.40% | 2.11% | 2.18% |
| 12 quarters | 2.30% | 2.32% | 2.02% | 2.04% |
| | | | | |
| Target* | 2.30% | | 2.00% | |
| Average of past 4 quarters | 2.17% | | 1.71% | |
| Current estimate of local mean $\tilde{\tau}_{R,t}$ | 2.04% | | 1.53% | |

*We estimate the implied CPI target as the PCE target of 2% plus the average difference between the CPI and the PCE over the past 20 years.

As explained above, given that both current inflation and the latest estimate of the local mean are below the inflation objective of 2 percent for the core PCE (and the implied target of 2.3 percent for the core CPI), then inflation must rise above that level to achieve the target. Moreover, the shorter the time frame for hitting the target, the greater the required overshoot. However, none of these estimates call for large, sustained deviations from the target.

By the nature of this exercise, there are many inflation trajectories that would deliver the same average values. To see this, take the case of the core PCE with no policy lag with an objective of hitting the 2 percent target in 8 quarters. Given that the current level of the local mean is 1.53%, this requires that PCE inflation average 2.11% over the next two years. If inflation were to move smoothly from its currently level, and then fall to the target, it could follow a path like the one shown in Figure 4.2. In the example, core PCE inflation slowly moves up to a peak slightly above 2.4 percent before gradually falling back to the target of 2 percent. As a result, the local mean slowly rises.

**Figure 4.2: Possible Path that Raises the Local Mean of PCE Inflation to the 2-percent Target**




Source: Authors' calculations.

The lesson from this exercise is that, since the local mean tends to move gradually, it would be challenging to engineer a path where core inflation did not also move slowly. So, while a very temporary large overshoot followed by a quick reversion to target is arithmetically feasible, it seems unrealistic. Admittedly, this simulation relies on reduced-form estimates for the local mean. Nevertheless, we find the magnitudes to be plausible benchmarks for the discussion regarding overshooting.

## 5. Conclusion

Having examined inflation in the United States over the past 30 years, we are led to several conclusions. The basic results of the 2007 USMPF report are confirmed: inflation is well-described by a simple, highly persistent, process. That is, the Global Financial Crisis and its aftermath have not changed the fact that inflation contains a local (time-varying) mean that tends to move slowly, staying at its new level once it changes.

This characterization of the inflation process, which holds most closely for the core price measures (that is, excluding food and energy), leads us to examine whether a central bank should worry if it observes a small shift of inflation expectations (say, by two or three tenths of a percentage point) that is not mirrored in other indicators? In other words, what is the *independent* information content of inflation expectations in the *current* environment? Our answer is that, once we take account of the local mean, expectations tell us very little about the dynamics of future inflation. The same is true of labor market slack, where we find that deviations of unemployment from measures of the natural rate, while statistically associated with moves in inflation, have an influence that is very small in scale. Put differently, when unemployment rises, inflation falls, but the decline is extremely modest.

In trying to move inflation to target, it is important to realize that there are other channels besides expectations and wages (which could be affected by labor market slack) that the central bank can influence and that matter for price-setting. For instance, central bank actions that alter the exchange rate can change import costs which in turn impact prices. Likewise, movements in the dollar and financial conditions more broadly could also operate through shifting aggregate demand to influence pricing behavior.

Our characterization of inflation suggests that the local mean is currently about one-half percentage point below the FOMC's objective of 2 percent, as measured by the change in the PCE price index. Given that the inflation trend is primarily determined by the history of inflation itself, the implication is that policymakers will need to overshoot their objective to bring inflation reliability back to target. That said, our estimates of the degree to which PCE inflation needs to exceed 2 percent is modest: the average deviation would be on the order of several tenths of one percentage point for a period of one to two years.

In closing, we are reminded of the policy challenges faced four decades ago that were of a different order of magnitude. Imagine walking in to the office of Paul Volcker at the Federal Reserve or Charles Schultz at the Council of Economic Advisers in early 1980 and explaining that you were experiencing difficulty in keeping inflation at its 2 percent target. After some inquiry, they would come to realize that your immediate concern was that you were having trouble raising inflation from a bit more than 1.5 percent to 2.0 percent. Facing inflation that had fluctuated between 3 and 15 percent over the previous decade, they would surely have

responded (politely) that this was a problem they would love to have. As the contrast with the 1970s makes abundantly clear, it is appropriate to emphasize that our discussions are in the spirit of trying to build on the triumph of modern central banking in delivering inflation that has been both low and stable for the better part of three decades.

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## Appendix to Section 3: G6 Inflation Dynamics

This appendix presents our work describing the co-movement and dynamics of inflation in five other major advanced economies that parallels what we present for the United States in Section 3. The analysis focuses on the headline and core measure of the consumer price indices for Japan (JPN), the United Kingdom (GBR), Canada (CAN), Germany (DEU), and France (FRA), shown in Figures A3.1 and A3.2. The same series for the United States are included for comparison. Over the past three decades, annualized quarterly headline inflation across these countries has generally fluctuated in a range of 0 to 5 percent, similar to that in the United States; the range for core inflation has been narrower within that band. Japan has been a consistent outlier to the low side of this range, and a number of large idiosyncratic shocks to inflation have arisen. For instance, the headline figures in the early 1990s show a jump in prices at the beginning of the U.K. recession as well as around the German unification. The three occasions that Japan raised its consumption tax (in 1989, 1997 and 2014) also are evident.

### A3.1 Principal component analysis

Table A3.1 reports estimates of the principal components of the headline and core series, respectively, across countries. As in Section 3, panel A of the table shows the fraction of the variance for the series in the figures associated with each component. For both headline and core inflation, the first component accounts for around 55 percent of the variance and the second component accounts for about another 15 percent. The weights for the second component are interesting. In each case, the combination selected places opposite weights on Canada and Germany, with little weight on the United States, France, and the United Kingdom, and some weight on Japan that is in the same direction as Germany. Presumably this reflects the fact the Canada has a more natural-resource-intensive economy, while Germany had relatively low and stable inflation for much of the sample. The third component largely identifies Japan as standing out from the other countries and accounts for another 10 percent of the variation.

Overall, we read these results as suggesting that, while there is substantial co-movement across countries, country-specific differences do matter even for core-inflation series.

