

Has the Anchoring of Inflation Expectations Changed in the United States during the Past Decade?

By Taeyoung Doh and Amy Oksol

Monetary policy has changed dramatically in the United States over the past decade, with potential implications for investors' inflation expectations. During the financial crisis and Great Recession of 2007–09, the Federal Reserve's conventional policy tool, the nominal short-term interest rate, was constrained by its effective lower bound. At the time, monetary policy makers were concerned the U.S. economy might slip into a deflationary trap similar to Japan's during the period of 1999–2003. As a result, the Fed responded aggressively to stabilize the economy through multiple rounds of large-scale asset purchases (LSAPs) and forward guidance on the future interest rate. In addition, the Federal Open Market Committee (FOMC) adopted a formal inflation target at its meeting in January 2012, emphasizing that “communicating this inflation goal clearly to the public helps keep longer-term inflation expectations firmly anchored.”

Well-anchored inflation expectations are a key measure of successful monetary policy, because in the long run, inflation is mainly determined by monetary policy. Inflation expectations drifting away from the central bank's implicit or explicit inflation targets can generate highly inflationary or disinflationary episodes. For example, businesses expecting a higher inflation rate may increase current prices to offset

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high future costs of production. Similarly, consumers expecting prices to fall may delay their spending, reinforcing disinflationary pressures with the resulting lack of demand.

Prior to the financial crisis, researchers found that the level and volatility of inflation expectations decreased dramatically from 1981:Q3 to 2008:Q2, suggesting investors' inflation expectations were well anchored (Clark and Davig 2011). But did their expectations remain anchored after the crisis, during a period of unconventional monetary policy?

We use a model consistent with previous research to examine whether inflation expectations became unanchored after the crisis. Our analysis of three metrics of inflation expectations—their level, volatility, and persistence—suggests that the degree of anchoring deteriorated somewhat in late 2010, coinciding with the start of the second round of LSAPs, but has improved since then. Other rounds of LSAPs and the adoption of a formal inflation target are associated with better anchoring of inflation expectations to varying degrees. Finally, we find inflation expectations have remained well anchored more recently (2017:Q3), returning to their pre-crisis behavior.

Section I defines the level, volatility, and persistence metrics as well as the data used to construct inflation expectations. Section II discusses the channels through which monetary policy can affect inflation expectations. Section III introduces a model for inflation expectations and analyzes how the Federal Reserve's monetary policy actions affected the anchoring of inflation expectations over the past decade.

I. Measuring the Degree of Anchoring in Inflation Expectations

To evaluate the degree to which inflation expectations have been anchored over time, we first examine the level, volatility, and persistence that summarize their long-run predictive distribution.¹ These metrics allow us to quantify the degree to which inflation expectations are anchored. If the level of inflation expectations gets closer to the central bank's longer-run objective, for example, then inflation expectations are better anchored. If the volatility of inflation expectations declines, then inflation expectations are also better anchored. Finally, if unanticipated shocks to inflation expectations have less persistent effects over the long run, then inflation expectations are better anchored. All three

metrics are consistent with the FOMC's interpretation of price stability in terms of "preventing persistent deviations of inflation from its longer-run objective."

Both financial market data and survey forecasts can be used to measure inflation expectations. One widely used, market-based measure of inflation expectations is the "breakeven inflation rate," calculated as the difference between yields on nominal U.S. Treasury bonds and Treasury Inflation-Protected Securities (TIPS) of the same maturity. The breakeven inflation rate reveals the additional compensation that bond market investors demand for putting money in nominal bonds whose value will decline in real terms with inflation. As the risk of higher future inflation increases, investors will demand more compensation, thereby driving down the prices of nominal bonds and driving up their yields relative to TIPS. Therefore, a higher breakeven rate suggests investors perceive a higher risk of future inflation. The advantage of using financial market data is that they provide high-frequency information about inflation expectations and are available at more horizons than survey data. However, they can also be contaminated by market-related factors other than inflation expectations, such as trading liquidity.

One alternative is to use direct observations of investors' inflation expectations from survey data. Since survey participants provide their actual inflation expectations, the data are not contaminated by other factors.² Additionally, inflation forecasts using survey data tend to generate more accurate out-of-sample forecasts than those using actual inflation data or financial market data (Ang, Bekaert, and Wei 2007; Faust and Wright 2013; Mertens 2016). However, available forecast horizons in survey data are limited compared with market-based measures.

Aruoba (2016) overcomes this shortcoming by fitting an inflation expectations curve, which plots the average inflation expected between today and any point three to 120 months in the future, with survey data from three different sources: the Survey of Professional Forecasters (SPF), Blue Chip Economic Indicators (BCEI), and Blue Chip Financial Forecasts (BCFF).³ Table 1 summarizes the forecast horizons and frequency of collection and publication for all three surveys. One complication in combining data from these surveys is that the frequencies and forecast horizons differ significantly. To account for these differences, Aruoba (2016) starts out by assuming that the spot inflation expectations for a particular horizon (h), which represent the expected

Table 1

Survey Data Sources Used in the Inflation Expectations Curve

Source	Frequency of publication	Frequency of forecasts	Horizons
Survey of Professional Forecasters	Quarterly	Quarterly, annual	-1 quarter to +4 quarters; current year to +2 years; average over +5 yrs, average over +10 years
Blue Chip Economic Indicators	Monthly	Quarterly, annual*	From current quarter** to +7 quarters; +5 years following next year, 5 year forward
Blue Chip Financial Forecasts	Monthly	Annual***	+5 years following next year, 5 year forward

* Annual forecasts only available in March and October issues

** May also include previous quarter if currently in first month of a quarter

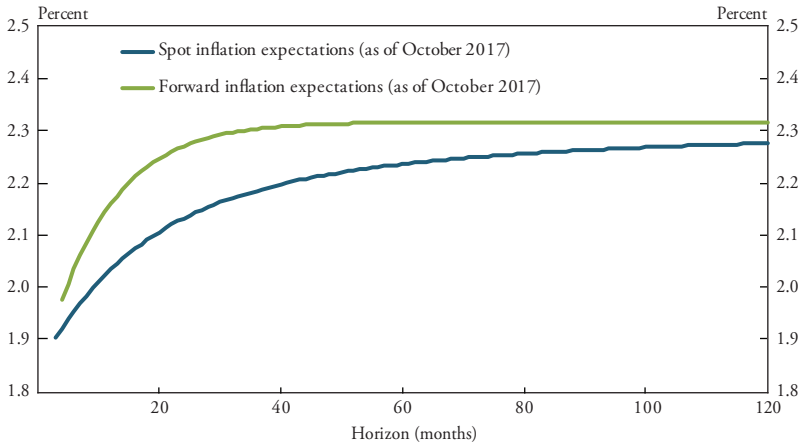
*** Annual forecast only available in June and December issues
Source: Aruoba (2016).

