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An Empirical Assessment of the Relationships Among Inflation and Short- and Long-Term Expectations

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Abstract

This paper uses a detailed literature review and an empirical analysis of three models to assess the links among inflation and survey measures of long- and short-term expectations. In the first approach, we jointly estimate a model of inflation, survey expectations and monetary policy, where each is a function of a common time-varying inflation trend. In the estimates, long-term expectations track closely the unobserved trend that is an important factor in inflation dynamics, implying that changes in long-run expectations can lead to persistent movements in inflation. In the second approach, we estimate a time-varying parameter VAR with stochastic volatility. This model relaxes the cross-equation and constant parameter restrictions from the first model. Impulse response analysis shows a relatively stable relationship between inflation and survey measures of inflation, although with some modest changes consistent with improved anchoring of long-term expectations. Finally, we rely on a conventional VAR framework incorporating several macroeconomic variables, including both short- and long-term measures of expected inflation. In these estimates, shocks to either measure of expectations lead to a rise in the other measure and some limited pass-through to inflation. Shocks to inflation cause both short- and long-term expectations to rise. Other factors such as monetary policy, economic activity, and food price inflation also affect expectations and inflation.

JEL Classification: E31, E32, E52

Keywords: expectation, trend inflation, inflation dynamics

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1 Introduction

In the conventional New Keynesian model with rational expectations, current inflation is a function of the expected inflation rate next period and a measure of resource utilization. Monetary policy anchors short- and long-run expectations by responding aggressively to movements in current inflation.[1] In this framework, the relationships among inflation, short-run expectations, and long-run expectations are precise, where each is a function of fundamental shocks impinging on the economy, as opposed to expectational shocks. As a result, short- and long-run expectations generated by the model are redundant. That is, in the New Keynesian context there is no need for the central bank that responds aggressively to inflation to separately monitor inflation expectations in addition to actual inflation. In practice, however, measures of short- and long-run expectations are not usually considered redundant, even if one has a good forecasting model of inflation.

Accordingly, this paper assesses the additional information that expectations data may convey, and what influences expectations. More specifically, we consider the following questions.

1. How do expectations influence inflation? Do the roles of short-run and long-run expectations differ?

2. What influences expectations? That is, how do expectations depend on past inflation, the state of the economy, and monetary policy? How do long-run expectations relate to short-run expectations?

3. What's changed over time? Have the relationships among inflation and expectations changed in recent years, making inflation and expectations more or less anchored? What might account for any changes?

Our assessment begins with a detailed survey of the literature. We then proceed to our own empirical analysis of these questions, based on three different time series models and survey measures of short- and long-term inflation expectations from 1981:Q3 to 2008:Q2. Each model addresses a different aspect of the relationship between inflation and expectations. The first model uses survey data to extract a measure of survey participants' view of trend inflation. The second model assesses the stability of the relationship between inflation and survey measures. The third model addresses what factors move expectations and how expectations impact inflation.

More specifically, under the first approach, we jointly estimate a model of inflation, survey expectations and monetary policy. This approach combines elements

[1] That is, monetary policy reacts sufficiently aggressive to inflation so as to yield a unique bounded equilibrium.

from Kozicki and Tinsley (2006) and Kiley (2008b) by specifying inflation and the interest rate as a function of a common time-varying inflation trend. The trend can be thought of as a measure of the forecaster's perception of the central bank's implicit inflation goal. Cross-equation restrictions impose that survey measures conform, up to an error, to forecasts from the process governing inflation. Shifts in the trend then affect actual inflation, short-run expectations, long-run expectations, and the interest rate. The model estimates reveal that long-term expectations track closely the unobserved inflation trend. Consequently, even small movements in long-term expectations convey important information regarding survey participants' views of trend inflation, which is an important determinant of inflation dynamics. In turn, movements in long-term expectations are associated with persistent changes in inflation.

The second approach relaxes the constant parameter and cross-equation restrictions by estimating a time-varying VAR with stochastic volatility. The specification is similar to Cogley and Sargent (2005) and Clark and Nakata (2008), except we include short- and long-term expectations. Coefficient estimates and impulse response analysis show a relatively stable relationship between inflation and survey measures of inflation, but with some evidence of modestly increased anchoring of long-term expectations. Shocks to long-term expectations produce significant, commensurate increases in short-term expectations and inflation. Shocks to short-term expectations produce smaller, sometimes insignificant increases in long-term expectations and inflation. Shocks to inflation generate a temporary rise in short-term expectations and a small rise in long-term expectations. In addition, measures of volatility of expectations and core inflation have declined substantially throughout the sample period.

Given the stability of the relationship between inflation and expectations, the third approach moves to a conventional VAR framework incorporating several macroeconomic variables. The approach is similar to Leduc, Sill and Stark (2007), except we embed long-term inflation expectations in addition to short-term expectations and use some disaggregated elements of the CPI. This model, too, relaxes the cross-equation restrictions incorporated in our first model. We find that shocks to either measure of expectations lead to a rise in the other measure and some limited pass-through to inflation. Shocks to inflation, or even just food price inflation, cause both short- and long-term expectations to rise. Shocks to monetary policy eventually lower short- and long-term expectations, although only temporarily.

Overall, based on a literature survey and our own evidence, we suggest the following answers to the questions listed above.

1. Expectations are an important force in inflation dynamics, with long-run expectations, which are tantamount to trend inflation, more important than short-run expectations. A wide range of prior studies have found a key role for survey-based expectations in inflation dynamics. Our own estimates yield the same. In our initial state-space framework, trend inflation, which is essentially equiva-

lent to the long-run inflation expectation, receives greater weight in the equation determining short-run inflation dynamics than lagged realizations of inflation. In our VAR estimates, shocks to expectations (particularly long-term expectations) result in some pass-through to actual inflation.

2. Existing research and our own evidence indicate that inflation expectations respond to a range of variables, including past inflation, the state of the economy, and monetary policy actions. In our VAR analysis, innovations to CPI inflation pose the greatest risk to keeping short- and long-term expectations anchored. Short-term expectations respond more sharply than do long-term expectations. Shocks to food price inflation, economic activity, and monetary policy also move expectations.

3. A range of studies suggest inflation and expectations are probably better anchored today than 30 years ago. However, drawing on prior research and our own results, it is less likely than a change has occurred in the past 25 years. However, even in the past 25 years, the volatility of expectations and trend inflation has fallen, and some evidence indicates that trend inflation has become a relatively smaller source of volatility in inflation. While these changes imply a smaller role for trends and long-run expectations in inflation movements, they are consistent with improved anchoring of inflation. Most explanations offered to date focus on changes in the behavior of monetary policy.

The paper proceeds as follows. Section 2 provides a detailed literature review. Section 3 describes the data used in our empirical analysis. Sections 4 through 6 present results from our three models, in sequence. Section 7 concludes.

2 Literature Survey

We organize our survey around the two broadest questions of interest: (1) how do expectations influence inflation, and (2) what influences expectations — that is, how do expectations depend on past inflation, economic activity, and monetary policy actions? For each of these questions, we also consider: (a) how long-run and short-run expectations relate, (b) what, if anything, has changed over time, and (c) what might have caused any changes. In the case of the influence of expectations on inflation, we first organize the literature into those portions that use explicit (survey) measures of expectations and those that use a time-varying trend of inflation instead of (or, in one case, in addition to) an explicit measure of expectations. We further group the evidence on question (1) into studies based on (i) reduced form/structural VAR analysis and (ii) DSGE or New Keynesian Phillips Curve (NKPC) analysis. In the case of question (2), we simply group the evidence into studies based on (i)

reduced form/structural VAR analysis and (ii) analysis of inflation compensation. We conclude the section with a brief summary of what are, in our assessment, broad issues warranting further research.

In the interest of brevity, our survey focuses on work with inflation and expectations, omitting a wide array of other work of some relevance to some of the issues. For example, as will become clear below, the role of expectations in the inflation process bears on the persistence of inflation. In our review, we focus on that part of the persistence literature that examines the role of expectations or time-varying trends in the persistence of inflation, and omit those that do not explicitly consider expectations or time-varying trends.

2.1 How do expectations influence inflation? Short-run versus long-run expectations? What has changed over time, and why?

2.1.1 Evidence from using survey-based measures of expectations

A number of studies using reduced-form time series models or structural VARs have found that survey measures of expectations play a key role in the dynamics of inflation. Leduc, Sill, and Stark (2007) add eight-month ahead inflation expectations to an otherwise conventional macroeconomic VAR and examine the roles of shocks to expectations, monetary policy, fiscal policy, and oil prices in accounting for the sharp rise in inflation in the 1970s. They report that, prior to 1979, shocks to inflation expectations had essentially permanent effects on both inflation and expectations. Since 1979, however, the impacts of expectations shocks have been temporary. Expectations shocks continue to impact inflation, but die out relatively quickly. The change across samples appears to be associated with monetary policy: prior to 1979, the real federal funds rate initially declined in response to the expectations shock, but since 1979 the real rate has risen significantly in response to expectations shocks.[2]

Clark and Nakata (2008) use a time-varying parameter VAR in the change in long-run expectations, inflation less long-run expectations, economic activity, and the funds rate less long-run expectations to examine whether inflation and expectations have become better anchored over time. In their framework, long-run expectations play a central role in driving inflation dynamics. Reduced-form coefficient estimates indicate that the influence of expectations on inflation is modestly higher now than 20 or so years ago. Impulse response estimates show that, compared to 20 or more years ago, inflation and expectations appear to be slightly better anchored. Shocks to inflation

[2]Using a different data set and sample period, Choy, Leong, and Tay (2006) obtain qualitatively similar results from a similar framework, except shocks to expectations account for a smaller fraction of the variance of inflation than in Leduc, Sill, and Stark (2007).

die out slightly faster and produce less of an increase in long-term expectations. Nonetheless, counterfactual analysis indicates that the relatively low volatility of core inflation and long-run expectations in the past decade or two is largely due to smaller shocks to inflation and expectations, rather than changes in other model coefficients.

Canova and Gambetti (2008) use VAR models (both constant and time-varying parameter specifications) to examine the predictive content of one-year ahead expectations for inflation. Granger causality tests and parameter estimates indicate expectations have consistently had predictive content for inflation in data for 1960 through 2005. Demertzis, Marcellino, and Viegi (2008) use bivariate VARs in inflation and long-run expectations (both constant and time-varying parameter specifications) to assess whether the anchoring of inflation and expectations has changed over time. Their coefficient estimates and impulse responses indicate the anchoring of inflation and expectations has improved over time.

Some related models or analyses also give long-run expectations a key role in inflation dynamics. Most notably, long-run expectations are a key determinant of inflation behavior in the FRB/US model. Historically, long-run expectations in FRB/US were typically based on forecasts from simple VARs.[3] Today, though, long-run inflation expectations in the model are measured with survey data.[4] Long-run expectations also play a key role in inflation dynamics in the reduced-form Phillips curve used by Macroeconomic Advisers (2007), which relates changes in core inflation to lags and to the differential between core inflation and long-run expectations.

A number of studies estimate some form of a NKPC using expectations measured with survey data, often for the purpose of assessing the role of forward-looking expectations vs. backward-looking forces.[5] A general theme that emerges from this literature is that expectations are an important factor in driving inflation dynamics, though the extent varies across studies. The estimates in Roberts (1995, 1997) and Brissimis and Magginas (2008) indicate that, with expectations measured with surveys, the NKPC with purely-forward looking expectations fits the data reasonably well, without a need for backward-looking terms. However, Kozicki and Tinsley (2002), Adam and Padula (2003), and Nunes (2006) report that a purely forward-looking model does not fit the data as well as a model with both forward-looking survey expectations and backward-looking components.[6]

[3]See Brayton, et al. (1997).

[4]See Mishkin (2007).

[5]We abstract from a long literature estimating the NKPC with actual future inflation instead of survey expectations, in which the key issue is what is required to account for the persistence of inflation. See Kiley (2008b) for a recent example, and Kiley (2008b) and Brissimis and Magginas (2008) for recent literature reviews.

[6]One issue in this literature that could lead to some differences across studies is the treatment of revisions to inflation data. Roberts (1995, 1997) uses CPI data, which aren't revised. Brissimis and Magginas (2008) use data on the GDP deflator, but take some care to match up their measure of actual inflation with the varying data vintages reflected in the survey expectations. The other

2.1.2 Evidence using a econometric estimates of a time-varying inflation trend

Several papers discuss the close conceptual correspondence between statistical estimates of trend inflation and long-run inflation expectations.[7] Trend inflation can be thought of as the long-run forecast of inflation, which a long-run survey expectation captures. In turn, movements in trend inflation are likely attributable to shifts in the central bank's inflation target, as in Cogley and Sbordone (2008). Of course, in the United States, the Federal Reserve has no explicit inflation target. Instead, the inflation goals of policy are implicit in its actions and public communication. In a series of papers, Kozicki and Tinsley (see, e.g., Kozicki and Tinsley (2006)) argue that trend inflation provides a measure of private sector perceptions of the implicit inflation goal of policy. Accordingly, research using a time-varying inflation trend is closely related to research using a time-varying inflation target.

Many studies have used reduced-form time series models or structural VARs to examine the importance of time-varying inflation trends in the dynamics of inflation. In this work, the inflation trend plays an important role in inflation dynamics. Kozicki and Tinsley (1998, 2001a,b, 2002) present evidence that inflation dynamics are best captured by models with a time-varying trend, in which the trend reacts with a lag to movements in actual inflation. Long-run forecasts of inflation from these models correspond reasonably well with long-run expectations from surveys. In some of this work, long-term bond yields are used along with data on inflation to help pin down estimates of trend inflation. Using just the federal funds rate and a Taylor rule, Leigh (2005) obtains a qualitatively similar estimate of an implicit inflation target.

Kozicki and Tinsley (2006) develop a VAR framework that explicitly links together inflation, trend inflation (which they view as a measure of private sector perceptions of the implicit inflation goal), and expectations. In this model, expectations (in their analysis, one-year and 10-years ahead) are noisy indicators of forecasts of inflation implied by an inflation model with a time-varying trend rate of inflation, which follows a random walk process. Actual inflation and expectations provide indicators of the unobserved trend rate of inflation. As the horizon increases, the inflation expectation depends more on the inflation trend and less on actual past inflation. The model estimates yield an inflation trend that is quite similar to the survey measure of the long-run expectation. Chernov and Mueller (2008) use a similar model, expanded to include bond yields.

A number of other studies have also found that trend inflation, modeled as a ran-

three studies mentioned also use GDP deflator data, but abstract from real time data and revision issues, except that Kozicki and Tinsley (2002) report obtaining similar results in a shorter sample in which data revisions should be less of an issue.

[7] For example, see Kozicki and Tinsley (2006), Mishkin (2007), and Cogley, Primaceri, and Sargent (2008).

dom walk, can account for much of the variation in actual inflation. For example, Cogley and Sargent (2005), Cogley, Primaceri, and Sargent (2008), and Cogley and Sbordone (2008) estimate VARs with time-varying parameters and a time-varying inflation trend. Stock and Watson (2007) and Cecchetti, et al. (2007) estimate univariate trend-cycle models of inflation. Kiley (2008a) estimates a bivariate trend-cycle model of inflation, using total and core inflation together, with a common trend. Across these studies, certainly, the magnitude of trend fluctuations sometimes differs considerably. However, in all cases, trend inflation has changed significantly over time, and plays a key role in inflation dynamics. Based on a Phillips curve with a time-varying inflation trend, Piger and Rasche (2006) conclude that inflation dynamics are driven primarily by changes in trend, with relatively small contributions from economic activity and supply shocks. Several studies that allow time variation in the sizes of shocks to trend inflation — Piger and Rasche (2006), Stock and Watson (2007), Cecchetti, et al. (2007), and Cogley, Primaceri, and Sargent (2008) — have found that the trend component is considerably smaller in data for the last decade or two than in prior years. Cecchetti, et al. (2007) go on to consider the relationship between trend inflation and survey measures of long-run expectations, and find that Granger causality runs both directions: changes in expectations presage subsequent movements in trend, while movements in trend also anticipate changes in expectations.