**Table A3.1 Principal Component Analysis of Various Inflation Series**

| A. Incremental fraction of the variance accounted for by each component | | | | | |
|---|---|---|---|---|---|
| | **Comp1** | **Comp2** | **Comp3** | **Comp4** | **Comp5** |
| Five U.S. Series from Figure 3.1 | 0.743 | 0.159 | 0.071 | 0.028 | 0.001 |
| HCPI 6 Countries from Figure 3.2 | 0.542 | 0.145 | 0.119 | 0.094 | 0.054 |
| CCPI 6 Countries from Figure 3.3 | 0.566 | 0.176 | 0.087 | 0.072 | 0.058 |
| B. Weights on the underlying series used to form each component | | | | | |
| **United States** | | | | | |
| | **Comp1** | **Comp2** | **Comp3** | **Comp4** | **Comp5** |
| HCPI | 0.437 | -0.560 | 0.288 | 0.291 | 0.573 |
| CCPI | 0.425 | 0.550 | 0.341 | 0.580 | -0.253 |
| HPCE | 0.474 | -0.419 | 0.158 | -0.340 | -0.678 |
| CPCE | 0.456 | 0.457 | 0.090 | -0.653 | 0.385 |
| PGDP | 0.442 | 0.002 | -0.876 | 0.193 | 0.007 |
| **Headline CPI** | | | | | |
| | **Comp1** | **Comp2** | **Comp3** | **Comp4** | **Comp5** |
| USA | 0.463 | -0.128 | -0.064 | 0.495 | 0.194 |
| JPN | 0.330 | 0.425 | 0.811 | -0.109 | -0.193 |
| GBR | 0.427 | -0.065 | -0.134 | -0.748 | 0.478 |
| CAN | 0.417 | -0.509 | 0.234 | 0.296 | 0.205 |
| DEU | 0.331 | 0.715 | -0.412 | 0.254 | 0.151 |
| FRA | 0.459 | -0.169 | -0.310 | -0.178 | -0.795 |
| **Core CPI** | | | | | |
| | **Comp1** | **Comp2** | **Comp3** | **Comp4** | **Comp5** |
| USA | 0.489 | -0.028 | 0.087 | 0.055 | 0.030 |
| JPN | 0.406 | 0.178 | -0.867 | 0.084 | -0.164 |
| GBR | 0.438 | -0.115 | 0.112 | -0.853 | 0.100 |
| CAN | 0.406 | -0.446 | 0.073 | 0.423 | 0.602 |
| DEU | 0.189 | 0.869 | 0.223 | 0.083 | 0.373 |
| FRA | 0.452 | 0.020 | 0.417 | 0.276 | -0.679 |

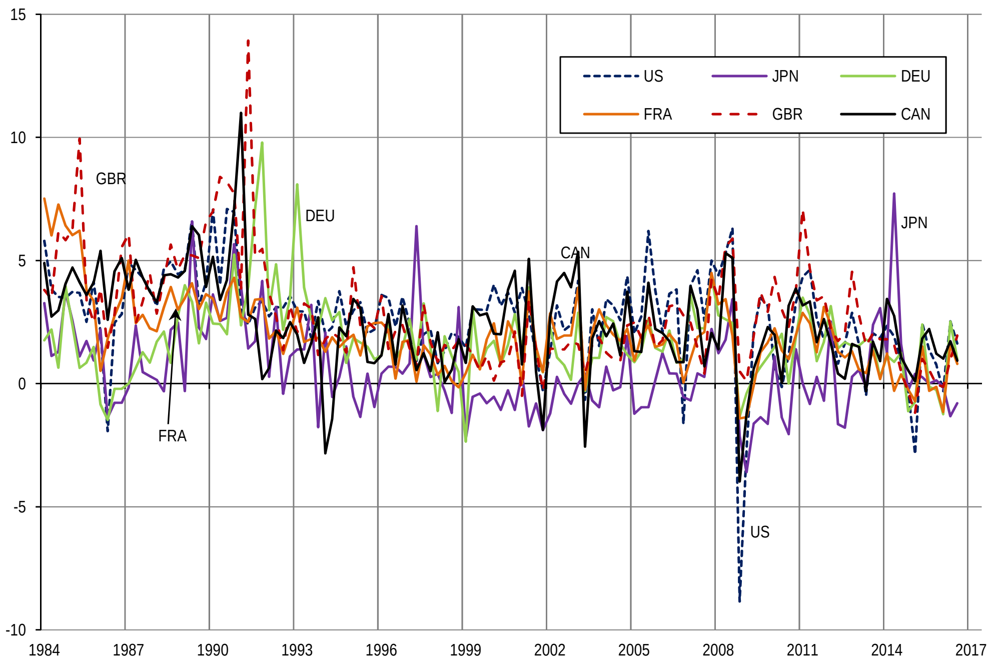
## A3.2 Statistical model

Using the UCSV model outlined in section 3, our estimates of the local means for inflation across the G6 are shown in Figures A3.3 and A3.4 for headline and core CPI. The associated estimates of the standard deviations of the local means are given in Figures A3.5 and A3.6, and the standard deviations of inflation innovations (the deviations of actual inflation from its local mean) are given in Figures A3.7 and A3.8. The cross-country patterns of these model estimates are more divergent than was the case across various measures of inflation for the United States. For the United Kingdom, the local means for both headline and core series show considerable volatility through the 1991 recession, though both series settle down by the mid-1990s. In Japan, the local mean for the core series becomes negative in 1999 and remains negative until the second quarter 2013 (when Governor Kuroda was appointed). The local means for both headline and core inflation for Germany, France, and Canada are relatively stable after the mid-1990s, and for the most part are lower than in the United States. The volatility of the local mean for these three countries also is broadly similar to the United States (using either core or headline) from the late 1990s onward. For Japan and the United Kingdom, the headline measures move up noticeably towards the end of the sample (and the same is true for the core measure in Japan.)

Finally, regarding the volatility of the innovations to inflation itself, the patterns found in the United States are somewhat present for headline inflation across the G6, although the United States lies at the lower end of the G6 range for most of the period shown. All the countries show a hump around 2008 that presumably reflects the boom and bust in oil prices, though none are as large as in the United States. Canada also shows a temporary rise and fall of the innovation variance in both its core and headline measure in the early 2000s.

