Federal Reserve Bank of Dallas
Globalization and Monetary Policy Institute
Working Paper No. 117
http://www.dallasfed.org/assets/documents/institute/wpapers/2012/0117.pdf

Re-establishing Credibility: The Behavior of Inflation Expectations in the Post-Volcker United States*

J. Scott Davis
Federal Reserve Bank of Dallas

May 2012
Revised: February 2014

Abstract

Long-term inflation expectations remained remarkably volatile in the United States for years after the well-documented switch to a more stable monetary regime in the early 1980s. This volatility cannot be explained by the standard New Keynesian model. This paper introduces a model where agents are unsure about the central bank's commitment to their inflation target. They assume that the central bank will partially accommodate any unexpected inflation. Thus a series of high inflation observations can lead them to believe (incorrectly) that the central bank has adopted a high target. The model can match the observed volatility of long-term inflation expectations.

JEL codes: D83, E31, E50

* J. Scott Davis, Federal Reserve Bank of Dallas, 2200 N. Pearl Street, Dallas, TX 75201. 214-922-5124. Scott.davis@dal.frb.org. I would like to thank conference participants at the 2013 System Macro Meeting at the Boston Fed and the 2012 Midwest Macro Meetings and seminar participants at the Hong Kong Monetary Authority for many helpful comments and suggestions. I would also like to thank Mick Devereux, Ben Keen, Enrique Martinez-Garcia, Christian Matthes, Roger Farmer, Keith Sill and Mark Wynne. The views in this paper are those of the author and do not necessarily reflect the views of the Federal Reserve Bank of Dallas or the Federal Reserve System.

The fact that there was a monetary regime change in the United States beginning in 1979 with the Fed chairmanship of Paul Volcker is well documented.[1] Most researchers attest that after 1980, and especially after 1984, the United States had entered a new monetary regime with a commitment to a low and stable inflation rate. However, even though the United States had adopted a new monetary regime after 1984, inflation expectations, particularly long-run inflation expectations, remained volatile for more than a decade after the end of the Volcker disinflation. Over the period from 1984 to 1997, long-run measures of inflation expectations, like 10-year-ahead expectations, or far-forward measures, like the 5-year-5-year forward, were around two-thirds as volatile as observed inflation. Since 1998, that relative volatility has dropped by half and they are now around one-third as volatile as observed inflation.

The papers mentioned earlier document the change in monetary regime in the United States that took place in the early 1980's. This paper will not address that episode, instead this paper will address the reestablishment of Fed credibility over the decades following the Volcker disinflation. The fact that the Fed had lost credibility during the Great Inflation of the 1970's and would have to regain the trust of the public was foreshadowed by Fed Chairman Volcker in Congressional testimony in 1979: "An entire generation of young adults has grown up since the mid-1960's knowing only inflation, indeed an inflation that has seemed to accelerate inexorably. In the circumstances, it is hardly surprising that many citizens have begun to wonder whether it is realistic to anticipate a return to general price stability, and have begun to change their behavior accordingly." (Volcker (1979) and reprinted in Malmendier and Nagel (2013))

This paper will show how the fact that "many citizens have begun to wonder whether it is realistic to anticipate a return to general price stability" is evident in the dynamics of inflation expectations, particularly long-term infla-

[1] See Clarida, Gali and Gertler (2002), Lubik and Schorfheide (2004), Boivin and Giannoni (2006), Stock and Watson (2007), Blanchard and Gali (2007), Blanchard and Riggi (2009), Leduc, Sill and Stark (2007), Mehra and Herrington (2008), Goodfriend and King (2005), Benati (2008), Schorfheide (2005) and Del Negro and Eusepi (2012), Bianchi (2013) among others.

tion expectations, after 1984. Clark and Davig (2011) show that there has been a steady decline in both the level and the volatility of measures of long-run inflation expectations over the past 30 years, and they attribute this to the fact that the anchoring of inflation expectations have improved over the past few decades, primarily due to a shift towards a more systematic and transparent monetary policy. Using the dynamics of long-term inflation expectations to infer something about central bank credibility, Gürkaynak, Sack and Swanson (2005) find that in the U.S., long-run inflation expectations, proxied by far-forward Treasury yields, respond to macroeconomic news. Far-forward rates, which they argue are mainly composed of inflation expectations, should not respond to macroeconomic news if long-run inflation expectations are truly anchored. Gürkaynak, Levin and Swanson (2006) do a similar exercise but compare the response of far-forward rates in the U.S., the UK, and Sweden to macroeconomic news. They find that far-forward rates respond very little to news in inflation targeting Sweden and respond the most in the U.S. Their sample contains data from the UK from both before and after the independence of the Bank of England. They find that far-forward rates from pre-independence UK behave more like those from the U.S., but far-forward rates from post-independence UK behave more like Sweden. Similarly Beechey, Johannsen and Levin (2011) use far-forward inflation expectations derived from inflation swaps and find that far-forward inflation expectations in the U.S. are more sensitive to current macroeconomic news than those in a number of inflation targeting European countries. Goldberg and Klein (2005) use the response of the yield curve to macroeconomic news to chart the establishment of European Central Bank credibility in the first years of the euro's existence.

Thus this paper will address two interesting questions related to the dynamics of inflation expectations in a post-Volcker United States. The first is why do we observe any volatility in long-run inflation expectations in the post-Volcker United States? The commonly cited regime shift in U.S. monetary policy occurred in 1979. There was a sharp fall in inflation expectations in the early 1980's, but even after this switch to a stable monetary regime there is considerable volatility in far-forward measures of inflation expectations like the 5-year-5-year forward. The standard New Keynesian model cannot reproduce many of the dynamics of inflation expectations that we observe in the data. Authors usually include rule-of-thumb pricing behavior, as in Gali and Gertler (1999), sticky information, as in Mankiw and Reis (2002), or price and wage indexation, as in Christiano, Eichenbaum and Evans (2005), to introduce what Fuhrer (2006; 2011) refers to as "intrinsic" inflation persistence. These features help the model explain the persistence of inflation or the dynamics of short-run inflation expectations, but this paper will show that even with these modifications, the standard New Keynesian model cannot account for the volatility of far-forward measures of inflation expectations that we observe in the data.

The second, and closely related question that this paper wishes to address is why has there been a considerable fall in the volatility of long-run measures of inflation expectations over the period since 1984? If the change in monetary regime occurred in the early 1980's, why do the volatility of long-run inflation expectations fall much later?

To explain the persistence and variability of long-run inflation expectations, this paper will construct a model where agents are unsure about the central bank's inflation target. If the central bank has limited credibility and cannot perfectly anchor beliefs about the long-run level of inflation, then agents will update their beliefs about the central bank's inflation target based on past observations of inflation. Thus a period of high inflation can lead to higher long-run inflation expectations, which become self-fulfilling.[2]

A number of authors have proposed modifications to the standard New Keynesian model to account for observed shifts in trend inflation and long-term inflation expectations. Cogley and Sbordone (2008) estimate a model with a role for both variable trend inflation and price indexation. They find that variable trend inflation is responsible for the persistence of inflation in

[2] The mechanism is similar in spirit to the expectations trap in Albanesi, Chari and Christiano (2003). The difference is that the formal expectations traps literature is based on discretionary policy. Here the central bank can commit (it follows a Taylor rule policy function), but agents are unsure about the central bank's target and believe that the central bank will partially accommodate any increase in inflation.

the data, and after accounting for variable trend inflation, price indexation is unimportant.[3] Similarly, Ireland (2007) estimates a model that allows for variable trend inflation and finds that the Fed's inflation target was low during the 1950's, rose throughout the 60's and 70's, and since then has fallen back to pre-1970's levels.

Throughout this paper we will refer to the model where agents are unsure about the central bank's inflation target, and thus the long-run level of inflation, as the *limited credibility* model. This paper will show that a New Keynesian model with limited credibility preforms much better than the benchmark model with full credibility in its ability to explain the volatility of inflation expectations that we observe in the data. We then compare the results from model with limited credibility to the benchmark New Keynesian model with either price and wage indexation or near permanent shocks, which are two features that researchers use to add inflation persistence to the benchmark New Keynesian model. The models with indexation or with near-permanent shocks do just as well as the model with limited credibility in matching the dynamics of short-run inflation expectations, but these two models preform rather poorly in explaining the behavior of long-run inflation expectations. Only the model with limited credibility can match the volatility and co-movement of long-run measures of inflation expectations. We then calibrate the model to match the observed levels of Federal Reserve credibility in the pre- and post-1998 periods. Simply by changing the level of central bank credibility, holding all else fixed, the model can explain nearly all of the observed changes in the volatility of inflation expectations in the U.S. over the last few decades.

The fact that the diminished credibility of the Fed could persist for years after the switch to a stable monetary regime in the early 1980's is supported by micro/survey based data on memories of past inflationary episodes. Using a panel of responses from the World Values Survey, Ehrmann and Tzamourani (2012) find that while memories of hyperinflation episodes never dissipate,

[3] In a related empirical study, Levin and Piger (2004) find that once you allow for a structural break in the level of inflation, which occurs in most countries in the late 1980's - early 1990's, in most countries, fluctuations in inflation are simply transitory fluctuations around the variable mean, and the inflation process has very little persistence.

memories of less dramatic high inflation episodes dissipate after about 10 years. Malmendier and Nagel (2013) find that an individual's expectations of inflation are shaped by their own personal history of inflation, so memories of past episodes of high inflation should fade as older cohorts are replaced by younger ones. They find that the effects of the Great Inflation of the 1970's on survey based inflation expectations in the United States only begin to fade in the early 1990's.