A number of recent studies use DSGE-based models to examine the role of a time-varying inflation trend or target in inflation dynamics. Ireland (2007) estimates with 1959-2004 data a DSGE model with a time-varying inflation target that is known to the public. In one version, the target follows a simple random walk; in another, the target is allowed to respond to supply shocks. While the model estimates suggest the implicit target did move in response to supply shocks, the estimated targets from the two models are quite similar. The estimates imply that changes in the implicit target have accounted for a significant portion of variation in inflation. Belaygorod and Dueker (2005) obtain a qualitatively similar, although even more variable, target with a DSGE model estimated for 1985-2004.

To assess the causes of the reduced volatility and persistence of inflation, Cogley, Primaceri, and Sargent (2008) estimate a DSGE model with a time-varying inflation target that is known to the public, for samples of 1960-79 and 1982-2006. The model-based inflation target is qualitatively similar to the trend estimated from a VAR with time-varying parameters, although probably more variable. Their estimates imply that the reduced volatility and persistence of inflation is mostly due to a falloff in the volatility of the inflation target, with the increased responsiveness of monetary policy to deviations of inflation from target making a smaller, but notable, contribution.[8] Note that, in such analysis, the change in inflation dynamics is typically a

[8]Based on DSGE model estimates for the 1983-2004 period, Benati and Surico (2008) find that changes in the policy reaction function alone (with a constant inflation target) can account for the

change in reduced-form properties, rather than the structural NKPC. Emphasizing the distinction, Carlstrom and Fuerst (2008) use a calibrated DSGE model (applied to detrended inflation) to show that the decline in the reduced-form persistence of inflation can be attributed to an increase in the responsiveness of monetary policy to inflation and a decline in the relative size of technology shocks.

However, in light of the global nature of the upward and downward trends of inflation in the 1970s and 1980s, Cecchetti, et al. (2007) note that it is likely difficult to identify a global change in monetary policy preferences that could account for the global synchronization of inflation trends. Nonetheless, the trends in inflation across some countries seem to line up with systematic deviations from simple Taylor rules, pointing to a role for changes in monetary policy preferences. Cecchetti, et al. (2007) go on to use a simple DSGE model to assess what model features and changes over time are necessary to account for the estimated changes in the univariate properties of inflation. They conclude that the model requires very forward-looking agents and very small shocks to monetary policy, more so in the past 20 years than in the prior period. So their analysis, too, highlights the importance of expectations in inflation dynamics.

Cogley and Sbordone (2008) consider in detail the implications of a time-varying inflation trend for the form of the NKPC, developing and estimating an alternative form of the model that does not require (as does most of the literature) that firms not optimizing their prices in a given period index their prices to the inflation trend. Based on trend estimates obtained from a VAR like that of Cogley and Sargent (2005), they show that no indexation or backward-looking component is needed to model inflation dynamics once changes in trend inflation are taken into account.[9]

To assess the sources of inflation persistence, Erceg and Levin (2003) consider a calibrated DSGE model with a time-varying inflation target unobserved by the public, about which the public learns through economic outcomes and policy actions. Their results indicate that persistent target changes (and learning about the target) are crucial to the dynamics of inflation, particularly to its persistence. Notably, in their results, one-year ahead inflation expectations decline faster than does actual inflation following a persistent (negative) shock to the inflation target.

Roberts (2007) also considers a DSGE model (partly calibrated and partly estimated) with learning about just the unobserved inflation target, to determine whether learning or backward-looking inflation dynamics (sticky inflation) can better account

reduced predictability of inflation. Primaceri (2006) finds that a model with policymakers learning about the structure of the economy can entirely account for the rise and fall of inflation in the post-war period; he reports that allowing potential breaks in the inflation goal do not alter this finding.

[9]The estimated trend in Cogley and Sbordone (2008) is somewhat less variable than the estimate in Cogley and Sargent (2005), but well within 90 percent credible sets.

for the persistence of inflation. He concludes that allowing learning reduces the evidence of sticky inflation, more so in the 1984-2004 period than the 1959-2003 period, such that there is little evidence today of sticky inflation once learning about an implicit target is taken into account. Here, as in other papers in the literature, time variation in the inflation target (or trend) absorbs or explains a significant portion of the reduced-form persistence of inflation.

Milani (2006) estimates DSGE models with a time-varying inflation target, with one version featuring rational expectations and the other version featuring learning about the policy target and all other model coefficients. With rational expectations, the estimated target is quite similar to Ireland's (2007), showing considerable variation over time. With learning, the estimated target is quite different, and even more variable.

Overall, the research cited in this section points to a key role for survey-based expectations in inflation dynamics. While there remains some debate about the importance of forward-looking expectations versus backward-looking components in inflation dynamics, an array of evidence shows that expectations or trend inflation are a primary source of variation in inflation. In fact, in some work, incorporating survey measures of expectations or trend inflation often substantially weakens or eliminates the importance of backward-looking components of inflation (except any backward-looking aspects captured in the survey expectation or the trend).

Less clear from extant work are distinct roles for short-term versus long-term expectations: most studies use one or the other. As Kozicki and Tinsley (2006) point out, as the horizon increases, expectations should become more reflective of the perceived long-run goal of policy (or trend inflation) and less reflective of recent movements in inflation. Therefore, in a reduced form sense, there may be scope for short-run and long-run expectations to separately influence inflation dynamics. However, there is little direct evidence of such distinct influences.

As to changes over time in the influence of expectations or trends on inflation, the evidence generally suggests inflation has been better anchored in the past 20 or so years than in the prior period, although some evidence suggests no change. Some studies have found that shocks to expectations have less impact on inflation today than in the past (e.g., Leduc, Sill, and Stark (2007)). Some evidence indicates that, in a reduced form sense, the influence of expectations on inflation has increased (e.g., Clark and Nakata (2008)). However, the volatility of expectations and trend inflation has clearly fallen, and some evidence indicates that trend inflation has become a relatively smaller source of volatility in inflation (e.g., Stock and Watson (2007) and Cogley, Primaceri, and Sargent (2008)). While such changes imply a smaller role for trends and long-run expectations in inflation movements, they are consistent with improved anchoring of inflation.

Of the limited work to date on the sources of these changes, most has focused on

explanations relating to monetary policy. Some studies have found that the reduced volatility and persistence of inflation is mostly due to a falloff in the volatility of an implicit inflation target (e.g., Cogley, Primaceri, and Sargent (2008)). Others attribute changes in the behavior of inflation more to other changes in the conduct of monetary policy (e.g., Benati and Surico (2008)). Still other studies highlight the importance of learning by the public or the central bank in inflation dynamics and changes over time in dynamics (e.g., Erceg and Levin (2003) and Roberts (2007)).

More generally, the learning-based framework sketched by Bernanke (2007) seems like the most widely accepted approach to linking inflation to inflation trends and long-run expectations. In practice, the structure of the economy is changing over time and unknown to the public and the central bank. What is more, in the case of the U.S., the implicit inflation goal of the central bank has not been known to the public.[10] Consequently, both the public and the central bank must engage in learning over time, extracting from observed data on the economy signals about the structural features of the economy and, in the case of the public, the central bank's implicit inflation goal. This learning process likely gives inflation expectations — potentially at not only long but also short horizons — an explicit role in the structural dynamics of the economy. One challenge, though, is to provide an interpretation of expectations shocks. In this sort of model, are unexpected changes in expectations best attributed to sunspots or omitted fundamentals (as in, e.g., Leduc, Sill, and Stark (2007))? Are they simply manifestations of other structural shocks, such as to the unobserved inflation goal?

2.2 What influences expectations? How do long-run expectations relate to short-run expectations? What has changed over time, and why?

A long literature has examined a very broad question about the determinants of inflation expectations: are survey data rational or efficient forecasts of inflation, or do surveys reflective some less than fully rational behavior (e.g., adaptive components)?[11] In the interest of brevity, we will simply refer to a recent study, Croushore (2006), which provides a good summary of the literature, and argues that inflation forecasts appear to be rational once some econometric and data problems in past studies are corrected.

[10] In recent years, though, public statements by some FOMC members have made clearer the inflation objectives of those members. In addition, the FOMC's decision in 2008 to extend the horizon of forecasts provided to the public four times per year have probably provided more information on the inflation goals of Committee members.

[11] Some other work examines the value of survey expectations in forecasting inflation out of sample. Ang, Bekaert, and Wei (2007) find that, in recent data, survey measures of expectations provide better forecasts of inflation than do a wide range of time series models.

Related studies such as Roberts (1997, 1998), Carroll (2003), and Curtin (2005) seek to assess the roles of rationality and adaptive behavior in inflation surveys. Carroll (2003) develops a model in which consumer expectations adjust toward professional forecasts, which are usually based on more information, because of the cost and benefit to consumers of acquiring information.[12] In addition, studies such as Lamont (2002) and Ottaviania and Sorensen (2006) have examined the behavior of professional forecasters, to assess the incentives for forecasters to report something other than an "honest," objective forecast for strategic reasons, such as to manipulate beliefs about the forecasters' abilities.

van der Klaauw, et al. (2008) use individual-level responses to survey questions to assess what prices consumers typically think of in responding to the University of Michigan's survey. They find that question wording has a considerable impact on what consumers consider in formulating an answer. For example, the conventional Michigan questions about "prices in general" that yield the widely used Michigan measures of inflation expectations tend to lead respondents to think about prices of items they usually buy, or about item (e.g., gas) prices that have recently been rising. In contrast, when asked (in supplemental questions developed by the authors, not the standard Michigan survey questions) to instead report expectations for the 'rate of inflation', consumers report thinking more about items most Americans purchase or about the aggregate inflation rate. In addition, their expectations for the 'rate of inflation' are less correlated with prices for food, gas, or other specific items.

Based on macroeconomic analysis, various studies have highlighted the dependence of long-term inflation expectations on just past inflation. Kozicki and Tinsley (2001a,b, 2002) show that long-term expectations seem to trail actual inflation. Cecchetti, et al. (2007) show that long-term expectations respond to past movements in trend inflation. Because their estimate of trend is a function of past movements in actual inflation, it follows that long-term expectations depend importantly on past inflation.

A number of recent studies have used time series models to examine the influences of inflation and other variables on medium- or long-term inflation expectations. Leduc, Sill, and Stark (2007) present evidence on the expectations impacts of shocks to oil prices, fiscal policy, monetary policy, and expectations, using 8-month ahead inflation expectations. According to their estimates, shocks to oil prices, monetary policy, and expectations all have significant impacts on expectations. However, their evidence may be read as suggesting that expectations are reasonably well anchored in the 1979-2001 period. In that sample, oil price increases (shocks) cause both inflation and short-term expectations to rise, inflation more so than expectations. Monetary policy tightenings cause both inflation and short-term expectations to fall, inflation

[12]However, a recent evaluation of consumer expectations by Thomas and Grant (2008) finds consumer expectations to be rational and efficient.

more so than expectations. An expectations shock has only temporary effects on inflation. In contrast, in the 1952-79 period, a policy shock generates a price puzzle, with both inflation and expectations rising immediately after the unanticipated tightening. And, in this sample, an expectations shock leaves the expected inflation rate permanently higher.

Some aspects of their results suggest monetary policy has played a role in the improved anchoring of inflation expectations: in the second sample, but not the first, policy tightens enough in response to an expectations shock to raise the real interest rate. Other results make the evidence less clear: in the case of an oil price shock, the real interest rate response is sharper in the second sample than the first, even though the oil price shock has a bigger impact on inflation in the second sample than the first.

Based on a similar analysis of impulse responses from a VAR including one-year ahead survey expectations of inflation, Mehra and Herrington (2008) conclude that inflation expectations have been better anchored since 1979 than before, with respect to shocks to oil prices, commodity prices, inflation expectations, and inflation itself. One of the sharpest changes has been in the impact of commodity prices on inflation expectations — commodity shocks account for much less of the variation in expectations since 1979 than before.

Clark and Nakata (2008) use a time-varying parameter VAR in long-run expectations, inflation less long-run expectations, economic activity, and the funds rate less long-run expectations to examine the influences of these variables on long-run inflation expectations. In their impulse response estimates, shocks to inflation have a statistically significant impact on long-run expectations. However, the impact is quantitatively small, more so now than 20 or so years ago. Counterfactual analysis indicates that the incredible stability of long-run expectations in the past decade or so is primarily the result of very small shocks to core inflation and expectations, rather than changes in other model coefficients (and, therefore, monetary policy).

Kiley (2008b) couples (1) a Taylor rule with (2) learning about an unobserved inflation target to estimate the impacts of monetary policy actions and the economy on long-term inflation expectations. Learning means the public's estimate of the inflation target follows from extracting the signal from the random walk target process and the Taylor rule. Kiley estimates the model by further assuming that the public perception of the target can be measured directly from long-term survey expectations (after removing the first three years of data from the 10-year horizon). In estimates from data for 1979-2004, inflation expectations respond significantly to policy actions (particularly, deviations of the actual funds rate from the Taylor rule-implied value), economic activity, and inflation. However, as noted below in section 4, the impacts are quantitatively small.

A number of recent studies have used data on inflation compensation from TIPS or

far-forward nominal bond yields to assess the responsiveness of inflation expectations to news in the economy (with news defined as deviations of actual data releases from market expectations).[13] Gurkaynak, Sack, and Swanson (2005) show that far-forward nominal yields respond to news on the economy. For example, a higher-than-expected CPI or non-farm payrolls release tends to cause far-forward bond yields to rise. Gurkaynak, Sack, and Swanson go on to show that, in a simple macroeconomic model, allowing time variation in the central bank's inflation target can explain the behavior of interest rates. In this model, the target is a function of past inflation and the past target; the public learns about the target from the actions of the central bank.

Gurkaynak, Levin, and Swanson (2006) show that, in U.S. data, both far-forward nominal rates and inflation compensation respond to news on the economy. In data for the United Kingdom, the same is true for data prior to the establishment of the Bank of England's independence, but not in data since then. In post-BOE independence data for the U.K. and in data for Sweden, far-forward nominal rates and inflation compensation do not respond to news. Similarly, in Beechey, Johannsen, and Levin (2008), long-term inflation compensation responds to news in the U.S. but not the Euro area; short-term compensation responds to news in both economies. All of this evidence suggests that long-run inflation expectations (in particular, public perceptions of the long-run goal of monetary policy) are not fully anchored in the United States.

Finally, some studies have assessed the anchoring of inflation and inflation expectations by examining how shocks to short-run TIPS compensation impact long-run compensation. Potter and Rosenberg (2007) and Jochmann, Koop, and Potter (2008) treat inflation and expectations as being anchored if pass-through from short-run to long-run compensation declines as the horizon increases and contained if pass-through is high inside the central bank's comfort zone for inflation and low outside the comfort zone. Jochmann, Koop, and Potter (2008) use a model (really, a class of models) that allows pass-through to vary with time, with the level of short-run compensation, or with deviations of compensation from a central value. Potter and Rosenberg (2007) use a broadly comparable model. Both studies find that shocks to short-term expectations pass through to long-term expectations when inflation lays within a comfort zone but not outside that zone. Therefore, expectations as measured by TIPS compensation do not seem to be fully anchored.

Overall, existing research indicates that inflation expectations respond to a range of variables: oil prices, commodity prices, past inflation, the state of the economy, and

[13]Note, though, that the findings in Gurkaynak, Sack, and Wright (2008) might be seen as warranting some caution in drawing strong conclusions on the behavior of U.S. inflation expectations from TIPS compensation. Gurkaynak, Sack, and Wright argue that inflation compensation is a better indicator of inflation risks than the expected inflation rate. Similarly, D'Amico, Kim, and Wei (2008) recommend caution in taking TIPS breakeven rates as measures of inflation expectations.

monetary policy actions. A more limited volume of work shows that the responses of short-run expectations are normally sharper than the responses of long-run expectations. Similarly, some historical comparisons generally suggest expectations have become better (but not completely) anchored, responding less than used to be the case to various shocks in the economy. For example, while some evidence shows long-run expectations respond to shocks to inflation or to monetary policy actions, the impacts are now quantitatively small.