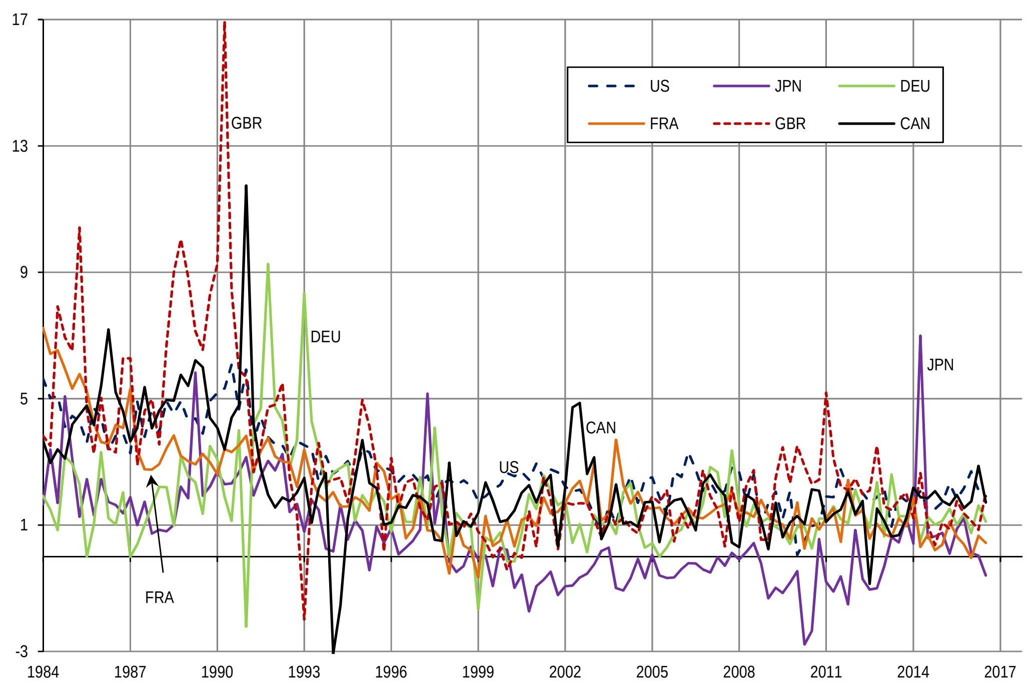
Overall, our UCSV model-based estimates suggest that a constant variance assumption for core inflation is a reasonable approximation for Germany and France, much the same as it is for the United States. For the other countries, however, there are either large movements in volatility of the trend at the beginning of the sample (Canada and the United Kingdom) or the end of the sample (Canada).

**A3.1 G6 Headline CPI Inflation, 1984-2016**



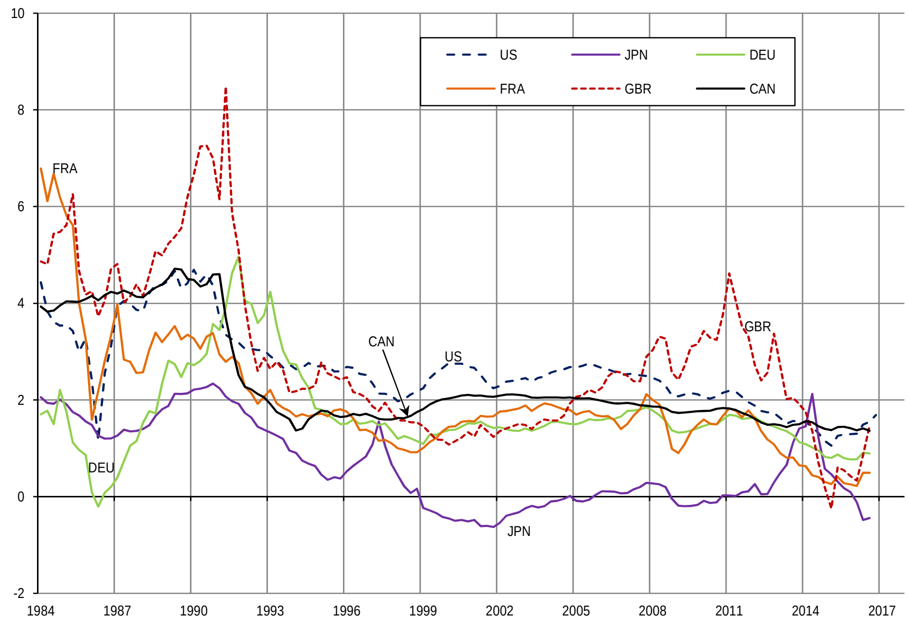

Source: National sources.

**A3.2 G6 Core CPI Inflation, 1984-2016**



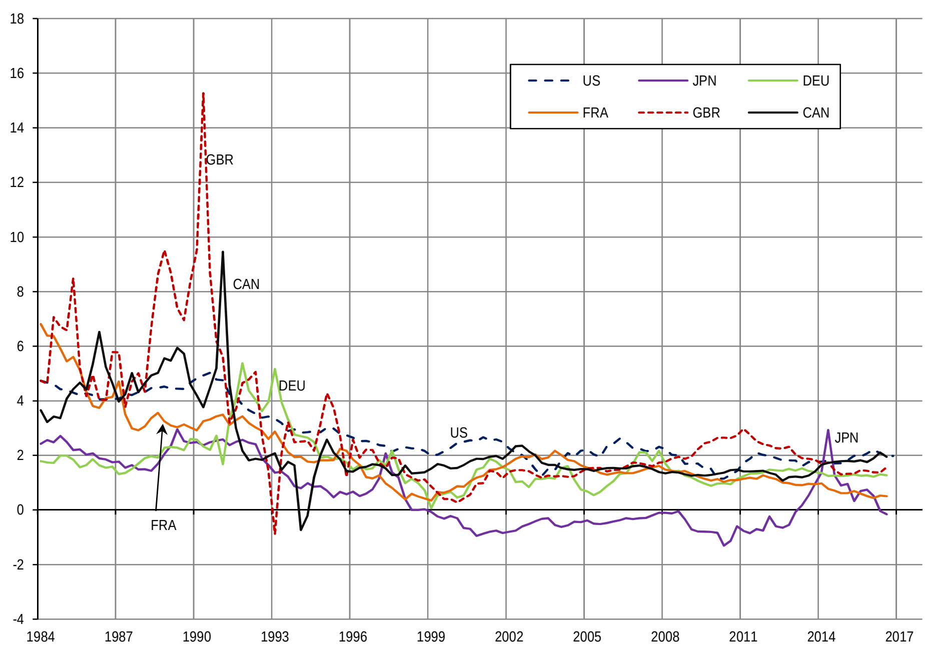

Source: National sources.