inflation averaged between the current period, (t), and a specific future period, ($t+h$), are spanned by three latent variables that vary at the monthly frequency.⁴ In the fitted curve, any point in the spot inflation expectations curve is a function of the three latent variables. We estimate parameters and latent variables by matching the curve-implied forecasts of inflation with the observed median survey forecasts for consumer price index (CPI) inflation.⁵

Once we obtain the spot inflation expectations curve from Aruoba (2016), we can compute inflation expectations at any horizon, analogous to the five-year, five-year forward breakeven inflation measure. Since the spot inflation expectations curve spans multiple horizons, from three to 120 months, it can provide one-month-forward inflation expectations at any horizon from three to 119 months. For example, the value of the forward inflation expectations for the 12-month horizon at time t represents the expected inflation between $t+12$ and $t+13$. Chart 1 illustrates the spot inflation expectations curve and the corresponding one-month-forward inflation expectations curve as of October 2017. Each point on the spot inflation expectations curve shows the expected inflation between the current month and some point in the future—for example, the spot curve suggests that expected inflation would average a little over 2.1 percent between today and 60 months from now. The corresponding one-month-forward inflation expectations curve shows what expected inflation would be one-month ahead of that future point—for example, the expected inflation between month 60 and

Chart 1

Inflation Expectations at Multiple Horizons



Notes: Each point on the spot inflation expectations curve shows what the expected inflation would be between the current month and the future month given by the horizon at the point. The corresponding one-month-forward inflation expectations curve shows what the one-month-ahead expected inflation would be from the horizon at the point. Sources: Federal Reserve Bank of Philadelphia and authors' calculations.

month 61. The flattening of the forward inflation expectations curve after 36 months suggests that inflation expectations beyond that horizon would converge to the long-run level in three years.

II. Using Monetary Policy to Anchor Inflation Expectations

Changes in monetary policy can directly or indirectly affect all three metrics of anchored inflation expectations—level, volatility, and persistence. For instance, a central bank can directly affect the level of inflation expectations by announcing an explicit target rate for inflation. This action can, in turn, indirectly reduce the volatility of inflation expectations by reducing uncertainty about the central bank's intent. In addition, both the volatility and persistence of inflation expectations may decline if the central bank adjusts the nominal interest rate more aggressively to stabilize inflation around its target. If investors anticipate the central bank will respond aggressively to inflationary shocks, they may assume the effects of these shocks will dissipate sooner and set prices accordingly. As a result, actual inflation and inflation expectations will be less responsive to exogenous shocks (Davig and Doh 2014). Furthermore, the central bank can boost aggregate

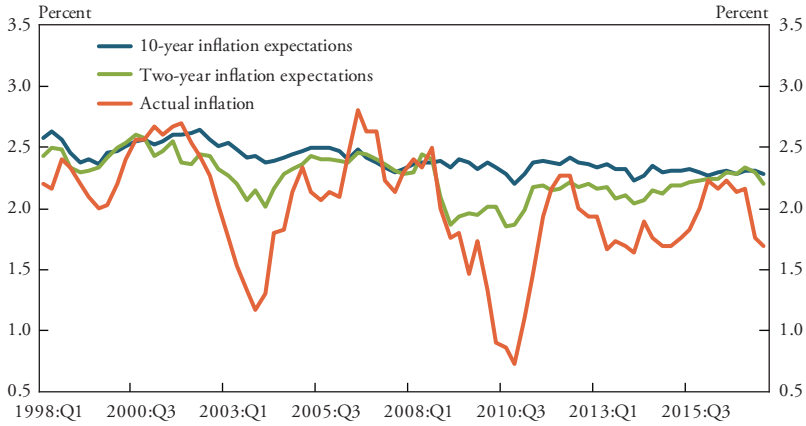
demand and thereby push up inflation expectations by easing financial market conditions. Through these channels, monetary policy can affect both near-term and long-term inflation expectations.

Although monetary policy makers are mostly concerned about movements in long-term inflation expectations, they must also monitor fluctuations in near-term inflation expectations, which may spill over into long-term inflation expectations in the future.⁶ Chart 2 plots two measures of inflation expectations—the two-year and 10-year inflation rates—along with the actual inflation rate from January 1998 to October 2017. Although two-year inflation expectations moved together with the actual inflation rate, 10-year inflation expectations remained relatively stable. Nonetheless, if movements in two-year inflation expectations spilled over into 10-year inflation expectations over time, the distribution of 10-year inflation expectations might shift.

Japan's experience in the 1990s provides a cautionary tale regarding this risk. While long-term (five-to-10 year) inflation expectations were quite stable in Japan during the late 1990s, near-term (one-year) inflation expectations often deviated quite noticeably on the downside. Actual inflation became negative from 1999 to 2003, tracking the plunge in short-run inflation expectations (Fuhrer 2017). Long-term inflation expectations eventually dropped below 1 percent in the early 2000s, concurrent with this prolonged period of deflation.⁷ Japan's experience suggests substantial changes in near-term inflation expectations should be watched carefully, as they could augur similar changes in long-term inflation expectations.

Changes in monetary policy actions and inflation expectations in the United States over the past decade highlight how a concern for drifting inflation expectations shaped monetary policy. During the financial crisis of 2008, policymakers were concerned about the possibility of deflation and stagnation and took aggressive steps to avoid it. Table 2 summarizes the timing and purpose of the Fed's policy responses during this period, including multiple rounds of LSAPs intended to facilitate economic recovery by easing financial market conditions. Each of these unprecedented, aggressive policy responses had the potential to better anchor inflation expectations at the FOMC's implicit (before January 2012) or explicit (after January 2012) long-run target. In each statement that announced LSAPs, the FOMC acknowledged the risk that

Chart 2
Inflation Expectations and Actual Inflation



Note: Data are quarterly, constructed by taking three-month averages.
 Sources: Federal Reserve Bank of Philadelphia and U.S. Bureau of Labor Statistics (Haver Analytics).

