HOW DID QUANTITATIVE EASING REALLY WORK?
A New Methodology for Measuring the Fed’s Impact on Financial Markets

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ABSTRACT

This paper introduces a new methodology for measuring the impact of unconventional policies. Specifically, the paper examines how such policies reshaped market perceptions of how the Fed would behave in the future—not merely the expected path for policy rates, but how the central bank would adjust that path in response to different combinations of future inflation and growth. In short, it studies how quantitative easing affected investor beliefs about the future policy reaction function. The paper (1) proposes a novel model of market expectations for the central bank’s future policy reaction function based on the Taylor Rule; (2) shows that empirical estimates of the model exhibit structural breaks that coincide with innovations in unconventional policies; and (3) finds that such policy innovations were associated with regime shifts in the behavior of 10-year U.S. Treasury yields, as well as unusual performance in risk assets such as credit spreads and equities. These findings provide evidence that a key causal channel for unconventional policies was via their impact on market expectations for the Fed’s future policy reaction function. These shifts in expectations, in turn, appear to have had larger, more persistent, and more pervasive effects across financial markets than found in previous studies.

Monetary economics today is obsessed with balance sheets—and rightfully so. More than ten years after the global financial crisis, policy interest rates remain exceptionally low in much of the industrialized world. With limited room to cut rates, global central banks like the European Central Bank (ECB) are already responding to economic weakness with the renewed deployment of asset purchases and other balance sheet tools. That fact alone makes it important to have a clear understanding of how such policies have worked in the past, the scope of their effects, and the mechanisms through which they have operated.

Most of the debate about quantitative easing (QE) in the United States has focused on the impact of various Federal Reserve asset purchase programs on longer-term interest rates, particularly the 10-year U.S. Treasury yield. A succession of studies beginning with the pioneering work of Gagnon et. al. (2011) and Krishnamurthy and Vissing-Jorgensen (2011) found that Fed asset purchase programs significantly reduced 10-year Treasury yields. A survey by Borio and Zabai (2016) finds an average estimated reduction of roughly 100 basis points.

But skeptics continue to challenge the effectiveness of asset purchases. Recent work by Greenlaw et. al. (2018) argues that after accounting for factors such as post-announcement reversion and reactions to data releases, Fed purchases had a modest effect on 10-year yields.
Even surveys finding that earlier rounds of quantitative easing like QE1 were consequential assess evidence for the impact of later rounds like QE3 to be considerably weaker (Yu 2016).

There are several gaps in the existing literature.

First, evaluating the effectiveness of quantitative easing by focusing solely on realized bond yields is inherently flawed. The conventional narrative for QE’s transmission mechanism to the broader economy focuses on the causal chain whereby central bank purchases boost bond prices, thus stimulating investment and consumption via the intermediate channel of lower bond yields. But this ignores the powerful expectations channel through which central bank policy operates. If central bank actions positively shock expectations for future economic prospects, that may directly shift the willingness of businesses and households to invest and consume. Success in breaking deflationary expectations can catalyze increased consumption and investment.

But such a shift toward reflationary expectations—higher growth, higher inflation—also tends to increase bond yields! In theory, therefore, the impact of “successful” central bank balance sheet policy on realized risk-free yields is ambiguous. At minimum, any central bank success in generating reflationary expectations would mitigate observed downward effects on yields, understate the full impact of QE policies, and help account for why bond yields increased during some implementation periods cited by QE skeptics.

Second, events studies are not a realistic model for how markets assimilate information. Event studies focus only on the impact on asset prices during narrowly defined periods. This is done in order to filter out drivers of asset price changes other than the phenomenon under study. Unfortunately, this reasonable methodological choice poorly represents how markets actually incorporate information before and after key events. Not only do investors seek to anticipate potential policy actions in advance, they also digest the full consequences of announced policy actions for an extended period after the fact.

Moreover, sustained moves in markets reflect allocation decisions by large pools of capital, not traders reacting to news on the fly. These pools include pension funds, endowments, sovereign wealth funds, institutional asset managers, and others. The investment committees of such organizations discuss, debate, and unspool the full implications of central bank actions on an ongoing basis—not just on days when the Fed speaks—and in ways that have interaction effects with incoming information. The narratives constructed by such actors guide portfolio strategy and thereby shape the trajectory of prices in asset markets far beyond initial policy announcements.