**A3.3 Estimated Time-Varying Local Means for Headline CPI Inflation across the G6 Countries, 1984-2016**



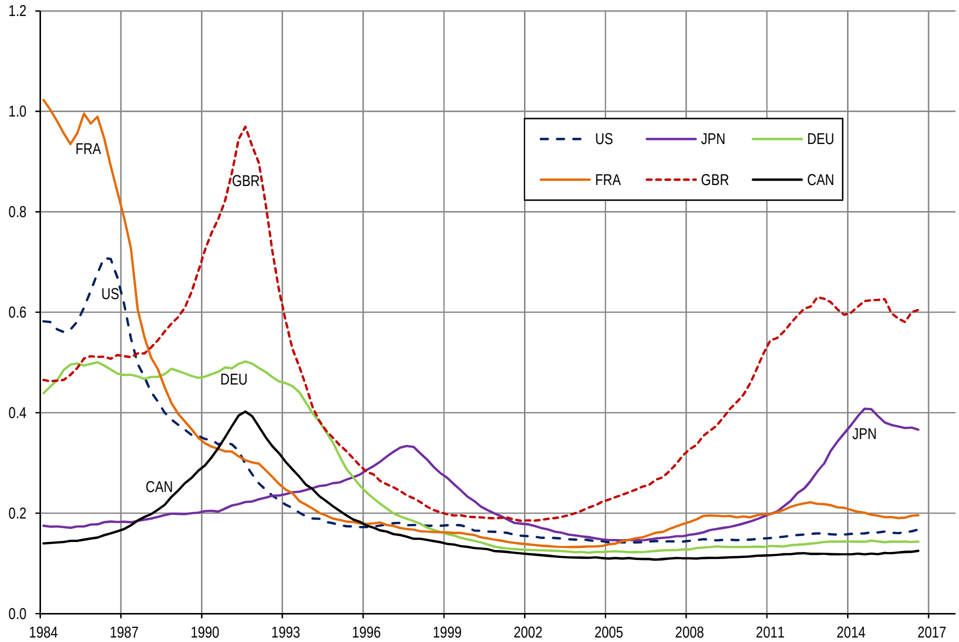

Source: Authors' calculations.

**A3.4 Estimated Time-Varying Local Means for Core CPI Inflation across the G6 Countries**



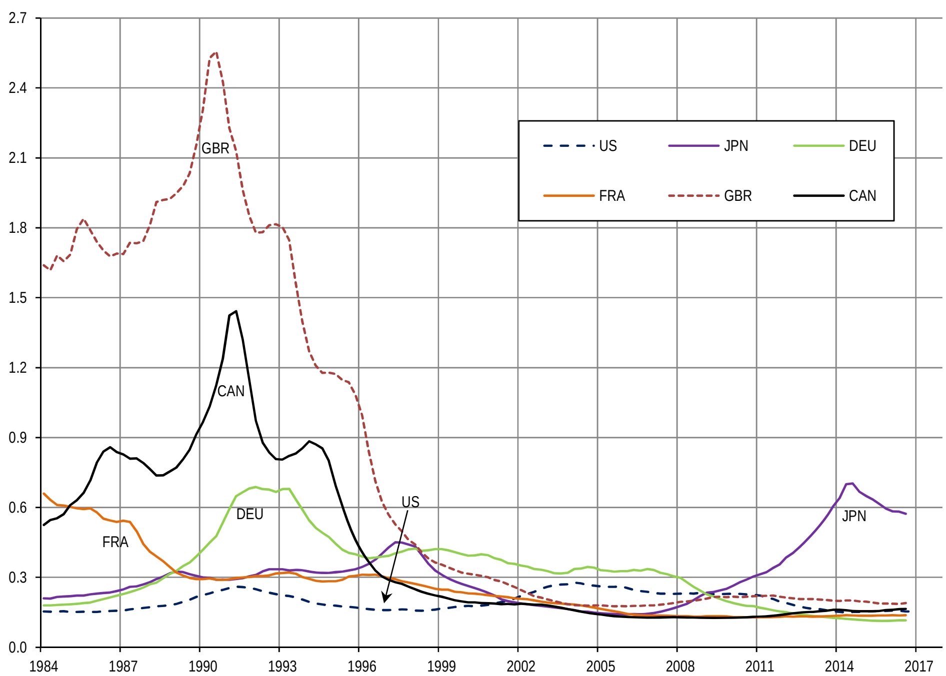

Source: Authors' calculations.

**A3.5 Time-Varying Standard Deviation of the Local Mean for Headline CPI Inflation across the G6 Countries**



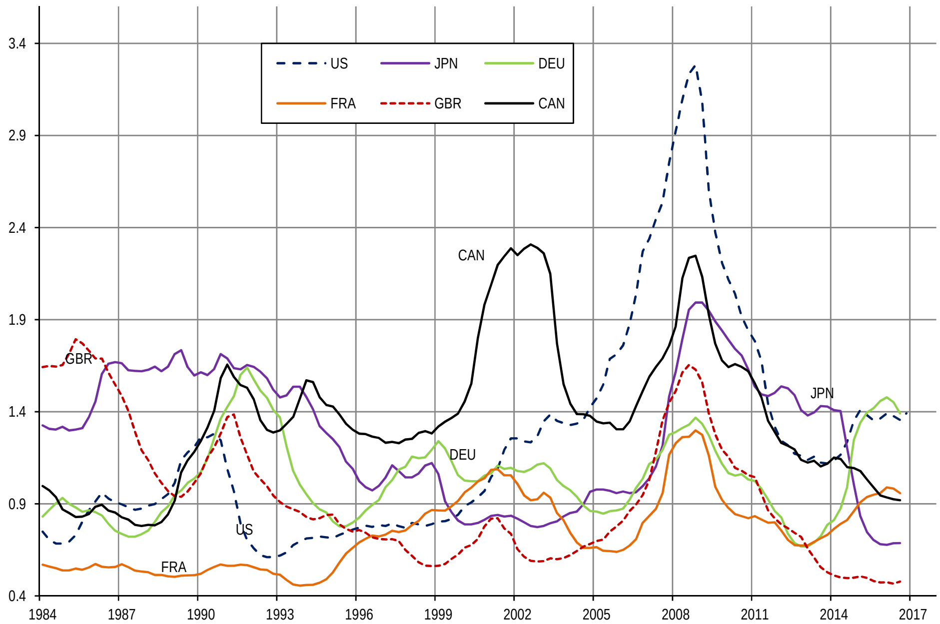

Source: Authors' calculations.

