Inflation in the Great Recession and Gradual Recovery: Surprises and Puzzles

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October 11, 2016

Abstract

Inflation in the Great Recession of 2007-9 and the subsequent Gradual Recovery has been surprising and puzzling to many economists. Using accounting methods – models and empirical designs developed by other economists – this paper isolates three elements that were a surprise relative to information in June 2009 and that are, to differing extents for various models, puzzling in 2016.

1 Introduction

The behavior of inflation during the Great Recession of 2007-2009 and the subsequent Gradual Recovery has been surprising and puzzling to many economists. In my review of the experience, a "surprise" will be an aspect of inflation that was not forecasted to occur, but seems understandable in retrospect, while a "puzzle" will be an element that is currently not well understood.

This paper uses accounting techniques to consider the inflation experience of 2008 through 2016. That is, it will draw on underlying models and empirical designs developed and estimated by other economists to review the behavior of inflation. There are, of course, many different measures of inflation. Since this is a conference at a Federal Reserve Bank, the main focus is on the behavior of the "core" Personal Consumption Expenditure price index which is a central focus of U.S. monetary policy.

1.1 The three accounting techniques and their applications

The accounting techniques are applied to three aspects of inflation experience and inflation models as these have developed over 2008-2016.

1.1.1 Inflation, unemployment, trends and expectations

The first accounting is for core PCE inflation and uses a framework that has grown increasingly popular over the period, namely the "long-term trend" framework that Watson (2014) and Yellen (2015) have employed to study inflation during the recession and recovery.[1] These studies differ in a number of details, with Watson using an estimated univariate trend and Yellen using long-term expected inflation from surveys. But they have a common empirical implication, which can be summarized using a simple approximate linkage between inflation and unemployment.

In terms of the evolution of inflation, there are three puzzling features that are identified vis-à-vis this type of model: the sharp drop in late 2008, the recent rates of inflation below the Fed's 2% target, and an intervening interval in which inflation exceeds the model-based accounting.

[1] Yellen's lecture is principally about the dynamics of headline inflation, with the core inflation model mainly an input.

The "trend inflation" framework's popularity has grown along with skepticism toward earlier "New Keynesian" models that featured powerful inflation consequences of shorter-term measures of inflation expectations interacting with an inflation persistence mechanism.

While it has not been my practice to work with survey expectations in prior empirical research, it is a desirable choice for studying inflation dynamics in an interval is widely regarded as sufficiently unusual so that conventional rational expectations methods may founder. In using survey expectations, the paper follows the early work of Roberts (1995) on New Keynesian pricing and the recent interpretations of the Great Recession and its aftermath by Fuhrer (2011, 2012) and Fuhrer, Olivei, and Tootell (2012).

A simple forward-looking model with short-term survey inflation expectations measures makes two of these three elements look less puzzling. However, the behavior of inflation during late 2008 remains quite puzzling.

1.1.2 Micro price adjustments: frequency and size

Since the work of Bils and Klenow (2004), there has been an active research program measuring aspects of micro price dynamics that accelerated with empirical work by Klenow and Kryvstov (2008) and Nakamura and Steinsson (2008) along with quantitative theory Golosov and Lucas (2007) and by these authors. This literature is well known for the finding that price adjustments are frequent, but it has also documented that the frequency has changed over time in the U.S. For one example, Nakamura, Steinsson, Sun and Villar [2016] find that monthly frequency averaged about 11% over the 1978-2014 period, but was as high as 17% near the start of that interval. For another example, Vavra (2015) and Berger and Vavra (2015) have highlighted the fact that the frequency of price adjustment changes substantially during recessions. For example, for a particular universe of prices drawn from BLS's research database of survey data that underlies the Consumer Price Index, Berger and Vavra (2015) find that the frequency of adjustment – averaged across individual prices – rose from about 11% per month to about 12.5% per month in the last half of 2008. Then, over the balance of the recession, the frequency of adjustment declined to about 9%.

The second accounting approach uses summary data kindly provided by David Berger and Joseph Vavra (hence, BV) to document elements of the dynamics of frequency and size of price adjustment during the 2008-2012 interval. The micro pricing literature has been marked by widely differing views concerning the importance of these two factors for inflation. One can read the work of Nakamura and Steinsson (2008) as suggesting that the dynamics of inflation are to be understood principally in terms of changing fractions of positive price adjustments, with relatively constant size of positive and negative adjustments and a stable frequency of price declines. One can read the work of Klenow and Krytsov (2008) as suggesting that inflation – particularly at higher frequencies – is mainly driven by changes in the size of price adjustments, with a negligible role for changing frequencies.

The BV data concerns price changes that the literature terms "regular price adjustments" with sales and product substitutions excluded. Ideally, given the focus on core PCE inflation, one would look at a particular part of the BLS research database (BLS-RDB) and link it to a particular part of the PCE index.[2] In constructing the CPI, the BLS relies on the survey information in the BLS-RDB only for part of its index: it uses other methods to construct prices of shelter and used vehicles. For comparability to the PCE, ideally, one would explore the micro data excluding food and energy and extract shelter as well as food and energy from the PCE.

However, the BV data corresponds to a wider universe with food and energy components, so that my accounting can only be suggestive. For this universe, the BV micro-based CPI construct (comparable to a CPI less shelter and used vehicles) is dominated by the size of price adjustments throughout the 2008-11 interval, in line with the findings of Klenow and Kryvstov (2008). To aid in future interpretations of this and other periods, some recommendations are made about public access summaries that could be constructed by the BLS as part of its "research series" program.

1.1.3 Labor costs and inflation

The third accounting approach involves exploring the behavior of inflation and labor costs, as in Gali and Gertler (1999) and King and Watson (2012). Results for this section are not yet available. .

[2] That this is feasible is illustrated by Vavra (2015), who studies the cyclical variation frequency and size for such a core CPI. Unfortunately, BLS restrictions meant that he has retained only band-pass filtered data which is (a) hard to use in an accounting approach and (b) stops in 2009 due to leads spent in constructing the filter.

1.2 A historical context

To evaluate the extent to which the behavior of inflation has been surprising, it is useful to think back to mid-2009. When the FOMC met in June, there was evidence that the US economy had stopped contracting, with particular evidence of a leveling off in consumer spending. (In fact, the NBER would later the end of the recession to that month.) However, during the first half of the year, the unemployment rate had continued to rise and staff projections were that it would shortly increase to 10%. The core rate of inflation been 2% in the first half of the year, but the staff attributed a portion of that to a one-time effect of large increases in tobacco excise taxes. Headline inflation had been higher, due to increases in energy and other commodities.

How rapidly would the economy recover? What would be the effect of persistent slack – as reflected in the unemployment rate and other measures of real activity – on the path of inflation? The Board staff offered three perspectives using various types of models. The first was a simple accelerationist model, estimated using a rolling regressions approach. The second was the a forecast using the large-scale FRB-US model under the assumption of a binding zero lower bound through 2012. The third was a small DSGE model which featured separate behavior of goods and service sectors together with standard wage and price frictions. I will discuss the first two of these models in the current section and the next, while returning to the topic of the third model in section 4 below.

1.2.1 A simple accelerationist structure

The Fed staff estimated a simple Phillips curve with an accelerationist structure using annual data, specifically a regression of the change in the annual inflation rate on a measure of the unemployment gap. To allow for changing structure, it was estimated with rolling 20 year windows. The resulting slope coefficient is plotted in the top panel of Figure 1.1. During the estimation period, the slope coefficient declined in absolute value from about -.4 to about -.2.[3] This empirical accelerationist specification has a long tradition in economics dating to work in the early 1970s and remains a staple of macroeconomics textbooks. For example, Charles Jones (2011, chapter 14) begins with an expectations augmented Phillips curve specification, $\pi_t = e_t + c(u_t - \underline{u})$,

[3] I am indebted to Michael Kiley for explaining the calculations to me. Published research by Roberts (2006) reports similar calculations and coefficient estimates.

then makes the assumption that expectations are formed according to $e_t = \pi_{t-1}$ and employs the framework to discuss the risks of deflation in the Great Recession.[4]

To illustrate the predictions of this approach, the bottom panel of Figure 1.1 computes a simulated inflation path using a slope of $c = .2$ together with annual average actual unemployment starting after June 2009, so that the first year makes use of unemployment during July 2009 through June 2010 and so on. The initial condition is an inflation rate of 2%: given the sustained decline in unemployment, there is deflation after 2 years and the resulting long-run level is -1.5%.

1.2.2 The FRB-US forecast

The Board staff also calculated the behavior of inflation and unemployment within the FRB-US model under the assumption that the funds rate would be at the zero lower bound through late 2012. In making their projection, they assumed that inflation expectations would remain anchored, appealing to observed stability in two long-term inflation expectations measures, the Reuters/Michigan survey and the Survey of Professional Forecasters.[5] However, in the FRB-US model of the time, inflation dynamics were influenced by expectations of nearby future inflation formulated in a model consistent manner.

The top panel of Figure 1.2 provides information on these "extended forecasts" and the actual experience, for unemployment as measured by the civilian unemployment rate and year-over-year inflation measured by the "core" PCE inflation rate.[6] The staff forecast for unemployment was quite accurate through early 2011. However, the staff – like many members of the FOMC and outside economists including me – underestimated the duration of the interval of high unemployment.

The bottom panel of Figure 1.2 shows that the inflation forecast was for a substantial interval of low inflation, but no deflation. Relative to the sharply declining path of unemployment, the inflation path is delayed, as a consequence of inertial mechanisms built into the wage-price block of the FRB-US model. Further, even after forecasted unemployment returns toward a normal level of about 5%, forecasted inflation remains low, at about 1.5% at the end of 2013 although it presumably as-

[4] I have not made any systematic review of current textbooks, but stumbled across this example as part of a visit to a lecture by one of my junior colleagues.

[5] Upper right corner of Exhibit 5.

[6] Personal Consumption Expenditure excluding Food and Energy (chained index). Series JCXFE

ymptotes to the 2% level under the anchored expectations assumption. In any event, the forecast for 2013 is sharply different from the accelerationist model.

During June 2009 through the end of 2013, the deviations of forecasted unemployment from 5% sum to about 53.5% and the deviations of forecasted inflation from 2% sum to about 17.5% so that there is a ratio of about .33 for these persistent variations.

One curious element of Figure 1.2 is that core inflation in early 2009 is well below the staff "forecast" in June 2009. This reflects major revisions in the core PCE inflation rate that occurred at some point after the meeting: the Q4 2008 year-over-year inflation rate was revised downward by about .3% and the Q1 2009 year-over-year inflation rate was revised downward by about .6%.[7]

These various elements will figure in our discussion throughout the paper: the *surprisingly rapid decline* in inflation in late 2008 and early 2009; the *surprisingly high rate* of inflation during the middle of the period; and the *surprisingly low rate of inflation* at the end of the period. These are surprises vis-a-vis the Fed staff's June 2009 information and forecasts. We will be learning about whether these are also to be regarded as puzzles.

2 Visions of inflation dynamics, 2007 and 2015

The class of inflation models studied here can usefully be summarized by the following linear specification. The inflation rate π_t is related to (i) a measure of expected near-term future inflation, e_t which would be $E_t\pi_{t+1}$ under rational expectations, with the coefficient f governing the strength of this forward-looking effect; (ii) past inflation with the coefficient l governing the strength of this backward-looking effect; (iii) a measure of a long-term expected inflation τ_t with the coefficient m governing the strength of this trend effect; (iv) a measure of real activity s_t, with the coefficient c governing the strength of this cyclical effect; and (v) one or more additional factors x_t that will be treated as real determinants (including changes in relative prices) with the coefficient g controlling the strength of their effect.

[7] From ALFRED, the 2008 Q4 percentage change from a year ago was 1.9% using the JCXFE_20090529 series and was 1.6% using the most recent data. The comparable numbers for 2009 Q1 were 1.8% and 1.2%

$$\pi_t = fe_t + l\pi_{t-1} + m\tau_t + cs_t + gx_t \tag{1}$$

Frequently, analysts impose the "neutrality" restrictions on the coefficients,

$$1 = f + l + m$$

which is most easily understood if x is real and has zero mean.[8]

In this discussion, several particular parameter cases are referred to by labels that are now defined.

The **accelerationist model** seen in section 1.2 above corresponds to changes in inflation being linked to a real activity measure, so that $l = 1$ and $f = m = 0$.

A **standard New Keynesian model** was the consensus framework circa 2007: it has both forward and backward components with $f + l$ close to 1, but no long-term expectations component ($m = 0$). The standard specification put forward as a link between inflation and real marginal cost by Gali and Gertler (1999) and Sbordonne (2002), then widely incorporated into small-scale DSGE models such as Smets and Wouters (2007) with an additional specification governing wage dynamics. However, even the price equation of the early FRB-US model had similar elements and the current FRB-US inflation specification has an extremely small trend influence (i.e., a small value of m).[9] Alternative versions such as those of Fuhrer and Moore (1995) looked through the marginal cost nexus, linking directly to output or unemployment gap measures.

A **long-term expectations model** is emerging as a consensus framework: it places substantial emphasis on τ_t and downplays the influence of e_t by setting $f = 0$ We turn next to exploring it.

[8] Under the neutrality assumption, this expression can be converted to one for "detrended" inflation, under the assumption that $E_t\tau_{t+1} = \tau_t$, as follows

$$\pi_t - \tau_t = fE_t(\pi_t - \tau_{t+1}) + l(\pi_{t-1} - \tau_{t-1}) + l(\tau_t - \tau_{t-1}) + cs_t + gx_t$$

with $l(\tau_t - \tau_{t-1})$ perhaps being small.