Table 2
Timing of LSAPs and the Adoption of a Formal Inflation Target

Event	Date	Policy action announced
LSAP 1	March 2009	Fed purchases up to \$1.75 trillion in total assets, intended to “facilitate the extension of credit to households and small businesses.”
LSAP 2	Nov. 2010	Fed purchases \$600 billion of longer-term Treasury securities to promote a stronger recovery and stable inflation.
Inflation target	Jan. 2012	FOMC adopts a 2 percent inflation target to keep inflation expectations “firmly anchored” and to uphold the Fed’s statutory mandate.
LSAP 3	Sept. 2012	Fed increases holdings of long-term securities by \$85 billion per month to “increase policy accommodation.”

Source: Board of Governors of the Federal Reserve System.

inflation might run below a rate consistent with stable prices. For instance, in the March 18, 2009 statement announcing the first round of LSAPs, the FOMC mentioned that it saw “some risk that inflation could persist for a time below rates that best foster economic growth and price stability in the longer term.” The FOMC raised a similar concern in the statement announcing the second round of LSAPs, stating that “measures of underlying inflation have trended lower in recent quarters” (2010b). And the FOMC also mentioned a subdued outlook for inflation in the statement following the September 13, 2012 meeting that announced the third round of LSAPs: specifically, the Committee anticipated that “inflation over the medium term likely would run at or below its 2 percent objective.”

However, the projected effect of LSAPs on inflation expectations was not without controversy. Although most FOMC participants saw the second round of LSAPs as helpful for lifting inflation expectations, some participants, such as then-Governor Kevin Warsh, expressed concern that the second round would increase the risk of future inflation and distortions in currency and capital markets without much effect on economic growth (FOMC 2010a).

In addition to multiple rounds of LSAPs, the adoption of a formal inflation target in January 2012 might also have affected the anchoring of inflation expectations. Although the FOMC announced the adoption of a formal inflation target in a consensus statement, academic researchers and policymakers had previously debated its merits. Some researchers argued that it would lower long-run inflation and provide more room for countercyclical stabilization policy by reducing concerns about the Federal Reserve’s ability to achieve stable prices (Goodfriend 2005). But some policymakers resisted the idea of a formal inflation target, arguing that adopting a target would constrain policy flexibility in future contingencies with little additional benefit, given that long-run inflation expectations had been as stable in the United States as in other inflation-targeting countries, such as Sweden, since 1990 (Kohn 2005).

The Great Recession of 2007–09 enhanced the case for adopting a formal inflation target. Policymakers at that time wanted to make sure the Federal Reserve’s credibility in achieving price stability had not eroded in a way that would hamper aggressive policy responses to stabilize the economy. As then-Chair Ben Bernanke noted during a press

conference on January 25, 2012, the FOMC adopted a formal inflation target of 2 percent, measured by the price index for personal consumption expenditures (PCE), to “foster price stability” and “enhance the FOMC’s ability to promote maximum employment in the face of significant economic disturbances.” According to this view, LSAPs and the adoption of a formal inflation target were complementary measures to achieve the same goal of well-anchored inflation expectations.

To evaluate whether LSAPs and the adoption of the inflation target were indeed associated with well-anchored inflation expectations, we track the time variation in the degree of anchoring around these major monetary policy events in the subsequent analysis.

III. Analyzing the Effect of Monetary Policy on Anchoring Inflation Expectations: Evidence from Survey Data

To quantitatively measure how well inflation expectations are anchored, we incorporate survey data information into an empirical macroeconomic forecasting model and use this model to predict future values of inflation expectations. While the model’s predictions may differ from the current level of inflation expectations, the predicted future value of inflation expectations is still a relevant measure for monetary policy, as it may help a central bank take preemptive actions to reduce the risk of unanchored inflation expectations.

Anchored inflation expectations require inflation expectations to be stable not only at the current level but also in future projections. Therefore, we look at changes in the probability distribution of future projected values of inflation expectations to observe possible shifts in the degree of anchoring of inflation expectations. In general, characterizing changes in the distribution over time is a very challenging, complex task. However, the three metrics of anchored inflation expectations discussed in the previous section provide an effective way to summarize changes in the long-run predictive distribution. By associating the timing of shifts in these metrics with the timing of major changes in monetary policy—such as LSAPs and the adoption of a formal inflation target—we can examine whether policy changes helped long-term inflation expectations become better anchored.

We use two measures of inflation expectations in our estimated forecasting model to examine possible spillovers from changes in

near-term inflation expectations to long-term expectations. We choose the 10-year and two-year inflation expectations from the spot inflation expectations curve in Aruoba (2016) as proxies for long-term inflation expectations and near-term inflation expectations, respectively. We choose 10-year expectations because 10 years is the longest horizon for which we can obtain survey data on inflation forecasts; we choose two-year expectations because monetary policy typically affects inflation with a one-year lag (Svensson 1996). Our estimated forecasting model links future values of 10-year inflation expectations to the current and past values of two-year inflation expectations. Whether the two measures move together has implications for the degree of anchoring. If the current and past values of two-year inflation expectations influence 10-year inflation expectations, the persistence metrics for both horizons are likely to move together, because forecastable variations in two-year inflation expectations would show up as forecastable variations in 10-year inflation expectations, too. In this way, increased persistence in two-year inflation expectations—an increased probability of inflation deviating from its long-run average level—would likely lead 10-year inflation expectations to become unanchored. However, if two-year inflation expectations do not influence 10-year inflation expectations, the two persistence metrics should move independently.

A multivariate forecasting model of inflation and inflation expectations

We consider a vector autoregression model (VAR) of five macroeconomic variables to estimate the three metrics of anchored inflation expectations. Following Clark and Davig (2011), we use monthly observations for headline CPI inflation (π_t) and the Chicago Fed National Activity Index (CFNAI, denoted a_t) as well as the short-term interest rate (r_t) and two-year ($\pi_{t,2yr}^e$) and 10-year ($\pi_{t,10yr}^e$) inflation expectations. To measure the stance of monetary policy when the federal funds rate was constrained at its effective lower bound, we use the estimated shadow rate in Doh and Choi (2016). This measure backs out the short-term interest rate implied by government and private borrowing conditions, including long-term rates, and is not constrained by the effective lower bound on the short-term interest rate.⁸ Thus, the shadow rate can capture the additional monetary stimulus the Federal Reserve provided by influencing long-term interest rates through