**A3.6 Time-Varying Standard Deviation of the Local Mean for Core CPI Inflation across the G6 Countries**



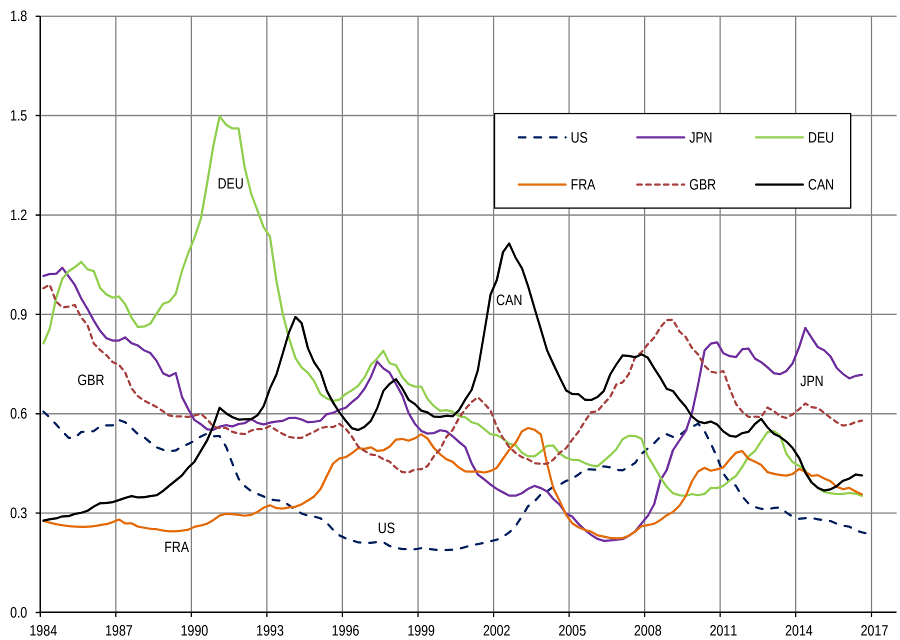

Source: Authors' calculations.

**A3.7 Time-Varying Standard Deviation of the Inflation Innovations for Headline CPIs across the G6 Countries**




Source: Authors' calculations.

**A3.8 Time-Varying Standard Deviation of the Inflation Innovations for Core CPIs across the G6 Countries**




Source: Authors' calculations.

## Appendix to Section 4

The following two tables report summary statistics for the variables used in the regressions in Section 4. Table A4.1 reports information for the levels of the variables, and Table A4.2 for the first differences.

**Table A4.1: Summary Statistics: Levels**

| Variable | Mean | Median | St. Deviation | 25th Percentile | 75th Percentile |
|---|---|---|---|---|---|
| Core CPI Inflation | 2.415 | 2.306 | 0.986 | 1.884 | 2.715 |
| Core PCE Inflation | 1.940 | 1.868 | 0.760 | 1.396 | 2.269 |
| Core CPI Recursive $\tau$ | 2.495 | 2.273 | 0.914 | 1.887 | 2.747 |
| Core PCE Recursive $\tau$ | 2.043 | 1.764 | 0.701 | 1.566 | 2.229 |
| $\pi^e$ Greenbook 4-quarters ahead | 2.332 | 2.200 | 0.811 | 1.838 | 2.850 |
| $\pi^e$ SPF 4-quarters ahead | 2.412 | 2.305 | 0.507 | 2.050 | 2.670 |
| $\pi^e$ SPF 40-quarters ahead | 2.620 | 2.500 | 0.433 | 2.370 | 2.575 |
| $\pi^e$ Blue Chip 4-quarters ahead | 2.615 | 2.400 | 0.627 | 2.200 | 3.000 |
| $\pi^e$ Michigan 4-quarters ahead | 3.004 | 2.967 | 0.524 | 2.733 | 3.167 |
| $\pi^e$ Michigan 40-quarters ahead | 3.048 | 2.900 | 0.427 | 2.800 | 3.100 |
| Unemployment Gap | 0.706 | 0.278 | 1.494 | -0.337 | 1.300 |
| Chicago Fed Financial Conditions Index | -0.405 | -0.605 | 0.530 | -0.700 | -0.260 |
| Percentage change in M2 | 5.490 | 5.491 | 3.111 | 3.509 | 7.248 |
| Percent change in Nonfinancial Debt | 5.977 | 5.976 | 3.744 | 3.655 | 8.107 |
| Percent change in Trade-weighted Dollar Index | 2.619 | 2.737 | 10.316 | -5.450 | 8.742 |

**Table A4.2: Summary Statistics: First Differences**

| Variable | Mean | Median | St. Deviation | 25th Percentile | 75th Percentile |
|---|---|---|---|---|---|
| Core CPI Inflation | -0.030 | -0.012 | 0.637 | -0.457 | 0.365 |
| Core PCE Inflation | -0.031 | -0.082 | 0.576 | -0.432 | 0.394 |
| Core CPI Recursive $\tau$ | -0.024 | -0.027 | 0.160 | -0.122 | 0.080 |
| Core PCE Recursive $\tau$ | -0.022 | -0.039 | 0.123 | -0.105 | 0.060 |
| $\pi^e$ Greenbook 4-quarters ahead | -0.025 | 0.000 | 0.242 | -0.134 | 0.100 |
| $\pi^e$ SPF 4-quarters ahead | -0.012 | -0.010 | 0.182 | -0.110 | 0.110 |
| $\pi^e$ SPF 40-quarters ahead | -0.015 | 0.000 | 0.095 | -0.050 | 0.000 |
| $\pi^e$ Blue Chip 4-quarters ahead | -0.020 | 0.000 | 0.142 | -0.100 | 0.100 |
| $\pi^e$ Michigan 4-quarters ahead | -0.016 | 0.000 | 0.430 | -0.167 | 0.200 |
| $\pi^e$ Michigan 20-quarters ahead | -0.018 | 0.000 | 0.127 | -0.100 | 0.100 |
| Unemployment Gap | 0.003 | -0.033 | 0.318 | -0.200 | 0.167 |
| Chicago Fed Financial Conditions Index | -0.007 | -0.020 | 0.274 | -0.100 | 0.070 |
| Percentage change in M2 | 0.023 | 0.082 | 2.965 | -1.265 | 1.413 |
| Percent change in Nonfinancial Debt | -0.026 | 0.649 | 4.961 | -2.713 | 2.700 |
| Percent change in Trade-weighted Dollar Index | 0.031 | 1.530 | 12.492 | -8.195 | 8.505 |