Recently, some authors have modified the standard New Keynesian model to say that agents don't have complete information about the central bank's inflation target, and must learn this from observations of past inflation. Milani (2007) incorporates "learning" into the standard New Keynesian model, estimates the model, and finds that when learning is included, you do not need to incorporate features like price indexation or habit formation in consumption to get the persistence of macroeconomic variables. Similarly, Lansing (2009) constructs a model where agents use a Kalman filter approach to deduce whether a shock to inflation is permanent or transitory, and he shows that this model can reproduce the observed time-varying persistence and volatility of U.S. inflation. Andolfatto and Gomme (2003) and Erceg and Levin (2003) construct models where agents are unsure about either the money growth rule or the central bank's inflation target, and must infer the target from past observations of inflation. They show how this learning is necessary to explain the large output loss that accompanies a transition from a high inflation regime (high money growth rate or high inflation target) to a low inflation regime (low money growth rate or low inflation target). Similarly Schorfheide (2005) and Del Negro and Eusepi (2012) estimate a DSGE model with either complete information or a role for learning and find that the model with complete information does well in explaining most of the historical experience in the U.S., but the model with learning is necessary to explain the Volcker disinflation of the early 1980's. Orphanides and Williams (2004; 2007) and Gaspar, Smets and Vestin (2006; 2011) present models where agents' have imperfect information about the parameters in the central bank's policy rule function or where they are unsure if a shock to inflation is transitory or permanent, and evaluate optimal monetary policy in this environment of limited information/limited credibility.

This paper will proceed as follows. Some statistics describing the behavior of inflation expectations in the U.S. over the 30 years since the Volcker disinflation are presented in section 1. The theoretical model is described in section 2. The model is a cashless version of the benchmark New Keynesian model described in Christiano, Eichenbaum and Evans (2005), but expectations are formed using this concept of limited credibility. The calibration of the model is discussed in section 3. Here special attention is paid to exactly how to calibrate the model to reflect historical observations of central bank credibility and the anchoring of inflation expectations. The results from the model are presented in section 4. Here we will examine both the path of inflation and inflation expectations since 1984 and simulated moments from the model to see how the model with limited credibility preforms much better than the model with full credibility in matching the dynamics of inflation expectations, especially long-run inflation expectations. Finally section 5 concludes with some directions for further research.

1 The Dynamics of Inflation Expectations

In this section, we present some statistics on the dynamics of inflation expectations in the United States over the last 30 years. Furthermore, we will discuss how there was a sharp decrease in the volatility of inflation expectations between the first and second half of this sample period.

We will consider measures of both short-run inflation expectations and long-run inflation expectations. The three measures are: the expected change in the price level over the next year (one-year-ahead inflation expectations, $E_t\left(\pi_{t+1}\right)$), the expected annual inflation rate over the next ten years (10-year-ahead inflation expectations, $E_t\left(\frac{1}{10}\sum_{i=1}^{10}\pi_{t+i}\right)$), and the expected inflation rate over a period beginning five years from now and ending ten years from now (5-year-5-year forward inflation expectations, $E_t\left(\frac{1}{5}\sum_{i=6}^{10}\pi_{t+i}\right)$).

Figure 1 plots U.S. inflation, one-year-ahead inflation expectations, 10-year-ahead inflation expectations, and 5-year-5-year forward inflation expectations from 1984 to 2011. The data has been demeaned. U.S. inflation is defined as the year-over-year percentage change consumer price index (CPI), and inflation expectations are taken from the dataset compiled by the Federal Reserve Bank of Cleveland and described in Haubrich, Pennacchi and Ritchken (2011). This dataset contains measures of n year ahead inflation expectations for the U.S. for $n = 1...30$. Expectations are observed monthly from January 1982 to the present.

The figure shows that inflation expectations, particularly long-run measures of inflation expectations, have fallen steadily over the last 30 years. The figure shows that there was a sharp fall in the level long-term inflation expectations that occurred in the very beginning of the sample, but even after that initial drop, long-run measures of inflation expectations have not remained constant but have continued to fall over the last 30 years. Later, when presenting the results from the New Keynesian model with full credibility and with limited credibility, we will show that only the model with limited credibility that gets improves over time can replicate the steady fall in the level of long-run inflation expectations in the U.S. over the past 30 years.

Table 1 presents some evidence about the cross-time evolution of the volatility and persistence of inflation expectations in the United States. In the table, the sample is split into an early sample, from 1984 to 1997, and a later sample, from 1998 to 2011. The table also includes a third column reporting the statistics from the 1998-2007 period. The first thing to notice is that the volatility of inflation rose between the earlier sample and the later sample, but comparison with the third column (the truncated late sample) shows that this rise in inflation volatility is entirely due to the dramatic swings in inflation associated with the global financial crisis beginning in 2008. If the post 2007 period is excluded from the sample, the volatility of inflation fell by 20% between the pre-1998 period and the post-1998 period. In addition to the overall fall in inflation volatility between the early and late sample periods, there was a fall in the relative volatility of inflation expectations. One-year-ahead inflation expectations were 70% as volatile as inflation in the early sample period, but in the later period, year-ahead expectations were only $50 - 60\%$ as volatile as inflation. In the early period, long-term measures of inflation expectations were nearly two-thirds as volatile as observed inflation, but in the later period they were only one-third as volatile as observed inflation.

In addition, there is a sharp reduction in the correlations between current inflation and future inflation expectations between the earlier and the later time periods. In the early period, the correlation between current inflation and year-ahead inflation expectations was nearly 0.7, while the correlations between current inflation and long-run measures of expectations were greater than 0.5. In the later period (ending in 2007), the correlation between current inflation and one-year-ahead expectations drops to about 0.3, while current inflation and longer term measures of expectations are nearly uncorrelated. The correlation between current inflation and 10-year-ahead expectations falls to about 0.06, and the correlation with 5-year-5-year forward expectations falls to 0.00.

2 The Model

The model with limited central bank credibility is based on the standard New Keynesian model in Christiano, Eichenbaum and Evans (2005). There are monopolistically competitive intermediate goods firms that produce a differentiated product that is then aggregated into a final good used for consumption, investment and government purchases. There are also households that supply a differentiated type of labor. Calvo (1983) pricing in both the intermediate goods sector and the household sector gives rise to nominal wage and price rigidities.

Due to these wage and price rigidities, a firm or a household knows that if given the opportunity to change their price today, their new nominal price will most likely be in place for at least a few periods into the future. Thus when setting an optimal price or wage, price setters have to take into account not only current conditions, but the expectation of future conditions. In the standard New Keynesian model, the expectation of future variables is determined using rational expectations. We abstract from that here. Instead we assume that agents are unsure about the central bank's inflation target. Following a surprise in current observed inflation, they believe that the central bank may accommodate some of the unexpected inflation and thus may adopt a new, higher inflation target. While the actual inflation target never changes, agents don't know this, and every period they update their belief about the central bank's target using past observations of inflation. Eventually they realize that the central bank's preferred measure of long-run inflation has not changed, but their incorrect assumptions could persist for some time. Thus agents will revise upward their beliefs about the central bank's inflation target following a series of high inflation observations. If agents form expectations expecting high inflation, then these high expectations get incorporated into the price and wage setting decisions, leading to higher inflation.

2.1 Production

Final goods, used for private consumption, government consumption, and investment are formed through a Dixit and Stiglitz (1977) aggregation of intermediate goods from firms $i \in [0\ 1]$:

$$C_t + I_t + G_t = \left(\int_0^1 y_t\left(i\right)^{\frac{\sigma-1}{\sigma}} di \right)^{\frac{\sigma}{\sigma-1}} \tag{1}$$

where $y_t\left(i\right)$ is the quantity produced by firm i, and σ is the elasticity of substitution between intermediate goods from different firms. When considering the results from simulations of the model, in one set of simulations we will simulate the model under stochastic government spending shocks. There will be more about the calibration of the exogenous process for G_t in section 3, but the steady state value of G_t is set such that in the steady state, government spending is 20% of GDP.

From the aggregator function in (1), the demand for the intermediate good from firm i is:

$$y_t(i) = \left(\frac{P_t(i)}{P_t}\right)^{-\sigma} (C_t + I_t + G_t) \tag{2}$$

where $P_t(i)$ is the price set by firm i, and $P_t = \left(\int_0^1 (P_t(i))^{1-\sigma} di\right)^{\frac{1}{1-\sigma}}$.

The firm produces intermediate goods by combining capital and labor in the following Cobb-Douglas production technology:

$$y_t(i) = A_t h_t(i)^{1-\alpha} k_t(i)^{\alpha} - \phi \tag{3}$$

where $h_t(i)$ and $k_t(i)$ are the labor and capital employed by the firm in period t, ϕ is a small fixed cost term that is calibrated to ensure that firms earn zero profit in the steady state, and A_t is a stochastic productivity parameter common to all firms.

From the firm's cost minimization problem, the demand from firm i for labor and capital is given by:

$$\begin{aligned} h_t(i) &= (1-\alpha)\frac{MC_t}{W_t}(y_t(i)+\phi) \\ k_t(i) &= \alpha\frac{MC_t}{R_t}(y_t(i)+\phi) \end{aligned} \tag{4}$$

where W_t is the wage rate, R_t is the capital rental rate and $MC_t = \frac{1}{A_t}\left(\frac{W_t}{1-\alpha}\right)^{1-\alpha}\left(\frac{R_t}{\alpha}\right)^{\alpha}$.

Price setting by intermediate goods firms In period t, the firm will be able to change its price with probability $1-\xi_p$. If the firm cannot change prices then they are reset automatically according to $P_t(i) = \pi_{t-1}^I P_{t-1}(i)$, where $\pi_{t-1}^I = \pi_{ss}$, the steady state gross inflation rate. In an alternative version of the model we will consider the case where prices are indexed to the previous period's inflation rate, $\pi_{t-1}^I = \frac{P_{t-1}}{P_{t-2}}$.