LSAPs and forward guidance on the future path of the short-term interest rate. When the short-term interest rate is not constrained by the effective lower bound, the shadow rate is highly correlated with the federal funds rate itself, making it a useful metric to capture the monetary policy stance both on and off the effective lower bound. In the VAR, we order inflation expectations before inflation, real activity, and the shadow rate.⁹ The variables are summarized in the vector y_t :

$$y_t = \left[\pi_{t,10yr}^e, \pi_{t,2yr}^e, \pi_t, a_t, r_t \right].$$

We transform monthly variables into quarterly variables by taking three-month average values of inflation and the activity index. Since our inflation expectations data are only available starting in January 1998, our sample period is 1998:Q1 to 2017:Q3. We estimate VAR(1) to obtain the three metrics of anchored inflation expectations.¹⁰ The model can be written as:

$$y_t = A_{0,t} + A_{1,t}y_{t-1} + \Sigma_t \epsilon_t, \text{ Var}(\epsilon_t)$$

The five VAR residual shocks (ϵ_t) follow a multivariate normal distribution and are serially and cross-sectionally uncorrelated. The VAR coefficients ($A_{0,t}, A_{1,t}$) and covariance matrix ($\Sigma_t \Sigma_t'$) are time varying, because we estimate the VAR(1) for rolling samples of 40 quarters. In this way, we can identify the timing of shifts in the metrics of anchored inflation expectations.

The anchoring of U.S. inflation expectations during the recent decade

From the estimated VAR model, we can derive a long-run predictive distribution of inflation expectations that provides information on the probabilities of possible future outcomes.¹¹ As the debates on LSAPs considered the future risk of inflation expectations drifting above the Federal Reserve's long-run objective, we use the long-run predictive distribution to quantify the probability of this risk.

Because the long-run predictive distribution considers the cumulative effects of future shocks, the range of possible outcomes is much wider than in the short-run predictive distribution. For this reason, we look at changes in the long-run predictive distribution of inflation expectations in our analysis. Furthermore, the long-run distribution allows us to see through the temporary effects of unanticipated shocks.

Under our assumptions about the distribution of the VAR's residual shocks, the long-run predictive distribution is completely determined by the long-run mean and the long-run variance, which are closely related to the three metrics of anchored inflation expectations.¹²

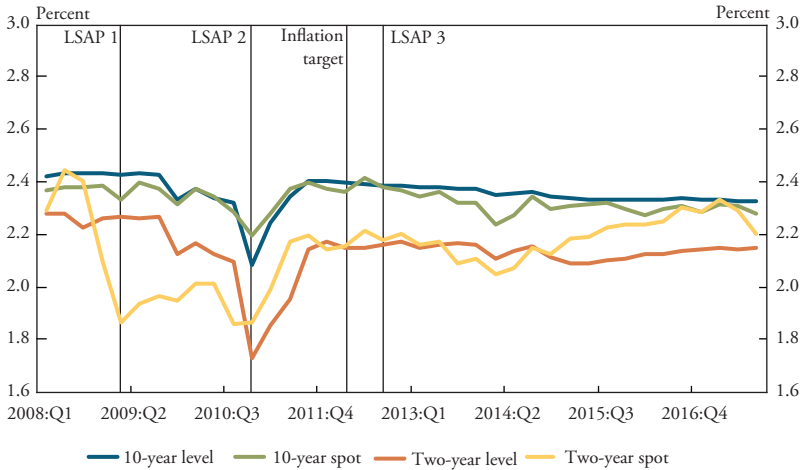
The level metric can be equated with the long-run mean, while the volatility metric can be equated with the long-run variance. The persistence metric provides information on the factors driving the long-run variance. The long-run variance of inflation expectations may go up either because persistence goes up or because the range of potential shocks widens. In other words, by looking at the long-run variance metric together with the persistence metric, we can identify which factor drives the long-run variance metric. The distinction is relevant for policy, because monetary policy can reduce the long-run volatility of inflation expectations more effectively by influencing the parameters determining persistence than by influencing the volatility of unanticipated shocks, which are more likely to change for reasons other than monetary policy.

To assess whether inflation expectations became less anchored after the financial crisis, we first look at the level metric, defined as the mean of inflation expectations in the long-run predictive distribution. This value represents the central point around which future values of inflation expectations would fluctuate over a long time. A significant shift in the level metric would change the probability of inflation expectations crossing certain thresholds in the future, influencing the calculation of risks in both directions. The rolling-sample estimates of the VAR model provide time-varying estimates of this level metric, which we use to calculate the future risk of inflation expectations becoming unanchored.

Chart 3 shows the evolution of the model-implied, long-run mean values for both two-year and 10-year inflation expectations. The horizontal axis represents the timing of the last observation used in each sample. As the 40-quarter window rolls forward, estimates change due to changes in the rolling sample's first and last observations. For instance, the change in the level metric from the rolling sample ending in 2010:Q4 when the second round of LSAPs was adopted to the rolling sample ending in 2011:Q1 can be attributed to the deletion of the 2001:Q4 observation and the addition of the 2002:Q1 observation—only these two observations differ from the previous rolling sample.

Chart 3

Long-Run Average and Current Values of Inflation Expectations



Note: “Level” represents the long-run mean from the VAR model, while “spot” describes the current value of the spot inflation expectations.

Sources: Federal Reserve Bank of Philadelphia and authors’ calculations.

For this particular change in rolling samples, we find that estimates of the three metrics barely change even if we use an alternative rolling sample that adds the observation for 2011:Q1 but does not drop the initial observation from the previous rolling sample (2000:Q4). For the other rounds of LSAPs and the adoption of a formal inflation target, retaining the initial observation from the previous rolling sample produces changes in the metrics that are qualitatively similar but have some quantitative differences. Hence, we attribute changes in the metrics related to anchoring during these quarters to changes in the ending quarter rather than changes in the beginning quarter of rolling samples.

After the global financial crisis of 2008, the two-year and 10-year measures drifted down by 15 and 30 basis points, respectively, until 2010:Q3. However, both estimates recovered two-thirds of their declines by the start of the second round of LSAPs in 2010:Q4. Afterward, 10-year inflation expectations gradually declined by 10 basis points and stabilized at 2.33 percent as of 2017:Q3, while two-year inflation expectations experienced small ups and downs before stabilizing at 2.15 percent in the same quarter.