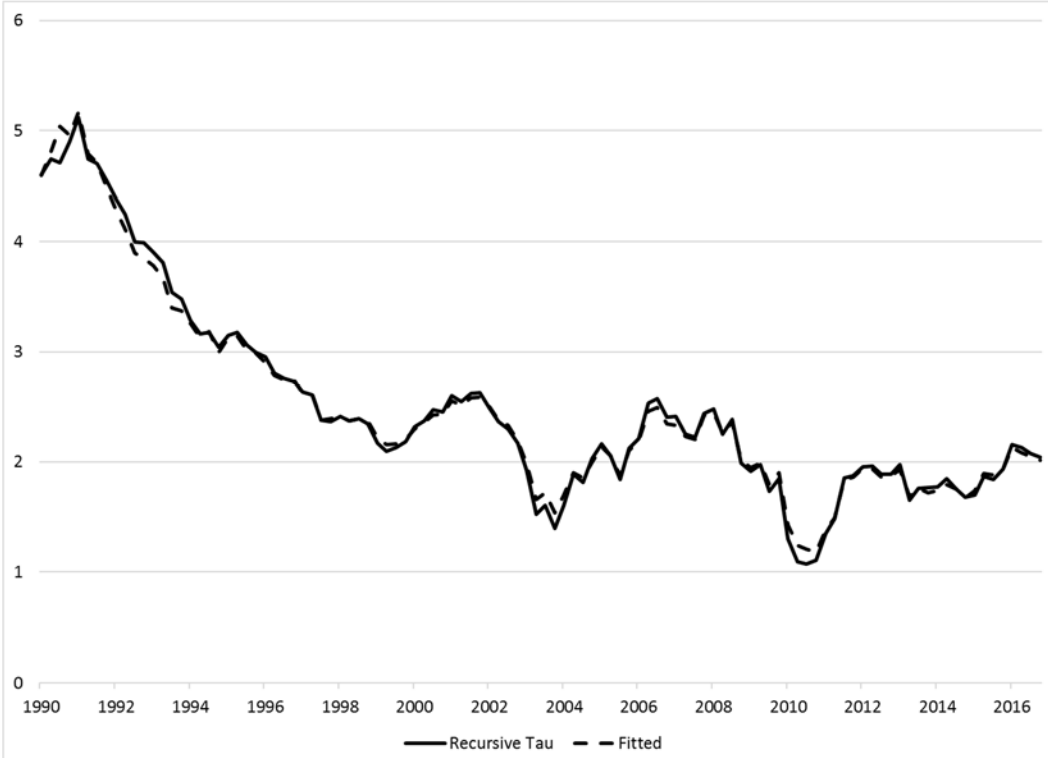
The following table reports the results of the estimates of text equation (4.4):

**Table A4.3: The Determinants of Deviations of Inflation from the Local Mean** $(\pi_t - \tilde{\tau}_{R,t})$

| | Core CPI | | | | | Core PCE | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) |
| Lagged deviation from $(\pi_{t-1} - \tilde{\tau}_{R,t-1})$ | 0.255 (3.71) | 0.327 (3.50) | 0.275 (4.11) | 0.209 (3.43) | 0.323 (3.22) | 0.311 (3.84) | 0.236 (1.80) | 0.280 (2.72) | 0.213 (3.33) | 0.235 (1.85) |
| Greenbook 4-quarters ahead $(\pi^e_{t,t+4} - \tilde{\tau}_{R,t})$ | 0.111 (0.81) | 0.029 (0.26) | | | | -0.112 (-0.86) | 0.063 (0.32) | | | |
| SPF 4-quarters ahead $(\pi^e_{t,t+4} - \tilde{\tau}_{R,t})$ | | | | | 0.078 (0.29) | | | | | 0.142 (0.34) |
| SPF 40-quarters ahead $(\pi^e_{t,t+40} - \tilde{\tau}_{R,t})$ | | 0.009 (0.04) | | | -0.034 (-0.11) | | -0.391 (-1.44) | | | -0.448 (-1.20) |
| Blue Chip 4-quarters ahead $(\pi^e_{t,t+4} - \tilde{\tau}_{R,t})$ | | | 0.062 (0.45) | | | | | -0.211 (-1.16) | | |
| Michigan 4-quarters ahead $(\pi^e_{t,t+4} - \tilde{\tau}_{R,t})$ | | | | 0.126 (2.87) | | | | | 0.139 (2.88) | |
| Unemployment Gap, lagged $(U_{t-1} - U^*_{t-1})$ | -0.016 (-0.56) | -0.014 (-0.30) | -0.031 (-0.94) | -0.055 (-2.23) | -0.013 (-0.29) | -0.026 (-0.61) | 0.018 (0.30) | -0.015 (-0.55) | -0.012 (-0.79) | 0.019 (0.31) |
| Constant | -0.035 (-0.86) | -0.051 (-0.73) | -0.050 (-1.02) | -0.095 (-2.01) | -0.050 (-0.77) | -0.028 (-0.31) | 0.171 (1.06) | 0.050 (0.35) | -0.215 (-2.85) | 0.156 (0.96) |
| $R^2$ | 0.105 | 0.126 | 0.098 | 0.154 | 0.126 | 0.097 | 0.119 | 0.110 | 0.136 | 0.121 |