Of those studies that explicitly consider potential explanations for the improved anchoring, most focus on the conduct of monetary policy (e.g., Leduc, Sill, and Stark (2007) and Mehra and Herrington (2008)). However, Clark and Nakata (2008) find that the high stability of long-run inflation expectations in the past 10-20 years is entirely attributable to smaller shocks to inflation and expectations; in their estimates, changes in model coefficients (such as in monetary policy) seem to play no role. To this point, no studies have undertaken a structural investigation of the improved anchoring of expectations; existing structural investigations focus on actual inflation, without explicit consideration of measures of inflation expectations (apart from trends).

2.3 Summary of areas for further research

As this review suggests, existing research has yet to fully or definitively answer a number of questions about the behavior of inflation and inflation expectations. For convenience, we provide below a listing of the questions that, in our assessment, warrant further research.

1. What is the relative importance of forward-looking versus backward-looking components in inflation dynamics?

2. What accounts for the fall in the volatility, persistence, and predictability of inflation? Does the behavior of inflation expectations display the same changes? If so, what accounts for any shifts in the behavior of expectations? What role did monetary policy play, and which aspects of monetary policy — changes in the implicit inflation goal or responsiveness of policy to inflation and the state of the economy — were more important? Why were some of the changes in the behavior of inflation global in nature?

3. To the extent the inflation goal of monetary policy varied over time, what drove the changes? Are the forces the same as those that have been suggested as explanations for shifts in the reaction of monetary policy to inflation and the state of the economy?

4. For forecasting inflation, what accounts for the superiority of some survey expectations over model-based forecasts? What are the models missing, and can

the gap be closed?

5. How do expectations impact inflation dynamics in a structural economic model with learning and structural change? What are the implications for the conduct of monetary policy?

6. What should policymakers make of movements in survey indicators of inflation forecast uncertainty, or in dispersion across survey responses? For example, if survey measures of long-term expectations show a pickup in uncertainty or disagreement, does it necessarily mean the respondents have become more skeptical of the central bank's commitment to long-term price stability? Does policy need to react in some way?

7. Today, what determines or influences expectations, in microeconomic (measurement) and macroeconomic terms?

8. In a structural economic model, is there a distinct role for short-term versus long-term expectations? Do the data support a distinct role?

9. What is a shock to inflation expectations as it may be captured by a macroeconomic VAR — omitted fundamentals or sunspots?

10. What do TIPS yields say about the anchoring of inflation expectations, distinguishing inflation risk from point expectations?

11. Have the recent changes in the FOMC's public communication efforts (e.g., more frequent publication of forecasts, and the extension of the forecast horizon to three years) impacted the anchoring of inflation expectations? Might a more explicit inflation goal impact anchoring? Would that goal need to take a particular form to impact anchoring? Would the benefits to the economy be material?

Combining various approaches used in the literature described above, in the remainder of the paper we focus on our own analysis of the relationships among inflation and inflation expectations.

3 Data Description

In the interest of ensuring comparability between our measures of expectations and inflation, we focus on actual inflation in the CPI and survey-based measures of CPI

expectations, at a quarterly frequency.[14] Our primary results are robust to measuring actual inflation with the PCE price index. We obtained our raw data on the CPI, core CPI, CPIs for food and energy, and federal funds rate from the Board of Governors' FAME database.[15] We obtained the Chicago Fed's National Activity Index from the Chicago Fed's website.

For inflation expectations, we rely primarily on CPI forecasts — one and 10 years ahead — from the Federal Reserve Bank of Philadelphia's Survey of Professional Forecasters (SPF). We obtained both one-year ahead and 10-year ahead median forecasts of the CPI from the Philadelphia Fed's web site. The one-year forecast as of period t refers to a forecast of inflation from $t+1$ through $t+4$, made in the middle of quarter t. The 10-year ahead forecast is a projection of the average inflation rate over the next 10 years. Because the SPF 10-year forecast series does not begin until 1991:Q4, we spliced the source SPF series for 1991:Q4-2008:Q2 to a 1979:Q4-1991:Q3 series from Blue Chip. We use Blue Chip because its participants are conceptually similar to those of the SPF and because, since 1991, the long-term forecasts reported by Blue Chip and the SPF have been very similar.

We obtained Blue Chip forecasts of the average inflation rate over the next 10 years from hard copies of the Blue Chip Consensus.[16] Because Blue Chip provides long-term forecasts only twice per year, we linearly interpolated the series to the monthly frequency, and then selected those observations in the months used by SPF (February, May, August, and November) to fill in our quarterly time series.[17]

We have also verified the robustness of our results to using median consumer expectations from the University of Michigan's survey.[18] As highlighted in van der

[14]The timing of our estimation sample — 1982:Q3 through 2008:Q2 — reduces the importance of methodological inconsistencies with historical CPI data. Historically, the biggest methodological break in the CPI is the January 1983 change to a rental equivalence basis for housing costs. Our estimation sample only includes two observations from 1982.

[15]We formed quarterly averages of the indexes and funds rate, as well as the CFNAI, as simple averages within the quarter.

[16]We obtained a 10-year forecast by averaging the forecasts for 1-5 and 6-10 years ahead reported in the Blue Chip Consensus. For 1979:Q4-1982:Q4 and 1983:Q4 (actually the months in these quarters in which there are actual Blue Chip data), Blue Chip provides expectations for the GNP deflator, but not the CPI. Because the CPI forecasts and deflator forecasts are very similar (sometimes the same, sometimes very slightly different, without a consistent gap) in the few years in which CPI forecasts first become available, for these early source observations we fill in the CPI forecasts with deflator forecasts.

[17]Starting in 1983, the Blue Chip surveys always include the long-term forecasts in the months of March and October. In the prior years, the surveys sometimes occurred in the months of May and November.

[18]In the Michigan analysis, we used 12-month and 5-10 year ahead expectations. In the case of the long-term expectations, which weren't reported every month until April 1990, we obtained a full time series by linearly interpolating between the observations available in the February 1975 to March 1990 period. In this interpolation, we used Hoey survey forecasts (provided by Sharon Kozicki) and Blue Chip forecasts, both 5-10 years ahead, as indicators. We obtained the raw Michigan data from

Klaauw, et al. (2008), measuring consumer inflation expectations poses a number of issues (some described above in section 2.2). However, at least in the case of our primary empirics, using consumer expectations yields results very similar to those obtained with professional forecasts. Carroll (2003) develops a model in which it is costly for consumers to acquire information, such that consumer expectations adjust toward professional forecasts, which are usually based on more information.

4 A State-Space Approach with Time-Varying Trend Inflation

We begin our analysis with a relatively restrictive model where inflation dynamics are driven by an unobserved, time-varying trend and realizations of past inflation. Changes in the inflation trend are attributable to changes in the implicit inflation goal of monetary policy. Survey expectations reflect forecasts of inflation based on past inflation, monetary policy actions, and the estimated trend. In this setup, expectations don't directly drive inflation. Instead, they are observable measures that reflect the true forces driving inflation, such as the unobserved trend. The framework combines elements of the models used in Kozicki and Tinsley (2006) and Kiley (2008b).

More specifically, the model in this section uses inflation, short- and long-term survey expectations and the federal funds rate to extract an unobserved trend rate of inflation. Inflation follows an autoregressive process with a time-varying trend and survey expectations are modeled as the conditional expectations, plus noise, of the inflation process at different horizons. This framework imposes a set of cross-equation restrictions that ensures consistency between the process for inflation and survey measures.

The approach is similar to Kozicki and Tinsley (2006), except for two key differences. First, we jointly estimate the process for inflation and monetary policy. The benefit of joint estimation is that it allows two channels to impact long-term inflation expectations. The first channel is backward-looking, where high realizations of past inflation may raise long-term expectations. The second channel is forward-looking, where deviations to the estimated monetary reaction function can cause forecasters to re-evaluate their long-term inflation forecasts. Kiley (2008b) uses just a reaction function and long-run inflation expectations to extract estimates of an unobserved inflation target. The second difference relative to Kozicki and Tinsley (2006) is our data sample and treatment of missing data. Kozicki and Tinsley use a longer, monthly sample that includes an extended period in which long-run expectations are not available, which requires a generalization of the state-space estimation to allow missing

the Board of Governors' FAME database.

data. We instead focus on a shorter, quarterly sample over which both our expectations series are always available.

The process for inflation follows

$$\pi_t = (1 - \alpha(1))\,\pi_t^* + \alpha(L)\,\pi_{t-1} + \varepsilon_{\pi,t}, \tag{1}$$

where $\varepsilon_{\pi,t} \sim N(0, \sigma_\pi^2)$ and $\alpha(L) = \alpha_1 + \alpha_2 L + \cdots + \alpha_p L^{p-1}$. This process can equivalently be represented in companion form as

$$\pi_t = \iota_1' C z_t + \iota_1'(I - C)\,\iota \pi_t^* + \varepsilon_{\pi,t}, \tag{2}$$

where $z_t = [\pi_{t-1}, \pi_{t-2}, ..., \pi_{t-p}]'$, I is a conformable identity matrix, ι is a $p \times 1$ vector of ones and ι_i' is a $p \times 1$ vector of zeros, except the i^{th} element is unity. We use a model with 4 lags, so $p = 4$. The companion matrix is

$$C = \begin{bmatrix} \alpha_1 & \alpha_2 & \cdots & \alpha_p \\ I_{(p-1)\times(p-1)} & & & 0_{(p-1)\times 1} \end{bmatrix}.$$

Trend inflation follows

$$\pi_t^* = \pi_{t-1}^* + v_t, \tag{3}$$

where $v_t \sim N(0, \sigma_v^2)$.

One interpretation of trend inflation is that it represents the private sector's inference regarding the central bank's long-term inflation objective. One important point, however, is that the SPF long-term forecasts report the average inflation rate over the next ten years. Given this horizon, a substantial change in the mean SPF long-term forecast would require forecasters to perceive an important shift in inflation dynamics or a change in any implicit inflation objective of the central bank. From this standpoint, short-run fluctuations in inflation or deviations from an estimated policy rule are unlikely to cause forecasters to sharply reassess their long-term expectations, especially if the central bank is credibly able to commit to medium and long-term goals.

The model of survey expectations uses the autoregressive model for inflation in (1) along with the law of iterated expectations. Iterating (1) forward and taking expectations conditional on information at t yields

$$S_{t+k|t} = k^{-1} \sum_{i=1}^{k} E_t \pi_{t+i} + u_{k,t} \tag{4}$$

which is the conditional value for survey expectations of horizon k, plus noise, that are consistent with the underlying process for inflation. The error is $u_{k,t} = k^{-1} \sum_{i=1}^{k} \left(S_{t+i|t} - E_t \pi_{t+i}\right)$,

which arises from measurement and approximation error.[19] As the horizon lengthens, survey expectations will depend more on the inflation trend and less on actual realizations of past inflation.

The monetary reaction function is given by

$$i_t = r + \pi_t^* + \gamma_\pi \left(\pi_t^C - \pi_t^*\right) + \gamma_x x_t + \varepsilon_{i,t}, \tag{5}$$

where $\varepsilon_{i,t} \sim N(0, \sigma_i^2)$, π_t^C is core CPI inflation and x_t is the Chicago Fed National Activity Index (CFNAI). The CFNAI is the first principal component of a large set of economic indicators covering real economic activity and is based on earlier work by Stock and Watson (1999). The use of the CFNAI as the measure of real activity relates to work that estimates policy reaction functions using factor analysis, such as Bernanke and Boivin (2003).

The complete state-space representation is given by

$$\begin{aligned} y_t &= D + F\pi_t^* + Hz_t + \varepsilon_t, & (6)\\ \pi_t^* &= \pi_{t-1}^* + v_t, & (7) \end{aligned}$$

where

$$\begin{aligned} D &= \left[\begin{array}{cccc} 0, & r, & 0, & 0, \end{array}\right]', & (8)\\ F &= \left[\begin{array}{cccc} (1-\alpha(L)) & 1-\gamma_\pi & f_4(C) & f_{40}(C) \end{array}\right]', & (9)\\ H &= \left[\begin{array}{cccccc} \alpha_1 & \alpha_2 & \alpha_3 & \alpha_4 & 0 & 0 \\ 0 & 0 & 0 & 0 & \gamma_\pi & \gamma_x \\ h_{4,1}(C) & h_{4,2}(C) & h_{4,3}(C) & h_{4,4}(C) & 0 & 0 \\ h_{40,1}(C) & h_{40,2}(C) & h_{40,3}(C) & h_{40,4}(C) & 0 & 0 \end{array}\right], & (10) \end{aligned}$$

and $y_t = \left[\pi_t, i_t, S_{t+4|t}, S_{t+40|t}\right]'$ and $z_t = \left[\pi_{t-1}, \pi_{t-2}, \pi_{t-3}, \pi_{t-4}, \pi_t^C, x_t\right]'$. $S_{t+4|t}$ denotes one-year ahead (i.e. short-term) expectations and $S_{t+40|t}$ denotes ten-year ahead (i.e. long-term) expectations. The cross-equation restrictions are a function of the companion matrix, C, and are the same as in Kozicki and Tinsley (2006):

$$\begin{aligned} f_k(C) &= \iota_1' \left(I - \left(k^{-1} \sum_{j=1}^{k} C^{j+1}\right)\right) \iota & (11)\\ h_{k,i}(C) &= k^{-1} \iota_1' \left(\sum_{j=1}^{k} C^{j+1}\right) \iota_i, & (12) \end{aligned}$$

[19] Approximation error arises because we assume a diagonal covariance matrix for the innovations to the measurement equations in the model. Small, non-zero, correlation exists between inflation and survey expectations, since an innovation to inflation within a period can cause survey expectations to move in the same period. However, we estimated a version of this model and found it to have very minor implications. For comparability to Kozicki and Tinsley (2006), we follow their approach and shuffle this small approximation error into the measurement error on survey expectations.

α_1	α_2	α_3	α_4	r	γ_π	γ_x
.396*	−.138	.264*	−.046	2.240*	.621*	.375
(.069)	(.08)	(.093)	(.075)	(.236)	(.203)	(.331)

Table 1: Parameter Estimates (* indicates significance at the 5% level)

where $i \in \{1, 2, ..., p\}$.

Estimation is done via maximum likelihood and parameter estimates are given in Table 1. The sum of the coefficients on lagged inflation is .45, indicating the inflation trend is slightly more important in influencing short-term inflation dynamics.[20] Estimates for parameters in the monetary reaction function appear plausible. The constant real rate is 2.24, the federal funds rate responds aggressively and significantly to deviations of core CPI inflation relative to trend and the coefficient on the measure of economic activity has the correct sign, but is not significant.

The other objects of interest from estimation are trend inflation and the Kalman gains on the forecast errors. Turning first to trend inflation, Figure 1 reports the trend for the model given in (6)-(7). Clearly, the trend closely tracks the observed long-term survey expectation of inflation. Figure 2 plots the year-over-year change in the headline CPI and trend. As noted by Kozicki and Tinsley (2001a,b, 2002), forecasters' view of trend inflation was slow to change, as is apparent for the first part of the 1980s when inflation was persistently below both the long-term survey measures and trend.

The model generates forecasts of survey expectations that are consistent with the estimated process for inflation and thus, long-term survey expectations provide a contemporaneous source of information for monitoring the private sector's view of trend inflation. If long-term survey expectations differ from their forecasted value, the implication is that forecasters have revised their estimate of trend inflation.

To make this point precise, estimation implies that the Kalman gain on forecast errors on long-term expectations is roughly unity, indicating that long-term survey expectations basically track trend inflation. In some respects, this may appear obvious. However, this implication not only derives from the cross-equation restrictions that are imposed on the processes for inflation and expectations, but also on the relative variances of the shocks to long-term expectations and trend inflation. The variance of the inflation target is low, but the estimated variance of the innovation to the long-term survey measure is much lower.