Because we derive our inflation expectations from CPI inflation forecasts, the overall level of inflation expectations is higher than the

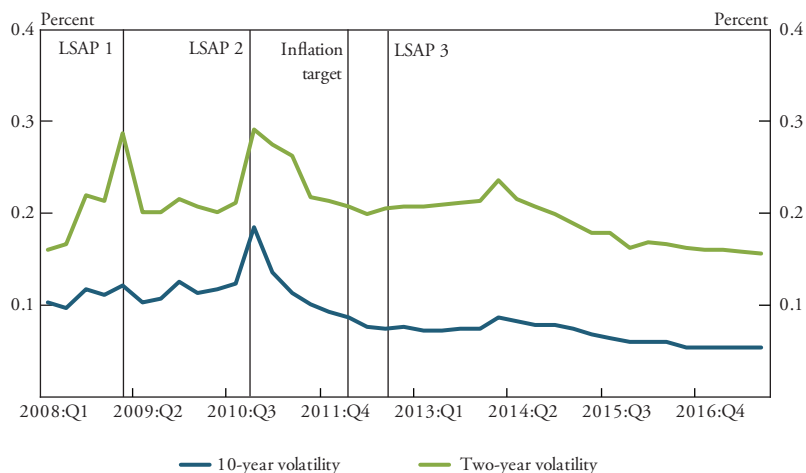
FOMC's 2 percent target, which is based on the PCE inflation rate. Haubrich and Millington (2014) suggest that the CPI inflation rate is about 0.5 percentage point higher than the PCE inflation rate on average. Therefore, the 2.33 percent CPI-based level of 10-year inflation expectations can be translated to 1.83 percent PCE-based inflation, a level close to but lower than the 2 percent target.

The level metric of inflation expectations suggests that the second round of LSAPs coincided with the reversal of a downward trend in inflation expectations. Chart 3 shows that our level metric declined more than the corresponding spot value of inflation expectations around this time, suggesting spot values underestimate the extent to which inflation expectations became unanchored. Interestingly, announcing a formal inflation target barely moved the long-run mean value of 10-year inflation expectations. One explanation for this subdued response is that the announced 2 percent target of PCE inflation was roughly consistent with a CPI inflation rate of about 2.4 percent, which was the long-run mean of 10-year inflation expectations at the time, suggesting that the average level of long-run inflation expectations was already anchored around 2 percent.

The volatility metric of 10-year inflation expectations declined substantially over the past decade, suggesting inflation expectations have become better anchored more recently. To compute this metric, we calculate the model-implied long-run standard deviations of inflation expectations. These statistics likely capture how much the future outcomes of inflation expectations will vary over a long time. Chart 4 shows that the volatilities of inflation expectations jumped in 2009:Q1 and 2010:Q4 (corresponding to the first and second round of LSAPs, respectively) but dropped quickly after. Given the lag in collecting survey responses, however, the effect of LSAPs on the inflation expectations of survey participants is more likely to show up in the following quarters (2009:Q2 and 2011:Q1).¹³ Hence, the timing of changes in the volatility metric may be consistent with the interpretation that the start of LSAPs led survey participants to revise their expectations. Overall, the volatility of 10-year inflation expectations declined by 49 percent from the start of the sample ending in 2008:Q1 to the sample ending in 2017:Q3. For comparison, the level metric declined by only 4 percent. The more substantial decline in the volatility metric relative to the level metric implies

Chart 4

Long-Run Volatility of Inflation Expectations



Note: “Volatility” represents the long-run standard deviation from the VAR model.
Sources: Federal Reserve Bank of Philadelphia and authors’ calculations.

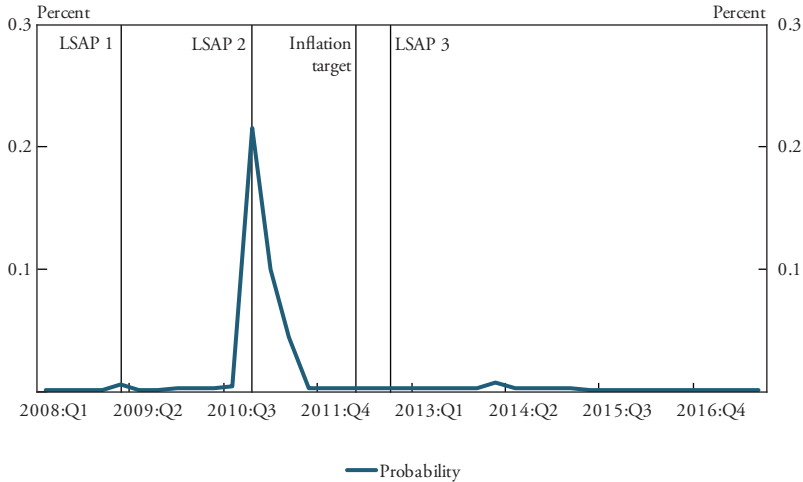
that the risk of inflation expectations surging or plummeting has been significantly reduced.

By combining the level and volatility metrics, we can calculate the probability of any future outcome for inflation expectations. In this way, we can use the probability of inflation falling below a certain threshold—1 percent for the PCE inflation rate or 1.5 percent for our CPI inflation measure—to measure whether inflation expectations have become unanchored.¹⁴ Chart 5 shows that the probability of inflation falling below the CPI threshold was negligible (below 1 percent) for 10-year inflation expectations throughout the past decade. The probability was similarly negligible for two-year inflation expectations much of the past decade—for the rolling sample ending in 2010:Q4, however, the probability of two-year expectations falling below 1.5 percent spiked to 21 percent before declining again to a negligible level by 2011:Q3. Taken together, however, our estimates of the levels and volatilities in the long-run predictive distribution of inflation expectations suggest that the second round of LSAPs was associated with a large reduction in the risk of inflation expectations falling substantially below the FOMC’s target.