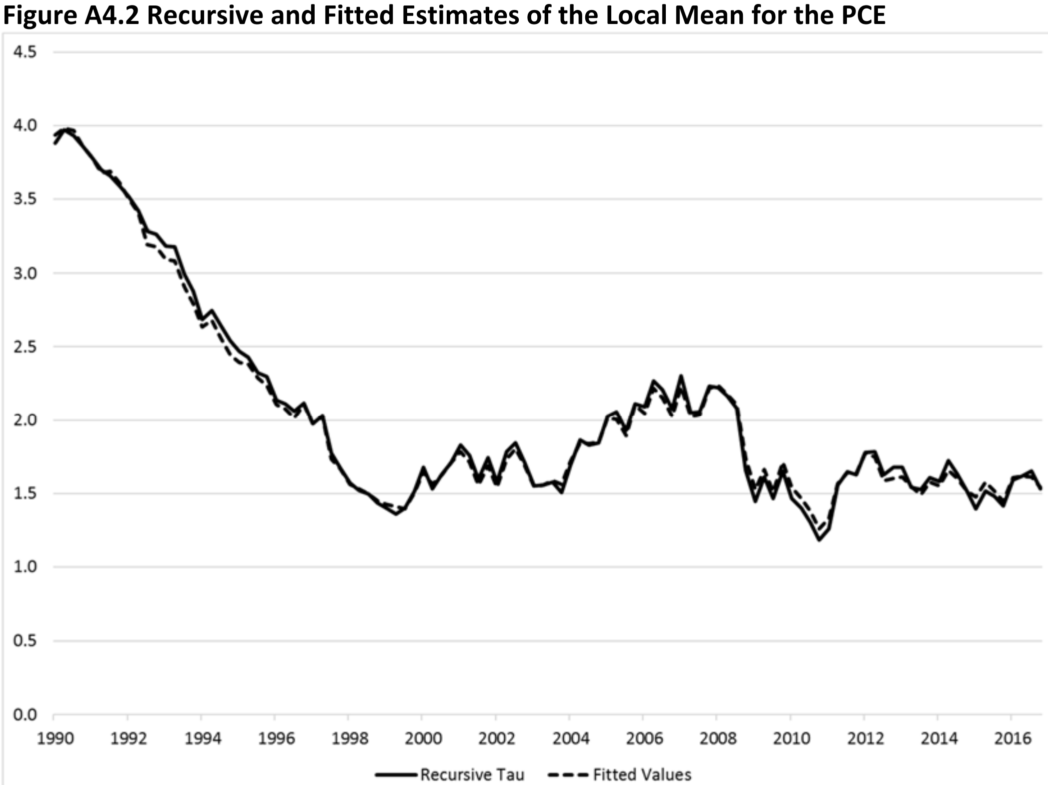
Note: Asymptotic t-ratios, computed with using robust standard errors, are in parentheses. Highlighted estimates are those for which the t-ratio is greater than 1.96, the 5% critical value for a two-sided test.

**Figure A4.1 Recursive and Fitted Estimates of the Local Mean for the CPI**



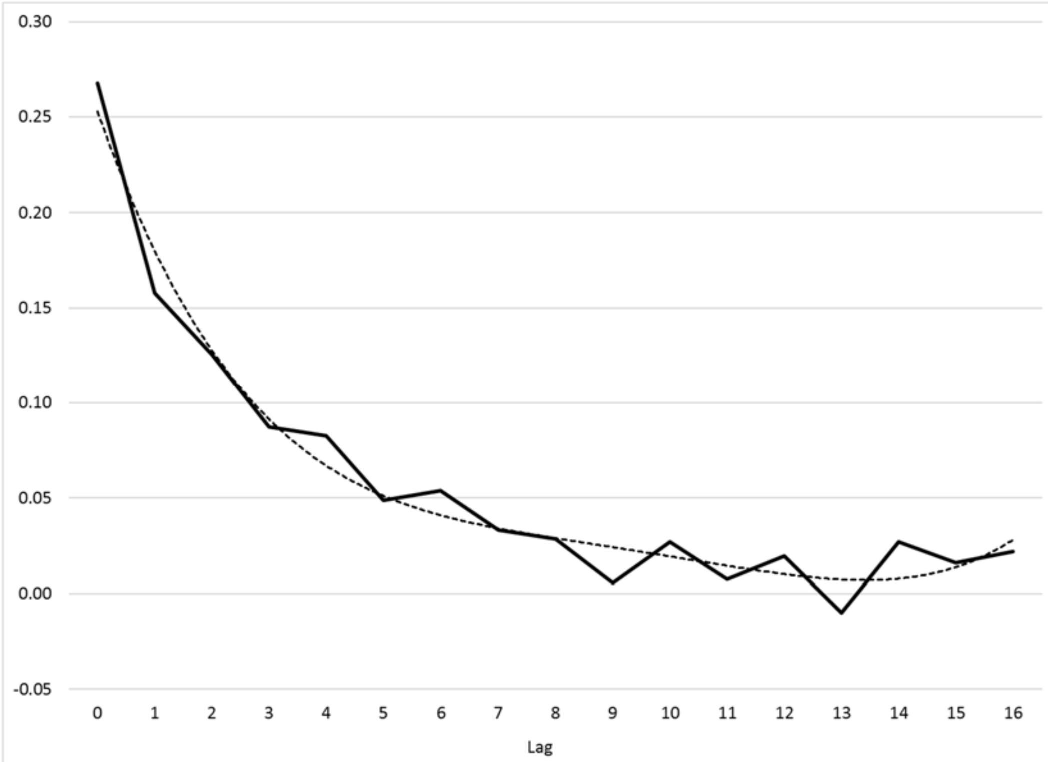

Note: Fitted value is constructed using estimates of text equation (4.7).