[9] Early FRBUS is described at https://www.federalreserve.gov/pubs/feds/1996/199642/199642pap.pdf. Current FRBUS has small a very small long-term expectations effect https://www.federalreserve.gov/econresdata/notes/feds-notes/2014/november-2014-update-of-the-frbus-model-20141121.html

2.1 The long-term expectations model

In a range of studies, economists have employed a "trend inflation" model for exploring U.S. history and, most specifically, for interpreting the behavior of inflation since 2008. One example is Watson's (2014) comparison of the behavior of unemployment and inflation during the 1979-1985 and 2007-2013 intervals. A second is Yellen's (2015) lecture on inflation dynamics that covers the broad sweep of inflation over 1960-2015, but focuses on explaining why headline PCE inflation has fallen below the Fed's 2 percent target since 2008.[10]

At the heart of each analysis is trend inflation τ_t, although this is implemented in different ways: for Watson, it is an estimated univariate stochastic trend of the Stock and Watson (2007) form, while for Yellen it is based on the Survey of Professional Forecaster's 10 year ahead estimate. Notably, each study employs a variant of the general model with $f = 0$, so that near-term inflation expectations are not a determinant of actual inflation. Yellen's framework for core inflation is a two-lag version,

$$\begin{aligned} \pi_t &= l_1\pi_{t-1} + l_2\pi_{t-2} + m\tau_t + cs_t + gx_t \\ &= .31\pi_{t-1} + .23\pi_{t-2} + .41\tau_t + .08s_t + .57x_t \end{aligned} \tag{2}$$

with s_t being the gap between the standard total civilan unemployment rate and the CBO's historical estimate of the long-run natural rate and x_t being a measure of the change in real imports prices (discussed further below). The coefficients on the inflation series are restricted so that they sum to one. Watson's empirical framework is

$$\pi_t = \tau_t + \beta(L)s_t + ... \tag{3}$$

where $\beta(L)$ is a polynomial in the lag operator and there are additional terms including distributed lags of import and other prices as well as variables developed by Gordon that capture Nixon-era price controls.[11]

While superficially different, these two frameworks have remarkably similar implications for the behavior of inflation since 2008. For sustained change in unemploy-

[10] Blanchard (2016) summarizes his own use of this type of model, individually and with various collaborators.

[11] Watson begins with lags of inflation, but then inverts a polynomial in the lag operator to arrive at (3).

ment or trend inflation, each implies

$$\pi_t \simeq \tau_t - .20s_t + ...$$

That is, for Yellen, the distributed lag coefficients lead to

$$\frac{m}{1-l_1-l_2} = 1 \quad \text{and} \quad \frac{c}{1-l_1-l_2} = \frac{.08}{.41} = .195$$

and Watson (2014, page x) reports estimates a sum of coefficients estimate over 1959:Q2-2013:Q4 of $\beta(1) = -.20$ with a standard error of .04 and split sample estimates of $\beta(1) = -.21$ prior to 1984 and $\beta(1) = -.19$ afterward.[12]

If the trend is constant at $\tau_t = 2$ and $s_t = u_t - 5$, then the approximate inflation model takes the form that I will use as a reference point throughout the discussion,

$$\pi_t = 2 - .20(u_t - 5)$$

which is convenient for two reasons. First, it provides perspective on the consequences of various model assumptions on lag structure, expectation formation, and shocks. Second, since it is simply a scaled version of an unemployment gap, it reminds us about this measure of the evolution of the real economy during the 2008-2016 period.

2.2 The PCE indices and inflation rates

For the reader's convenience, Figure 2.1 displays the levels of the PCE and the core PCE over 2007-2011, along with quarter-to-quarter and year-over-year inflation rates. The discussion below will focus mainly on the quarter-to-quarter changes, while the inflation measures discussed in section 1 are year-over-year.

2.3 Survey expectations

Given my interest in exploring the interaction of survey expectations with inflation and unemployment during 2008-2016, I use the general specification (1) and explore

[12] The use of sums of coefficients to capture the effects of persistent movements in inflation or unemployment dates back to early work on the Phillips curve by Solow and Gordon, which attracted influential criticisms from Lucas and Sargent. . It is not being used for testing long-run neutrality in the current setting, though, but rather simply as a means of approximating the influence of sustained changes in variables. It was previously found to be a very convenient and useful approximation of the link between inflation and unit labor cost (King and Watson (2012)).

the consequence of various expectations assumptions in the Yellen model and related setup. Figure 2.2 shows the four SPF measures of expected inflation used. The first three are forecasts of *core* PCE inflation: the SPF 1 quarter forecast (SPF 1Q), the two quarter ahead forecast (SPF 2Q), and the four quarter year ahead forecast (SPF 1YR). The fourth is the forecast of *headline* PCE for ten years in the future. However, given the behavior in Figure 2.1, one might be comfortable with equating core and headline forecasts at long horizons.

There are several notable features of these series. First, the decline in inflation in the latter part of 2008 appears largely unanticipated. Second, after it was underway, the 10 year forecast barely budged – the anchored expectations behavior used by the staff in 2009, depicted in Yellen (2015) and widely discussed – while all of the shorter term measures dropped substantially. Third, the shorter the term, the more the survey expectations series displays the same "yammering" as in the quarterly inflation rates in Figure 2.1, suggesting that the SPF participants are actively seeking to forecast these transitory swings. Fourth, the expectations series increase in 2011 and 2012, but remain lower than 2 percent at the end of the period.

2.4 Constructing inflation dynamics

With a measure of inflation expectations and historical unemployment in hand, one can simulate the path of inflation which would take place in the absence of shocks x. All simulations use the same slack measure, the unemployment rate less a constant 5% natural rate, chosen for simplicity and transparency. All simulations start in 2008Q3 with both lags of inflation at the quarterly rates in most recent data revisions (but the results are not visually different if 2% is used as the starting point).

The results for the trend inflation model are the dark solid line in Panel A of Figure 2.3: it is the model's prediction for the core PCE quarterly inflation rate, which can be contrasted to the dashed line which repeats the actual core PCE inflation rate from the center panel of Figures 2.1 above. Two reference lines are included: the blue line is the model with expected long-term inflation rate is held constant at 2% through the period, while the red line corresponds to the simple reference model $\pi_t = 2 - .2(u_t - 5)$. In the Yellen long-term expectations model, inflation declines to about 1.25% in late 2010, which is similar to the path when the long-term inflation expectation are fixed at 2% (blue line). Both of these models incorporate the influence of lags on the behavior of inflation so that there is a slower response than in the simple model (red line).

But all three models miss on features of the quarter-to-quarter inflation dynamics:

(1) The dramatic decline in inflation in late 2008 and early 2009;

(2) The return to inflation averaging about 2% centered on 2011;

(3) The low rates of inflation beginning in 2014 and ownwards;

Interestingly, because the simple model has an immediate effect of unemployment on inflation, it comes closest to capturing the behavior of inflation during the earliest part of the Great Recession.

Time averaging: The bottom panel of Figure 2.3 shows the model's implication for year-over-year inflation (moving averages of the simulated series in the top panel). The simulation begins in 2008Q3, so that series match up to that point and diverge as the effects of initial observations wear off. (This corresponds to the treatment of inflation in the June 2009 forecasts discussed in Section 1). The resulting data and model series are now smoother, but the puzzles about the three time intervals remain intact.

Import price shocks: Yellen's (2015) model incorporates the effect of changing import prices, based on some detailed calculations by Fed staff using unpublished information from the BEA. From the description, the import price shock is constructed by first creating the annualized change in an import price index less the lagged year-over year rate of change of the core PCE index, then multiplying by a measure of the share of imported goods. To proxy for this measure, I took a annualized one quarter percentage change in the series that Watson (2014) uses for non-petroleum imports[13], subtracted the lagged year-over-year core inflation rate, and then multiplied by the 2011 share of imported goods in personal consumption less food and energy (.12, as reported by Hale and Hobijn in an August 2011 FRB-SF Economic Letter).[14] The import shock defined in this manner is displayed in the top panel of Figure 2.4, along with the effect that it has on the simulation as it moves through the lag structure. The consequences of the import shock for the predicted path core inflation are shown in the bottom panel, which repeats the simulation result from Figure 2.3 as a reference measure. According to this calculation, import shocks do

[13] The series used by Watson is identified as PIMP_NP and matches B187RG3Q086SBEA from FRED.

[14] http://www.frbsf.org/economic-research/publications/economic-letter/2011/august/us-made-in-china/

not contribute much to core inflation dynamics since 2008, which is in accords with findings using Watson's (2014) approach that employs a related measure of import shocks.[15]

2.5 Short-term expectations effects

The standard New Keynesian model places significant weight on short-term expectations of inflation. How would the nature of inflation dynamics change if expectations about nearer-term inflation replaced the trend? Rational expectations theory indicates that the effects on a "slope" can be substantial when unemployment variations are persistent. For example, if we consider a purely forward-looking model of the New Keynesian form, with β close to one,

$$\pi_t = \beta E_t \pi_{t+1} + \gamma s_t$$

and we assume that $s_t = \rho s_{t-1} + z_t$ with z_t being unpredictable, then the reduced form relationship is

$$\pi_t = \frac{\gamma}{1 - \beta\rho} s_t = c s_t$$

For a value of ρ of .95 and β close to 1, then there is a c which is 20 bigger than γ (in absolute value). A researcher using data on short-term survey expectations would want to use γ but the methods of Watson (2014) and Yellen (2015) would estimate something close to c. If the researcher instead used c, then a simulated path of inflation would be twenty times more responsive in the model than in reality.

When one puts a short-term expectations measure directly into (1), dropping $m\tau_t$ but using the coefficient on m as the coefficient on a short-term expectations variable (e_t) then this sort of effect take place. If we look back at Figure 2.2, the SPF 1YR series is the least volatile of the series and this is the horizon that has been previously used by Fuhrer and research collaborators.

Partly Forward-Looking: The inflation dynamics with the one year ahead measure are shown as the blue line in Panel A of Figure 2.5, which (a) uses the Yellen lag parameters; and (b) drops the slope from -.08 to -.03. This slope coefficient

[15] The results are small using Watson's method in two senses. First, his estimated sum of coefficients on import inflation is statistically insignificant. Second, using the replication materials available on his website, one can compute a measure of fitted core inflation with and without his import price series. The results are not very different, in line with the findings in Figure 2.4.

means that the model shares many features with the long-term expectations model of Yellen (2015), which is the solid black line in the Figure as previously. The simple model $\pi_t = 2 - .2(u_t - 5)$ is the solid red line in the Figure as previously. As we explore the implications of alternative specifications in the rest of this section, these two models will always serve as reference points.

The behavior of inflation in 2008 remains a puzzle, as does the inflation of 2011. However, the fact that the SPF 1Y series remains below 2% toward the end of the period, when the unemployment gap has returned to close to zero, means that the choice of the expectations variable matters for Puzzle #3.

Fully Forward-Looking: Fuhrer (2011) has experimented with a fully forward-looking specification using one year ahead expectations, which is shown in Panel B of Figure 2.5, again using a slope of -.03. Inflation drops more rapidly in this model in the last quarter of 2008 and the first quarter of 2009. But the expectations shift cannot capture the full decline in inflation.

The fully forward-looking model ($f = 1, l = m = 0$) also yields higher inflation than the long-term expectations model during the middle of the Gradual Recovery, although not as much as observed, and preserves the earlier implication that inflation is below the 2 percent level in the latter part of the period.

2.6 Results for Shorter-Term Expectations

Figure 2.6 shows results for the purely forward-looking model with $f = 1$, using one the SPF2Q and SPF1Q measures displayed in Figure 2.2. (The slope is maintained at -.03). In the top panel, the simulated inflation with SPFQ2 drops dramatically in late 2008 via a forward-looking variation on the accelerationist result. The bottom panel shows that use of very near-term inflation measures leads to great volatility in inflation, which is likely one of the consideration which has prompted some to move away from the benchmark NK model.

2.7 Summing up

This section has described the "long-term expected inflation model" which is increasingly in use and identified three aspects of inflation during 2008-2016 that are puzzling relative to it. In fact, these are three features of inflation which are surprising relative to the forecasts made at the June 2009 FOMC meeting, but these remain when the more slowly declining path of actual unemployment is incorporated into a dynamic simulation of the 2008-2016 interval. This section also display some simple inflation specifications that depend on measures of expected inflation which are shorter term in nature. To my eye, these are promising in terms of capturing aspects of puzzles #2 and #3, but they are less so with respect to puzzle #1. The promise makes it desirable to extend the econometric work of Fuhrer (2011, 2012) to examination of 2008-2016 interval.

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3 Micro Price Dynamics

The assumed degree of price stickiness is a key parameter in time dependent models of inflation dynamics. The influential work by Bils and Klenow (2004) explored the 1995-1997 survey data underlying the U.S. consumer price index for 350 categories of goods and services covering about 70 percent of consumer spending. They documented three main facts: (i) that the frequency of price changes differed dramatically across goods; (ii) that price changes were much more frequent than suggested by prior studies, with half of price spells lasting less than 4.3 months; and (iii) that even if temporary price cuts (sales) were excluded, it was still the case that half of prices lasted 5.5 months or less. This initial work rapidly was augmented by additional CPI research by Klenow and Kryvtsov (2008) and Nakamura and Steinsson (2008), which documented dramatically large changes in individual prices on a month-to-month basis. Quantitative theoretical work by Golosov and Lucas (2007), as well as these authors, soon contrasted the implications of state dependent and time dependent pricing when matched to various micro pricing facts. Thus, by the onset of the Great Recession, the Bils and Klenow (2004) study had initiated a major research program that continues to be high energy area. The objective of my review of this literature is to ask "how does the work on micro pricing inform our understanding of inflation during the Great Recession and the Gradual Recovery."

3.1 A long term perspective

Before turning to this recent period, it is useful to begin with a longer-term perspective. Until recently, studies of micro price dynamics were limited to data beginning in 1988. However, recent work by Nakamura, Steinsson, Sun and Villar (2016) has constructed measures of adjustment frequency and the average size of price changes back through 1978 in a remarkable project that digitizes and interprets old BLS records in a careful manner.