Thus if allowed to change their price in period t, the firm will set a price to maximize:

$$\max_{P_t(i)} \tilde{E}_t \left(\sum_{\tau=0}^{\infty} \beta^{\tau} \left(\xi_p\right)^{\tau} \lambda_{t+\tau} \left\{ \Pi^I_{t,t+\tau} P_t\left(i\right) y_{t+\tau}\left(i\right) - MC_{t+\tau} y_{t+\tau}\left(i\right) \right\} \right)$$

where λ_t is the marginal utility of consumption in period t and

$$\Pi^I_{t,t+\tau} = \begin{cases} 1 & \text{if } \tau = 0 \\ E_t\left(\pi^I_{t+\tau-1}\right) \Pi^I_{t,t+\tau-1} & \text{if } \tau > 0 \end{cases}$$

As discussed in this paper's technical appendix, the firm that is able to change its price in period t will set its price to:

$$P_t\left(i\right) = \frac{\sigma}{\sigma - 1} \frac{\tilde{E}_t \left(\sum_{\tau=0}^{\infty} \beta^{\tau} \left(\xi_p\right)^{\tau} \lambda_{t+\tau} MC_{t+\tau} \left(\Pi^I_{t,t+\tau}\right)^{-\sigma} \left(P_{t+\tau}\right)^{\sigma} y_{t+\tau} \right)}{\tilde{E}_t \left(\sum_{\tau=0}^{\infty} \beta^{\tau} \left(\xi_p\right)^{\tau} \lambda_{t+\tau} \left(\Pi^I_{t,t+\tau}\right)^{1-\sigma} \left(P_{t+\tau}\right)^{\sigma} y_{t+\tau} \right)} \tag{5}$$

If prices are flexible, and thus $\xi_p = 0$, then this expression reduces to:

$$P_t\left(i\right) = \frac{\sigma}{\sigma - 1} MC_t$$

which says that the firm will set a price equal to a constant mark-up over marginal cost.

Notice that the optimal price $P_t\left(i\right)$ does not involve the usual rational expectations operator, $E_t\left(\cdot\right)$, but a modified operator $\tilde{E}_t\left(\cdot\right)$.

Instead of assuming that private agents know the central bank's inflation target with certainty, assume that agents are unsure about the inflation target and must use past observations of inflation to update their beliefs according to the following Kalman updating equation:

$$\tilde{\pi}_t = \tilde{\pi}_{t-1} + \phi \left(\pi_t - \tilde{E}_{t-1}\left(\pi_t\right) \right)$$

where $\tilde{\pi}_t$ is their belief about the inflation target at time t and $\tilde{\pi}_{t-1}$ is their belief about the target at time $t-1$. Thus ϕ is a parameter describing agents' beliefs about central bank accommodation. As will be seen later in this section, the central bank's actual inflation target doesn't change, but due to limited credibility, agents believe that the central bank may accommodate part of the surprise in inflation by raising the target. Over time agents realize that this is not true, the central bank did not accommodate part of the surprise in inflation, and their beliefs about the target converge to the actual target.[4]

Let Ω_t be the set of information about the structure of the economy, all parameters (other than the inflation target), and the sequence of shocks to affect the economy up to and including shocks in period t, then for any variable x_{t+i} for all $i = 1...\infty$ in the model:

$$\tilde{E}\left(x_{t+i}|\Omega_t\right) = E\left(x_{t+i}|\Omega_t, \tilde{\pi}_t\right)$$

and for notational simplicity define $\tilde{E}_t\left(x_{t+i}\right) \equiv \tilde{E}\left(x_{t+i}|\Omega_t\right)$.

Write the price set by the firm that can reset prices in period t as $P_t^*\left(i\right)$ to denote it as an optimal price. Firms that can reset prices in period t will all reset to the same level, so $P_t^*\left(i\right) = P_t^*$. Substitute this optimal price into the price index $P_t = \left(\int_0^1 \left(P_t\left(i\right)\right)^{1-\sigma} di\right)^{\frac{1}{1-\sigma}}$. Since a firm has a probability of $1-\xi_p$ of being able to change their price, then by the law of large numbers in any period $1-\xi_p$ percent of firms will reoptimize prices. Thus the price index, P_t, can be written as:

$$P_t = \left(\xi_p\left(\pi_{t-1}^I P_{t-1}\right)^{1-\sigma} + \left(1-\xi_p\right)\left(P_t^*\right)^{1-\sigma}\right)^{\frac{1}{1-\sigma}} \tag{6}$$

After combining the expression for the optimal price in (5) and the equation

[4] The updating equation in this model looks similar to that in Lansing (2009). There is a certain long-run level of inflation, agents don't know what it is, and must infer it from past observations of inflation using a Kalman updating equation. While mechanically the updating equation is very similar to Lansing (2009), the interpretation is very different. In Lansing (2009) agents observe an increase in current inflation and don't know if the shock is permanent or transitory. In this model, agents know about the shock that led to the unexpected change in inflation, but what they are unsure about is the credibility of the central bank. Agents question whether the central bank will use monetary policy to return inflation to the original desired level, or if they will accommodate part of the shock. In that way, this model is similar is spirit to those in Barro and Gordon (1983), Barro (1986), and agents' suspicion that the central bank may decide to accommodate some of an increase in current inflation is similar to the expectations trap models in Albanesi, Chari and Christiano (2003).

describing the evolution of the price index in (6), one can derive the usual New Keynesian Phillips Curve (NKPC) that relates inflation this period to current marginal costs and the expected value of inflation next period:

$$\hat{\pi}_t = \beta \tilde{E}_t \left(\hat{\pi}_{t+1}\right) + \frac{\left(1-\xi_p\right)\left(1-\beta\xi_p\right)}{\xi_p}\left(m\hat{c}_t\right) \tag{7}$$

Notice in this Phillips curve the expectation of next period's inflation is arrived at when agents are unsure about the central bank's target inflation rate, $\tilde{E}_t\left(\hat{\pi}_{t+1}\right)$. If instead agents had full information about the central bank's inflation target then this NKPC simply condenses to its usual form where $E_t\left(\hat{\pi}_{t+1}\right)$ replaces $\tilde{E}_t\left(\hat{\pi}_{t+1}\right)$.

In a later section we will compare the results of the model with limited central bank credibility to the model with full information and price indexation. As discussed earlier, full price indexation implies that firms that cannot reset their price in period t simply scale up their existing price by the previous period's inflation rate π_{t-1}. In this case the NKPC becomes:

$$\hat{\pi}_t = \frac{1}{1+\beta}\hat{\pi}_{t-1} + \frac{\beta}{1+\beta}E_t\left(\hat{\pi}_{t+1}\right) + \frac{\left(1-\xi_p\right)\left(1-\beta\xi_p\right)}{\xi_p\left(1+\beta\right)}\left(m\hat{c}_t\right) \tag{8}$$

From equation (8) it is easy to see how the price indexation introduces the lagged inflation term $\hat{\pi}_{t-1}$ into the Phillips curve and thus introduces persistence into the inflation process. It is not as obvious, but the fact that the future inflation term is denoted $\tilde{E}_t\left(\hat{\pi}_{t+1}\right)$ instead of $E_t\left(\hat{\pi}_{t+1}\right)$ also introduces the lagged inflation rate and thus persistence into the Phillips curve under limited credibility in equation (7). Recall that the expectations operator in the model with limited credibility, $\tilde{E}_t\left(\cdot\right)$, depends agent's beliefs about the central bank's inflation target, $\tilde{\pi}_t$, which in turn depends on past observations of inflation.

2.2 Households

Households, indexed $l \in [0\ 1]$, supply labor, own capital, and consume from their labor income, rental income, and interest on savings. Furthermore they pay lump sum taxes to the government to finance government expenditures.

The household maximizes their utility function:

$$\max \sum_{t=0}^{\infty} \beta^t \left[\ln \left(C_t \left(l \right) \right) - \psi \left(H_t \left(l \right) \right)^{\frac{1+\sigma_H}{\sigma_H}} \right] \tag{9}$$

subject to their budget constraint:

$$\begin{aligned} & P_t C_t \left(l \right) + P_t I_t \left(l \right) + T_t \left(l \right) + B_{t+1} \left(l \right) \\ = \; & W_t \left(l \right) H_t \left(l \right) + R_t K_t \left(l \right) + \Xi_t \left(l \right) + \left(1 + i_t \right) B_t \left(l \right) \end{aligned} \tag{10}$$

where $C_t\left(l\right)$ is consumption by household l in period t, $H_t\left(l\right)$ is the household's labor effort in the period, $T_t\left(l\right) = P_t G_t\left(l\right)$ are the lump-sum taxes paid by the household to finance government consumption, $B_t\left(l\right)$ is the household's stock of bonds at the beginning of the period[5], $W_t\left(l\right)$ is the wage paid for the household's heterogenous labor supply, $K_t\left(l\right)$ is the stock of capital owned by the household at the beginning of the period and $\Xi_t\left(l\right)$ is the share of firm profits that are returned lump sum to the household.

The household's capital stock, $K_t\left(l\right)$, evolves according to the usual capital accumulation equation:

$$K_{t+1}\left(l\right) = \left(1-\delta\right) K_t\left(l\right) + I_t\left(l\right)$$

where market clearing in the market for physical capital requires that the sum of the physical capital stock across households is equal to the sum of physical capital demand across firms, $\int_0^1 K_t\left(l\right) dl = \int_0^1 k_t\left(i\right) di$.