Finally, the narrow focus on the impact of QE on risk-free yields in most of the literature neglects the information and interpretive value that can be obtained examining price moves in a multi-asset context. While a single asset class reflects one dimension of what is happening in the economy and financial markets overall, that signal is incomplete and sometimes ambiguous (as discussed above with respect to risk-free yields against the backdrop of the expectations channel of QE). In the real world, information from one asset class is germane to interpreting movements in another. A broader constellation of asset prices produces a more data-rich mosaic from which to distill conclusions, cross-check results, and synthesize cohesive interpretations.
This paper proposes a new methodology for measuring the impact of central bank balance sheet policies on financial markets, applying the methodology to Federal Reserve policies between 2010 and 2018. The approach overcomes the above limitations in several ways:

- First, this study explicitly models how changes in Fed balance sheet policy shifted market expectations for the Fed’s future policy reaction function. It achieves this by using a Taylor Rule-based framework to model the market’s future expected policy rate as a function of the market’s expectations for future inflation and output. Controlling for these variables makes it possible to identify periods when the market perceives there to be outright shifts in the central bank’s future policy reaction function—that is, when the market expects that the central bank will select a different policy rate in the future than it would have previously given the identical expectations for inflation and output.

It is useful to illustrate this concept with an example. Assume that the month before a Federal Open Market Committee (FOMC) meeting, the market expects that the policy rate three years in the future will be 2 percent, expected inflation will be 1½ percent, and the expected output gap will be zero. The FOMC then meets, leaving the policy rate unchanged but taking other actions. In the month after the FOMC meeting, the market shifts its expected policy rate to 1½ percent while the market’s expectation for inflation and the output gap remain unchanged at 1½ percent and zero, respectively. This indicates that the market anticipates that there has been an accommodative shift in the central bank’s future policy reaction function—i.e., the market expects the Fed to choose a policy rate that is ¼ percentage points lower than before, despite identical inflation and output gap expectations.

- Second, the approach introduced here allows for a more flexible and realistic model for how markets assimilate information. By controlling for key variables that help explain changes in yields over time—expectations about future inflation and output dynamics—the reaction function model escapes the constraints of event studies that artificially limit impact analysis to a few narrow windows. We can thus examine whether policy innovations altered the trajectory of asset prices in a sustained manner, not just for a few hours or days.

Specifically, this study tests whether Fed balance sheet policies were associated with regime shifts in market perceptions of the Fed’s future policy reaction function. Using econometric techniques pioneered in the late 1990s for identifying multiple structural changes, the analysis “lets the data speak for itself” without imposing prior policy knowledge. This enables a comparison of how structural breaks in market expectations—identified through a data-only/policy-blind technique—correspond to the timing of actual Fed policy innovations.

- Third, the approach in this paper harnesses insights available from analyzing price moves across asset classes. To provide the controls required to apply the Taylor Rule to the market-expected future policy reaction function, data on expectations for inflation and output are extracted from other traded markets—specifically, the inflation swap and credit spread markets. Using cross-market data in this way allows us to disentangle changes in market-expected future rate trajectory that come from changes in the expected macroeconomic outlook versus outright shifts in market expectations about the central bank’s policy reaction function.

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1 As we shall see, using multi-asset market prices makes it possible to distinguish between “Odyssean” and “Delphic” interpretations of how central bank announcements may affect bond yields described by Campbell et. al. (2012).
The paper finds evidence of the far-reaching impact that Fed policies had on financial markets. It estimates that the innovations in Fed unconventional policies shifted market expectations for the Fed’s future policy reaction function down by as much as 225 basis points. The cumulative impact of the shifts associated with QE2, Forward Guidance and Operation Twist, and QE3 in turn pushed down 10-year Treasury yields by as much as 150 basis points—significantly more than found in previous studies. In addition, changes in unconventional policies are found to be associated with unusual performance in risk markets, another critical channel through which Fed policy shaped financial conditions and affected the broader economy. Half of the 10 largest quarterly rallies and sell-offs in equity markets between 2010 and 2018 began within one week of a major balance sheet announcement. Three of the five largest sell-offs in credit markets during the same period started within one week of the ends of QE1, QE2, and QE3. The probability that these events would coincide by chance is vanishingly low.