Finally, we look at the persistence of inflation expectations as a measure of anchoring. The persistence of a variable in a multivariate

Chart 5

Probability of Two-Year Inflation Expectations Falling below 1.5 Percent in the Long Run



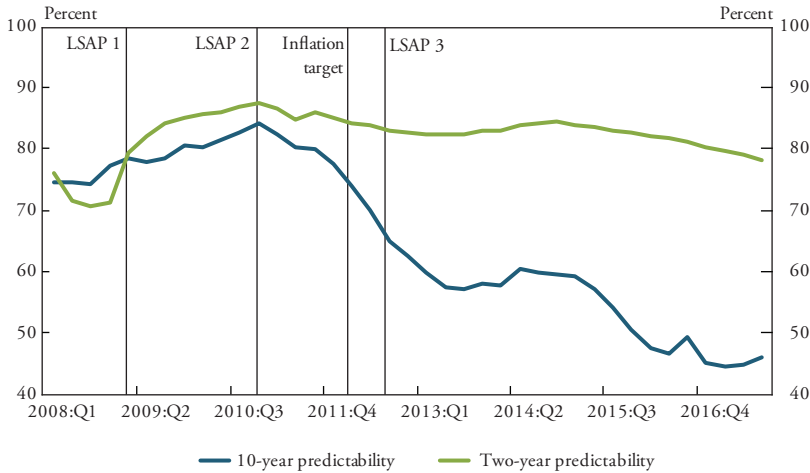
Source: Authors' calculations.

model is often measured by the variable's model-implied predictability (R^2), which is the relative magnitude of predictable variation to total variation.¹⁵ If shock volatility is unchanged, a higher predictability means that a temporary shock can trigger persistent deviations of inflation expectations from their long-run means.

Although the level and volatility of inflation expectations at the two different horizons generally co-moved over our sample, the persistence (or predictability) of two-year and 10-year inflation expectations differed significantly. Chart 6 shows the evolution of this metric for both two-year and 10-year inflation expectations. While the predictability of two-year inflation expectations fluctuated closely around the magnitude that prevailed during the pre-crisis sample period, the predictability of 10-year inflation expectations fell dramatically after 2010:Q4, when the second round of LSAPs began. The downward trend continued after the second round of LSAPs ended in June 2011 and after the adoption of a formal inflation target in 2012. This discrepancy in the predictabilities of 10-year and two-year inflation expectations implies that fluctuations in two-year inflation expectations became less important over time in explaining fluctuations in 10-year inflation

Chart 6

Percentage of Forecastable Variations for Inflation Expectations



Note: “Predictability” represents the percentage of variations in inflation expectations that are forecastable by the VAR model.

Sources: Federal Reserve Bank of Philadelphia and authors’ calculations.

expectations—in other words, the spillovers from short-term to long-term inflation expectations diminished.

The timing of the shifts in the persistence of long-term inflation expectations suggests that the announcement of a formal inflation target as well as multiple rounds of LSAPs contributed to better anchored inflation expectations.¹⁶ Overall, the timing of shifts in the three metrics (level, volatility, and persistence) of the anchoring of inflation expectations suggests that the second round of LSAPs was consequential in reversing the downward drift in inflation expectations. Other policy actions, such as the first round of LSAPs and the adoption of a formal inflation target, were also largely consistent with the timing of shifts in the volatility and persistence metrics toward better anchoring. While the realized value of long-term inflation expectations might have changed little during the recent decade, our time-varying estimates show that the model-implied distribution of inflation expectations has changed significantly at certain times. Our analysis is consistent with the view that the Federal Reserve’s actions, such as LSAPs and the adoption of a formal inflation target, led to better anchored inflation expectations. Furthermore, we do not find any meaningful evidence that the anchoring of inflation expectations in

2017:Q3, the final quarter for our sample, deteriorated relative to the degree of anchoring in the pre-crisis period.

Our results may seem to conflict with Reis (2016), who finds little change in inflation expectations around the announcement of the second round of LSAPs. Reis's analysis uses an event study methodology and inflation swap market data to back out the distribution of inflation expectations. We attribute the difference in our results mostly to the fact that financial markets already anticipated the second round of LSAPs before the November 3, 2010 announcement. Indeed, break-even inflation and other market-based inflation measures of inflation expectations jumped after August 27, 2010, when then-Chair Bernanke strongly suggested the possibility of additional asset purchases.¹⁷

IV. Conclusion

Inflation expectations have become better anchored in the United States during the past decade. We use three different metrics (level, volatility, and persistence) to quantify the degree of anchoring in inflation expectations and find that the timing of shifts in these metrics is associated with the Federal Reserve's unconventional policy actions. Our findings are consistent with the interpretation that the second round of LSAPs, which the Federal Reserve began in November 2010, was significant in preventing long-term inflation expectations from drifting down. In addition, the timing of shifts in the volatility and persistence metrics of inflation expectations is consistent with the interpretation that other rounds of LSAPs and the adoption of a formal inflation target also helped reduce the volatility and persistence of long-term inflation expectations. In general, our results as of 2017:Q3 suggest that inflation expectations have not become less anchored after the financial crisis and Great Recession when compared with their pre-crisis level. In particular, our results suggest the Federal Reserve's policies during the recent decade may have played a role in keeping them that way.

Appendix A

Constructing the Inflation Expectations Curve

The inflation expectations curve describes the expected inflation averaged from the current period until a particular time horizon. If we define $\pi_t(\tau)$ as the inflation expectations from the end of month t to the end of month $t + \tau$, Aruoba (2016) fits the following Nelson-Siegel (1987) yield curve for $\pi_t(\tau)$:

$$\pi_t(\tau) = L_t - \left(\frac{1 - e^{-\lambda\tau}}{\lambda\tau} \right) S_t + \left(\frac{1 - e^{-\lambda\tau}}{\lambda\tau} - e^{-\lambda\tau} \right) C_t, \quad (\text{A-1})$$

where L_t, S_t, C_t are assumed to follow independent autoregressive processes of the third order (AR[3]) and are interpreted as the level, slope, and curvature factor, respectively, given λ .

Aruoba (2016) obtains 59 inflation forecasts, x_t , by combining quarterly, annual, five-year, and 10-year forecasts from the SPF with quarterly and long-range forecasts from BCEI and BCFI. At each point in time, inflation forecasts in survey data can be well approximated by a linear function of various components in the inflation expectations curve, because we can construct the forward inflation expectations curve from $t + \tau$ to $t + \tau + 1$ ($\pi_{t+\tau \rightarrow t+\tau+1}$) by $(t + \tau + 1) \pi_t(t + \tau + 1) - (t + \tau) \pi_t(t + \tau)$. By using information in the forward inflation expectations curve, we can match any inflation forecast at any horizon included in different surveys.