Panel A of Figure 3.1 displays annual average data from the NSSV project kindly provided by the authors, which highlights two aspects of micro price dynamics which have been much stressed in the literature. First, price adjustments are *frequent*: according to the NS definition of a price adjustment (discussed further below), a measure of the median frequency of adjustment has a mean value of 10.7% over 1978-2014. Second, price changes are *large*: a measure of the absolute change has a mean value of 7.5% over 1978-2014. Further, Panel A of Figure 3.1 shows that there are two interesting linkages to inflation and real activity. First, the high inflation period of the late 1970s and early 1980s was marked by high frequency of price adjustment, reaching a maximum value of about 17% per month. Second, during several recessions, there are declines in the frequency of adjustment.

Panel B of Figure 3.1 (extracted from the NSSV paper) shows another breakdown of adjustment frequency stressed in the earlier work of Nakamura and Steinsson (2008): their measure of price adjustment frequency is quite volatile for positive price adjustments, but relatively stable for negative price adjustments. Coupled with the relatively stable measures of the average size of price increases and decreases reported in Nakamura and Steinsson (2008), one might conclude that a simple model of inflation dynamics should focus entirely on explaining the frequency of price increases (as suggested in King (2009)) rather than explaining the average size of adjustments with fixed frequency (as in the Calvo (1983) model and other time dependent setups). Note that panel B of Figure 3.1 also displays the annual inflation rate for the CPI less shelter, highlighting the comovement of inflation with the measure of adjustment frequency. Note also that the recent decline in inflation is associated with a sharp downward movement in the measure of the adjustment frequency.

3.2 Switching to the CPI

The BLS uses a different methodology for the CPI components for (1) shelter and (2) used vehicles. Thus, that these items do not figure in the survey data employed in the micro studies and that panel A of Figure 3.2 displays two series that are stripped of these components.[16] Both remove shelter, but one also removes food and energy along with used vehicles to get closer to a core measure of the CPI that could be constructed from BLS micro data.

Panel B of Figure 3.2 shows inflation measures for these two series over 2008

[16] http://www.bls.gov/cpi/cpifacuv.htm

through 2012, with these rates measured in terms of percent per month. Looking ahead to discussion of micro pricing research, a monthly inflation rate with a .5 corresponds to a 6=12*.5 percent annual inflation rate. To produce the series, monthly observations within a quarter are averaged because we will be restricted looking at quarterly averages of monthly frequency of adjustment and other aspects of the micro data.

One aspect of the panels of Figure 3.2 is stunning in retrospect: in the last quarter of 2008, the CPI less shelter index fell about fell about 5 1/2 percent[17]. (This corresponds to multiplying the monthly percentage change observations in panel B by 3). By contrast, the level of the CPI less food, energy, shelter and used vehicles was essentially unchanged during the last quarter of 2008, with a monthly inflation rate of -.07 and an overall decline of -.21%.

Just as in our discussion of PCE inflation, we see that there was a major decline in inflation during the second half of 2008. Earlier, we found that this was resistant to two forces which made inflation respond more quickly to the path of unemployment than in the Yellen model: (1) the elimination of lags; and (2) the use of survey inflation expectations for a year or less. At an annual rate, Figure 2.1 showed core PCE inflation fell about from about 2% at the start of the year to .5% in the fourth quarter.

3.3 What's a price change? Does it matter for inflation?

In micro price data, there are many situations where a nominal price changes for a time, perhaps due to a sale, and then returns to its prior value. Empirical research in this area has therefore distinguished between changes in prices and changes in "regular prices." The BLS survey records sales as these are identified by its workers, but micro price researchers also sometimes use algorithms to identify the level of the regular price at a point in time, enabling the analysis of changes in such regular prices.

In its constructing its price indices, the BLS includes changes in prices due to sales and does not employ the regular price construct, so that an inflation rate constructed along the lines of (4) may differ from its BLS counterpart. There are other sources

[17] Its decline in November 2008 alone was about 2 3/4 percent as may be checked using https://fred.stlouisfed.org/series/CUUR0000SA0L2#0

of discrepancy as well, depending on how an individual researcher handles product substitutions, stock-outs and other situations.

The existence of such temporary changes, product substitutions and so on into question the strict "menu cost" interpretation of price rigidity and economists disagree about how to treat these. For some researchers, such as Klenow and Kryvstov (2008), product substitutions are are price changes "pure and simple.". For others, such as Kehoe and Midrigan (2015), sales-related changes are to be governed by a different form of menu cost and the appropriate approximation for considering non-neutrality is to focus just on changes in "regular prices."

The analysis below makes use of summary statistics on monthly changes in regular prices assembled by David Berger and Joseph Vavra, who have begun the important work of exploring the cyclical behavior of the frequency of adjustment and the distribution of price changes in Vavra (2015) and Berger and Vavra (2015): they both provided extracts from their work and tutored me on aspects of it. Figure 3.3 shows the month-to-month changes in two inflation measures for "CPI excluding shelter". The first is the same as in Figure 3.2: it is the official BLS index. Recall that the data are quarterly averages of monthly percentage changes, so that an annual change of 3% corresponds to a value of 0.25%. The second is the monthly inflation rate obtained by aggregating regular changes in prices. Panel A of Figure 3.3 shows the two series over the full sample of 1988 through the end of 2011 (BV's sample based on trips to the BLS) and Panel B focuses in on the series 2008. The micro-based construction is smoother, reflecting that the authors have eliminated temporary price movements arising from sales and do not undertake the many complicated adjustments that the BLS uses to construct the published series. (The standard deviation of the BLS measure is 0.32 and that of the micro-based measure is 0.24) But the two series move together: there is a correlation of .75. Comparison of the two series gives some information about how inflation depends on how price changes are measured.

3.4 An accounting framework

To understand the construction of this series and others discussed below, it is useful to employ an accounting framework put forward by Klenow and Kryvtsov (2008) and elaborated by Nakamura and Steinsson (2008). To begin, consider a set of survey observations on individual prices P_{jt} as in the BLS survey. Define the log price relative for the good j as $\log(P_{jt}) - \log(P_{j,t-1})$. Then, a measure of inflation can be constructed.

$$\pi_t = \sum_{j=0}^{J} \eta_{jt}[\log(P_{jt}) - \log(P_{j,t-1}) \tag{4}$$

with weights η_{jt} capturing expenditure shares, sampling and so on[18]

This specification may be viewed as an approximation to a change in a price index or a literal recipe for creating the measure of inflation. For many of the prices, the changes will be zero.

Klenow and Kryvstov (2008) propose a decomposition of inflation into the weighted fraction of prices changed in the period, which will be called f_t in this discussion, the average size of price changes, which will be called m_t. More specifically, defining a_{jt} as a selection (dummy) variable for non-zero price changes, the decomposition is

$$\pi_t = f_t m_t \tag{5}$$

with

$$f_t = \sum_{j=0}^{J} v_{jt} a_{jt}$$

and

$$m_t = \frac{\sum_{j=0}^{J} v_{jt}[\log(P_{jt}) - \log(P_{j,t-1})}{\sum_{j=0}^{J} v_{jt} a_{jt}}$$

This framework can be elaborated in various ways. First, Nakamura and Steinsson (2008) utilize a breakdown into positive and negative price changes. Within the accounting framework, this would be

$$\pi_t = f_t^- m_t^- + f_t^+ m_t^+$$

with $f_t = \sum_{j=0}^{J} v_{jt} a_{jt}^-$ and $m_t^- = [\sum_{j=0}^{J} v_{jt} a_{jt}^- [\log(P_{jt}) - \log(P_{j,t-1})]/\sum_{j=0}^{J} v_{jt} a_{jt}^-$ as well as similar constructions for f_t^+ and m_t^+. Second, Berger and Vavra study the distribution of non-zero price changes in detail: at each date, they compute statistics describing the shape of the distribution including moments and percentiles. For the

[18] In broad form, the discussion accords with material in BLS 2015 Handbook of Methods, Chapter 17, page 18).

Evidence prior to 2008

So, is it m or f during 2008-2016?
Bils and Klenow: widely differing adjustment rates across types of goods.

latter task, my understanding is that they proceed as follows each month: (i) they select only nonzero price relatives; (ii) they rescale the weights on these relatives so that they sum to one; (iii) they then order the relatives from low to high; and (iv) sum the weights appropriately to form percentiles. For example, starting from the smallest price change, they sum the weights until the result is .10 and that price relative is the 10th percentile.

3.5 The evolution of adjustment frequency

The literature has explored two different measures of adjustment frequency. Klenow and Kryvstov (2008) consider the behavior of the fraction of prices changed, which is f_t in (4). Nakamura and Steinsson (2008) take median frequency across sectors. For the monthly data 1998-2011, Berger and Vavra calculated both of these measures and these are displayed in the two panels of Figure 3.4. The full sample is shown in Panel A: there is substantial time series variation in each of these measures. Further, with the exception of the 2000-2006 interval, these measures display broadly similar patterns. In particular, the two series move in a parallel fashion during 2008-11 as shown in Panel B.

The relatively close correspondence over 2008-2011 is important to us, because may indicate that the patterns are not driven by large changes in a small number of types of goods, which is somewhat comforting because, as explained above, we would ideally like to look at a series closer to a "core" construction such as the narrower inflation measure in Figure 3.2.

3.6 The evolution of price adjustments

The percentiles of the distribution of price adjustments produced by Berger and Vavra is shown in Figure 3.5, which is a complicated but informative figure about determinants of the micro-based inflation rate which we saw in Figure 3.3 and which is best interpreted as an inflation rate for "CPI less shelter and used vehicles, purged of sales." The median regular price change is the solid red line at the center of the graph, which fluctuates above and below zero. The mean value of the median price change over the 1988-2011 sample is .5%, which corresponds to a 3% annual inflation rate. In the BV data set, therefore, the fraction of positive adjustments is typically higher than the fraction of negative price adjustments (about 80% of the months).

The range of price changes is large, in line with the general findings of the literature. During recessions, the distribution shifts downward with all of the percentiles falling except for the 90th percentile. Further, as stressed by Vavra (2015), there is an increase in the spread of the distribution during the last two recession periods.

3.7 Price increases and decreases

The shifting distribution of non-zero price changes shown in Figure 3.5 has implications for the fraction of price changes and decreases in a given month. Given the Nakamura and Steinsson evidence on the frequency of price increases and decreases shown in panel B of Figure 3.1, I calculated an estimate of these fractions as follows. First, in each month, I fit a beta distribution (with a rescaled base) to the percentiles of the price relatives shown in Figure 3.6. Second, I calculated the probability of a negative price change given that distribution. Third, I multiplied the resulting probability by the average frequency of adjustment displayed in Figure 4. The result is shown for the full sample period in the top panel of Figure 3.6. There is substantial volatility in the calculated frequency of increases and decreases. Notably, during the latter two recession intervals, the frequency of decreases rises sharply and exceeds the frequency of increases.

The procedure of estimating the beta distribution is more complicated than necessary for the task of producing results reported in Figure 3.6. From Figure 3.5, we know that the median price change at the 50th percentile is negative during the last two recessions, so that the frequency of decreases must exceed that of increases during the period. A similar result is obtained just by taking a straight line interpolation between the median and its nearest neighbor to estimate the probability of a negative price change. The procedure should also provide information on other statistics of interest, such as the average size of price decreases and increases. However, at present, the method does not produce results for these other tasks which are robust to small changes in implementation.

3.8 The implicit mean of micro price adjustments

Using (4), the BV micro-based inflation rate from Figure 3.3 and the average frequency from Figure 3.4, we can calculate a value of the mean change as $m_t = \pi_t / f_t$. Figure 3.6 shows this series along with the median and two near-by percentiles. This implicit mean is highly volatile, much more than I expected even given the work of Klenow and Krytsov (2008).[19]

With a measure of the mean, one can ask the Klenow-Kryvtsov question "during a specific time interval, how much of inflation was accounted for by changes in f_t, and how much by m_t?" The two panels of Figure 3.8 show that fluctuations in the average size of price changes account for essentially all of the changes in the micro-based CPI series created by Berger and Vavra (2015): these figures are related to a main result of their paper, which is that the intensive margin dominates inflation when they implement a particular approach to breaking inflation into intensive and extensive components due to Cabellero and Engel (2007). The simpler procedure employed in Figure 3.8 is to take fix the mean adjustment frequency at its value over the full sample (1988-2011) and to then create an inflation measure as $f * m_t$. The result using the implicit mean inflation rate is shown in the top panel: the fixed frequency version matches the BV micro inflation series (with both the micro inflation series and the implicit mean series deseasonalized using quarterly dummies with coefficients estimated through 2007). A second perspective is provided by the lower panel of Figure 3.8, where two different simulated inflation series are calculated from the median price relative. (I construct these series because they do not rely on implicitly creating the mean, which could overstate its effect if the frequency is mismeasured). The solid line is $f_t * \phi_t^{50}$ and the dots are $f\phi_t^{50}$. Even when using the smoother median series, the variations in frequency are dominated by variations in the size of price changes.

To put matters in perspective, suppose that inflation is 1.8% per year, which is close to the sample mean for the micro-based CPI constructed by BV over 1998-2011. Then, monthly inflation is .15%. Suppose further that frequency is .11, the mean value over 1998-2011. Then, the average price relative must be 1.36%. If frequency were to fall to .9 (which would be the range of decline from 2008 through 2011) in Figure 3.4, holding fixed the price change, then monthly inflation would fall from .15% to .12% (and annual inflation to 1.4%). But the changes shown for the median in Figure 3.7 are much larger than this variation.

Thus, for 2008-2001 and earlier, the BV data set supports the conclusion that inflation is mainly accounted for by changes in the size rather than the frequency of

[19] Even though the the micro-based series has some seasonality, removal of it does not affect the general shape of the implicit mean picture over 2008-2011.

adjustment.