Each household supplies a differentiated type of labor. The function to aggregate the labor supplied by each household into the aggregate stock of labor employed by firms is:

$$H_t = \left(\int_0^1 H_t\left(l\right)^{\frac{\theta-1}{\theta}} dl \right)^{\frac{\theta}{\theta-1}} \tag{11}$$

[5] Market clearing in the bond market requires that the sum of bond holdings across all households equals zero, $\int_0^1 B_t\left(l\right) dl = 0$.

where market clearing in the labor market requires that $H_t = \int_0^1 h_t(i)\, di$. Since the household supplies a differentiated type of labor, it faces a downward sloping labor demand function:

$$H_t(l) = \left(\frac{W_t(l)}{W_t}\right)^{-\theta} H_t$$

2.2.1 Wage setting by households

In any given period, household l faces a probability of $1 - \xi_w$ of being able to reset their wage. If the household cannot change its wage then it is reset automatically according to $W_t(l) = \pi_{t-1}^I W_{t-1}(l)$, where $\pi_{t-1}^I = \pi_{ss}$, the steady state gross inflation rate. In an alternative version of the model we will consider the case where wages are indexed to the previous period's inflation rate, $\pi_{t-1}^I = \frac{P_{t-1}}{P_{t-2}}$.

Assume that complete asset markets exist that allow households to pool risk. The wage rate and the labor effort will be different across households due to nominal wage rigidity, but all other variables that appear in the household budget constraint are equal across households. Thus all households have the same level of consumption, $C_t(l) = C_t$ and the same marginal utility of consumption.

If household l is allowed to reset their wages in period t they will set a wage to maximize the expected present value of utility from consumption minus the disutility of labor.

$$\tilde{E}_t \left(\sum_{\tau=0}^{\infty} \beta^{\tau} (\xi_w)^{\tau} \left\{ \lambda_{t+\tau} \Pi_{t,t+\tau}^I W_t(l) H_{t+\tau}(l) - \psi \left(H_{t+\tau}(l) \right)^{\frac{1+\sigma_H}{\sigma_H}} \right\} \right)$$

Thus after technical details which are located in the appendix, the household that can reset wages in period t will choose a wage:

$$W_t(l)^{\frac{\theta}{\sigma_H}+1} = \frac{\theta}{\theta-1}\frac{1+\sigma_H}{\sigma_H}\psi\frac{\tilde{E}_t\left(\sum_{\tau=0}^{\infty}\beta^{\tau}(\xi_w)^{\tau}\left(\frac{W_{t+\tau}}{\Pi^I_{t,t+\tau}}\right)^{\frac{\theta}{\sigma_H}+\theta}(H_{t+\tau})^{\frac{1+\sigma_H}{\sigma_H}}\right)}{\tilde{E}_t\left(\sum_{\tau=0}^{\infty}\beta^{\tau}(\xi_w)^{\tau}\lambda_{t+\tau}\Pi^I_{t,t+\tau}\left(\frac{W_{t+\tau}}{\Pi^I_{t,t+\tau}}\right)^{\theta}H_{t+\tau}\right)} \tag{12}$$

If wages are flexible, and thus $\xi_w = 0$, this expression reduces to:

$$W_t(l) = \frac{\theta}{\theta-1}\frac{\frac{1+\sigma_H}{\sigma_H}\psi(H_t)^{\frac{1}{\sigma_H}}}{\lambda_t}$$

When wages are flexible the wage rate is equal to a mark-up, $\frac{\theta}{\theta-1}$, multiplied by the marginal disutility of labor, $\frac{1+\sigma_H}{\sigma_H}\psi(H_t)^{\frac{1}{\sigma_H}}$, divided by the marginal utility of consumption, λ_t.

Notice again that when expectations of future variables are used to calculate the current optimal wage, agents use the modified expectations operator, $\tilde{E}_t(\cdot)$, instead of the rational expectations operator, $E_t(\cdot)$.

Write the wage rate for the household that can reset wages in period t, $W_t(l)$, as $W_t^*(l)$ to denote it as an optimal wage. Also note that all households that can reset wages in period t will reset to the same wage rate, so $W_t^*(l) = W_t^*$.

All households face a probability of $(1-\xi_w)$ of being able to reset their wages in a given period, so by the law of large numbers $(1-\xi_w)$ of households can reset their wages in a given period. Substitute W_t^* into the expression for the aggregate wage rate $W_t = \left(\int_0^1 W_t(l)^{1-\theta}dl\right)^{\frac{1}{1-\theta}}$, to derive an expression for the evolution of the aggregate wage:

$$W_t = \left(\xi_w\left(\pi^I_{t-1}W_{t-1}\right)^{1-\theta} + (1-\xi_w)(W_t^*)^{1-\theta}\right)^{\frac{1}{1-\theta}}$$

In the model with limited credibility, the New Keynesian Phillips Curve relating wage inflation this period to expected future wage inflation and the marginal disutility of labor this period is given by:

$$\hat{\pi}_t^w = \beta \tilde{E}_t \left(\hat{\pi}_{t+1}^w \right) + \frac{(1-\xi_w)(1-\beta\xi_w)}{\xi_w} \left(\frac{\sigma_H}{\theta + \sigma_H} \right) \left(\frac{1}{\sigma_H} \hat{H}_t - \hat{\Lambda}_t - \hat{w}_t \right)$$

where $\pi_t^w = \frac{W_{t+1}}{W_t} - 1$.

If wages that could not be changed in a given period were reset using the previous period's inflation rate then the New Keynesian Phillips curve would be:

$$\hat{\pi}_t^w = \hat{\pi}_{t-1} - \beta\hat{\pi}_t + \beta E_t \left(\hat{\pi}_{t+1}^w \right) + \frac{(1-\xi_w)(1-\beta\xi_w)}{\xi_w} \left(\frac{\sigma_H}{\theta + \sigma_H} \right) \left(\frac{1}{\sigma_H} \hat{H}_t - \hat{\Lambda}_t - \hat{w}_t \right)$$

Just as before in the Phillips curve with price inflation, persistence is added to the model with indexation by the presence of the lagged inflation rate in the Phillips curve equation. In the model with limited credibility, the lagged inflation rate has an effect on the stock of central bank credibility and thus on $\tilde{E}_t \left(\pi_{t+1}^w \right)$. The full derivation of both Phillips curves is presented in the appendix.

2.3 Monetary Policy

The monetary policy instrument is the short-run risk free rate, i_t, which is determined by the central bank's Taylor rule function:

$$i_{t+1} = i_{ss} + \theta_i (i_{t-1} - i_{ss}) + (1-\theta_i)(\theta_p (\pi_t - \bar{\pi}) + \theta_y \hat{y}_t) + m_t \qquad (13)$$

where $\hat{y}_t = \frac{GDP_t}{\tilde{GDP}_t} - 1$, where $\tilde{GDP}_t$ is the level of GDP at time t in an economy with the same structure as the one just described and subject to the same shocks, only there are no price or wage frictions, $\xi_p = \xi_w = 0$, and m_t is an exogenous monetary policy shock. $\bar{\pi}$ is the central bank's inflation target, which is fixed and is not known by the private agents in the economy.[6]

[6] The transitory money supply shock m_t is needed to reconcile agents' (incorrect) beliefs about the central bank's inflation target with their observation of the nominal risk-free rate, the inflation rate, and the output gap. If the observed risk-free rate was set based on an

3 Calibration

The various parameters used in the model and their values are listed in table 2. The first five parameters, the discount factor, capital's share of income, the capital depreciation rate, the elasticity of substitution across varieties from different firms, the elasticity of substitution between labor from different households, and are all set to values that are commonly found in the literature.

The next two parameters are the Calvo wage and price stickiness parameters. The wage and price stickiness parameters are set to 0.75, implying that a household expects to change their wage and firms expect to change their prices once a year. We use the standard Taylor rule parameters for the parameters in the monetary policy function. The central bank places a weight of 0.5 on the output gap, 1.5 on the inflation rate, and 0.9 on the lagged interest rate.

3.1 Calibrating the anchoring of the target

In the version of the model where long-run inflation expectations are perfectly anchored, $\phi = 0$. In the version of the model with limited credibility, $\phi > 0$, implying that agents believe the central bank will partially accommodate any unexpected increase in inflation. Of course, this model is used to consider the behavior of inflation expectations after the Volcker disinflation, so we assume that there is no actual accommodation, but it takes a while for the Fed to earn credibility and convince agents that ϕ should be zero.

Assume that agents have in mind the following simple model when determining the ϕ parameter. Quarter-over-quarter inflation follows a simple AR(1) process:

$$\pi_t = \rho \pi_{t-1} + \upsilon_t$$

where ρ is the autoregressive parameter, which agents simply estimate from the data, and υ_t are innovations to inflation. Agents believe that a share ϕ

inflation target of $\bar{\pi}$ and yet agents believe that the target is $\tilde{\pi}_t$, then they believe that what they are seeing is a purely transitory monetary shock $m_t = (1 - \theta_i)(\theta_p(\tilde{\pi}_t - \bar{\pi}))$.

of this shock will be accommodated, and thus agents believe that the central bank's inflation target, $\bar{\pi}_t$, follows a unit root process and in period t will increase by $\phi \upsilon_t$:

$$\bar{\pi}_t = \bar{\pi}_{t-1} + \phi \upsilon_t$$

Since the inflation target is unobservable, agents construct a series for $\bar{\pi}_t$ from an H-P filtered series of π_t. Thus given the series of actual inflation and agent's beliefs about the target:[7]

$$\phi = \sqrt{\frac{var\left(\bar{\pi}_t - \bar{\pi}_{t-1}\right)}{var\left(\pi_t - \rho \pi_{t-1}\right)}}$$

Assume that agents calculate these variances with a 10-year rolling window. Using a panel of responses from the World Values Survey, Ehrmann and Tzamourani (2012) find that while memories of hyperinflation episodes never dissipate, memories of less dramatic high inflation episodes dissipate after about 10 years. Thus, we assume that when using past observations of actual and trend inflation to form their beliefs about the credibility of the central bank and the anchoring of inflation expectations, agents consider the behavior of actual and trend inflation over the past 10 years. This assumption is consistent with the evidence in Malmendier and Nagel (2013) who find that an individual's expectations of inflation are shaped by their own personal history of inflation, so memories of past episodes of high inflation should fade as older cohorts are replaced by younger ones. They argue that the effects of the Great Inflation of the 1970's on survey based inflation expectations in the

[7] As discussed earlier, the updating equation in this model looks very similar to that in Lansing (2009), but the interpretation is different. In Lansing (2009), there is a shock to the transitory component of inflation and a shock to the trend level of inflation. These shocks are i.i.d. Agents cannot observe which shock is responsible for the observed increase in inflation, so they must update their beliefs about the trend level of inflation using a Kalman updating parameter that minimizes the means square forecast error given the two unobservable i.i.d. shocks. In this model, agents observe the original shock, but they believe that the central bank will partially accommodate that shock. The updating equation in this model has to do with limited central bank credibility and doubts about the commitment to an inflation target, not uncertainty about shocks.