**Figure A4.2 Recursive and Fitted Estimates of the Local Mean for the PCE**



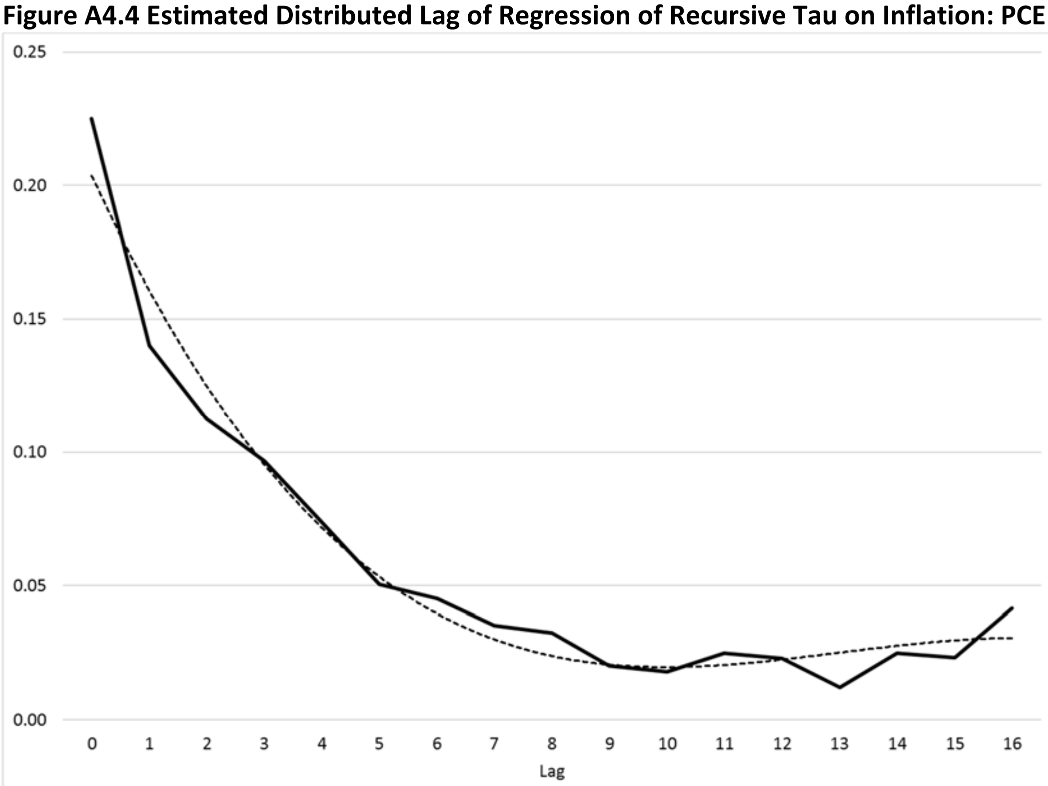

Note: Fitted value is constructed using estimates of text equation (4.7).

**Figure A4.3 Estimated Distributed Lag of Regression of Recursive Tau on Inflation: CPI**




Note: Coefficient estimates of text equation (4.7) along with a 3rd order polynomial for reference.

**Figure A4.4 Estimated Distributed Lag of Regression of Recursive Tau on Inflation: PCE**




Note: Coefficient estimates of text equation (4.7) along with a 3rd order polynomial for reference.

## Data Appendix

| Variables | Primary source | Secondary Source |
|---|---|---|
| **U.S. Price indexes** | | |
| Consumer price index: all items CPI-U SA 1982-84=100 | Bureau of Labor Statistics | Haver Analytics |
| CPI-U: all Items less food and energy, SA 1982-84=100 | Bureau of Labor Statistics | Haver Analytics |
| GDP implicit price deflator, SA 2009=100 | Bureau of Economic Analysis | Haver Analytics |
| Personal consumption expenditures: chain price index, SA 2009=100 | Bureau of Economic Analysis | Haver Analytics |
| PCE less food & energy: chain price index, SA 2009=100 | Bureau of Economic Analysis | Haver Analytics |
| **U.S. Inflation expectations and forecasts** | | |
| Blue Chip survey consensus four-quarter ahead forecast of quarter-to-quarter annualized CPI inflation | Blue Chip Survey | Haver Analytics |
| Greenbook forecasts of core CPI and core PCE inflation quarter-to-quarter annualized four-quarters ahead (mid-quarter observations) | Philadelphia Fed Real Time Data Research Center | |
| Michigan 1-year-ahead (12-month-ahead) expected change in prices (median increase, quarterly averages of monthly observations) | University of Michigan Survey of Consumers | Haver Analytics |
| Michigan 5-10 year inflation expectations: median expected annual rate of change in prices (quarterly averages of monthly observations) | University of Michigan Survey of Consumers | Haver Analytics |
| Survey of Professional Forecasters median four-quarter-ahead forecasts of quarter-to-quarter annualized core PCE, headline CPI and core CPI inflation | Philadelphia Fed | Haver Analytics |
| Survey of Professional Forecasters 10-year CPI inflation expectations | Philadelphia Fed | Haver Analytics |
| **Other U.S. variables** | | |
| U-3 unemployment rate | Bureau of Labor Statistics | Haver Analytics |
| Real-time unemployment rate | Philadelphia Fed Real-Time Data Research Center | |
| NAIRU (Non-accelerating inflation rate of unemployment) | Congressional Budget Office | St Louis Fed FRED |
| Real-time NAIRU or natural rate of unemployment | Bluebook forecasts from FOMC transcripts | Philadelphia Fed Real-time Data Research Center |

| **Variables** | **Primary source** | **Secondary Source** |
|---|---|---|
| Nominal broad trade-weighted dollar index | Federal Reserve Board | Haver Analytics |
| Chicago Fed National financial conditions index | Federal Reserve Bank of Chicago | St Louis Fed FRED |
| M2 Money Stock | Federal Reserve Board | St Louis Fed FRED |
| Private nonfinancial debt | Bank for International Settlements | |
| **<u>Price indexes for other countries</u>** | | |
| Japan: Consumer price index (CPI) | Ministry of Internal Affairs and Communications | Haver Analytics |
| Japan: CPI (all items excluding food and energy) | Ministry of Internal Affairs and Communications | Haver Analytics |
| Germany: Consumer price index (CPI) | Deutsche Bundesbank | Haver Analytics |
| Germany: CPI (total excluding energy) | Deutsche Bundesbank | Haver Analytics |
| France: Consumer price index (CPI) | Institut National de la Statistique et des Etudes Economiques (Insee) | Haver Analytics |
| France: CPI (all items excluding food and energy) | Organization for Economic Cooperation and Development | Haver Analytics |
| U.K.: Consumer price index (CPI) | Organization for Economic Cooperation and Development | Haver Analytics |
| U.K.: CPI (all items excluding food and energy) | Organization for Economic Cooperation and Development | Haver Analytics |
| Canada: Consumer price index (CPI) | Statistics Canada | Haver Analytics |
| Canada: CPI (all items excluding food and energy) | Statistics Canada | Haver Analytics |