At the same time, macroeconomists have a sense that changing adjustment frequency can be important for the linkage between inflation and real activity. Discussing his own estimates that the slope of the Phillips curve has declined since the 1980s but not much since 1994 or during the recent recession, Blanchard (2016) writes: " Given expected inflation, a (1%) decrease in the unemployment rate led to an increase in inflation of 0.7 percent in the mid-1970s. The effect is now closer to 0.2 percent. Various explanations have been offered for this evolution. The most convincing is that, as the level of inflation has decreased, wages and prices are changed less often, leading to a smaller response of inflation to labor market conditions." Vavra (2015) sees a connection between changing microeconomic volatility, the frequency of adjustment, and the size of adjustment which leads the Phillips curve slope to be lower in recessions (and other times of high volatility).

In addition to microeconomic evidence on price-setting using official survey data, economists have explored the nature of price adjustments for individual firms and groups of firms. One recent study by Eichenbaum, Jaimovitch and Rebelo (2011) focuses on the interplay between a variant of regular prices – which they call reference prices – demand and cost. It is to that interaction at the macro level to which I now turn. But before we do, it is useful to indicate a useful and reasonable set of calculations that micro price researchers and the BLS could produce.

3.9 New public research indices

BLS regularly produces some public access output of a "research series" form. For example, in working with labor data and having concerns about the jumpiness of standard BLS population series, it is useful to employ the research series "Labor force and employment smoothed for population control adjustments."

It would be useful for academics working on micro pricing to help BLS create new pricing research series, both in terms of the design and potentially in terms of development of algorithms that the BLS could simply make use of each month.

In this research, I'd like to have started with micro-based components of a core-like CPI series – excluding food and energy as well as shelter – with estimates of π_t, f_t and m_t. for regular and total price changes. In terms of understanding inflation during 2008-9 and more broadly, it would be desirable to have breakdowns of this core micro-based CPI into durables, nondurables, and services.

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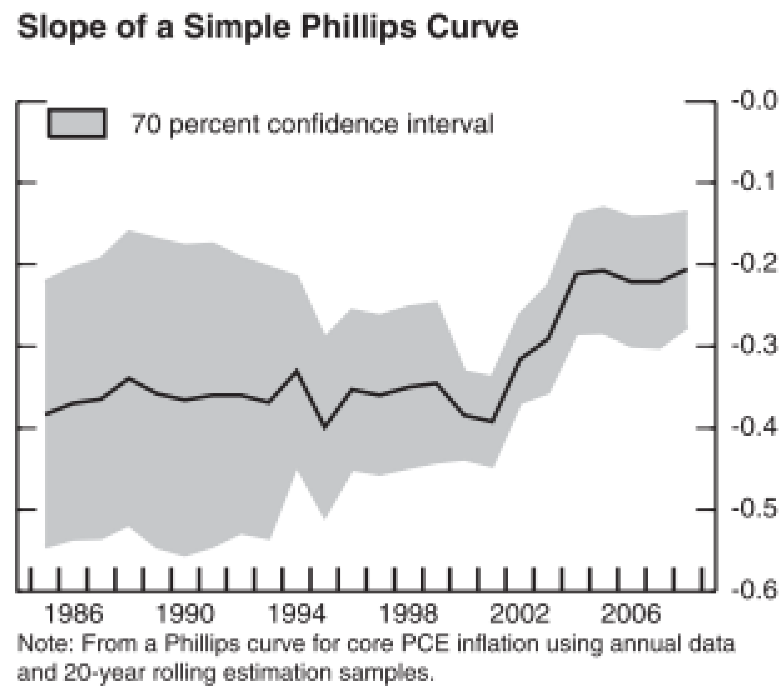


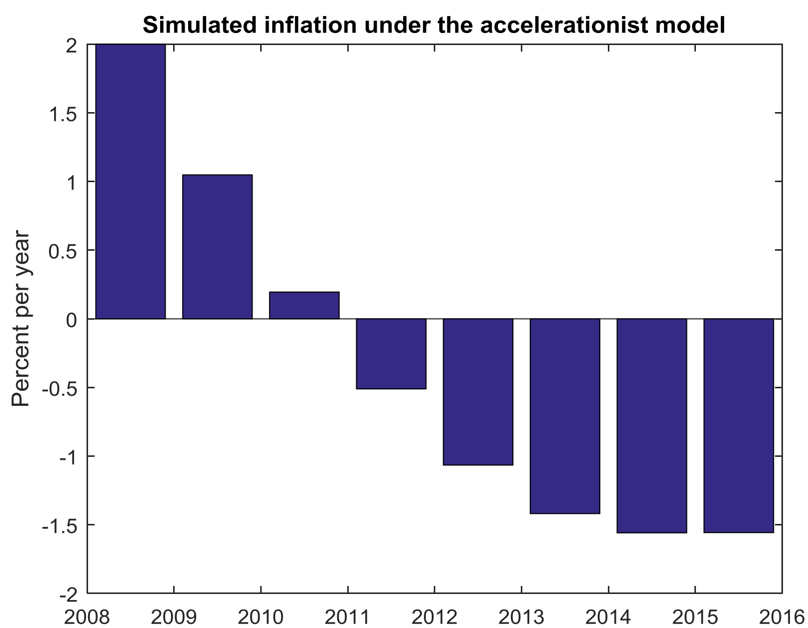


Figure 1.1: The Accelerationist perspective.

Top panel: Estimate of a simple Phillips Curve using rolling 20 year windows on annual data, taken from presentation materials for the June 23 2009 FOMC meeting, Exhibit 5.

Bottom panel: Counterfactual inflation calculated using $\pi_t = \pi_{t-1} - .2\ (U_t - 5)$, where U is annual average unemployment for each year starting July 2009 and the initial conditions in 2008 are π=2 and U=5.

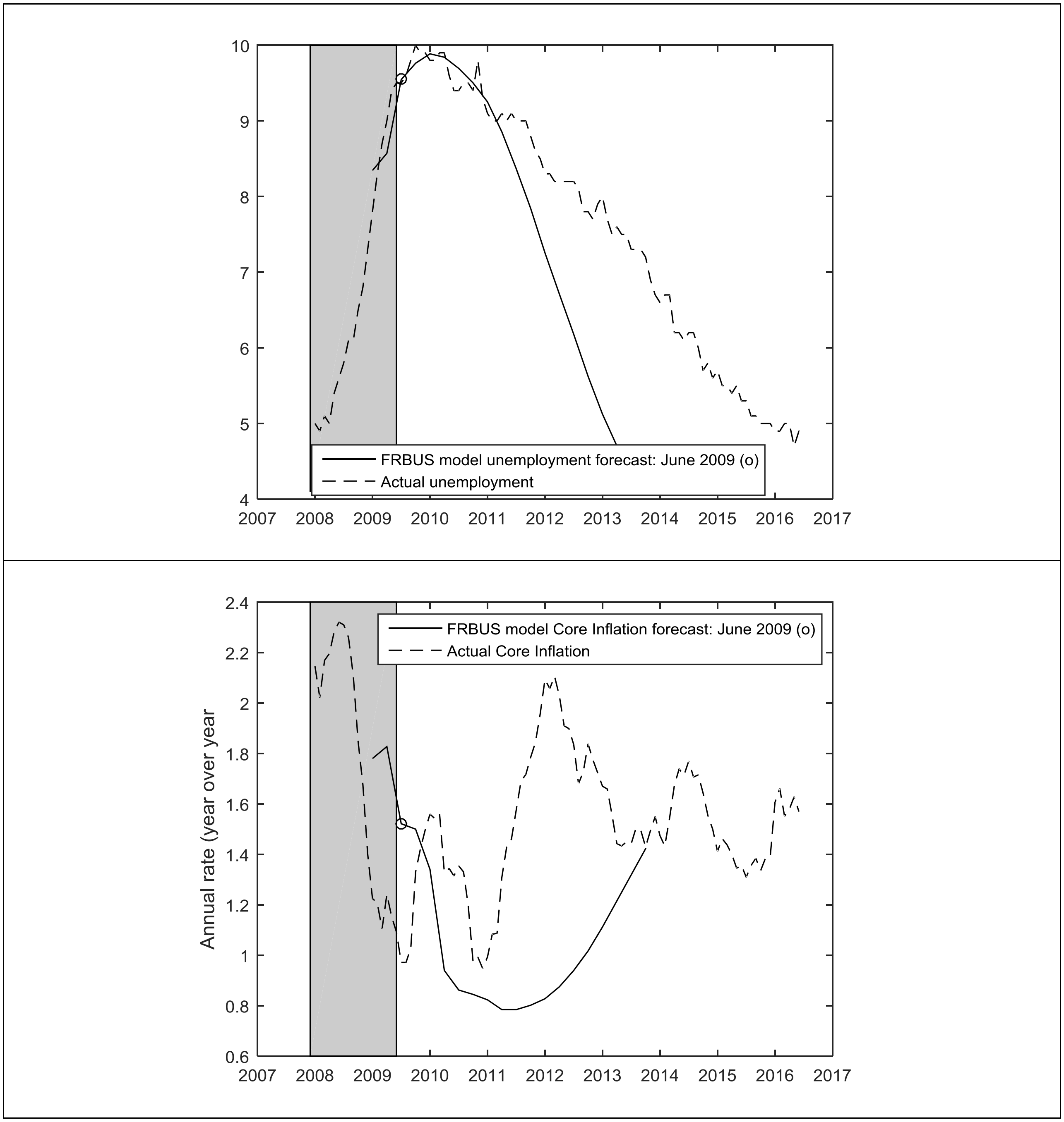


Figure 1.2: Inflation and Unemployment Forecasts in June 2009

Solid line: Fed Board Staff Extended Forecasts prepared for June 2009 FOMC meeting, as reported in Chart 8 of the BlueBook. Dashed Line: Actual unemployment and inflation experience. Unemployment: Civilian Unemployment Rate (Percent) Monthly, seasonally adjusted. Inflation: Personal Consumption Expenditure Excluding Food and Energy, Chain Type Price Index Monthly (Percent change from a year previous), seasonally adjusted.

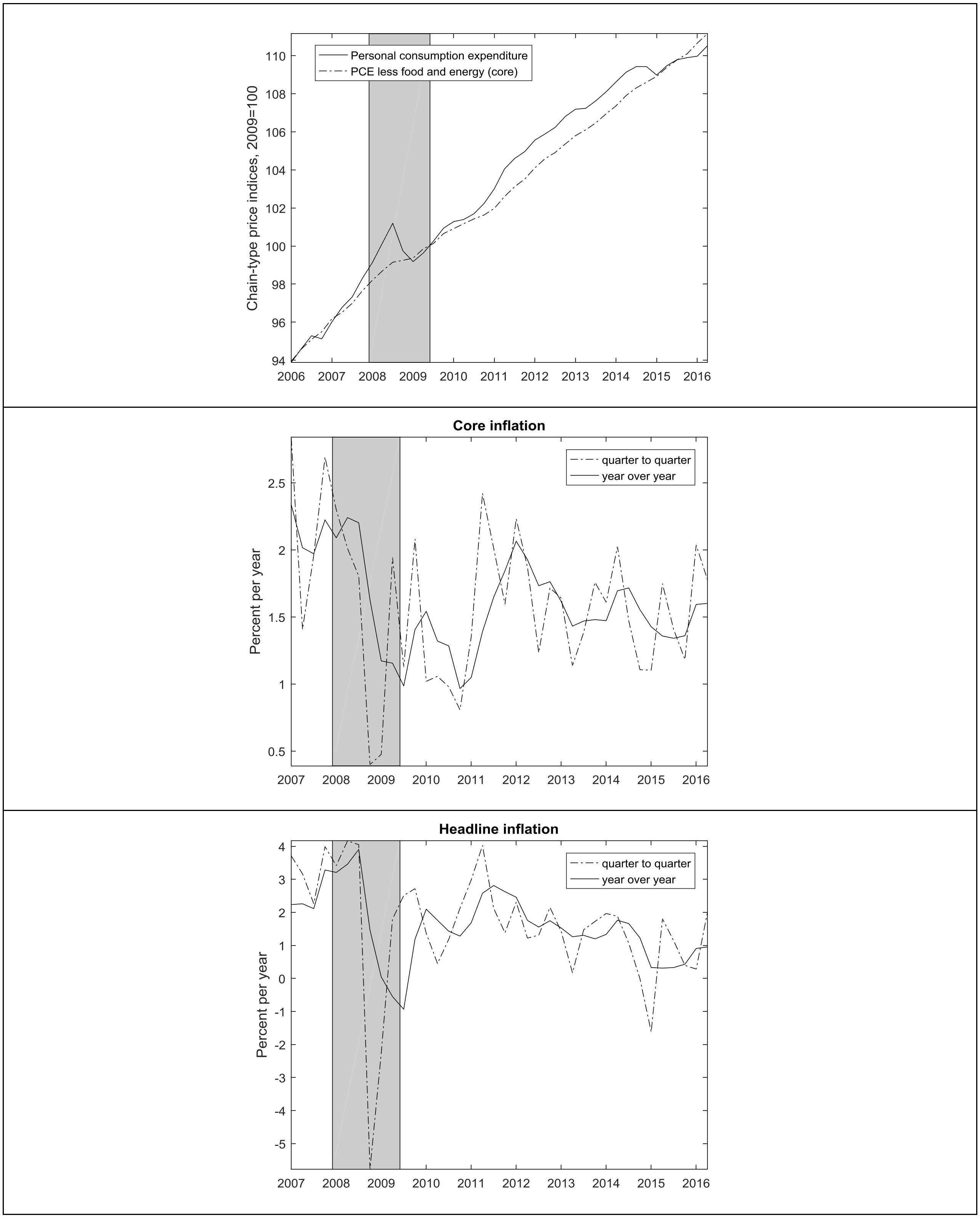


Figure 2.1 The Personal Consumption Expenditure price indices and measures of inflation