The implication of these relative variances for extracting the underlying inflation trend from long-term survey measures can be drawn from a simple example. For the

[20]This estimate of the AR coefficient sum is very similar to Kozicki and Tinsley's (2006).

moment, let the long-term survey-based measures equal

$$S_{t|t+40} = \pi_t^* + u_t, \tag{13}$$

where $u_t \sim N(0, \sigma_u^2)$ and $S_{t|t+40}$ is observed, but not π_t^* or u_t. This specification is actually very close to the estimated model, since $f_{40}(C)$ is near unity and $h_{40,i}(C)$ are near zero for each i. Given policymakers' interest lies primarily in deducing π_t^*, we can extract its value by specifying a prior mean and variance for π_0^*, and then update the inference regarding the trend using the Kalman filter,

$$\pi_t^* = \pi_{t|t-1}^* + K_t \eta_{t|t-1}, \tag{14}$$

where $\pi_{t|t-1}^*$ denotes the trend at t conditional on information at $t-1$ and $\eta_{t|t-1} = S_{t+40|t} - \pi_{t|t-1}^*$. The Kalman gain is given by

$$K_t = P_{t|t-1}\left(P_{t|t-1} + \sigma_u^2\right)^{-1}, \tag{15}$$

where

$$P_{t|t-1} = E\left[\left(\pi_t^* - \pi_{t|t-1}^*\right)^2\right] \tag{16}$$

is the mean square error of the inflation trend. In estimating the actual model, the mean square error for trend inflation is low, but σ_u^2 is much lower. Consequently, the estimated value for the Kalman gain is near unity on forecast errors for long-term survey expectations. Setting $K_t = 1$, we see that $\pi_t^* = S_{t+40|t}$, indicating policymakers can track trend inflation by focusing on long-term expectations. In contrast to long-term expectations, forecast errors on inflation, the interest rate and short-term expectations have Kalman gains near zero, so have very little implication concerning inferences on trend inflation.[21]

However, persistently high inflation will eventually feed through to higher short-term and eventually long-term expectations. Casual evidence from Figure 2 indicates that expectations of the inflation trend do change, but it takes time for forecasters to adjust their views. More formally, we test the cross-equation restrictions given by (11) and (12) to assess whether expectations based on the model for inflation given in (1) are a reasonable description of survey expectations. Freely estimating the parameters in the matrix H (i.e. see (10)) results in a higher likelihood value,

[21] The result that innovations to the monetary reaction function have little impact on the inference regarding the underlying inflation trend stands in contrast to Kiley (2008b). The difference could be a result of a number of factors, such as different estimation methods (Kalman filter vs. GMM), model (we explicitly model survey expectations) or data (he constructs a 7-year 3-year ahead measure of expected inflation, which he treats as the target). Also, Kiley's Kalman gain is roughly .02, indicating a 100 basis point deviation in the rule results in a .02% revision to the underlying inflation trend — so even under his specification, short-run deviations from the estimated reaction function play a limited role in affecting long-term expectations.

but does not indicate a formal rejection of the cross-equation restrictions.[22] This suggests the model does captures relevant aspects of the factors driving long-term survey expectations.

The bottom line of this exercise is that movements in long-term inflation expectations are unlikely to be the result of short-run noise, so should be viewed by policymakers as a reliable indicator of the perceived underlying inflation trend. Given the importance of trend inflation to inflation dynamics, even small movements in long-run expectations can then represent a persistent source of pressure on inflation. However, the model for inflation in this section is highly restrictive, imposing constant parameters across the sample. In the next section, we consider a much less restrictive model that allows for potentially richer interactions among inflation and expectations by letting parameters vary over time.

5 A Time-Varying VAR with Stochastic Volatility

We now turn to a model that not only relaxes the cross-equation restrictions of the model used in section 4 but also allows time-varying parameters and stochastic volatility. A key benefit of this approach is that it allows us to distinguish changes in the contemporaneous relationships among the variables from changes in the volatility of the shocks. In many respects, this approach swings the pendulum in the opposite direction relative to the previous model — that is, moving from a highly restrictive framework to one that imposes few restrictions on the relationships among inflation and expectations.

Because estimation is computationally demanding and may not be reliable in a large VAR with time-varying parameters, we restrict the number of variables in the system to include only long-term expectations, short-term expectations, and core inflation. Following studies such as Cogley and Sargent (2005) and Primaceri (2005), the model also incorporates stochastic volatility.

The model specification is as follows

$$y_t = \mu_t + B_{1,t} y_{t-1} + B_{2,t} y_{t-2} + B_{3,t} y_{t-3} + B_{4,t} y_{t-4} + A_t^{-1} H_t^{.5} \varepsilon_t, \tag{17}$$

$$A_t = \begin{bmatrix} 1 & 0 & 0 \\ a_{21,t} & 1 & 0 \\ a_{31,t} & a_{32,t} & 1 \end{bmatrix}, \qquad H_t = \begin{bmatrix} h_{1,t} & 0 & 0 \\ 0 & h_{2,t} & 0 \\ 0 & 0 & h_{3,t} \end{bmatrix},$$

[22] We set the weights on the inflation trend term - the $f_4(C)$ and $f_{40}(C)$ terms - to one minus the sum of coefficients on the lagged inflation terms, which are freely estimated. This relaxes the cross-equation restrictions, but continues to impose that expectations are a weighted sum of the inflation trend and lags of inflation, with the weights summing to one.

where $var(\varepsilon_t) = I$ and now $y_t = \left[S_{t+40|t}, S_{t+4|t}, \pi_t\right]'$. The vectors of parameters follow random walk processes:

$$\begin{aligned} B_t &= B_{t-1} + u_t \\ a_t &= a_{t-1} + v_t \\ \log h_t &= \log h_{t-1} + e_t. \end{aligned}$$

Following Benati (2008), we estimate the model chiefly with the method of Cogley and Sargent (2005), except that we allow the elements of A to be time varying, as in Primaceri (2005). Estimates of a VAR from a training sample of 10 years of data are used to set key elements of the prior.[23] We report posterior estimates based on a sample of 10,000 draws, obtained by first generating 10,000 burn-in draws and then saving every fifth draw from another 50,000 draws.

To identify the effects of shocks to each variable, we use a recursive identification scheme with the following ordering: long-term expectations, short-term expectations, core CPI inflation. Survey measures are placed first due to the timing of when the Survey of Professional Forecasters asks forecasters to submit their responses. Typically, the deadlines are in the middle of the second month of the quarter, which means forecasters will have seen, at best, CPI data on only the first month of the quarter. Recently, the survey deadlines are somewhat earlier, implying forecasters would not have any CPI inflation data within the quarter that they are submitting their forecast. The timing of the survey then suggests that innovations to inflation are unlikely to impact survey expectations within a given quarter. Long-term expectations are before short-term expectations since a forecaster revising his/her long-term forecast, for whatever reason, will also likely revise the short-term forecast. In contrast, a forecaster suddenly revising his/her short-term forecast may be less likely to revise the long-term forecast.

Figures 3 and 4 compare posterior medians of impulse responses (with 70 percent credible sets) implied by coefficient values at the beginning and end of the estimation sample, respectively. Focusing first on Figure 3, which reports responses based on parameter values in 1982:Q3, the first column shows a 50 basis point shock to long-term expectations generates a rise in short-term expectations of roughly equal magnitude.[24] Core inflation rises by about 100 basis points a year after the shock and then dissipates. In the second column, a shock to short-term expectations generates a temporary rise in long-term expectations with no significant pass-through to core

[23] In this training sample, long-run expectations are proxied by econometric estimates from Kozicki and Tinsley (2001a), and short-run expectations are measured with SPF forecasts of inflation in the GNP deflator. Following Del Negro (2003), we use a more informative prior on the initial coefficient values, setting the means at values from a VAR(1) and variances equal to twice the OLS variance of the VAR(4) coefficients, to reduce problems with explosive roots.

[24] Shocks to expectations in this setting are probably best interpreted as resulting from 'omitted fundamentals' in the VAR, rather than sunspot shocks.

inflation. The last column shows that a shock to core inflation elicits a modest and short-lived rise in short-term expectations that dies out relatively quickly. Figure 4 reports impulses responses based on parameter values in 2008:Q2. The only substantive difference compared to the responses from early in the sample is that shocks to short-term expectations no longer impact long-term expectations, as is apparent in the top graph in the middle column.

Figure 5 compares the posterior medians of impulse responses based on parameter values at several different dates. The responses are remarkably stable, suggesting that time variation in the autoregressive parameters (i.e. the $B_{i,t}$'s) is not a central feature of the post-1980 relationship between inflation and expectations.

Figure 6 reports posterior medians of the time-varying volatilities of the residual standard deviations. The volatility of shocks (both structural and reduced-form) to long-term expectations has varied over the sample, but exhibits a pronounced decline that began in the late 1990s. Volatility in the innovation to short-term expectations has also steadily trended down. Volatility to the innovation in inflation declined more rapidly than either long- or short-term expectations early in the sample, but has modestly risen over the past five years.

In this framework, long-term expectations can be 'anchored' in two ways, either by exhibiting little or no response to movements in inflation or having innovations with low volatility.[25] First, expectations are anchored if they are unresponsive to innovations to core inflation and short-term expectations. An innovation to core inflation can lead to a rise in long-term expectations if the central bank passively accommodates the shock and allows long-term expectations to rise. Similarly, an innovation to short-term expectations, perhaps due to rising energy or food prices, can lead to higher long-term expectations if the central bank passively accommodates the shock. Second, long-term expectations are better anchored following a decline in the stochastic volatility for the innovation to long-term expectations. Overall, anchored long-term expectations are then unresponsive to shocks and display a minimal amount of volatility.

Based on both notions of anchoring, we view long-term expectations as modestly better anchored in 2008:Q2 than in 1982:Q3. Referring to Figures 3 and 4, long-term expectations do not respond significantly to an innovation to short-term expectations in 2008:Q2, whereas they rose approximately 10 basis point the few quarters following the shock in 1982:Q3. However, expectations are not perfectly anchored. Following a shock to core inflation, long-term expectations rise slightly (less than two basis points, in response to a 50 basis point shock in core inflation), with no real difference in the response today versus the response in 1982.

[25] We focus on anchoring of long-term expectations because the SPF requests forecasts for headline inflation. One-year (i.e. short–term) expectations should move in response to fluctuations in energy and food prices, where such movements do not necessarily indicate expectations are unanchored.

The second notion of anchoring, which focuses on the volatility in the innovations to expectations, suggests long-term expectations are better anchored near the end of the sample. If we can interpret long-term survey expectations as professional forecasters' view of trend inflation, as the model in the section 4 suggests, then the degree of volatility attributable to trend inflation has declined substantially over the sample.

6 VAR Analysis

6.1 Benchmark Specification

The small time-varying VAR is useful for gauging the relationships among inflation and short- and long-term expectations. However, our next step is to move to a richer multivariate setting that can potentially identify other factors that impact inflation expectations, such as output or certain commodity prices. One drawback is that expanding the number of variables in a time-varying VAR with stochastic volatility is very demanding from a computational standpoint and may, if the increase in variables is great enough, even lead to unreliable estimates. So given the relative stability of parameter estimates, this section increases the number of variables and moves to a conventional VAR framework.[26]

The approach is similar to Leduc, Sill, and Stark (2007), who add eight-month ahead inflation expectations to an otherwise conventional macroeconomic VAR.[27] Our analysis builds on theirs in a few respects. First, we incorporate both short- and long-term expectations into the VAR. Second, we augment the VAR with either the food or energy component of the CPI to assess how shocks to these commodity bundles may impact inflation expectations. Finally, we significantly extend the data sample, to end in mid-2008 instead of 2001, and thereby capture more recent behavior.

The benchmark VAR contains five variables, with four lags of each, in the following order: long-term expectations, short-term expectations, CPI inflation, the Chicago Fed National Activity Index (CFNAI), and the federal funds rate. We use the CFNAI because it captures broader movements in economic activity than, say, just industrial production.

Figure 7 gives the impulse responses for each orthogonalized shock (with 70%

[26]Since stochastic volatility is an important feature of the data, we perform a robustness check later in the section by estimating a model with constant autoregressive parameters, but allowing for stochastic volatility.

[27]See also Choy, Leong, and Tay (2006), Canova and Gambetti (2008), Demertzis, Marcellino, and Viegi (2008), and Mehra and Herrington (2008).

confidence bands). The primary results are as follows.

- Shocks to long-term expectations generate a persistent rise in short- and long-term expectations. There is some pass-through to inflation, though of negligible significance. These results are consistent with the time–varying parameter VAR. Also, monetary policy tightens aggressively.

- Shocks to short-term expectations also generate a rise in long-term expectations and generate some temporary pass-through to inflation. Monetary policy temporarily tightens, but less so than under a shock to long-term expectations. Apart from the behavior of long-term expectations, our estimates are qualitatively similar to those of Leduc, Sill, and Stark (2007) for the 1979-2001 period.

- Shocks to inflation cause both short- and long-term expectations to rise, where the impulse to short-run expectations dies out relatively quickly compared to long-term expectations (although the differences are probably not statistically significant). Monetary policy eases due to a decline in economic activity. This shock appears to be capturing primarily 'supply side' disturbances.

- Shocks to economic activity elicit a rise in short-term expectations and inflation. Monetary policy aggressively tightens.

- A shock raising the federal funds rate eventually lowers short- and long-term expectations after about one year, though only temporarily. Inflation and economic activity also decline temporarily for a few quarters following the shock. From a qualitative standpoint, the impact on each variable is intuitively reasonable and in line with responses from estimated medium-scale DSGE models, such as Smets and Wouters (2007). Our estimates are qualitatively similar to those of Leduc, Sill, and Stark (2007) for 1979-2001, although with less dramatic responses, probably reflecting the difference in samples. Finally, the response of each variable has periods where the 70 percent confidence band is outside of zero, but each is of negligible significance.

Some of these results differ from the first section — namely that short-run innovations to inflation and monetary policy can move both measures of expectations. There are several potential reasons for this — however, the primary reason is that the model embedded in the VAR for survey expectations is less restrictive. Expectations in the VAR depend on lagged values of every variable in the system. Also, there are no cross-equation restrictions requiring expectations be consistent with the underlying process for inflation.

6.2 Augmenting the VAR with Disaggregated Price Data

The benchmark VAR provides some indications of how expectations interact with other macroeconomic variables. To address more specifically which factors impact expectations, we expand the VAR to include sector-specific price indices that may impact expectations. In particular, we include either the food or the energy component of the CPI index to get a sense for how movement in prices for goods in these baskets may affect expectations of future inflation.[28]

The VAR in this section is similar to the benchmark VAR, except for a few modifications. First, the CPI is now partially disaggregated, so is no longer appropriate to include both (i) a food or energy price component and (ii) the headline measure of inflation in the system. Instead, we replace headline CPI inflation with the core measure that excludes food and energy. Second, we have expanded the system, so must take another stand on identification. We order the energy or food component first because forecasters will have seen several weeks of data on the underlying commodities in these baskets before reporting their forecasts. However, it is reasonable that energy and food respond to shocks to expectations or economic activity, so we consider alternatives that ensure our results are robust to alternative orderings.

The estimates in Figure 8 indicate that shocks to CPI energy inflation have some impact on inflation expectations. Core inflation modestly rises in response, but is not significant, and economic activity temporarily declines. The shock seems to induce supply-side disturbances typically associated with energy shocks. Policy appears to balance the negative comovement in inflation and economic activity by leaving the federal funds rate mostly unchanged. Other aspects of the results, such as the impacts of expectations shocks, are similar to those from the benchmark case presented in section 6.1. However, in unreported results, we have found the responses of expectations to energy price shocks are not robust to alternative orderings, in particular an ordering of expectations, core inflation, energy inflation, CFNAI, and the funds rate. As a consequence, we are hesitant to draw strong conclusions on the impact of energy price shocks on expectations.