United States only begin to fade in the early 1990's.

Agent's beliefs about the credibility of the central bank, ϕ, calculated with a 10-year moving window, are presented in figure 2. The figure shows that ϕ increased greatly during the late 1970's and peaked at close to 0.08 in the early 1980's. This implies that whenever agents observed a 1 percentage point increase in unexpected inflation, they would assume that the central bank would partially accommodate this by raising the inflation target by 0.08 percentage points. The figure also shows that ϕ remained high throughout the 1980's, and only began to fall in the early 1990's. The ϕ parameter had an average value of 0.060 over the period 1984 to 1997 and an average value of 0.019 over the period 1998 to 2011. The figure shows that now the ϕ parameter is less than 0.01, meaning that beliefs about the anchoring of the Fed's inflation target have nearly reached the level consistent with full credibility. However, during the 1980's and into the early 1990's, Fed credibility was significantly lower, and as will be seen in the next section, only the model with limited credibility can explain the dynamics of inflation expectations, particularly long-term measures of inflation expectations, observed throughout the 1984 to 2011 period.

3.2 Shock Processes

In the next section, we will examine the responses of inflation expectations to both productivity and government spending shocks. For simplicity, we only consider the effect of one shock at a time, and we assume that each shock follows an AR(1) process with an autoregressive coefficient of 0.9. In one alternative version in the next section we will consider the case where the shock is nearly permanent with an autoregressive coefficient of 0.999.

Since the model is solved with a first-order approximation around the steady state, and only one shock is active at any time, the variance of the shock doesn't matter for most of the dynamics in the model. To ease the comparison between the model and the data, the variance of each shock is calibrated so that the standard deviation of inflation in the model with limited credibility is 1.05%, which the same as that in the U.S. during the pre-1998 period, as seen in table 1.

4 Results

Figure 3 plots the level of inflation and inflation expectations in the United States from 1984 to 2011. The figure plots the levels of inflation and inflation expectations observed in the data (the data has been demeaned), as well as the results from two simulations of the model. One set of simulation results is from the limited credibility model, and one is from the model with full credibility and full price and wage indexation. The sequences of productivity shocks driving the two simulations have been backed out of the of the model and are the sequences of productivity shocks that enable the model to exactly match the observed path of inflation (and thus the lines in the top left hand plot in the figure overlap by construction). Then with the sequence of shocks we can test how well the model is able to track the observed path of inflation expectations from 1984 to 2011.

Figure 3 shows that the model with limited credibility tracts the path of inflation expectations remarkably well. The model is able to replicate the steady decline in the level of long-term measures of inflation expectations over this period. This is in stark contrast to the model with full credibility and full price and wage indexation. The model with full credibility cannot replicate the dynamics of long-term measures of inflation expectations observed in the data.

From these simulations of the model where the sequences of shocks have been set such that the model can exactly match the observed path of inflation over the period 1984 to 2011, the correlation between the path of one-year-ahead inflation expectations in the data and those in the model with full credibility is 0.41, but the correlation between the path of one-year-ahead inflation expectations in the data and those in the model with limited credibility is 0.83. Similarly, the correlation between 10-year-ahead inflation expectations in the data and those in the model with full credibility is 0.12, but the correlation with those in the model with limited credibility is 0.92. The correlation between the 5-year-5-year froward expected inflation rate in the data and that in the model with full credibility is -0.12, but the correlation between the 5-year-5-year forward in the data and that in the model with limited credibility is 0.91.

4.1 Moments from model simulations

The volatility and persistence of current and expected inflation taken from simulations of the model under productivity shocks is presented in table 3. The table presents simulated moments from four versions of the model. The benchmark version of the model with full credibility, no price and wage indexation, and non-permanent shocks, the version of the model with limited credibility, the version of the model with full price and wage indexation, and the version of the model where the exogenous shock follows close to a unit root process.

The table is meant to compare the model with limited credibility with the other modifications of the New Keynesian model authors have proposed to raise the persistence of inflation. First, from the table it is clear that all three modifications, limited credibility, indexation, and permanent shocks, increase raise the relative volatility of One-year-ahead inflation expectations, and they improve the model's ability to match the positive co-movement between current inflation and inflation expectations (particularly long-run inflation expectations).

However, the models with price and wage indexation or permanent shocks fail to match the relative volatility of long-term inflation expectations. As is shown in table 1, in the United States in the 1980's long-run inflation expectations, either the 10-year-ahead expected inflation rate or the 5-year-5-year forward expected inflation rate are around half as volatile as current inflation. In the benchmark New Keynesian model they are around a tenth as volatile as current inflation. Adding intrinsic or inherited inflation persistence does go some way towards explaining the volatility of 10-year-ahead expectations, but these two modifications fail to raise the relative volatility of the 5-year-5-year forward expected inflation rate. Introducing price and wage indexation or a near permanent shock process actually leads to a fall in the relative volatility of the 5-year-5-year forward rate. Only the model with limited credibility, parameterized to match the anchoring of inflation expectations observed in the United States, can produce the observed relative volatility of long-run expected inflation.

Table 4 presents the same model simulation results, only now the model is driven by government spending shocks instead of productivity shocks. The results are similar, just as in the case where the model is driven by productivity shocks, only the version of the model with limited credibility can replicate the volatility of long-run inflation expectations. Just as before, the versions of the model with indexation or near permanent shocks bring a slight improvement in the ability of the New Keynesian model to match the relative volatility of 10-year-ahead inflation expectations, but do not begin to explain the volatility of the 5-year-5-year forward rate.

Comparing changes in credibility Table 5 presents the results from two simulations of the limited credibility model, one where the ϕ parameter has been set to match the observed credibility in the data from 1984 to 1997, $\phi = 0.060$, and one where the ϕ parameter has been set to match the observed credibility in the post-1998 data, $\phi = 0.019$. The first set of columns presents the results from simulations to the model under productivity shocks, the second set of columns presents simulated responses under government spending shocks.

Thus table 5 is meant to show whether or not the observed changes in the dynamics of U.S. inflation expectations from the 1980's to today can be explained by changes in central bank credibility, holding all else constant.

The first thing to notice is that the model can explain the fall in U.S. inflation volatility between the 1984 to 1997 period to the 1998 to 2007 period. In the data, U.S. inflation volatility fell by 18% over this period. The model predicts that a change in the ϕ parameter, holding all else fixed, should result in a 22% fall in inflation volatility.

The change in anchoring can also explain the fall in the relative volatility of various measures of expected inflation. In the data, the relative volatility of One-year-ahead inflation expectations fell by about 20% and that for long-run expectations fell by 40%. The model predicts that the relative volatility of one-year-ahead expectations should fall by about 20% and the volatility of long-run expectations should fall by 50%.

In the data the contemporaneous correlation between observed inflation and long-term inflation expectations fell by 50 percentage points. The models predict that the change in the anchoring parameter ϕ, holding all else constant, should result in a 40-50 percentage point fall in the correlation between inflation and long-term measures of inflation expectations.

5 Summary and conclusion

This paper provides a mechanism through which past observations of inflation can influence the public's perception of the central bank's inflation target and thus can influence inflation expectations into the future. This paper shows how this mechanism can lead to an increase in the volatility of inflation expectations in the benchmark New Keynesian model. Other features added to the standard New Keynesian model, like price and wage indexation, can improve on the model's ability to explain the volatility and persistence of current inflation and short-run inflation expectations, but only the model with limited credibility can match the volatility of long-run inflation expectations that we see in the data.

This concept of limited central bank credibility gives rise to two interesting directions for further research. The first is in an open economy. As described in the first paragraph of the introduction, when Milton Friedman said that "inflation is always and everywhere a monetary phenomenon", he was careful to qualify that inflation is a sustained increase in the general price level. Exogenous shocks, like an increase in commodity prices, could lead to a transitory increase in the price level, but a sustained increase over the long run must be driven by monetary policy, or at least the public's perception of monetary policy.

Thus an interesting extension of this limited credibility model to an open economy would be to consider how foreign shocks that cause a transitory increase in domestic inflation might affect inflation expectations when the central bank has limited credibility. In this case the transitory increase in prices due to the foreign shock could have a long-lasting effect on domestic inflation.[8]

The second, and closely related direction for further research, relates to the optimal conduct of monetary policy when the central bank's stock of credibility is limited. Orphanides and Williams (2004; 2007) and Gaspar, Smets and Vestin (2006; 2011) present models where agents' have imperfect information about the parameters in the central bank's policy rule function or where they are unsure if a shock to inflation is transitory or permanent. These models all show that in this environment, the central bank should be more aggressive when responding to changes in inflation.