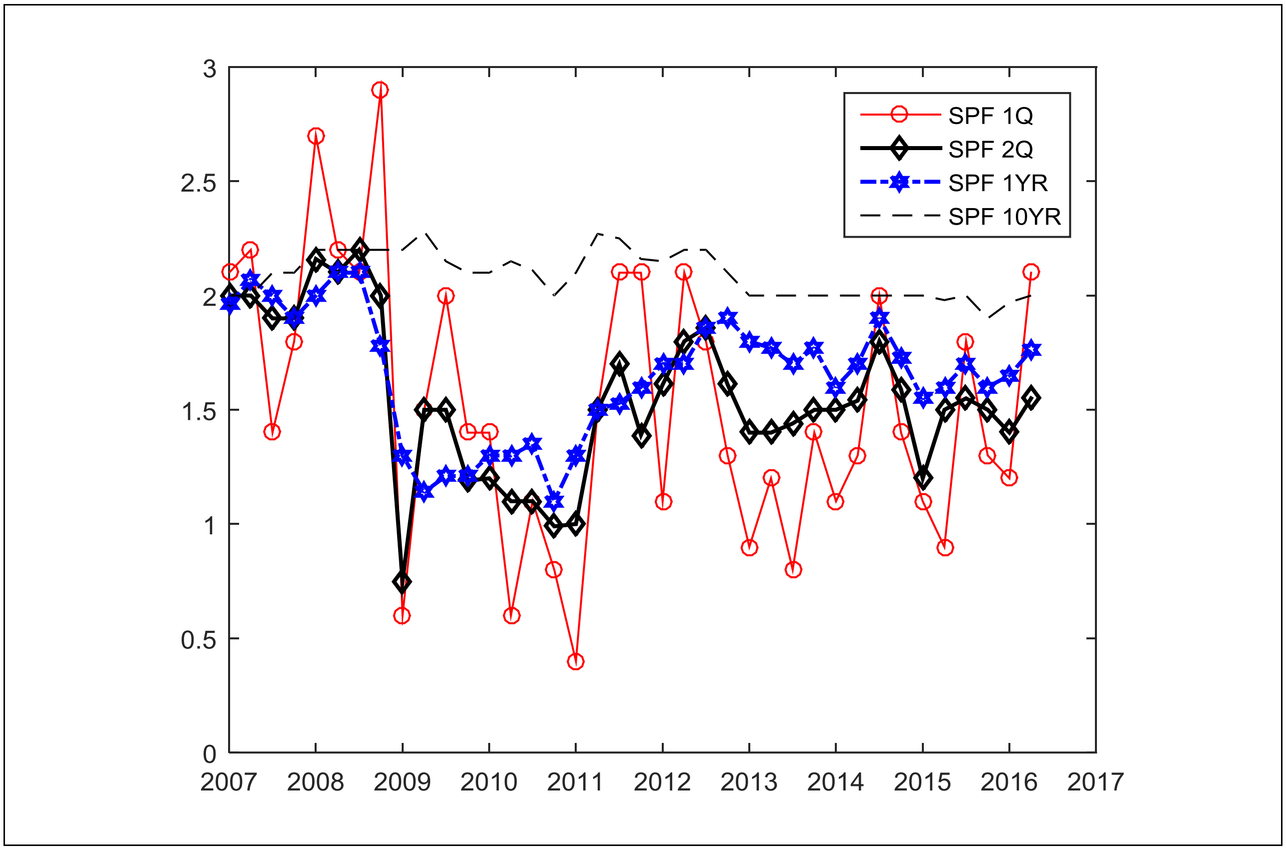


Figure 2.2: Forecasts from the Survey of Professional Forecasters assembled by the Federal Reserve Bank of Philadelphia. SPF 1Q, SPF 2Q and SPF 1YR are one quarter ahead, two quarter ahead and four quarter ahead forecasts of the Core PCE, while SPF 10YR is a forecast of the long-term Headline PCE inflation rate.

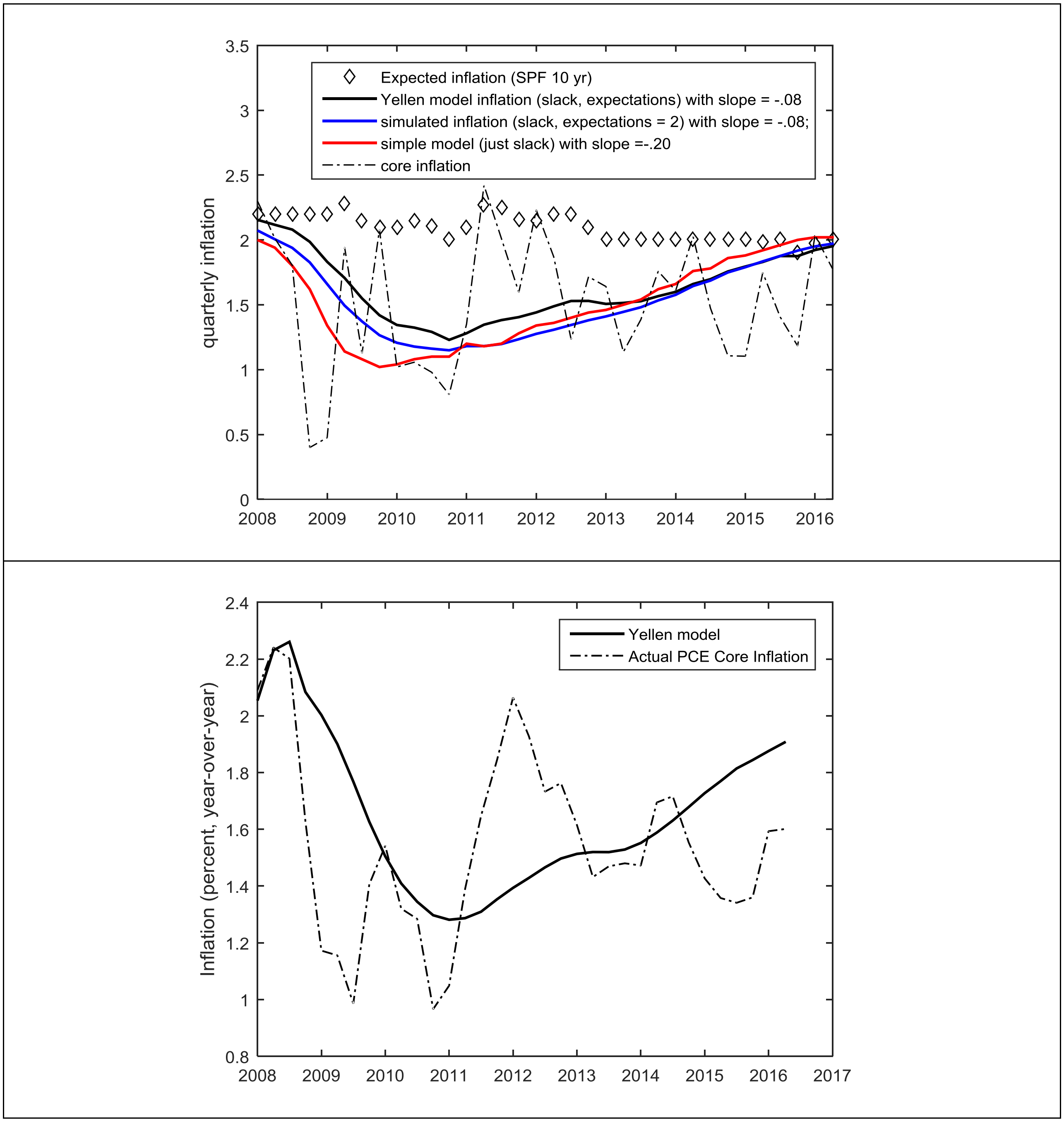


Figure 2.3: Simulated inflation series. The solid black line in both panels is a simulation of the long-term expectations model described in FRS Chairman Janet Yellen's lecture on Inflation Dynamics at the University of Massachusetts at Amherst in Fall 2015. The solid blue line is a variant with inflation expectations constant at 2%, while the solid red line is a simple reference specification described in the text. The dashed line in both panels is the actual Core PCE inflation rate. The top panel is a quarterly inflation rate (annualized) while the bottom panel is a year-over-year inflation rate.

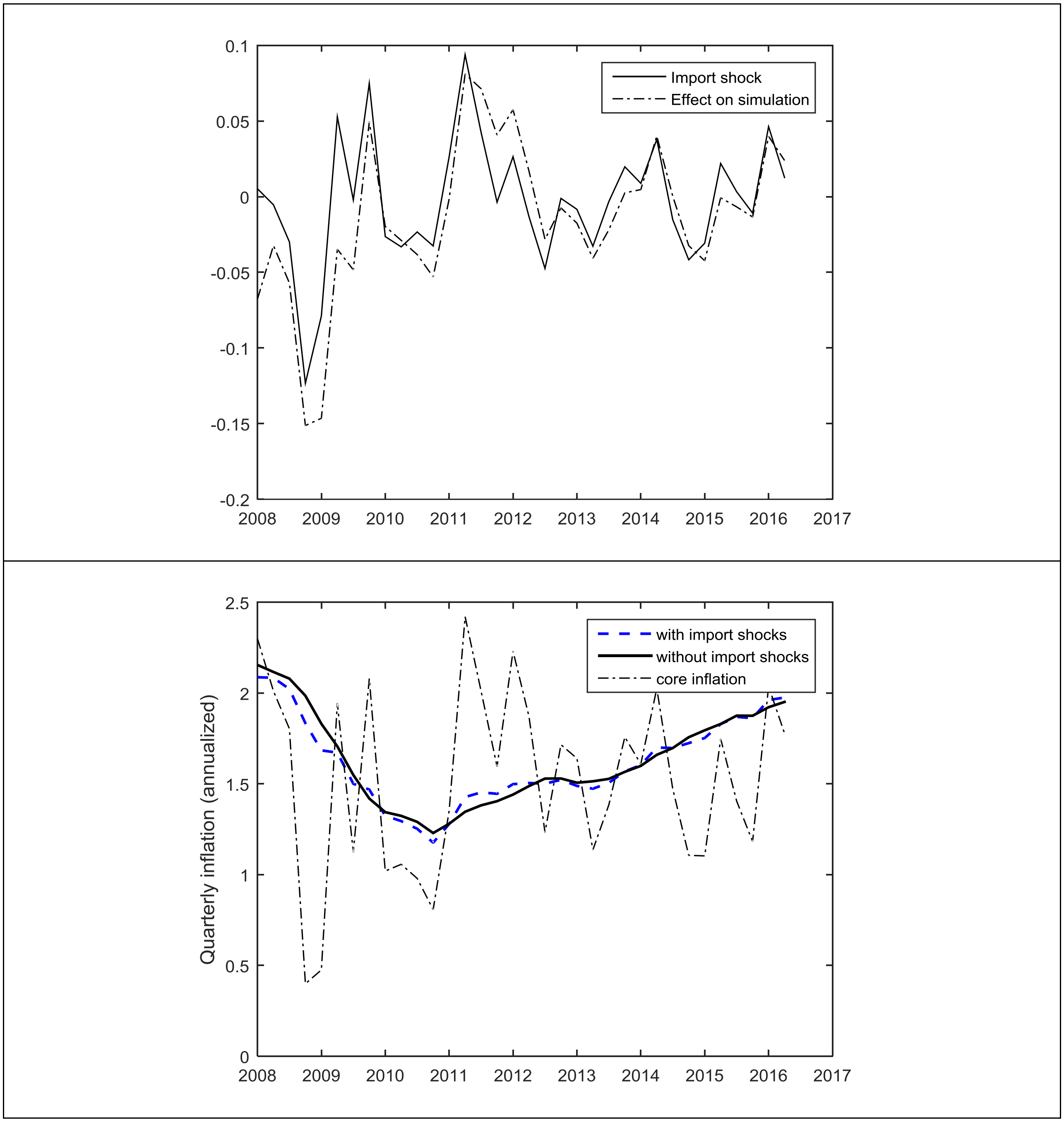
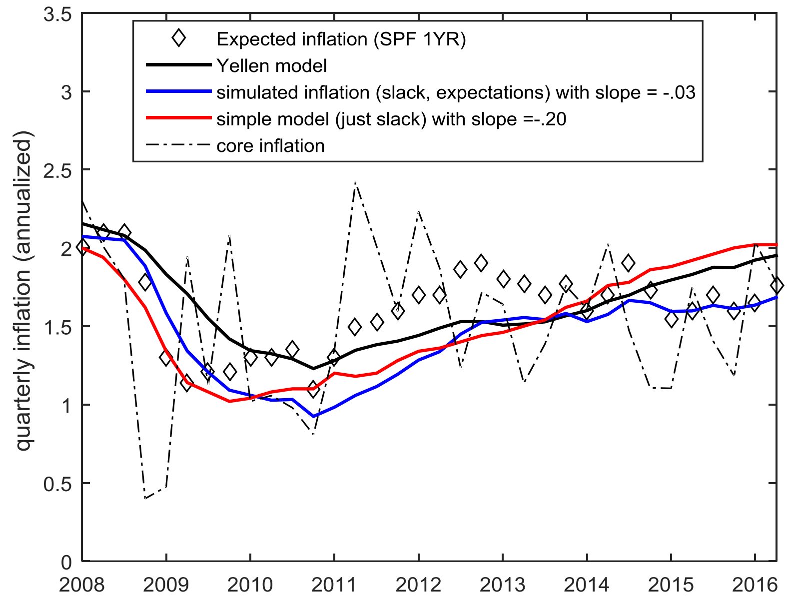


Figure 2.4: The top panel is a relative price of imports shock which is a simple version of a shock used in the Yellen (2015) study and is similar to one used by Watson (2014). The top panel includes the shock itself and its contribution to the model when fed through the distributed lag structure. The bottom panel is the model with and without the import shock and the actual quarterly Core PCE inflation rate.