The estimates in Figure 9 provide a more robust finding: shocks to CPI food inflation generate a relatively large and persistent impact on both short- and long-term expectations, as well as a significant increase in core inflation. This pattern holds up in alternative orderings: ordering food inflation after either expectations, core CPI inflation, or the CFNAI made little difference. One rational as to why food price inflation has a larger impact on expectations and core inflation is that energy is substantially more volatile than food prices. The volatility may cause forecasters to expect an increase in one quarter will be undone in near-term quarters, so they

[28] Weighting food and energy price inflation by their relative importances in the CPI yields results very similar to the reported estimates, which use unweighted inflation rates.

place low weight on energy price movements when formulating their expectations of headline inflation. In contrast, food price inflation has a tendency to be more persistent and has a larger weight in the overall CPI basket, causing forecasters to revise expectations in light of movements in food prices.

6.3 Robustness Checks

- Results from section 5's time-varying parameter VAR with stochastic volatility indicate that stochastic volatility is important. To further check our results from the conventional VAR analysis, we estimate a VAR using the same set of variables, but allowing for stochastic volatility.[29] The specification is as follows:

$$y_t = \mu + B_1 y_{t-1} + B_2 y_{t-2} + B_3 y_{t-3} + B_4 y_{t-4} + A_t^{-1} H_t^{.5} \varepsilon_t,$$

  which is similar to (17), except μ_t and $B_{i,t}$ are constant for all t. Results compared to the standard VAR are very similar, with one important exception. In general, there are no significant differences to report regarding impulse responses relative to the standard VAR. Of interest, however, are some of the movements in stochastic volatility. Figures 10 and 11 illustrate the dramatic rise in volatility in food and energy prices over the past several years. There has also been some rise in the volatility of short-term expectations and core inflation, but volatility still remains low relative to earlier in the sample. The volatility of long-term expectations remains low in recent years across specifications. These features are reinforced by using Cogley, Primiceri and Sargent's R^2 measure, which is the fraction of the conditional to unconditional variance of the forecast error. Figure 12 plots the R^2 measures for each variable and shows that predictability of long-term expectations has risen, whereas predictability of overall CPI inflation has fallen.

  The variance decompositions at a two-year horizon conditional on parameter values at the beginning and end of the sample are given in Table 2. An interesting aspect of these decompositions is the shift away from variance attributable to 'own shocks' for long-term expectations towards shocks to CPI inflation. Own shocks accounted for 65% of the variance in long-term expectations at the beginning of the sample, but fell to 23% by the end. CPI shocks, in contrast, accounted for 9% of variation in long-term expectations at the beginning of

[29] Fixing the VAR coefficients simplifies the TVP estimation described above. Conditional on the draw of A_t and H_t, the VAR coefficients are estimated with a flat prior, which is effectively equivalent to GLS estimation (specifically, the posterior mean and variance are effectively equivalent to the GLS estimates; in the Gibbs algorithm, we then take a draw from a normal distribution with mean and variance equal to the posterior mean and variance). Conditional on the VAR coefficients and H_t, the elements of A_t are estimated as in Primaceri (2005). Finally, conditional on the VAR coefficients and A_t, the log volatilities are estimated as in Cogley and Sargent (2005).

the sample and rose to 55% at the end. This implies the long-term expectations vary more today, in relative terms, in response to observables instead of unexplained factors. Overall, we can describe the volatility of long-term expectations as showing a substantial decline over the sample, where the volatility that remains is primarily explained by observable macroeconomic variables.

Table 2. Variance decomposition from baseline VAR with stochastic volatility, horizon of 8 quarters

	shock to:				
response of:	EXP10YR	EXP1YR	CPI	CFNAI	FFR
	based on 1982:Q3 volatilities				
EXP10YR	65 (19.9)	8 (9.5)	9 (9.4)	3 (4.1)	15 (16.3)
EXP1YR	26 (15.8)	41 (18.2)	5 (5.4)	10 (9.4)	18 (16.6)
CPI	9 (7.7)	18 (13.3)	37 (18.4)	9 (8.7)	27 (18.4)
CFNAI	8 (7.0)	17 (13.7)	10 (9.8)	34 (17.4)	31 (22.1)
FFR	10 (9.5)	6 (7.4)	5 (6.6)	30 (17.5)	49 (20.9)
	based on 2008:Q2 volatilities				
EXP10YR	23 (17.8)	10 (10.9)	55 (23.2)	4 (5.5)	8 (10.6)
EXP1YR	7 (7.2)	44 (18.4)	29 (18.3)	12 (10.9)	7 (8.6)
CPI	1 (1.1)	7 (6.8)	84 (10.3)	4 (4.8)	4 (4.8)
CFNAI	2 (2.5)	15 (12.6)	36 (19.4)	36 (18.4)	12 (11.9)
FFR	3 (3.7)	9 (9.9)	19 (17.4)	46 (20.6)	24 (16.3)

Notes:
1. Entries are posterior mean estimates of variance shares, in percent terms, with posterior standard deviations in parentheses.

- The impact of food on expectations is relatively robust to whether it is split between "food away from home" and "food at home." In general, the different indices have impacts similar to the overall food component. There is some sensitivity to whether food at home is ordered before or after food away from home (whichever is first has the bigger impact on expectations and inflation), but qualitatively, the results are similar across orderings.

- Adding wages, whether hourly earnings or compensation for the non-farm business sector, did not generate any meaningful results. That is, there is no clear evidence that wages and expectations of inflation react to one another.

- Using the University of Michigan's consumer survey instead of SPF expectations yields results that are similar along most dimensions, although different in some. Not surprisingly, shocks to consumer expectations are bigger and are less persistent, primarily because the University of Michigan series are noisier

than the SPF series. Shocks to 1-year expectations don't cause 10-year expectations to rise, and policy is measured as responding to 1-year but not 10-year expectations shocks.

- Using a model in the change in long-term expectations, short-term expectation less long-term expectations, and inflation less long-term expectations, and then adding back the long-terms levels to recover responses in levels yields similar results. The exception is that expectation shocks and responses are more persistent, as expected given the enforced unit root.

- Using PCE inflation instead of the CPI yields qualitatively similar results, with one noticeable difference being that a shock to 1-year (CPI) expectations has less impact on PCE inflation than CPI inflation.

6.4 VAR results summary

Relatively unrestricted VARs estimated with data for about the past 25 years indicate that shocks to expectations — long-run more so than short-run — have a significant impact on inflation. It appears that policy responses to shocks to expectations likely help to mitigate the impact of the shocks to expectations. Expectations appear to respond to a variety of other shocks in the economy: to actual inflation, food price inflation, economic activity, and monetary policy. So neither inflation nor expectations appear to be perfectly anchored. Of course, we shouldn't expect inflation and short-term expectations to not respond (at least temporarily) to shocks. We might instead focus on whether long-run expectations respond to shocks. While long-run expectations are clearly not perfectly anchored, at least the responses of long-run expectations to the shocks we consider are quantitatively small.

7 Conclusions

We conclude by providing summary answers — drawn from our literature review and our own evidence drawn from a range of empirical models — to the key questions of the paper.

1. How do expectations influence inflation? Do the roles of short-run and long-run expectations differ?

    - Overall, expectations are an important force in inflation dynamics, with long-run expectations, which are tantamount to trend inflation, more important than short-run expectations.

- A wide range of prior studies has found a key role for survey-based expectations in inflation dynamics. While there remains some debate about the importance of forward-looking expectations versus backward-looking components in inflation dynamics, expectations or trend inflation appear to be a primary source of variation in inflation. Apart from the results in this paper, there is little direct evidence on distinct roles of short-term vs. long-term expectations.
- In our initial state-space framework, trend inflation, which is essentially equivalent to the long-run inflation expectation, receives greater weight in the equation determining short-run inflation dynamics than lagged realizations of inflation. As a result, even small movements in long-run expectations can represent a persistent source of pressure on inflation.
- In our VAR estimates, shocks to short- and long-term expectations result in some pass-through to actual inflation. The pass-through is greater for a shock to long-term expectations, despite a sustained increase in the nominal federal funds rate.

2. What influences expectations? That is, how do expectations depend on past inflation, the state of the economy, and monetary policy? How do long-run expectations relate to short-run expectations?

    - Existing research indicates that inflation expectations respond to a range of variables: oil prices, commodity prices, past inflation, the state of the economy, and monetary policy actions. A more limited volume of work shows that the responses of short-run expectations are normally sharper than the responses of long-run expectations. Long-run expectations closely track trend inflation, which tends to respond with a lag to actual inflation.
    - In our VAR analysis, innovations to CPI inflation pose the greatest risk to keeping short- and long-term expectations anchored. Short-term expectations respond more sharply than do long-term expectations. Also, shocks to the interest rate play a role, though more modest.
    - In our VAR analysis of sector-specific prices, shocks to energy have little effect on core inflation, despite potentially having some impact on inflation expectations (in some identifications). In contrast, shocks to the food component significantly affect expectations and core inflation.

3. What's changed over time? Have the relationships among inflation and expectations changed in recent years, making inflation and expectations more or less anchored? What might account for any changes?

    - The existing literature suggests inflation has been better anchored in the past 20 or so years than in the prior period, although some evidence suggests no change. Similarly, some historical comparisons generally suggest

expectations have become better (but not completely) anchored, responding less than used to be the case to various shocks in the economy.

- Most strikingly, the volatility of expectations and trend inflation has clearly fallen, and some evidence indicates that trend inflation has become a relatively smaller source of volatility in inflation. While these changes imply a smaller role for trends and long-run expectations in inflation movements, they are consistent with improved anchoring of inflation.
- Of the limited work to date on the sources of these changes, most has focused on explaining the changes in the properties of inflation (not expectations) with shifts in the behavior of monetary policy. Some studies have found that the reduced volatility and persistence of inflation is mostly due to a falloff in the volatility of an implicit inflation target. Others attribute changes in the behavior of inflation more to other changes in the behavior of monetary policy. Still other studies highlight the importance of learning by the public or the central bank in inflation dynamics and changes over time in dynamics.
- Our own estimates, based on data for the past 25 or so years and models with time-varying parameters, suggest changes within this sample have been modest (some of the changes mentioned above occurred before the beginning of our sample). The only notable change is that long-run expectations seem to have become somewhat better anchored, partly in the sense that they are now slightly less responsive to inflation shocks than used to be the case but mostly in the sense that the volatility of shocks to long-run expectations has fallen sharply. The volatilities of shocks to short-run expectations and core inflation also fell sharply during our sample.

References

Adam, Klaus, and Mario Padula (2003), "Inflation Dynamics and Subjective Expectations in the United States," European Central Bank Working Paper 222.

Ang, Andrew, Geert Bekaert, and Min Wei (2007), "Do Macro Variables, Asset Markets or Surveys Forecast Inflation Better?" *Journal of Monetary Economics*, v.54, pp. 1163-1212.

Beechey, Meredith J., Benjamin K. Johannsen, and Andrew T. Levin (2008), "Are Long-Run Inflation Expectations Anchored More Firmly in the Euro Area than in the United States?" Federal Reserve Board FEDS Working Paper 2008-23.

Belaygorod, Anatoliy, and Michael J. Dueker (2005), "Discrete Monetary Policy Changes and Changing Inflation Targets in Estimated Dynamic Stochastic General Equilibrium Models," *Economic Review*, Federal Reserve Bank of St. Louis, November/December.

Benati, Luca (2008), "The 'Great Moderation' in the United Kingdom," *Journal of Money, Credit, and Banking*, v.40, pp. 121-147.

Benati, Luca, and Paolo Surico (2008), "Evolving U.S. Monetary Policy and the Decline of Inflation Predictability," *Journal of the European Economic Association*, v.6, pp. 634-646.

Bernanke, Ben S. (2007), "Inflation Expectations and Inflation Forecasting," speech at the Monetary Economics Workshop of the National Bureau of Economic Research Summer Institute, Cambridge, Mass., July 10.

Bernanke, Ben S. and Jean Boivin (2003), "Monetary Policy in a Data-Rich Environment," *Journal of Monetary Economics*, v.50, pp. 525-546.

Brayton, Flint, Eileen Mauskopf, David Reifschneider, Peter Tinsley, and John Williams (1997), "The Role of Expectations in the FRB/US Macroeconomic Model," *Federal Reserve Bulletin*, April.

Brissimis, Sophocles N., and Nicholas S. Magginas (2008), "Inflation Forecasts and the New Keynesian Phillips Curve," *International Journal of Central Banking*, v.4, pp. 1-22.

Canova, Fabio, and Luca Gambetti (2008), "Do Expectations Matter? The Great Moderation Revised," manuscript, Universitat Pompeu Fabra.

Carlstrom, Charles T. and Timothy S. Fuerst (2008), "Inflation Persistence and the Phillips Curve," manuscript, Federal Reserve Bank of Cleveland.

Carroll, Christopher D. (2003), "Macroeconomic Expectations of Households and Professional Forecasters," *Quarterly Journal of Economics*, v.118, pp. 269-298.

Cecchetti, Stephen G., Peter Hooper, Bruce C. Kasman, Kermit L. Schoenholtz, and Mark W. Watson (2007), "Understanding the Evolving Inflation Process," manuscript, Brandeis University, July.

Chernov, Mikhail, and Philippe Mueller (2008), "The Term Structure of Inflation Expectations," CEPR Discussion Paper 6809.

Choy, Keen Meng, Kenneth Leong, and Anthony S. Tay (2006), "Non-Fundamental Expectations and Economic Fluctuations: Evidence from Professional Forecasts," *Journal of Macroeconomics*, v.28, pp. 446-460.

Clark, Todd E., and Taisuke Nakata (2008), "Has the Behavior of Inflation and Long-Term Inflation Expectations Changed?" *Economic Review*, Federal Reserve Bank of Kansas City, First Quarter.

Cogley, Timothy, Giorgio E. Primiceri, and Thomas J. Sargent (2008), "Inflation-Gap Persistence in the U.S.," manuscript, University of California-Davis, April.

Cogley, Timothy, and Thomas J. Sargent (2005), "Drifts and Volatilities: Monetary Policies and Outcomes in the post WWII US," *Review of Economic Dynamics*, v.8, pp. 262-302.

Cogley, Timothy, and Argia M. Sbordone (2008), "Trend Inflation, Indexation, and Inflation Persistence in the New Keynesian Phillips Curve," *American Economic Review*, forthcoming.

Croushore, Dean (2006), "An Evaluation of Inflation Forecasts from Surveys Using Real-Time Data," Federal Reserve Bank of Philadelphia Working Paper 06-19, October.

Curtin, Richard (2005), "Inflation Expectations: Theoretical Models and Empirical Tests," manuscript.

D'Amico, Stefania, Don H. Kim, and Min Wei (2008), "Tips from TIPS: the Informational Content of Treasury Inflation-Protected Security Prices," Federal Reserve Board FEDS Working Paper 2008-30.

Del Negro, Marco (2003), "Discussion of Cogley and Sargent's 'Drifts and Volatilities: Monetary Policy and Outcomes in the Post WWII U.S.'," Federal Reserve Bank of Atlanta Working Paper 2003-26.

Demertzis, Maria, Massimiliano Marcellino, and Nicola Viegi (2008), "A Measure for Credibility: Tracking US Monetary Developments," manuscript, European University Institute.

Erceg, Christopher J., and Andrew T. Levin (2003), "Imperfect Credibility and Inflation Persistence," *Journal of Monetary Economics*, v.50, pp. 915- 944.

Gurkaynak, Refet S., Brian Sack, and Jonathan H. Wright (2008), "The TIPS Yield Curve and Inflation Compensation," Federal Reserve Board FEDS Working Paper 2008-05.

Gurkaynak, Refet S., Andrew T. Levin, and Eric T. Swanson (2006), "Does Inflation Targeting Anchor Long-Run Inflation Expectations? Evidence from Long-Term Bond Yields in the US, UK, and Sweden," CEPR Working Paper 5806.

Gurkaynak, Refet S., Brian Sack, and Eric Swanson (2005), "The Sensitivity of Long-Term Interest Rates to Economic News: Evidence and Implications for Macroeconomic Models," *American Economic Review*, v.95, pp. 425-436.