Posen (2011) argues that the central bank's reaction to a transitory increase in prices should depend on the anchoring of inflation expectations. If agents' beliefs about the inflation target are very sensitive to the observed inflation rate (in terms of the model, a high ϕ parameter) then then central bank will want to be very aggressive in responding to transitory increases in inflation, but as expectations become better anchored and agents' beliefs become less responsive to the observed inflation rate (a lower ϕ parameter) then the central bank may not want to be as aggressive in responding to transitory movements in prices. Thus an interesting direction for further research would be to quantify how the central bank's optimal monetary policy depends on

[8]In a similar vein, a number of papers have shown that the effect of transitory oil price shocks has diminished over time and go on to argue that one of the reasons for this change is improved central bank credibility (e.g. Blanchard and Gali (2007), Leduc, Sill and Stark (2007), Mehra and Herrington (2008), Blanchard and Riggi (2009), Evans and Fisher (2011)) However, these papers generally divide the sample into pre- and post-1979 periods. Given that the reestablishment of Fed credibility occurred much later, an interesting direction for further research would be to study the effect of oil price shocks on U.S. inflation pre- and post-1997.

this "anchoring" of inflation expectations.

References

Albanesi, Stefania, V.V. Chari, and Lawrence J. Christiano. 2003. "Expectations Traps and Monetary Policy." *Review of Economic Studies*, 70: 715–741.

Andolfatto, David, and Paul Gomme. 2003. "Monetary policy regimes and beliefs." *International Economic Review*, 44: 1–30.

Barro, Robert J. 1986. "Reputation in a model of monetary policy with incomplete information." *Journal of Monetary Economics*, 17: 3–20.

Barro, Robert J., and David B. Gordon. 1983. "A Positive Theory of Monetary Policy in a Natural Rate Model." *Journal of Political Economy*, 91(4): 589–610.

Beechey, Meredith J., Benjamin K. Johannsen, and Andrew T. Levin. 2011. "Are Long-Run Inflation Expectations More Firmly Anchored in the Euro-Area Than in the United States?" *American Economic Journal: Macroeconomics*, 3: 104–129.

Benati, Luca. 2008. "Investigating Inflation Persistence Across Monetary Regimes." *Quarterly Journal of Economics*, 123(3): 1005–1060.

Bianchi, Francesco. 2013. "Regime Switches, AgentsŠ Beliefs, and Post-World War II U.S. Macroeconomic Dynamics." *Review of Economic Studies*, 80: 463–490.

Blanchard, Oliver J., and Jordi Gali. 2007. "The Macroeconomic Effects of Oil Shocks: Why Are the 2000s So Different From the 1970s?" *NBER Working Paper no. 13368.*

Blanchard, Oliver J., and Marianna Riggi. 2009. "Why Are the 2000s So Different From the 1970s? A Structural Interpretation of Changes in the Macroeconomic Effects of Oil Prices." *NBER Working Paper no. 15467.*

Boivin, Jean, and Marc P. Giannoni. 2006. "Has monetary policy become more effective?" *Review of Economics and Statistics*, 88(3): 445–462.

Calvo, Guillermo A. 1983. "Staggered Prices in a Utility-Maximizing Framework." *Journal of Monetary Economics*, 12: 383–398.

Christiano, Lawrence J., Martin Eichenbaum, and Charles L. Evans. 2005. "Nominal Rigities and the Dynamic Effects of a Shock to Monetary Policy." *Journal of Political Economy*, 113: 1–45.

Clarida, Richard, Jordi Gali, and Mark Gertler. 2002. "A simple framework for monetary policy analysis." *Journal of Monetary Economics*, 49: 879–904.

Clark, Todd E., and Troy Davig. 2011. "Decomposing the Declining Volatility of Long-Term Inflation Expectations." *Journal of Economic Dynamics and Control*, 35(7): 981–999.

Cogley, Timothy, and Argia M. Sbordone. 2008. "Trend inflation, indexation, and inflation persistence in the new Keynesian Phillips Curve." *American Economic Review*, 98(5): 2101–2126.

Del Negro, Marco, and Stefano Eusepi. 2012. "Fitting observed inflation expectations." *Journal of Economic Dynamics and Control, forthcoming.*

Dixit, Avinash K., and Joseph E. Stiglitz. 1977. "Monopolistic Competition and Optimum Product Diversity." *American Economic Review*, 67: 297–308.

Ehrmann, Michael, and Panagiota Tzamourani. 2012. "Memories of high inflation." *European Journal of Political Economy*, 28(2): 174–191.

Erceg, Christopher J., and Andrew T. Levin. 2003. "Imperfect credibility and inflation persistence." *Journal of Monetary Economics*, 50: 915–944.

Evans, Charles L., and Jonas D.M. Fisher. 2011. "What Are the Implications of Rising Commodity Prices for Inflation and Monetary Policy?" *Chicago Fed Letter*, , (no. 286).

Fuhrer, Jeffrey C. 2006. "Intrinsic and Inherited Inflation Persistence." *International Journal of Central Banking*, 2(3): 49–86.

Fuhrer, Jeffrey C. 2011. "Inflation Persistence." In *Handbook of Monetary Economics*. Vol. 3A, , ed. Benjamin M. Friedman and Michael Woodford, 423–486. North Holland.

Gali, Jordi, and Mark Gertler. 1999. "Inflation dynamics: A structural econometric approach." *Journal of Monetary Economics*, 44: 195–222.

Gaspar, Vitor, Frank Smets, and David Vestin. 2006. "Adaptive Learning, Persistence, and Optimal Monetary Policy." *Journal of the European Economic Association*, 4: 376–385.

Gaspar, Vitor, Frank Smets, and David Vestin. 2011. "Inflation Expectations, Adaptive Learning, and Optimal Monetary Policy." In *Handbook of Monetary Economics*. Vol. 3B, , ed. Benjamin M. Friedman and Michael Woodford, 1055–1096. North Holland.

Goldberg, Linda S., and Michael W. Klein. 2005. "Establishing Credibility: Evolving Perceptions of the European Central Bank." *Federal Reserve Bank of New York Staff Report No. 231.*

Goodfriend, Marvin, and Robert G. King. 2005. "The Incredible Volcker Disinflation." *Journal of Monetary Economics*, 52(5): 981–1015.

Gürkaynak, 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 U.S., U.K., and Sweden." Federal Reserve Bank of San Francisco Working Paper no. 2006-09.

Gürkaynak, Refet S., Brian Sack, and Eric T. Swanson. 2005. "The Sensitivity of Long-Term Interest Rates to Economic News: Evidence and Implications for Macroeconomic Models." *American Economic Review*, 95(1): 425–436.

Haubrich, Joseph G., George Pennacchi, and Peter Ritchken. 2011. "Inflation Expectations, Real Rates, and Risk Premia: Evidence from Inflation Swaps." Federal Reserve Bank of Cleveland Working Paper no. 11-07.

Ireland, Peter N. 2007. "Changes in the Federal Reserves's inflation target: Causes and consequences." *Journal of Money, Credit, and Banking*, 39: 1851–1882.

Lansing, Kevin J. 2009. "Time Varying U.S. Inflation Dynamics and the New Keynesian Phillips Curve." *Review of Economic Dynamics*, 12(2): 304–326.

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*, 54: 433–459.

Levin, Andrew T., and Jeremy M. Piger. 2004. "Is inflation persistence intrinsic in industrial economies." *ECB Working Paper no. 334*.

Lubik, Thomas, and Frank Schorfheide. 2004. "Testing for Indeterminacy: An Application to U.S. Monetary Policy." *American Economic Review*, 94(1): 190–217.

Malmendier, Ulrike, and Stefan Nagel. 2013. "Learning from Infl ation Experiences." *mimeo.*

Mankiw, N. Gregory, and Ricardo Reis. 2002. "Sticky information versus sticky prices: A proposal to replace the New Keynesian Phillips Curve." *Quarterly Journal of Economics*, 117(4): 1295–1328.

Mehra, Yash P., and Christopher Herrington. 2008. "On the Sources of Movements in Inflation Expectations: A Few Insights From a VAR Model." *Federal Reserve Bank of Richmond Economic Quarterly*, 94(2): 121–146.

Milani, Fabio. 2007. "Expectations, learning and macroeconomic persistence." *Journal of Monetary Economics*, 54: 2065–2082.

Orphanides, Athansios, and John C. Williams. 2004. "Imperfect Knowledge, Inflation Expectations, and Monetary Policy." In *The Inflation-Targeting Debate.* , ed. Ben S. Bernanke and Michael Woodford, 201–246. University of Chicago Press.

Orphanides, Athansios, and John C. Williams. 2007. "Robust monetary policy with imperfect knowledge." *Journal of Monetary Economics*, 54: 1406–1435.

Posen, Adam. 2011. "The Soft Tyranny of Inflation Expectations." *International Finance*, 0: 1–26.

Schorfheide, Frank. 2005. "Learning and Monetary Policy Shifts." *Review of Economic Dynamics*, 8: 392–419.

Stock, James H., and Mark W. Watson. 2007. "Why Has U.S. Inflation Become Harder to Forecast?" *Journal of Money, Credit, and Banking*, 39(1): 3–33.

Volcker, Paul. 1979. "Statement Before the Joint Economic Committee of the U.S. Congress. October 17, 1979." *Federal Reserve Bulletin*, 65(11): 888–890.