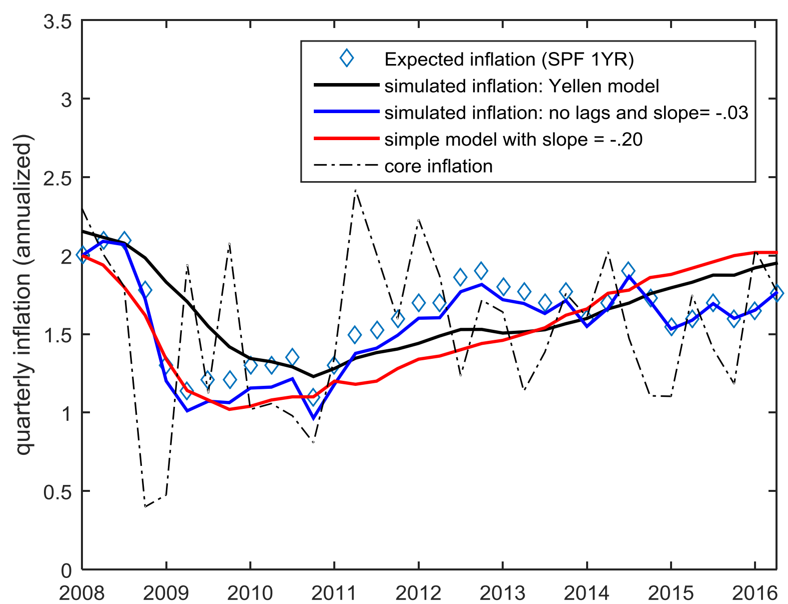


Figure 2.5: Two inflation specification with SPF 1YR inflation expectations (solid blue lines). Both specifications involve a smaller slope coefficient than the Yellen model. Top panel: distributed lag and expectation coefficients as in Yellen (2015). Bottom panel: Purely forward-looking model with a coefficient of one on expected inflation. Reference information common to both panels: the Yellen model and simple inflation model repeated from Figure 2.5

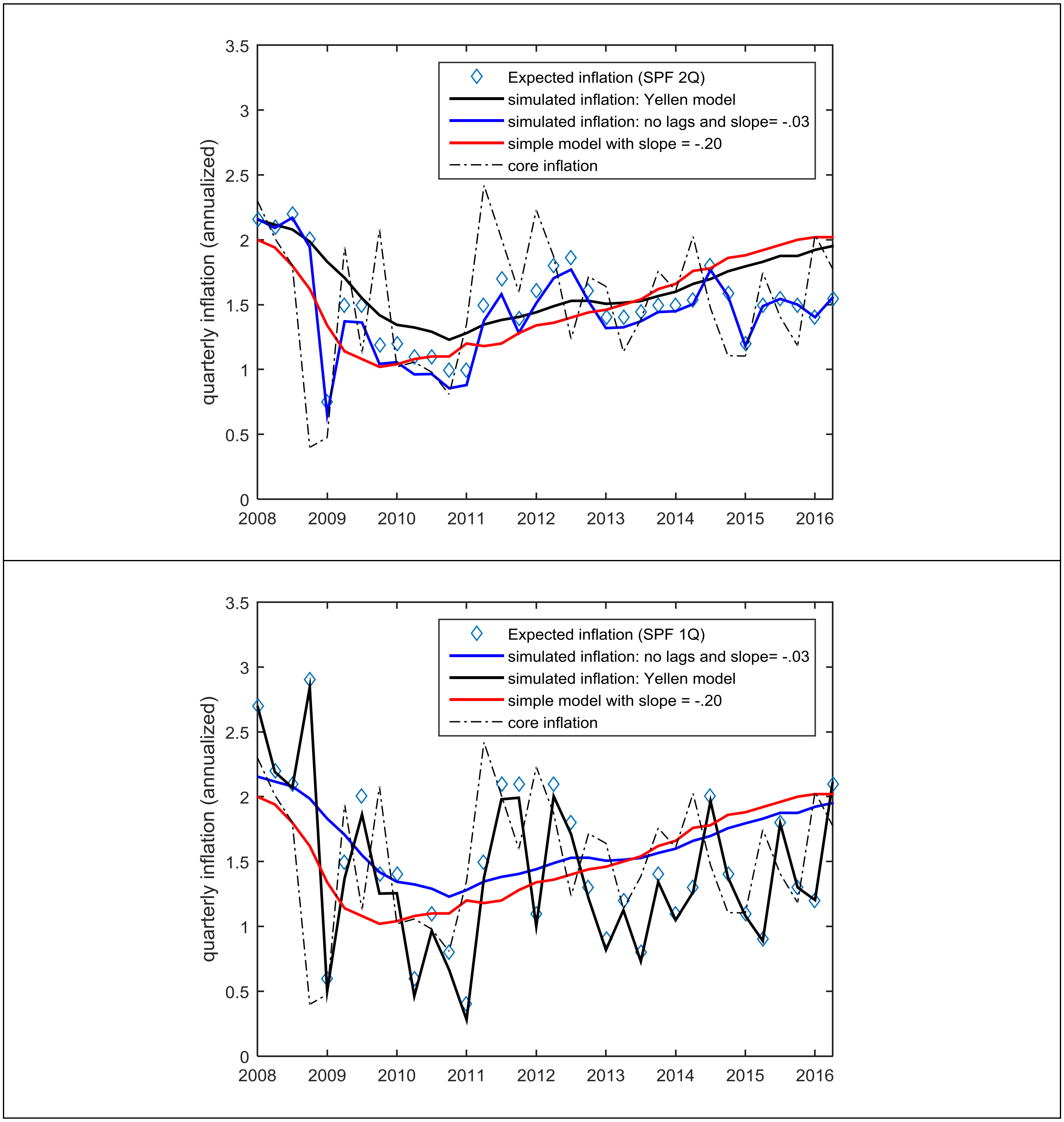


Figure 2.6: Inflation simulations with shorter-term inflation expectations in the purely forward-looking model. Top panel: SPF2Q. Bottom panel: SPF1Q

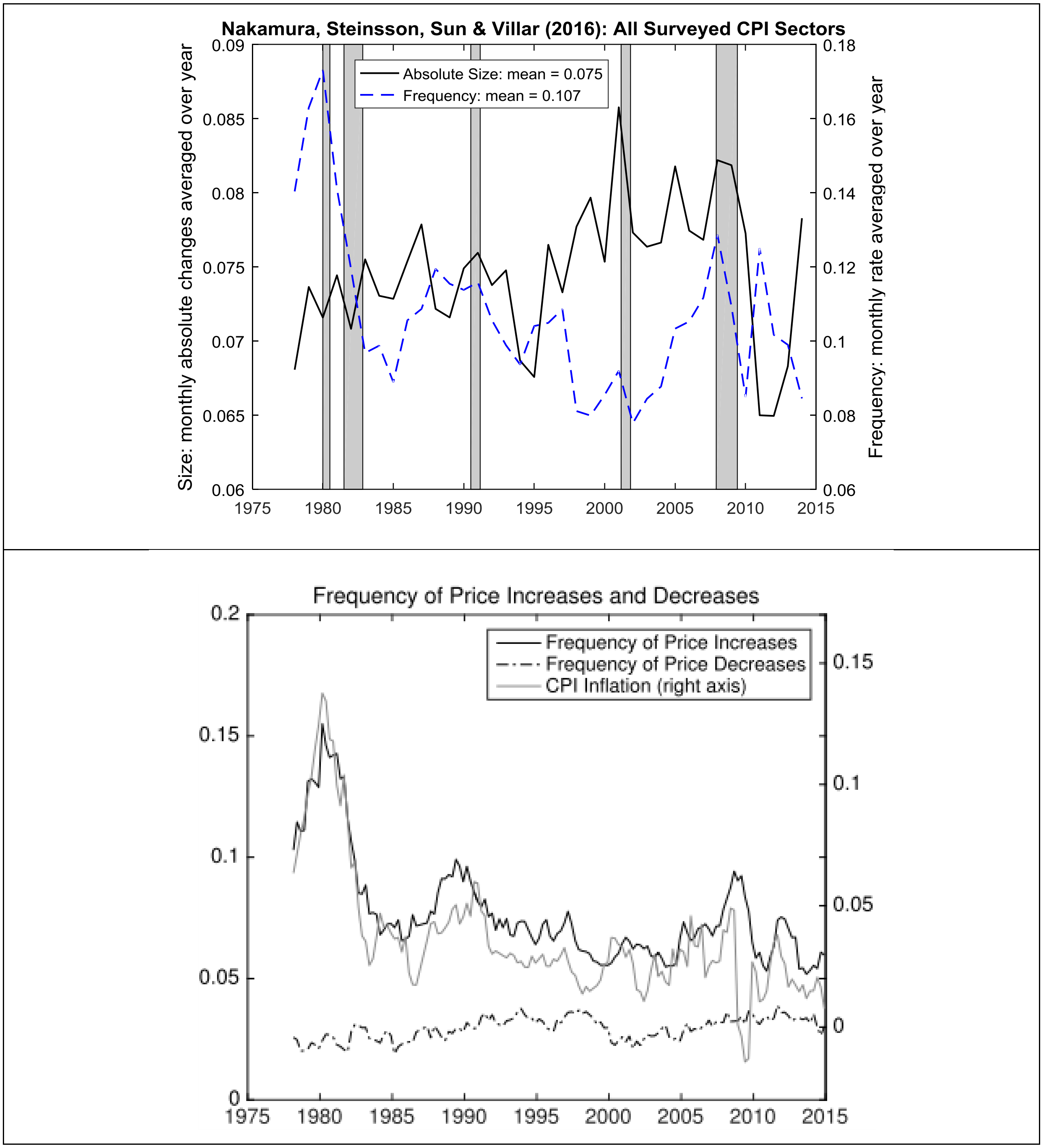
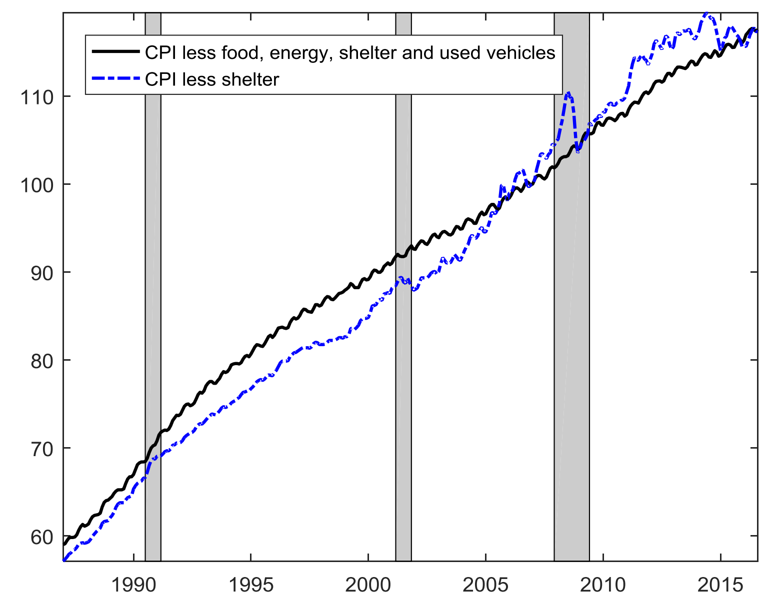


Figure 3.1: Measures of the frequency of price change and the average size of price adjustments based on the methodology of Nakamura and Steinsson (2008). Source: Nakamura, Steinsson, Sun and Villar (2016)



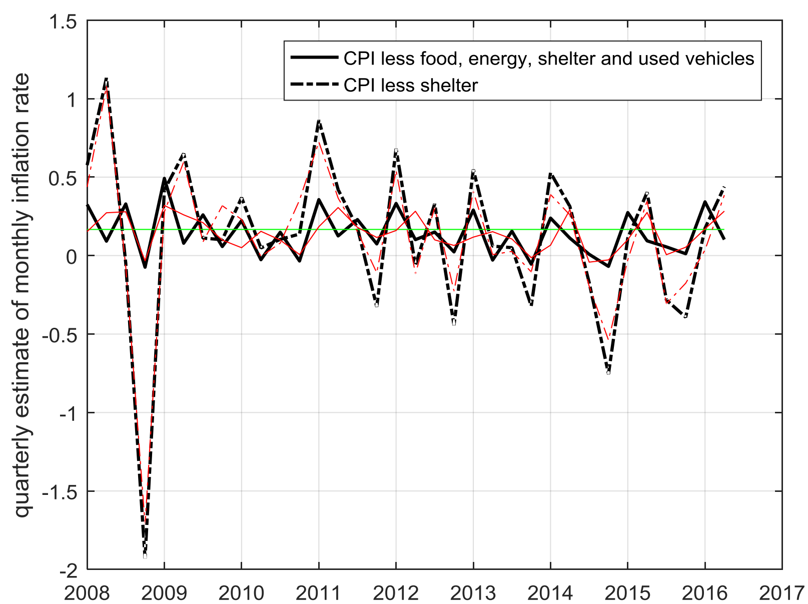


Figure 3.2: BLS CPI aggregates useful for thinking about results of micro studies. The micro price survey information is not used to produce CPI components for shelter or for used vehicles. However, it does contain information on food and energy components which are not included in core PCE or CPI.

Notice the units in the lower panel. A monthly inflation rate of 0.5% is an annual inflation rate of 6%. These units are the natural ones for relating changes in micro prices to aggregate inflation. The series are quarterly averages of monthly data.