Ireland, Peter N. (2007), "Changes in the Federal Reserve's Inflation Target: Causes and Consequences," *Journal of Money, Credit, and Banking*, forthcoming.

Jochmann, Markus, Gary Koop, and Simon M. Potter (2008), "Modeling the Dynamics of Inflation Compensation," manuscript, Federal Reserve Bank of New York.

Kiley, Michael T. (2008a), "Estimating the Common Trend Rate of Inflation for Consumer Prices and Consumer Prices Excluding Food and Energy Prices," Federal Reserve Board FEDS Working Paper 2008-38.

Kiley, Michael T. (2008b), "Monetary Policy Actions and Long-Run Inflation Expectations," Federal Reserve Board FEDS Working Paper 2008-03.

Kiley, Michael T. (2007), "A Quantitative Comparison of Sticky-Price and Sticky-Information Models of Price Setting," *Journal of Money, Credit, and Banking*, v.39, pp. 101-125.

van der Klaauw, Wilbert, Wandi Bruine de Bruin, Giorgio Topa, Simon Potter, and Michael F. Bryan, "Rethinking the Measurement of Household Inflation Expectations: Preliminary Findings," manuscript, Federal Reserve Bank of New York.

Kozicki, Sharon, and Peter A. Tinsley (2006), "Survey-Based Estimates of the Term Structure of Expected U.S. Inflation," Bank of Canada Working Paper 2006-46.

Kozicki, Sharon and Peter A. Tinsley (2002), "Alternative Sources of the Lag Dynamics of Inflation," in *Price Adjustment and Monetary Policy*, Bank of Canada Conference Proceedings, pp. 3-47.

Kozicki, Sharon, and Peter A. Tinsley (2001a), "Shifting Endpoints in the Term Structure of Interest Rates," *Journal of Monetary Economics*, v.47, pp. 613-652.

Kozicki, Sharon, and Peter A. Tinsley (2001b), "Term Structure Views of Monetary Policy Under Alternative Models of Agent Expectations," *Journal of Economic Dynamics and Control*, v.25, pp. 149-184.

Kozicki, Sharon, and P.A. Tinsley (1998), "Moving Endpoints and the Internal Consistency of Agents' Ex Ante Forecasts," *Computational Economics*, v.11, pp. 21-40.

Lamont, Owen (2002), "Macroeconomic Forecasts and Microeconomic Forecasters," *Journal of Economic Behavior and Organization*, v.48, pp. 265-280.

Leduc, Sylvain, Keith Sill, and Tom Stark (2007), "Self-Fulfilling Expectations and the Inflation of the 1970s: Evidence from the Livingston Survey," *Journal of Monetary Economics*, v.54, pp. 433-459.

Leigh, Daniel (2005), "Estimating the Implicit Inflation Target: An Application to U.S. Monetary Policy," IMF Working Paper 05/77.

Macroeconomic Advisers (2007), "The Gravitational Pull of Inflation Expectations," *Macro Focus*, January 18.

Mankiw, N. Gregory, Ricardo Reis, and Justin Wolfers (2003), "Disagreement About Inflation Expectations," *NBER Macroeconomics Annual*, pp. 209-248.

Mehra, Yash P. and Christopher Herrington (2008), "On the Sources of Movements in Inflation Expectations: A Few Insights from a VAR Model," *Economic Quarterly*, Federal Reserve Bank of Richmond, v.94, pp. 121-146.

Milani, Fabio (2006), "The Evolution of the Fed's Inflation Target in an Estimated Model under RE and Learning," manuscript, University of California–Irvine.

Mishkin, Frederic S. (2007), "Inflation Dynamics," National Bureau of Economic Research Working Paper 13147, June.

Nunes, Ricardo C. (2006), "Inflation Dynamics: The Role of Expectations," manuscript, Federal Reserve Board of Governors.

Ottaviania, Marco, and Peter Norman Sorensen (2006), "The Strategy of Professional Forecasting," *Journal of Financial Economics*, v.81, pp. 441-466.

Piger, Jeremy M., and Robert H. Rasche, "Inflation: Do Expectations Trump the Gap?" Federal Reserve Bank of St. Louis Working Paper 2006-013B, July.

Potter, Simon, and Joshua Rosenberg (2007), "Are US Inflation Expectations Anchored, Contained, or Unmoored," manuscript, Federal Reserve Bank of New York.

Primiceri, Giorgio (2005), "Time Varying Structural Vector Autoregressions and Monetary Policy," *Review of Economic Studies*, v.72, pp. 821-852.

Primiceri, Giorgio (2006), "Why Inflation Rose and Fell: Policy-Makers' Beliefs and U.S. Postwar Stabilization Policy," *Quarterly Journal of Economics*, v.121, pp. 867-901.

Roberts, John M. (2007), "Learning, Sticky Inflation, and the Sacrifice Ratio," manuscript, Federal Reserve Board of Governors.

Roberts, John M. (1998), "Inflation Expectations and the Transmission of Monetary Policy," manuscript, Federal Reserve Board of Governors.

Roberts, John M. (1997), "Is Inflation Sticky?" *Journal of Monetary Economics*, v.39, pp. 173-196.

Roberts, John M. (1995), "New Keynesian Economics and the Phillips Curve" *Journal of Money, Credit, and Banking*, v.27, pp. 975-984.

Smets, Frank, and Rafael Wouters, "Shocks and Frictions in US Business Cycles: A Bayesian DSGE Approach," *American Economic Review*, v.97, pp. 586-606.

Stock, James H., and Mark W. Watson (1999), "Forecasting Inflation," *Journal of Monetary Economics*, v.44, pp. 293-335.

Stock, James H., and Mark W. Watson (2007), "Has U.S. Inflation Become Harder to Forecast?" *Journal of Money, Credit, and Banking*, v.39, pp. 3-33.

Thomas, Lloyd B., and Alan P. Grant (2008), "The Accuracy and Rationality of US and Australian Household Inflation Forecasts: A Comparative Study of the Michigan and Melbourne Institute Surveys," *The Economic Record*, v.84, pp. 237-252.