For instance, BCFFs ask participants for their forecasts for four-year-ahead “year-over-year” inflation ($x_t^{4y,1y}$). Since the assumed time unit in the inflation expectations curve is one month, we can calculate the annual forward inflation at each month ($\pi_{t+\tau \rightarrow t+\tau+12}$) from the curve by summing monthly forward inflation forecasts during a year. To match the fact that survey data cover “year-over-year” inflation forecasts, Aruoba (2016) takes the average of annual forward inflation expectations during the 12 months four years from the current year. If survey data are obtained at March of any given year, we can construct the following variable from the inflation expectations curve to match the data:

$$x_t^{4y,1y} = \frac{1}{12} \sum_{s=46}^{57} \pi_{t+s \rightarrow t+s+12} \cdot^{18} \quad (\text{A-2})$$

We can specify similar measurement equations for other survey forecasts, too. For the actual estimation, we add measurement errors that follow mean-zero normal distributions to survey forecasts. The resulting equation is:

$$x_t = Z\alpha_t + \epsilon_t, \epsilon_t \sim N(0, H), \quad (\text{A-3})$$

where $\alpha_t = [L_t S_t C_t L_{t-1} S_{t-1} C_{t-1} L_{t-2} S_{t-2} C_{t-2}]$ and α_t evolves according to

$$(\alpha_t - \mu) = T(\alpha_{t-1} - \mu) + \eta_t, \eta_t \sim N(0, Q). \quad (\text{A-4})$$

Since (A-3) and (A-4) represent a linear and Gaussian state-space model, all the model parameters can be estimated by the maximum likelihood method using the Kalman filter. Once we obtain parameter estimates, we can back out the estimate for α_t and construct the inflation expectations curve at time t using that information.

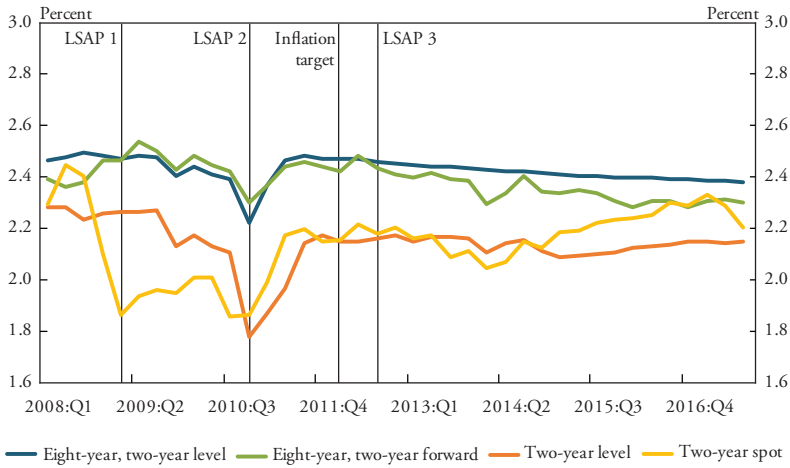
Appendix B

Alternative Measures of Long-Term Inflation Expectations

One potential caveat to our results is that our measure of long-term inflation expectations considers inflation averaged over 10 years, a window sufficiently short for a temporary but moderately persistent shock to influence inflation expectations. In contrast, a forward inflation expectations measure, such as expected inflation eight to 10 years from now, is insulated from a temporary shock, because it is outside a typical business cycle frequency of six to 32 quarters (Burns and Mitchell 1946). To check the robustness of our findings against this alternative measure of long-run inflation expectations, we calculate eight-year, two-year forward inflation ($\pi_{t+8yr\ 2yr}^e$) from the inflation expectations curve in Aruoba (2016). We recompute the three metrics of anchored inflation expectations with eight-year, two-year forward inflation as a proxy for long-term inflation expectations.

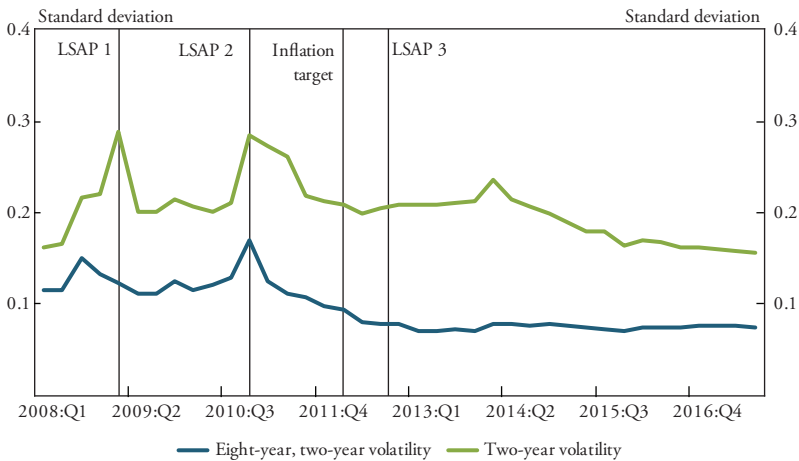
As Charts B-1 through B-3 illustrate, the overall pattern of the time variation in the three metrics is largely consistent with our previous analysis. Specifically, the significant shifts in the three metrics toward better-anchored inflation expectations coincide with the second round of LSAPs. The other rounds of LSAPs and the adoption of a formal inflation target are also associated with shifts in the volatility and predictability metrics toward better-anchored inflation expectations. However, one notable difference is the run-up in the predictability metric of the 10-year inflation expectations near the end of the sample period. Still, the degree of predictability remains lower than its value during the pre-crisis period and does not indicate any material deterioration in the anchoring of inflation expectations.

Chart B-1
Long-Run Average of Forward Inflation Expectations



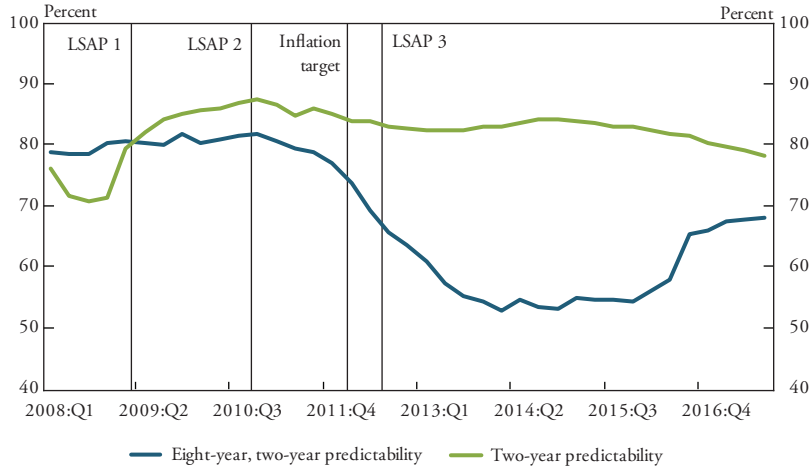
Note: “Level” represents the long-run mean from the VAR model, while “forward” describes the current value of the eight-year, two-year forward inflation expectations.
 Sources: Federal Reserve Bank of Philadelphia and authors’ calculations.