Table 1: Volatility and Persistence of inflation and inflation expectations. Inflation expectations data is from the dataset produced by the Federal Reserve Bank of Cleveland and described in Haubrich,Pennacchi, and Ritchken (2011)

		U.S. Data		
		$1984-1997$	$1998-2011$	$1998-2007$
Standard deviation (%)	π_t	1.05	1.30	0.86
Standard deviation	$E_t(\pi_{t+1})$	0.68	0.58	0.56
relative to π_t	$\frac{1}{10}\sum_{i=1}^{10} E_t(\pi_{t+i})$	0.64	0.36	0.39
	$E_t\left(\frac{1}{5}\sum_{i=6}^{10} \pi_{t+i}\right)$	0.59	0.32	0.36
Correlation with π_t	$E_t(\pi_{t+1})$	0.68	0.46	0.28
	$\frac{1}{10}\sum_{i=1}^{10} E_t(\pi_{t+i})$	0.54	0.21	0.06
	$E_t\left(\frac{1}{5}\sum_{i=6}^{10} \pi_{t+i}\right)$	0.51	0.15	0.00
Correlation with π_{t-1}	$E_t(\pi_{t+1})$	0.65	0.31	0.48
	$\frac{1}{10}\sum_{i=1}^{10} E_t(\pi_{t+i})$	0.54	0.14	0.08
	$E_t\left(\frac{1}{5}\sum_{i=6}^{10} \pi_{t+i}\right)$	0.51	0.09	-0.01
Autocorrelation	π_t	0.86	0.62	0.58
	$E_t(\pi_{t+1})$	0.86	0.55	0.33
	$\frac{1}{10}\sum_{i=1}^{10} E_t(\pi_{t+i})$	0.91	0.88	0.79
	$E_t\left(\frac{1}{5}\sum_{i=6}^{10} \pi_{t+i}\right)$	0.90	0.88	0.78

Table 2: Parameter Values

Symbol	Value	Description
β	0.99	discount factor
α	.36	capital share in production of value added
δ	0.025	capital depreciation rate
σ	10	elasticity of substitution (eos) across varieties from different firms
θ	21	eos between labor from different households
ξ_p	0.75	probability that a firm cannot reset prices
ξ_w	0.75	probability that a household cannot reset wages
θ_p	1.5	coefficient on inflation in the Taylor rule
θ_y	.5	coefficient on the output gap in the Taylor rule
θ_i	.9	coefficient on the lagged interest rate in the Taylor rule
ϕ	0.06 or 0.019	parameter describing agents' beliefs about central bank accommodation

Table 3: Simulated moments of inflation and inflation expectations from different versions of the model with TFP shocks.

		Benchmark	Limited Credibility	Indexation	Persistent Shock
Standard deviation	π_t	0.76	1.05	2.69	1.10
Standard deviation	$E_t\left(\pi_{t+1}\right)$	0.48	0.67	0.83	0.59
relative to π_t	$\frac{1}{10}\sum_{i=1}^{10} E_t\left(\pi_{t+i}\right)$	0.16	0.49	0.27	0.18
	$E_t\left(\frac{1}{5}\sum_{i=6}^{10} \pi_{t+i}\right)$	0.14	0.49	0.09	0.08
Correlation with π_t	$E_t\left(\pi_{t+1}\right)$	0.80	0.92	0.96	0.95
	$\frac{1}{10}\sum_{i=1}^{10} E_t\left(\pi_{t+i}\right)$	−0.11	0.73	0.91	0.93
	$E_t\left(\frac{1}{5}\sum_{i=6}^{10} \pi_{t+i}\right)$	−0.52	0.68	0.37	0.84
Correlation with π_{t-1}	$E_t\left(\pi_{t+1}\right)$	0.59	0.85	0.90	0.83
	$\frac{1}{10}\sum_{i=1}^{10} E_t\left(\pi_{t+i}\right)$	−0.20	0.74	0.83	0.86
	$E_t\left(\frac{1}{5}\sum_{i=6}^{10} \pi_{t+i}\right)$	−0.51	0.71	0.28	0.82
Autocorrelation	π_t	0.92	0.95	0.98	0.94
	$E_t\left(\pi_{t+1}\right)$	0.80	0.95	0.94	0.88
	$\frac{1}{10}\sum_{i=1}^{10} E_t\left(\pi_{t+i}\right)$	0.99	1.00	0.93	0.93
	$E_t\left(\frac{1}{5}\sum_{i=6}^{10} \pi_{t+i}\right)$	0.97	0.99	0.94	0.97

Table 4: Simulated moments of inflation and inflation expectations from different versions of the model with government spending shocks.

		Benchmark	Limited Credibility	Indexation	Persistent Shock
Standard deviation	π_t	0.74	1.05	2.96	1.14
Standard deviation	$E_t\left(\pi_{t+1}\right)$	0.57	0.74	0.88	0.36
relative to π_t	$\frac{1}{10}\sum_{i=1}^{10} E_t\left(\pi_{t+i}\right)$	0.21	0.47	0.35	0.14
	$E_t\left(\frac{1}{5}\sum_{i=6}^{10} \pi_{t+i}\right)$	0.21	0.45	0.14	0.12
Correlation with π_t	$E_t\left(\pi_{t+1}\right)$	0.93	0.97	0.98	0.79
	$\frac{1}{10}\sum_{i=1}^{10} E_t\left(\pi_{t+i}\right)$	0.10	0.81	0.90	−0.14
	$E_t\left(\frac{1}{5}\sum_{i=6}^{10} \pi_{t+i}\right)$	−0.52	0.68	0.45	−0.46
Correlation with π_{t-1}	$E_t\left(\pi_{t+1}\right)$	0.81	0.93	0.94	0.57
	$\frac{1}{10}\sum_{i=1}^{10} E_t\left(\pi_{t+i}\right)$	0.01	0.81	0.84	−0.22
	$E_t\left(\frac{1}{5}\sum_{i=6}^{10} \pi_{t+i}\right)$	−0.53	0.71	0.37	−0.45
Autocorrelation	π_t	0.93	0.96	0.99	0.89
	$E_t\left(\pi_{t+1}\right)$	0.89	0.97	0.96	0.81
	$\frac{1}{10}\sum_{i=1}^{10} E_t\left(\pi_{t+i}\right)$	0.99	0.99	0.95	1.00
	$E_t\left(\frac{1}{5}\sum_{i=6}^{10} \pi_{t+i}\right)$	0.99	0.99	0.94	0.98

Table 5: Comparing the moments of U.S. inflation and inflation from the 1980's and the 2000's to simulations of the model calibrated to match levels of credibility in the 1980's and the 2000's

		Model - Productivity Shocks		Model - Government Spending Shocks	
		Pre-'98 Credibility	Post-'98 Credibility	Pre-'98 Credibility	Post-'98 Credibility
Standard deviation	π_t	1.05	0.82	1.05	0.80
Standard deviation	$E_t(\pi_{t+1})$	0.67	0.51	0.74	0.60
relative to π_t	$\frac{1}{10}\sum_{i=1}^{10} E_t(\pi_{t+i})$	0.49	0.24	0.47	0.23
	$E_t\left(\frac{1}{5}\sum_{i=6}^{10} \pi_{t+i}\right)$	0.49	0.24	0.45	0.23
Correlation with π_t	$E_t(\pi_{t+1})$	0.92	0.86	0.97	0.95
	$\frac{1}{10}\sum_{i=1}^{10} E_t(\pi_{t+i})$	0.73	0.32	0.81	0.47
	$E_t\left(\frac{1}{5}\sum_{i=6}^{10} \pi_{t+i}\right)$	0.68	0.15	0.68	−0.02
Correlation with π_{t-1}	$E_t(\pi_{t+1})$	0.85	0.69	0.93	0.86
	$\frac{1}{10}\sum_{i=1}^{10} E_t(\pi_{t+i})$	0.74	0.29	0.81	0.43
	$E_t\left(\frac{1}{5}\sum_{i=6}^{10} \pi_{t+i}\right)$	0.71	0.18	0.71	0.01
Autocorrelation	π_t	0.95	0.93	0.96	0.94
	$E_t(\pi_{t+1})$	0.95	0.85	0.97	0.92
	$\frac{1}{10}\sum_{i=1}^{10} E_t(\pi_{t+i})$	1.00	1.00	0.99	0.99
	$E_t\left(\frac{1}{5}\sum_{i=6}^{10} \pi_{t+i}\right)$	0.99	0.99	0.99	0.99