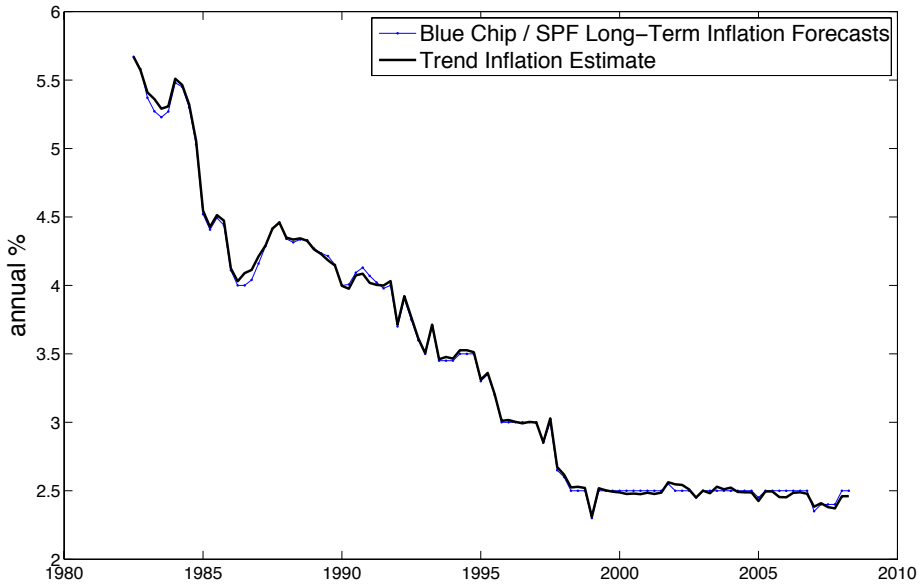

Figure 1: Trend Inflation and Long-term Survey Expectations

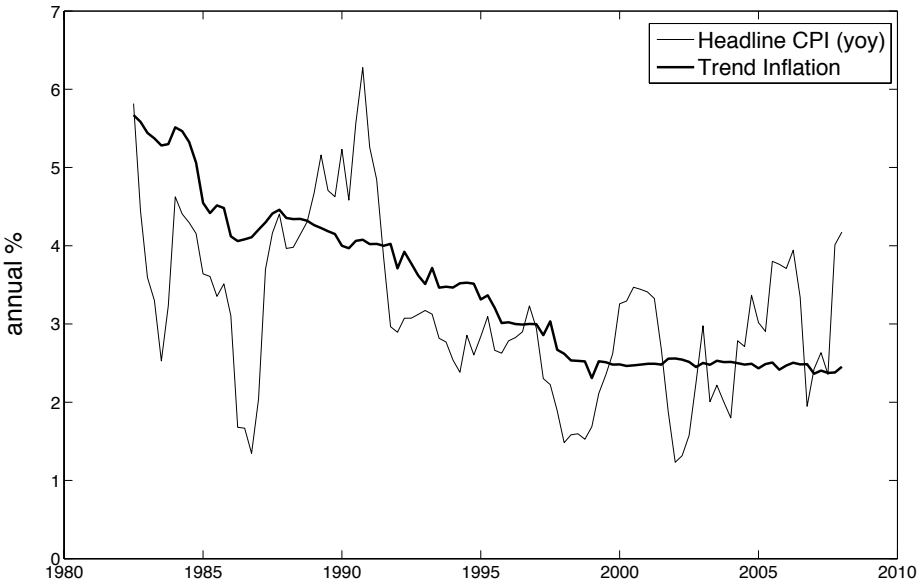

Figure 2: Headline CPI and Trend Inflation

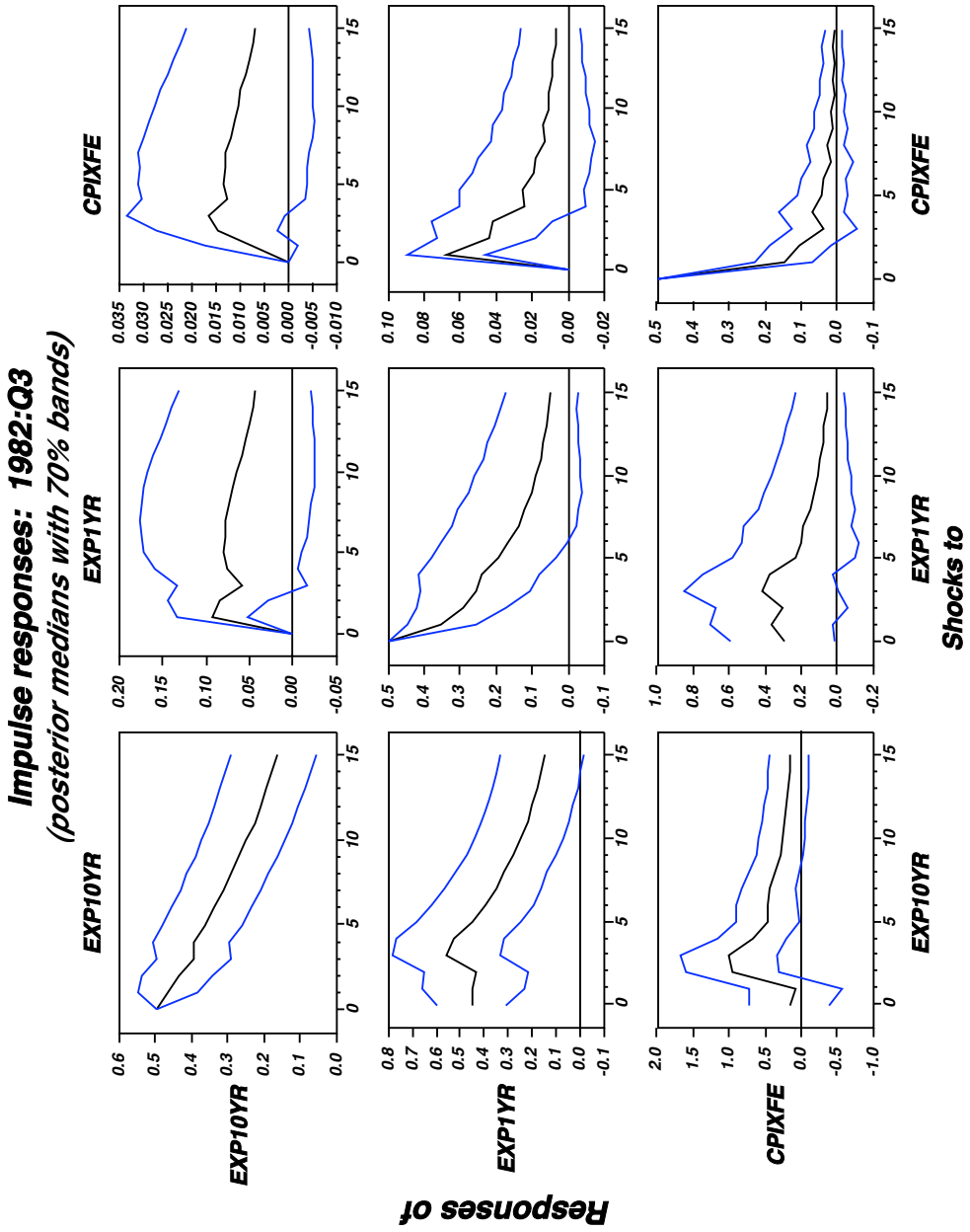

Figure 3: TVP-VAR with SV

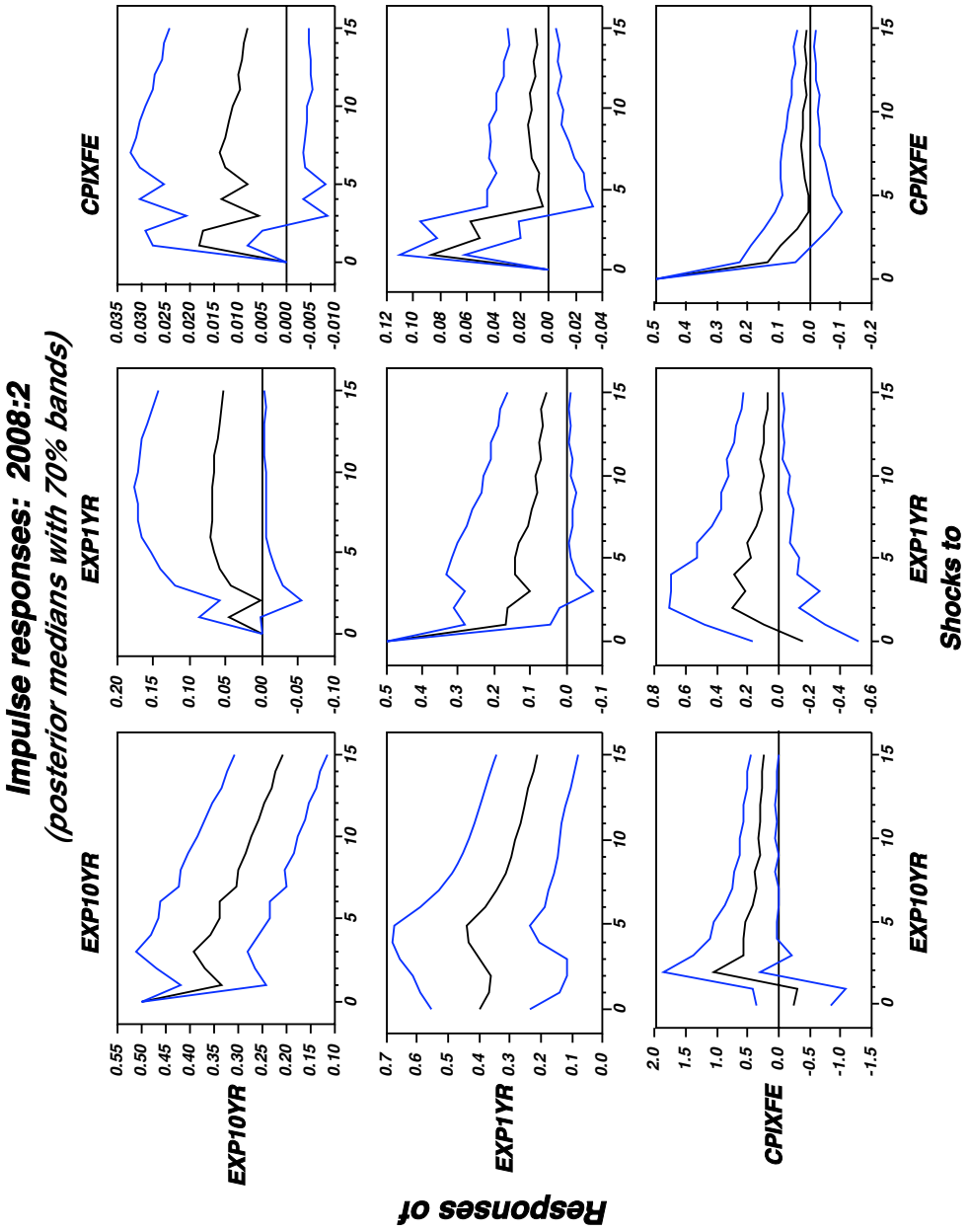

Figure 4: TVP-VAR with SV

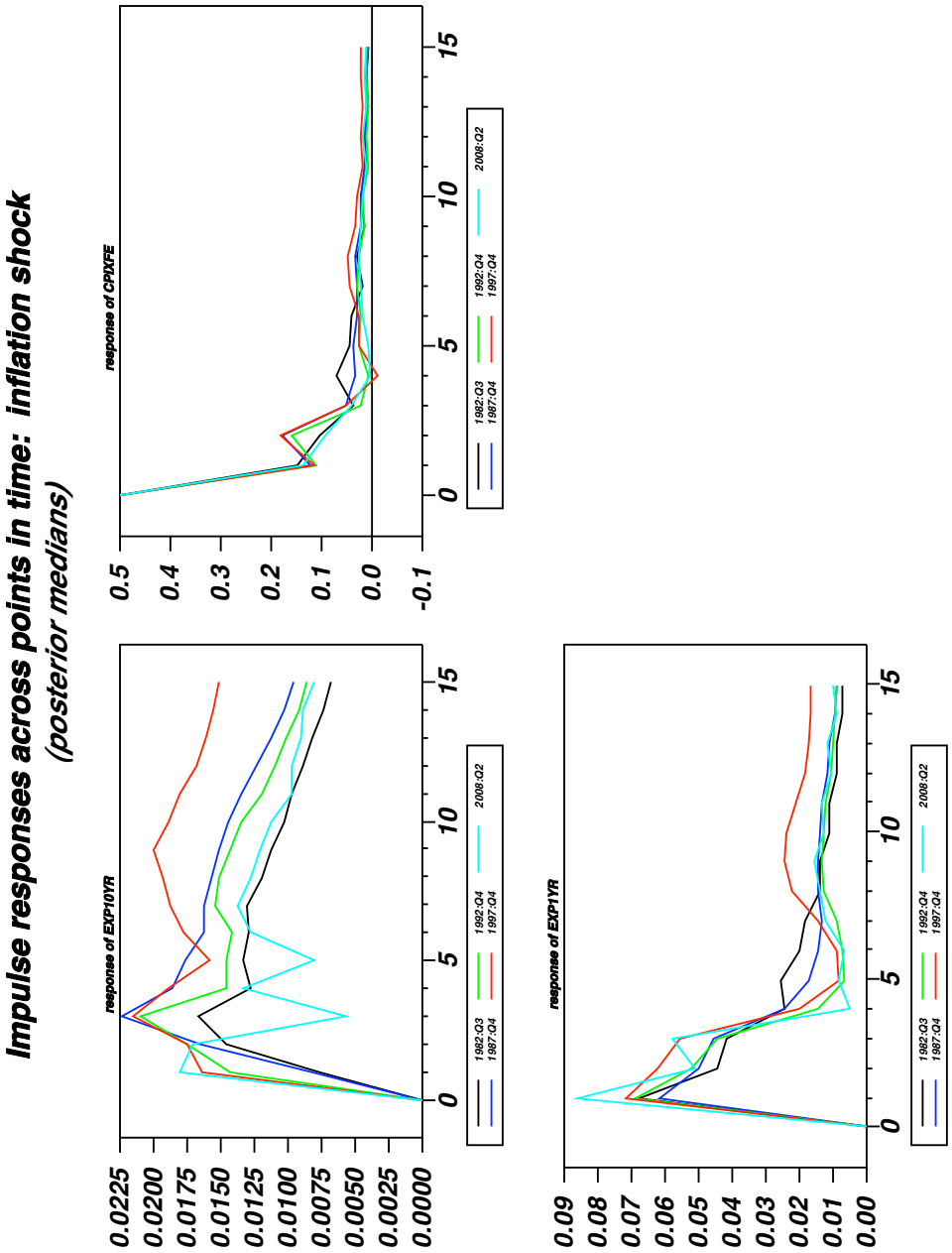

Figure 5: TVP-VAR with SV

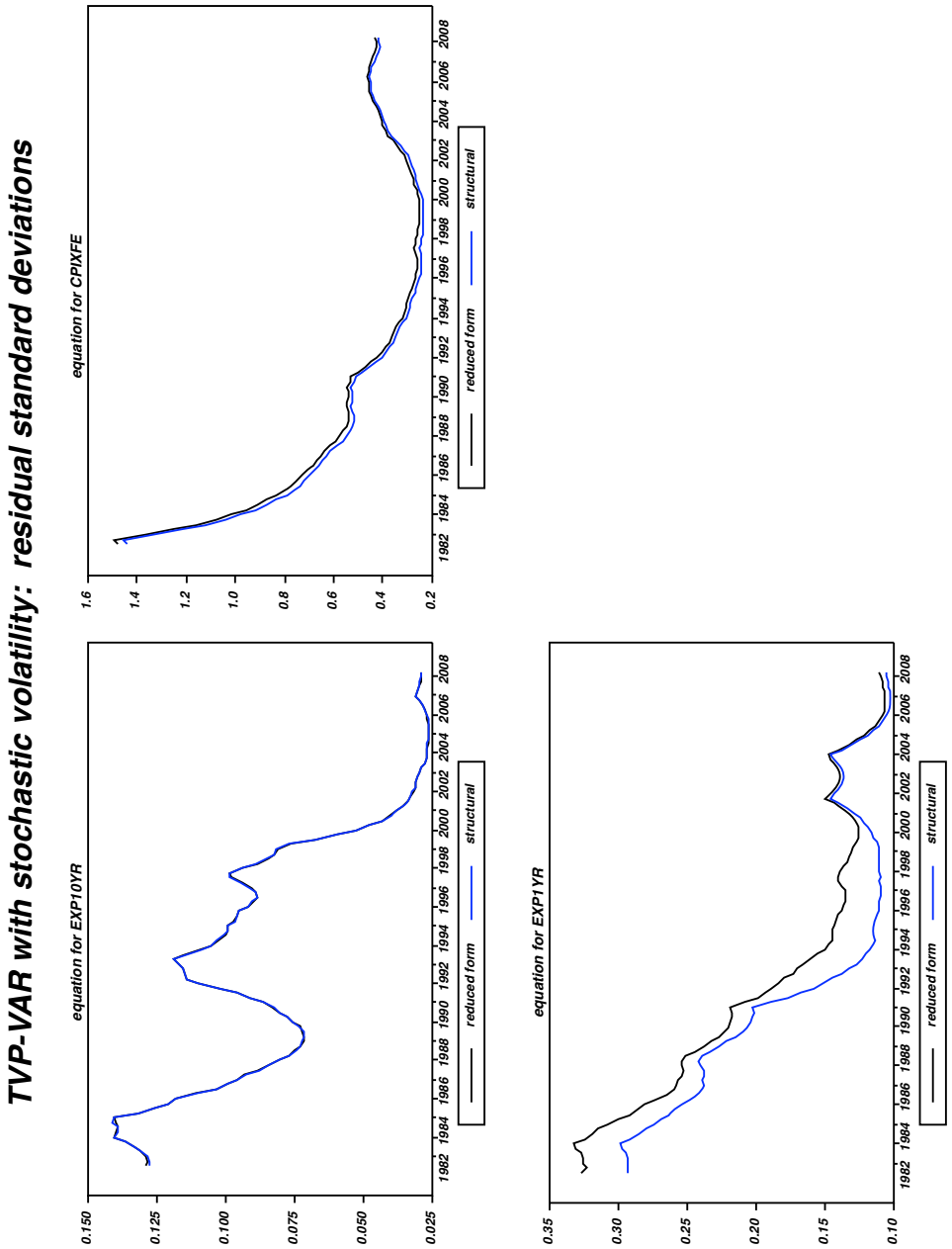

Figure 6: TVP-VAR with SV

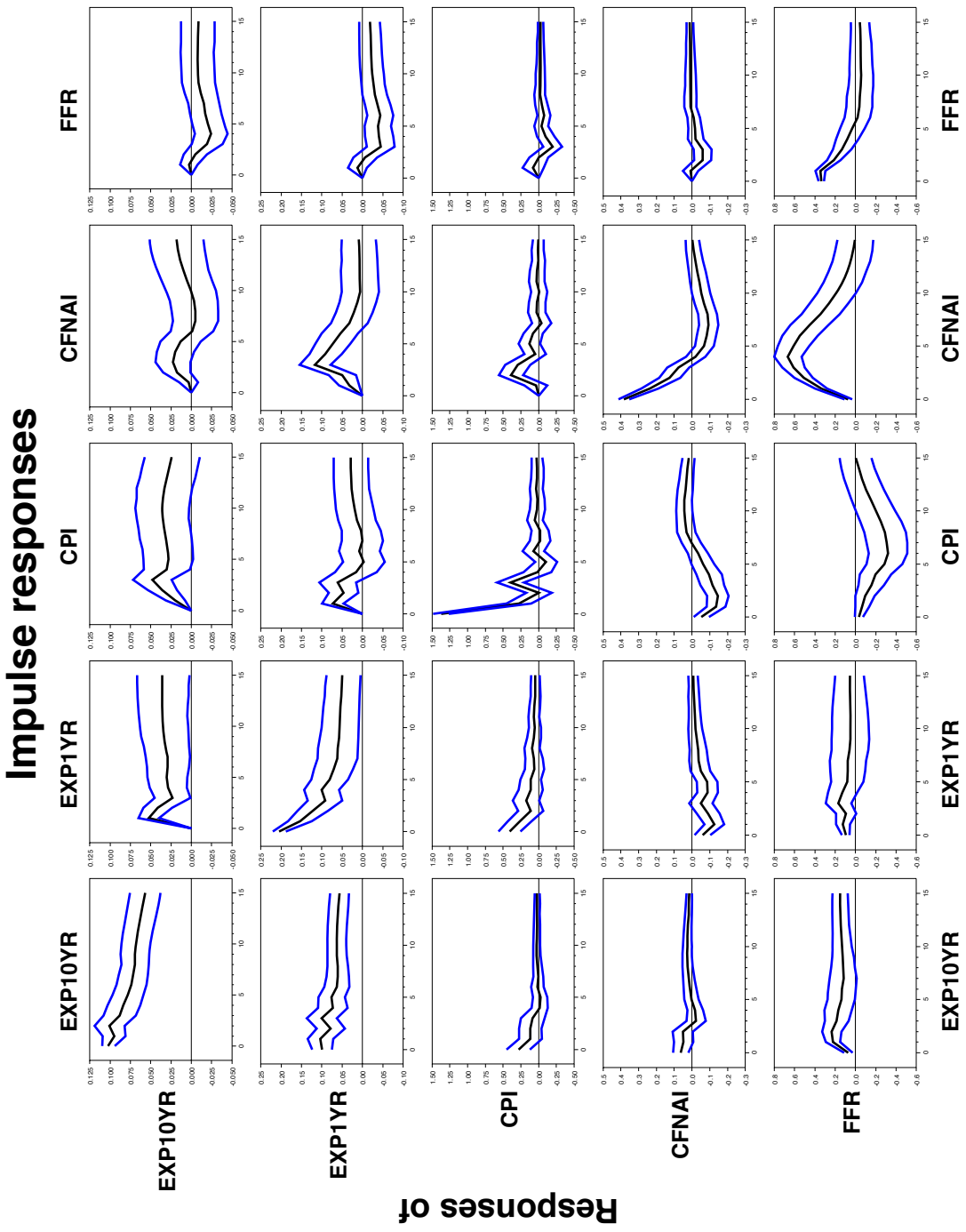

Figure 7: Benchmark VAR: Impulse responses with 1-standard deviation bands

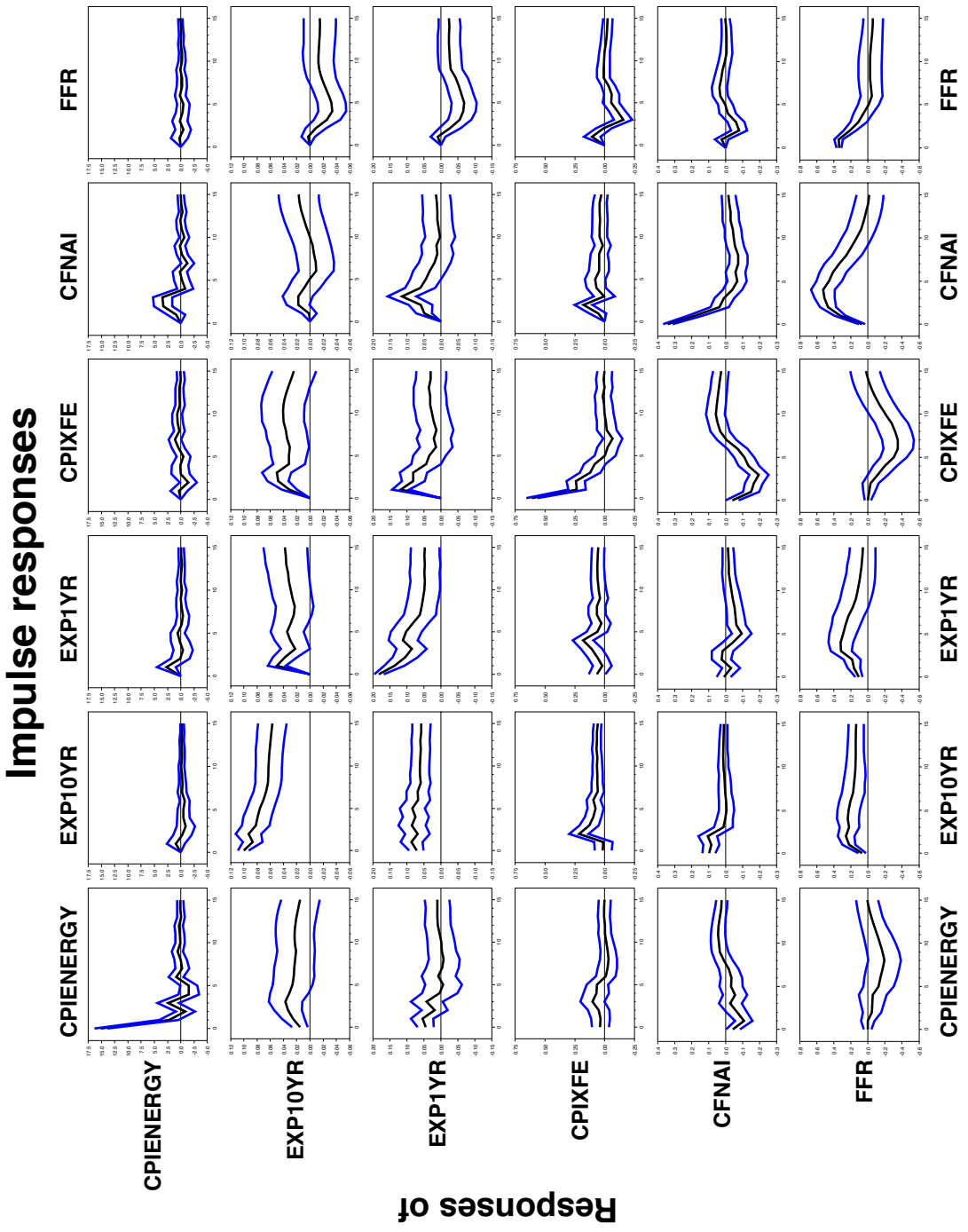

Figure 8: VAR including Energy Price Index: Impulse responses with 1-standard deviation bands