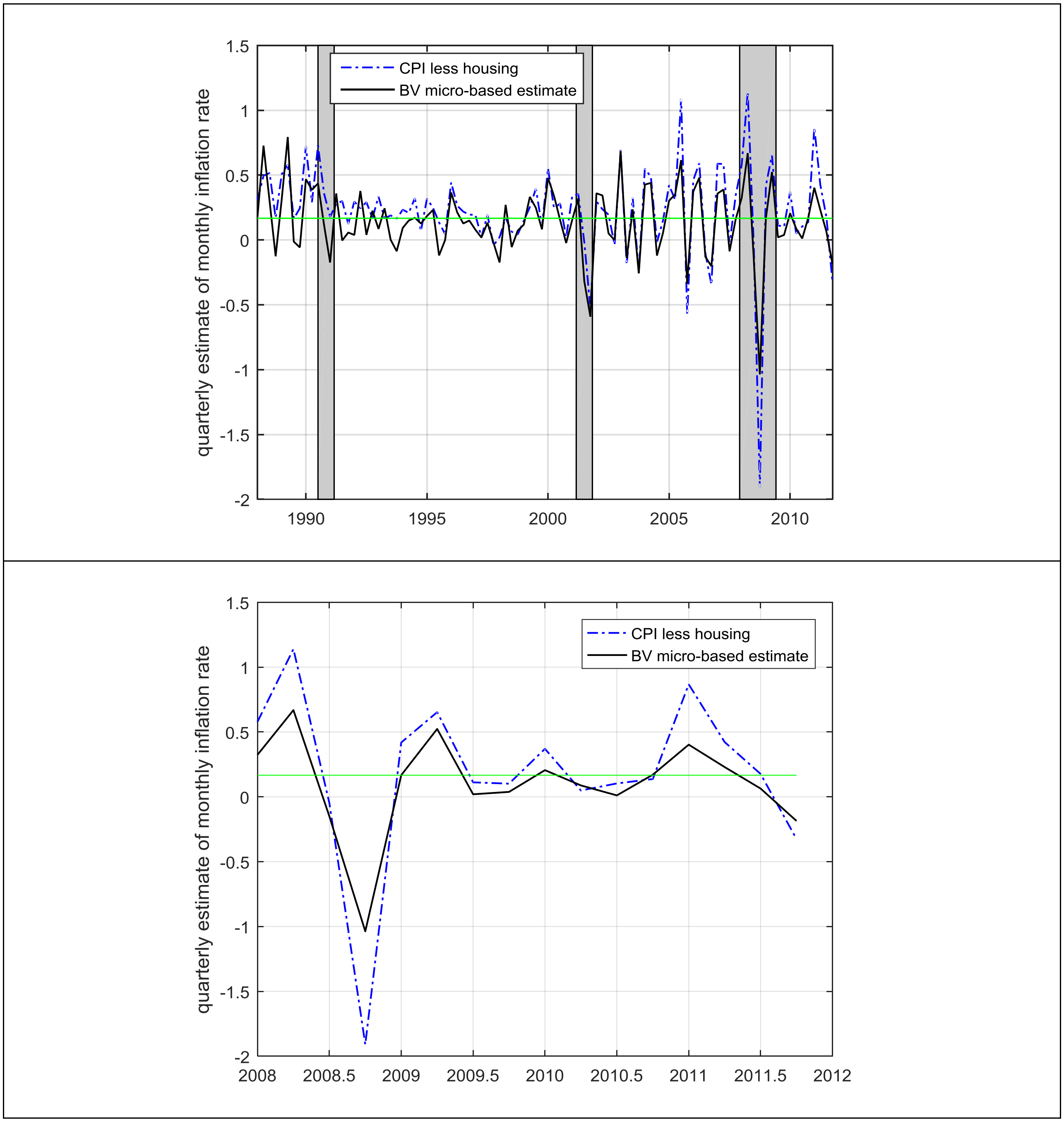


Figure 3.3 Each panel displays two series, measured as a monthly inflation rate. The CPI less housing is the same BLS aggregate shown in Figure 3.2 The other inflation rate is that calculated by Berger and Vavra (2015) from BLS micro data, as an average of the changes in individual prices.

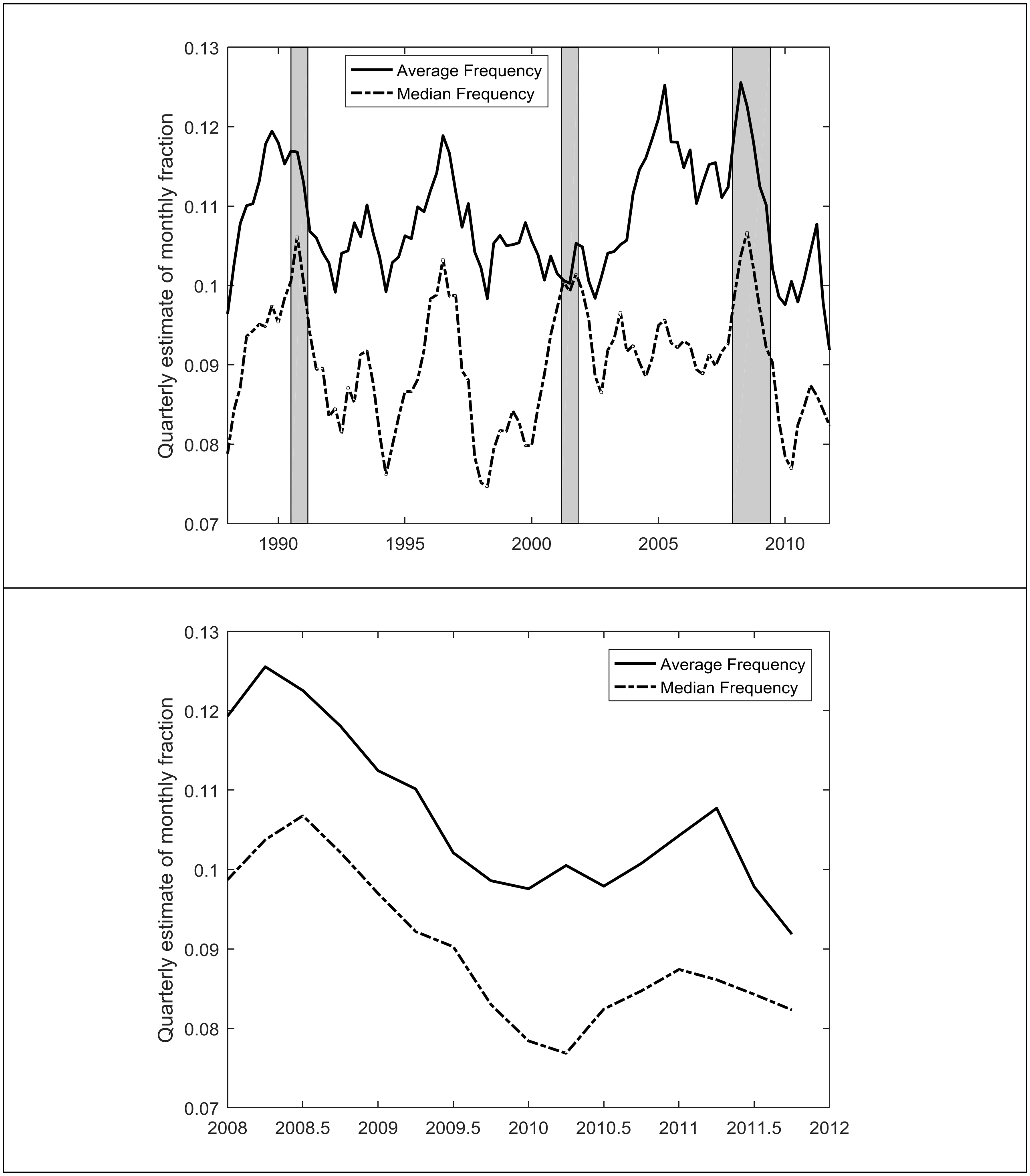


Figure 3.4: Estimates of the frequency of price adjustment produced by Berger and Vavra (2016). Quarterly averages of underlying monthly frequencies of adjustment (seasonal means removed). The median frequency of adjustment is taken across 1 digit industries, as in the work of Nakamura and Steinsson (2008). The average frequency of adjustment uses only BLS weights and is closer in design to Klenow and Kryvtsov (2008).

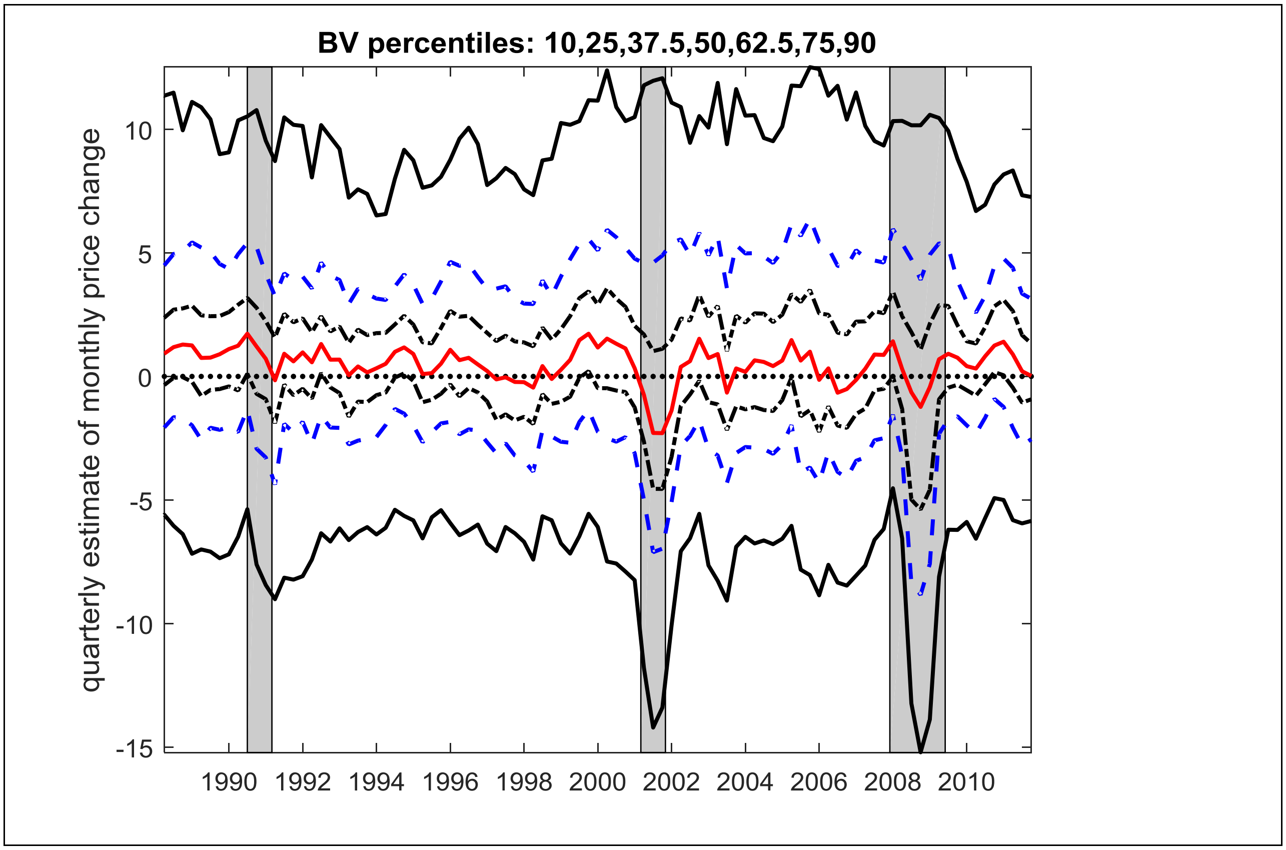


Figure 3.5: The evolving distribution of adjustments of "regular prices" captured with selected percentiles. Calculated by Berger and Vavra (2015) from BLS micro data. Quarterly averages of monthly figures.

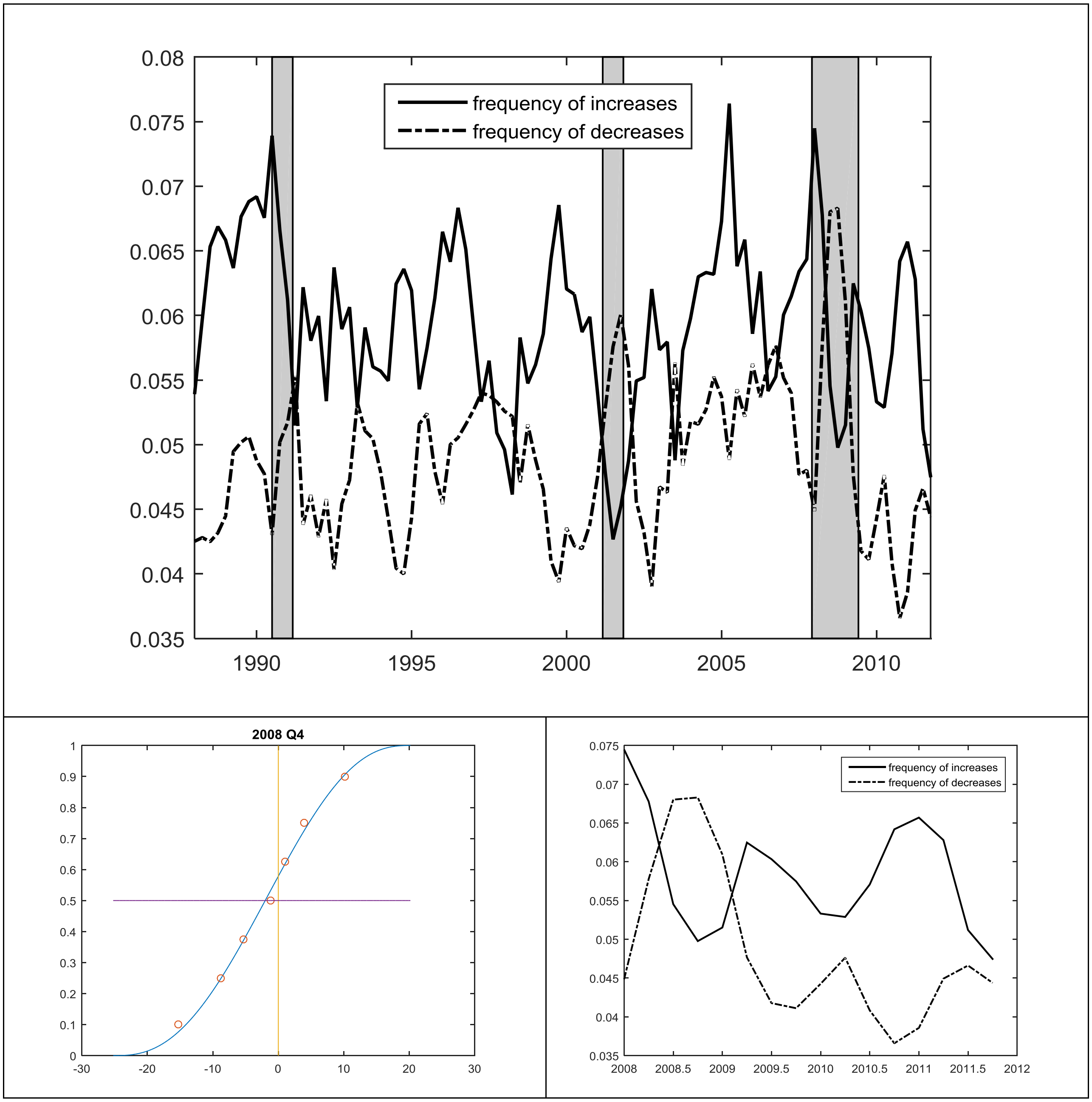


Figure 3.6: An estimate of the frequency of price increases and price decreases calculated from the data in Figure 3.5. Method illustrated with November 2008, a month in which the average frequency of adjustment in Figure 3.4 was just under .12. Using a beta distribution fit to the price relative percentiles (top left), the fraction of negative changes – conditional on adjustment – is .59. Hence, the frequency of negative adjustment overall is .068.