Chart B-2
Long-Run Volatility of Forward Inflation Expectations



Note: “Volatility” represents the long-run standard deviation from the VAR model.
 Sources: Federal Reserve Bank of Philadelphia and authors’ calculations.

Chart B-3
Percentage of Forecastable Variations for Forward Inflation Expectations



Note: “Predictability” represents the percentage of variations in inflation expectations that are forecastable by the VAR model.

Sources: Federal Reserve Bank of Philadelphia and authors’ calculations.

Endnotes

¹Kumar and others (2015) define five statistics to measure the degree of anchoring in inflation expectations based on individual responses to a survey: 1) the average expectation of each individual forecaster, 2) the cross-sectional dispersion in individual forecasts, 3) uncertainty in each individual's forecast, 4) the magnitude of forecast revision, and 5) the predictability of long-run expectations using short-run expectations. Although we do not consider the cross-sectional dispersion of forecasts because we focus on median forecasts, the four other statistics are strongly connected with our level (1), volatility (3), and persistence measures (4, 5).

²In fact, Andreasen and Christensen (2017) show that breakeven inflation measures are more correlated with survey-based measures of inflation expectations after adjusting for liquidity-related factors.

³Kozicki and Tinsley (2012) and Chernov and Mueller (2012) construct the term structure of inflation expectations using alternative methods. We choose to use Aruoba (2016)'s dataset because Kozicki and Tinsley (2012) rely on only one survey dataset (the Livingston Survey) and while the no-arbitrage term structure model used in Chernov and Mueller (2012) is theoretically appealing, it is not robust to the misspecification of the asset pricing model used in the paper. Aruoba (2016)'s data on inflation expectations are available on the Federal Reserve Bank of Philadelphia's website (<https://www.philadelphiafed.org/research-and-data/real-time-center/atsix>).

⁴The three variables are called "level," "slope," and "curvature," because empirical proxies for these factors are closely related to the average across different horizons, the difference between the long end of the curve and the short end of the curve, and the change in the slope of the curve, respectively. Further details on the construction of the inflation expectations curve are provided in Appendix A.

⁵Since the inflation expectations curve fits only median forecasts, it ignores the cross-sectional dispersion of inflation forecasts among survey participants, which may reduce the uncertainty surrounding inflation expectations. Williams (2003) attributes most of the cross-sectional dispersion in forecasts to the fact that each participant may use a different model that the available data cannot convincingly reject. Although this model uncertainty may be important, it is beyond the scope of our article.

⁶Policymakers may monitor spillover risk by looking at the evolution of forward inflation expectations above certain horizons instead of long-horizon inflation expectations. Since the forward inflation measure strips away short-term fluctuations, this measure may provide a cleaner proxy for anchored long-term inflation expectations.

⁷While Japan again experienced persistent deflation from 2009 to 2012 after the global financial crisis, long-term inflation expectations remained stable around 1 percent during this period, perhaps reflecting unconventional policies

adopted by major central banks around the world. However, the international repercussions of the Federal Reserve's policies are beyond the scope of this article.

⁸The construction of this measure relies on the assumption that the historical relationship between the short-term interest rate and long-term rates that prevailed before the federal funds rate reached its effective lower bound would be maintained once the effective lower bound became a binding constraint.

⁹This ordering follows Clark and Davig (2011), who identify a monetary policy shock from its lagged effect on the real economy and inflation. However, in this article, we do not focus on the identification of a structural shock, and the ordering does not matter much in our discussion of changes in metrics related to well-anchored inflation expectations.

¹⁰The VAR contains only one lag of the five variables. Longer lags would introduce too many additional parameters, since we use only 40 quarters of data in the rolling-sample estimation. We also estimate a model with two lags and find that the changes in our metrics of anchored expectations are essentially the same.

¹¹Whether the linear and Gaussian VAR(1) model can adequately capture the probabilities of tail events is unclear. One way to address this concern is to introduce nonlinearities explicitly using a time-varying parameter VAR(1) model in which VAR coefficients are assumed to follow random walk processes. Our rolling sample estimation approximates a time-varying parameter VAR(1) model in a simple way by allowing changes in the stationary distribution of the model each period. In fact, our volatility estimate of 10-year inflation expectations at the first rolling sample ending in 2008:Q4 is consistent with the volatility estimate of 10-year inflation expectations in Clark and Davig (2011), who estimate a time-varying parameter VAR model.

¹²Technically, any normal distribution is fully characterized by the mean and the variance. In our case, the long-run mean of y_t is $(I_5 - A_{1,t})^{-1} A_{0,t}$, and the long-run variance is $\sum_{j=0}^{\infty} A_{1,t}^j \sum_t \sum_t' A_{1,t}'$.

¹³Our interpretation linking the timing of the change in the volatility metric with LSAPs is also consistent with the month-to-month shift in the inflation expectations curve around LSAP events in Aruoba (2016).

¹⁴The comparable upside risk that inflation expectations would cross 3.5 percent was negligible throughout the past decade for both 10-year and two-year inflation expectations. Therefore, we omit a detailed discussion of the upside risk.

¹⁵Of course, if inflation expectations were constant without any variation, this metric would not be well defined, because the denominator (total variation) would be zero. However, constant inflation expectations with no future variation would be a very strong assumption. More realistically, we can assume the total predictable variation is zero under well-anchored inflation expectations but with non-zero chances for them to change in the future due to unanticipated shocks. In this case, the predictability is zero, in line with our definition of well-anchored inflation expectations.

¹⁶Our finding about the timing of the shift in the predictability metric after the adoption of a formal inflation target is consistent with Bundick and Smith (2018), who find that the sensitivity of long-horizon-forward breakeven inflation to surprise news in realized inflation declined after the adoption of a formal inflation target. In both cases, forecastable variations in the long-run inflation expectations declined. Our findings are also robust to the use of long-horizon-forward inflation instead of 10-year inflation expectations, as shown in Appendix B.

¹⁷This interpretation is consistent with Chart 6 of Reis (2016, p. 447).

¹⁸This derivation relies on the approximation using continuous compounding and geometric averaging as discussed in the appendix of Aruoba (2016).

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