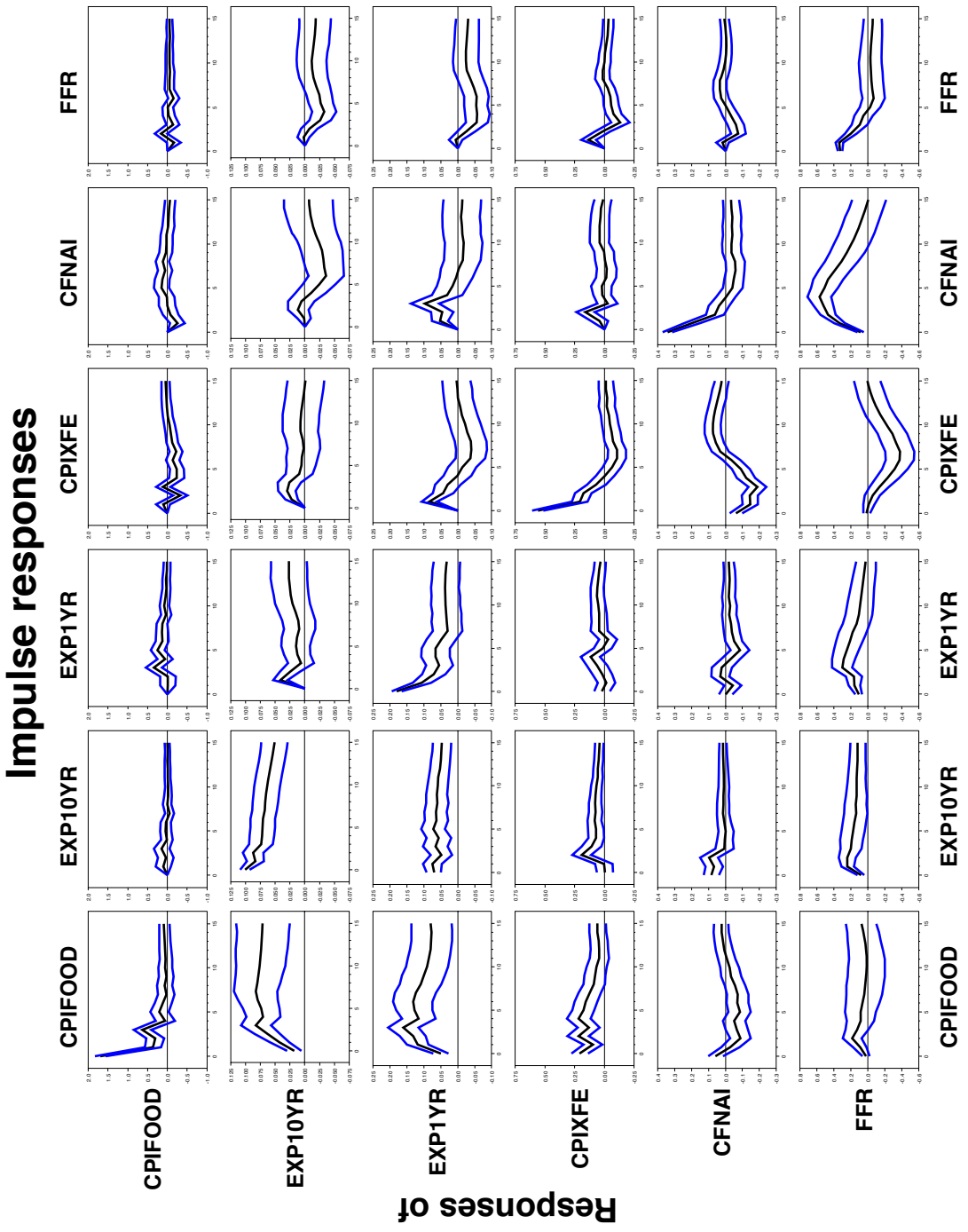

Figure 9: VAR including Food Price Index: Impulse responses with 1-standard deviation bands

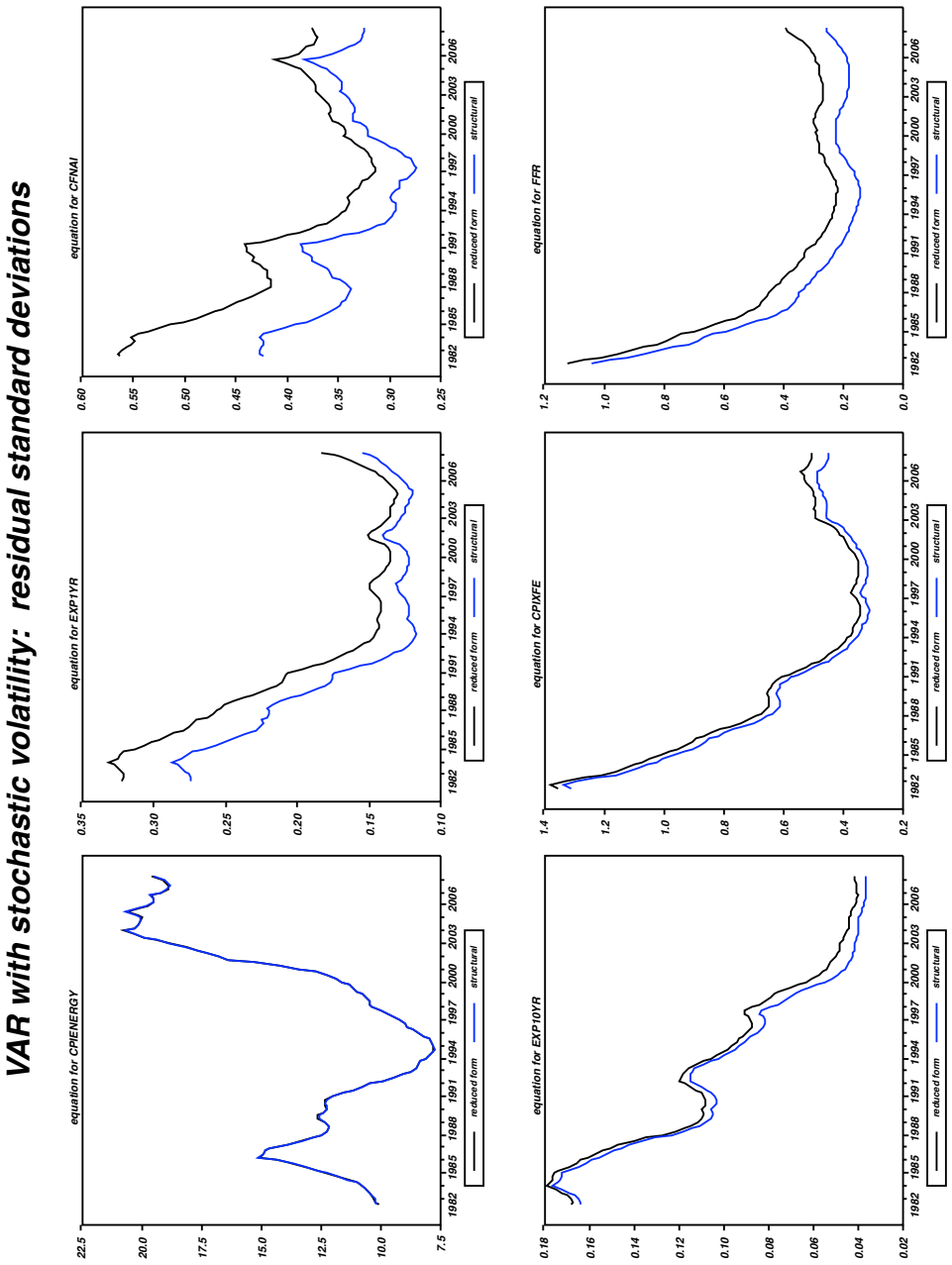

Figure 10: Stochastic Volatility from VAR with Disaggregated Energy Price Index

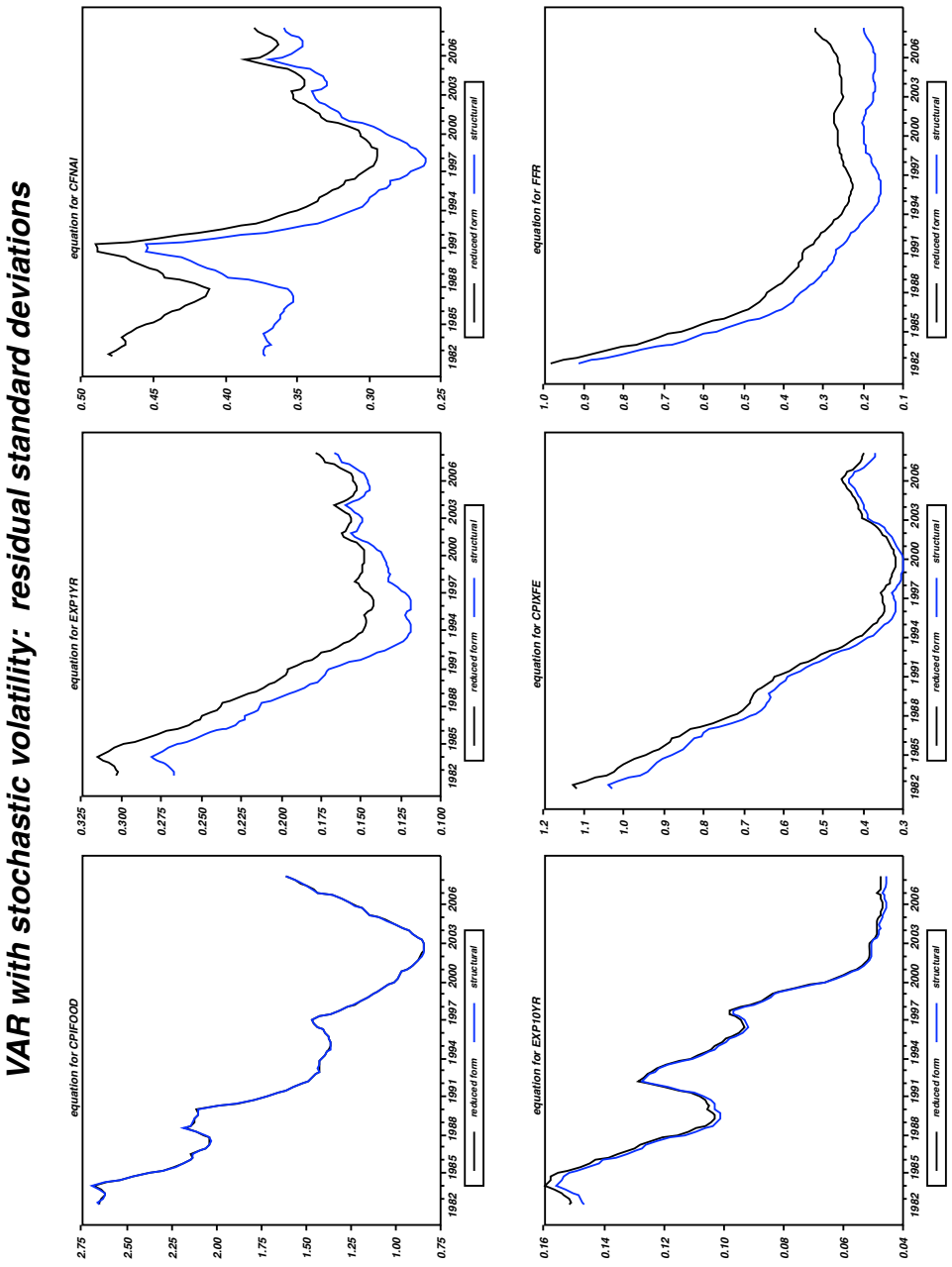

Figure 11: Stochastic Volatility from VAR with Disaggregated Food Price Index

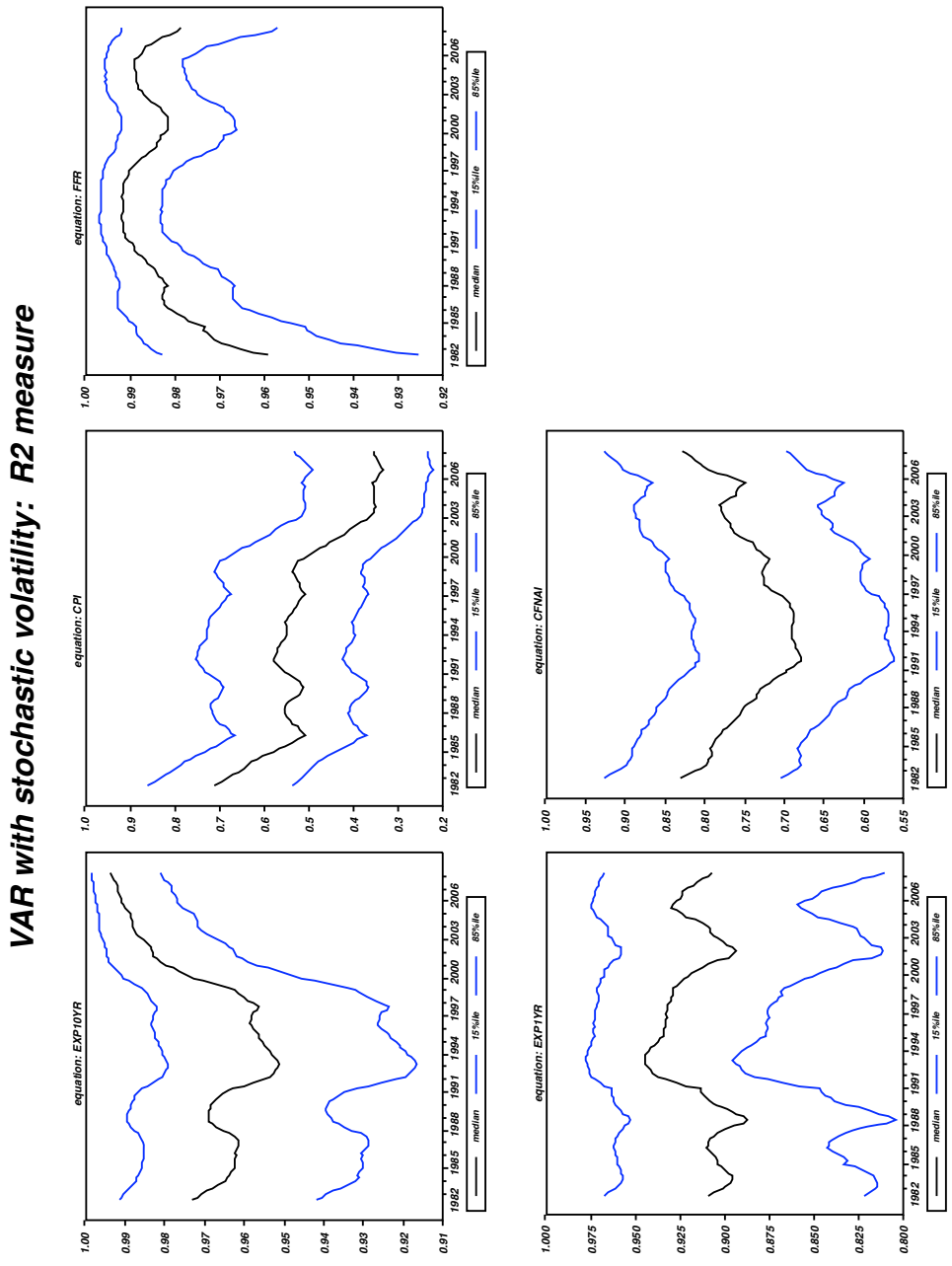

Figure 12: R-squared Measures from VAR with Stochastic Volatility