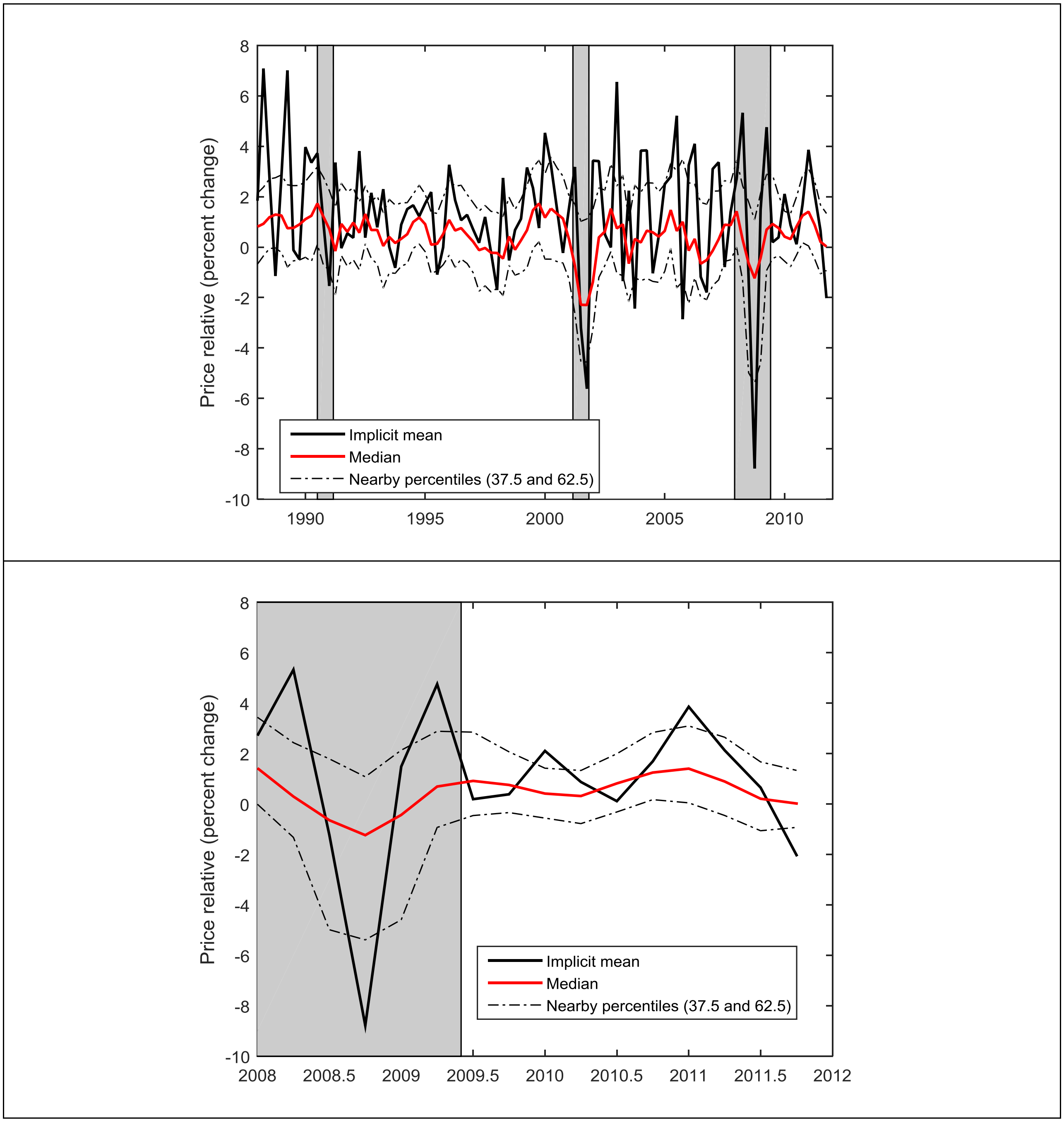


Figure 3.7: The implicit mean and other measures of price relatives The identity $\pi_t = f_t * m_t$ connects the inflation rate to the frequency and the mean price relative. The implicit mean is obtained by dividing the monthly BV micro-based inflation rate in Figure 3.3 by the average frequency in Figure 3.4.

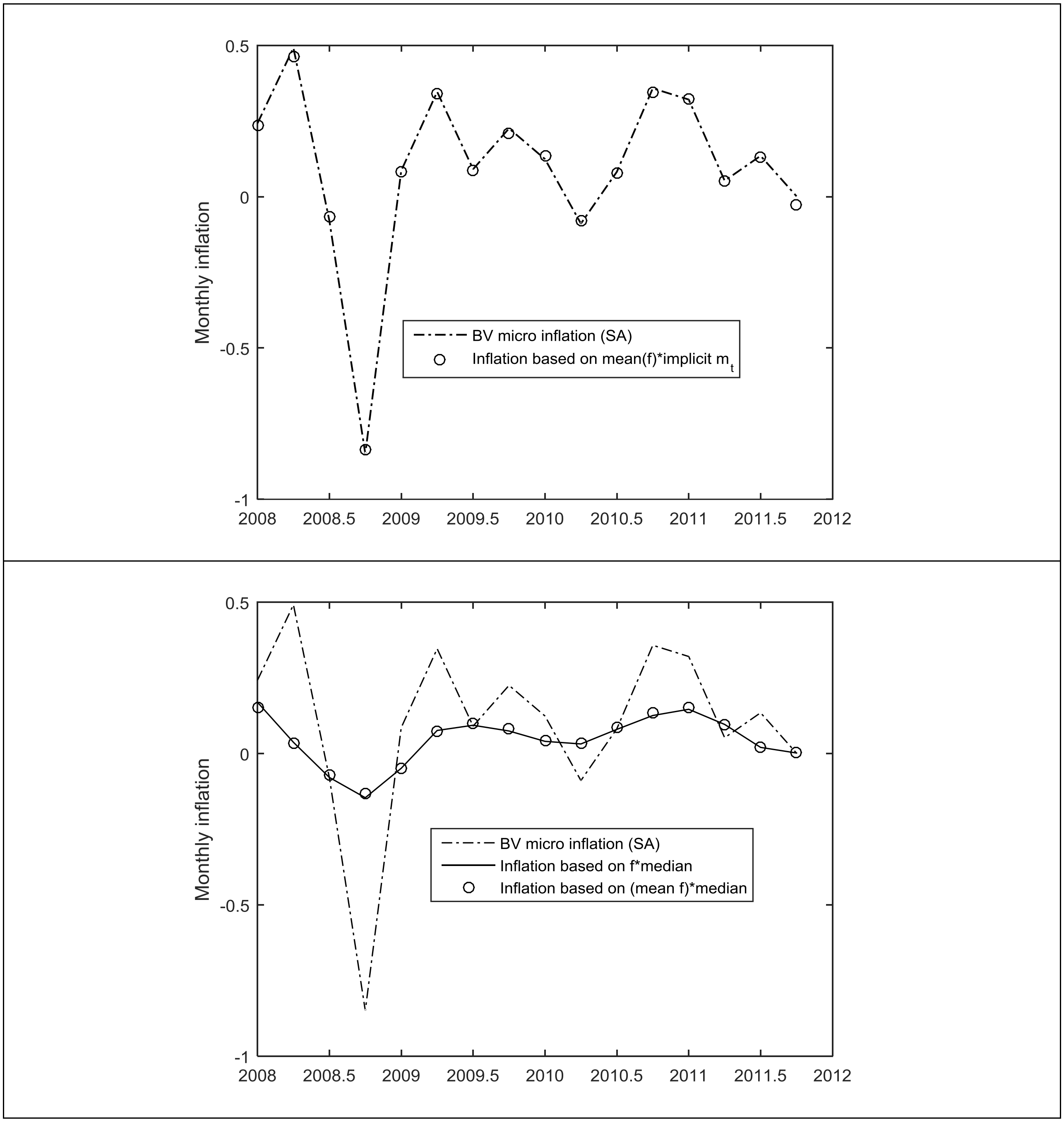
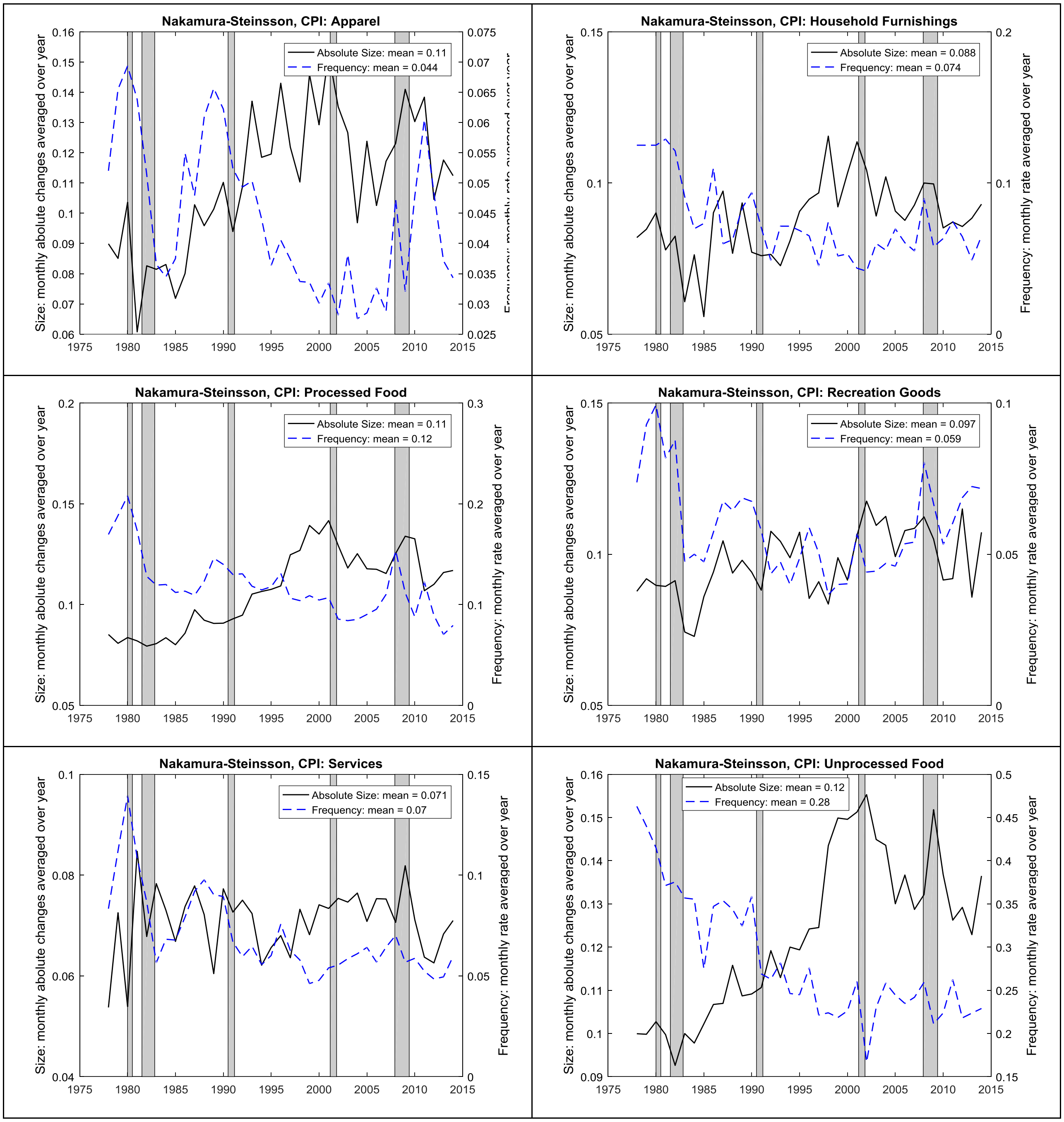


Figure 3.8: Inflation constructed using fixed frequency assumption (full sample mean). Top panel: mean frequency multiplied by implicit mean. Bottom panel: mean frequency multiplied by median. Implicit mean and median of the price relatives shown in Figure 3.6



Appendix Figure A-1