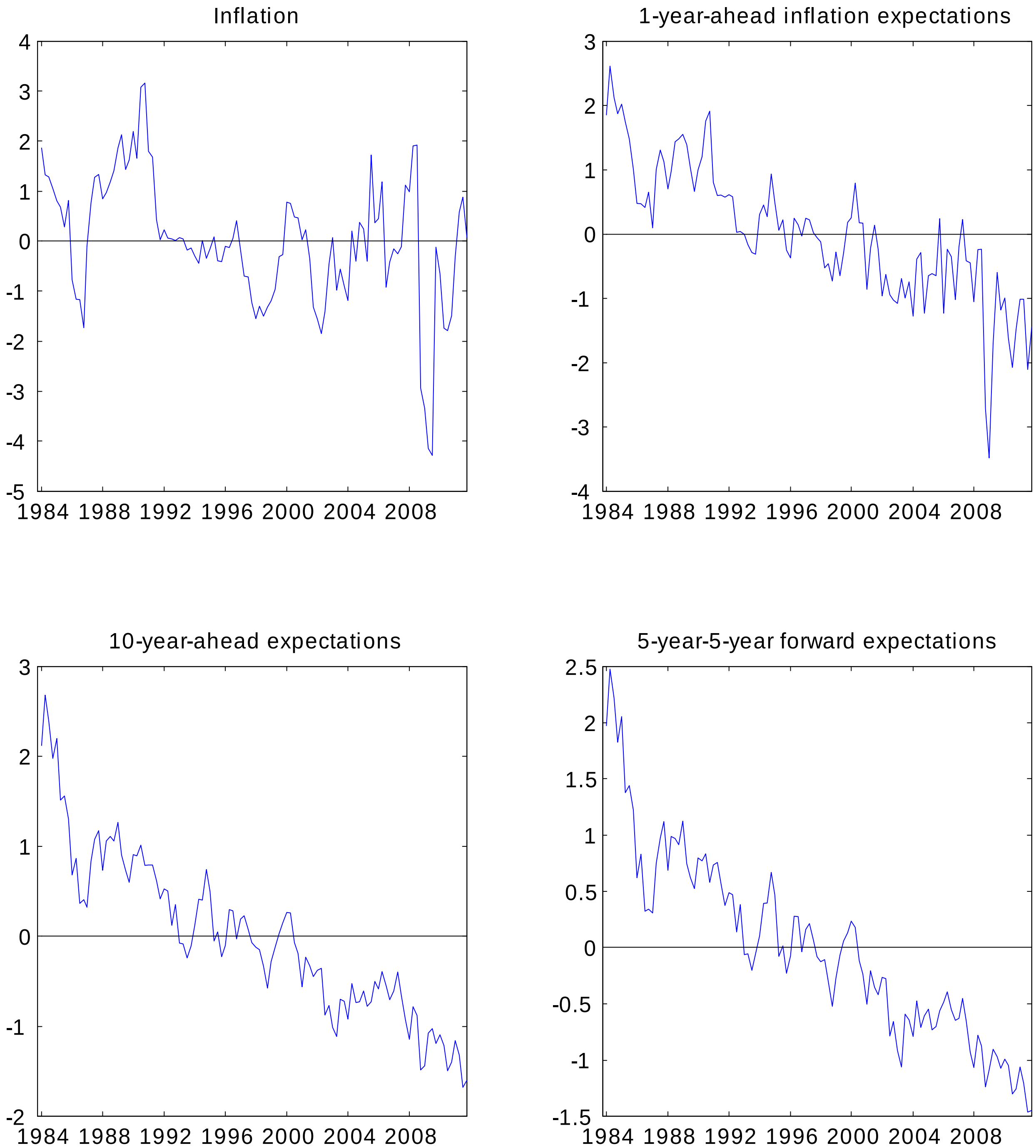

Figure 1: Headline inflation and measures of inflation expectations in the United States from 1984 to 2011.

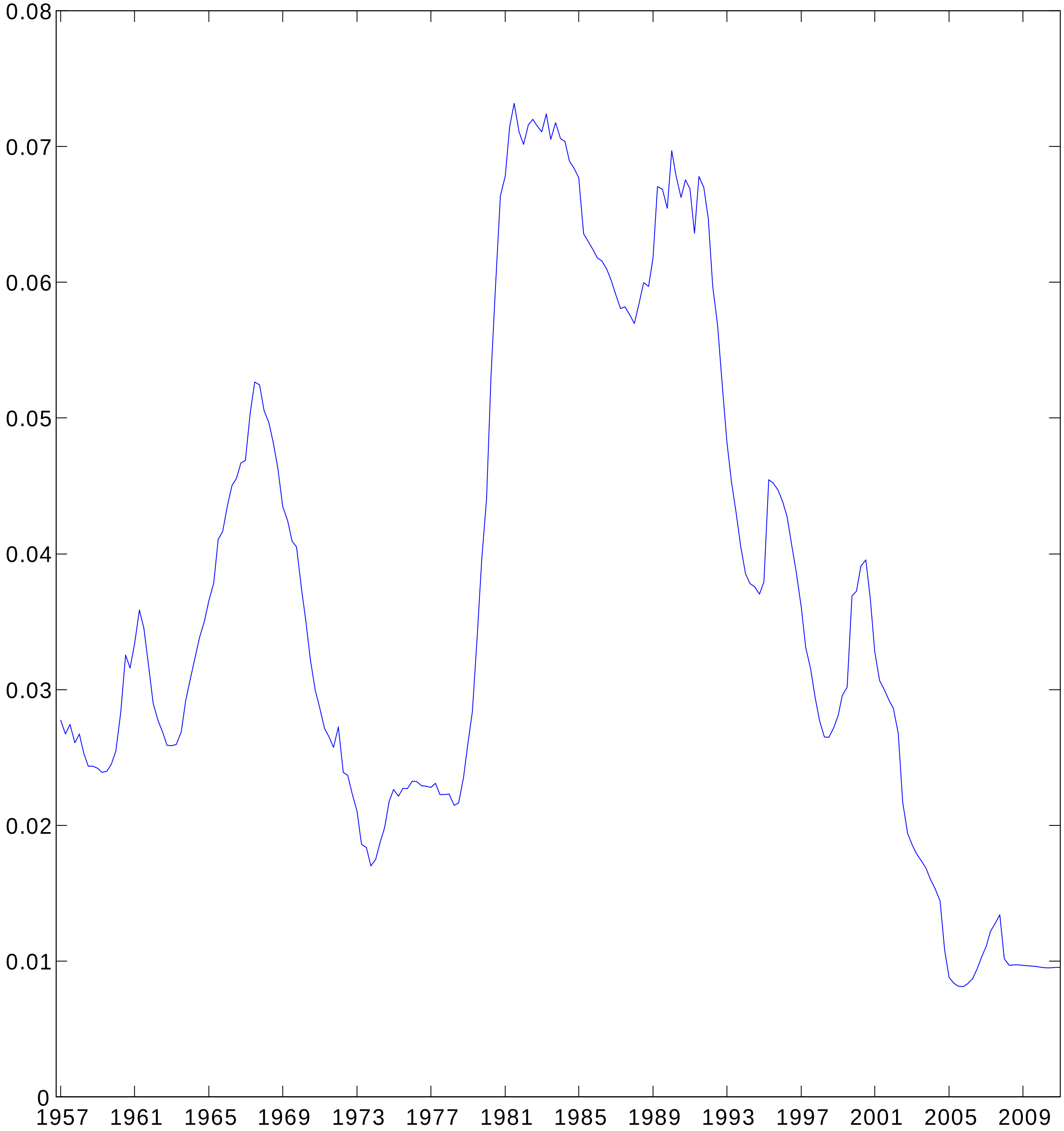

Figure 2: Estimated value of the inflation expectations anchoring parameter ϕ

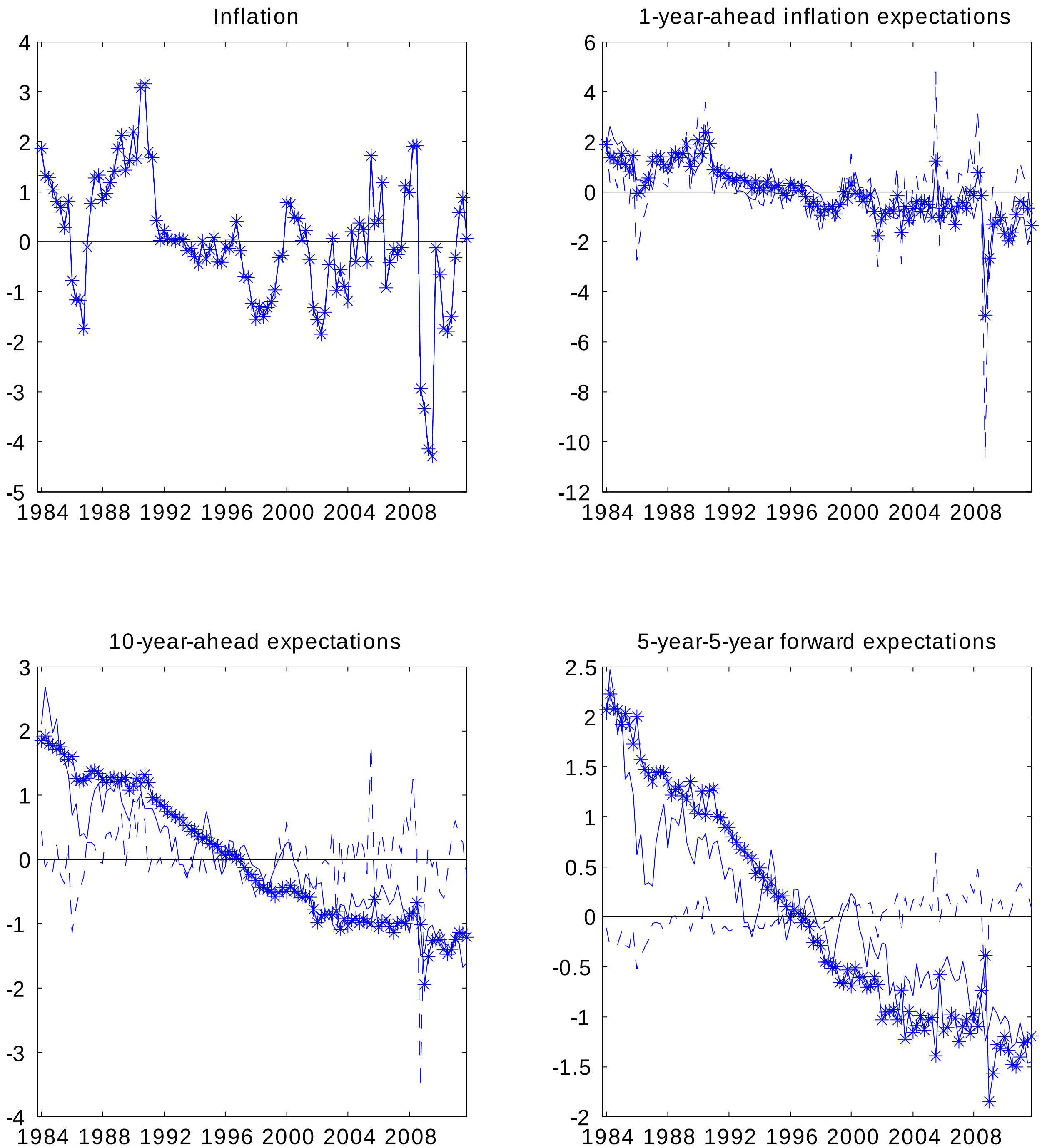

Figure 3: U.S. inflation and inflation expectations from 1984 to 2011. The solid line is the data, the dashed line is from simulations of the New Keynesian model with full price and wage indexation, the line with stars is from the New Keynesian model with limited central bank credibility.