The paper is organized as follows: Section 1 presents an abbreviated survey of the extensive literature on the effectiveness of QE in the United States, focusing on the research most relevant to the present study. Section 2 lays out the analytical framework, describing how the Taylor Rule framework can be applied to the market’s expectation of the central bank’s future policy reaction function. Section 3 details the empirical methodology and reports the results of its application to the United States during the period of active Fed balance sheet policy between 2010 and 2018. Section 4 extends the methodology to estimate the impact of Fed policies on 10-year Treasury yields. Section 5 describes and applies a method for examining the impact of balance sheet policies on risk markets. Section 6 concludes by summarizing the empirical findings, discussing normative implications, and identifying possibilities for future research.

SECTION 1 – KEY LITERATURE

As there are several excellent recent surveys on unconventional policies (Borio and Zabai 2016; Gagnon 2016; Kutter 2018), this section will briefly summarize the findings and methodological issues that are most relevant to situating the empirical work presented in the sections that follow.

The dominant method for measuring the impact of unconventional policies has been the event study, in which the researchers identify key policy announcements and examine the proximate changes in asset prices (especially the 10-year U.S. Treasury yield) in defined windows around those announcements. The windows can range from a few hours to a few days. The assumption is that proximate price moves isolate the impact of specified policies. Gagnon et. al. (2011) employed this technique in the first influential study of quantitative easing, identifying eight key policy announcements associated with QE1 and calculating that the cumulative impact of those announcements lowered the 10-year U.S. Treasury yield by 91 basis points.

Event studies are often combined with techniques that seek to identify the specific channels through which unconventional policies operate. One approach has been to examine the event impact on a variety of asset prices proxying different bond risk factors such as liquidity, safety, default, and prepayment (Krishnamurthy and Vissing-Jorgensen 2011). Another is to use models of the term structure of interest rates—especially dynamic term structure models—to decompose changes in yields into a forward rate trajectory component and a term premium
component. Downward shifts in the forward rate trajectory at key event dates are interpreted as evidence of a “signaling” channel in which unconventional policies generated expectations of a lower future rate path (Christensen and Rudebusch 2012; Bauer and Rudebusch 2014).

Changes in the term premium at key event dates are consistent with multiple alternative interpretations. One would be that unconventional Fed policies reduced the perceived uncertainty around the future rate path, thus reducing the required compensation for interest rate volatility. Another would be that investors anticipated that the implementation of asset purchases would—by removing duration risk from private portfolios and creating scarcity in specific securities—change market-clearing term premiums in segmented markets characterized by heterogenous investor preferences. These preferred habitats and market frictions create a “portfolio rebalancing” channel in which the Fed can affect asset prices by changing the volume and type of securities in private hands.

In general, studies seeking to pin down this portfolio rebalancing channel in action are not event studies. Rather, they seek to demonstrate the causal link between Fed purchases and market prices by showing that the quantity of bonds held by private investors is a statistically significant explanatory variable in models of bond yields and term premiums—ergo, QE policies that change the quantity of bonds outstanding affect market-clearing yields. Variations include using macro variables to model benchmark yields (Chadha, Turner, and Zampolli 2013) as well as granular studies examining individual securities (D’Amico et. al. 2012).

In terms of bottom-line conclusions, the bulk of studies in all of these categories have found that quantitative easing policies lowered bond yields. QE1 has garnered the most attention and strongest evidence, with the literature typically finding smaller impacts for subsequent balance sheet policies (QE2, Operation Twist, and QE3). For example, the survey of Borio and Zabai (2016) suggests an impact of QE1 in the neighborhood of 100 basis points versus around 30 basis points for QE2 and Operation Twist.

A notable dissent comes from recent work by Greenlaw et. al. (2018), who have disputed findings of a large effect for QE1 by arguing that previous event studies do not capture a sufficiently robust set of events. By including more days with Fed policy news—and by using newswire reports to identify an “event” for every day with a yield change greater than one standard deviation from average—Greenlaw and colleagues find that Fed policy was less important than macro developments in explaining yield changes over key periods.

The introduction previewed some key gaps in this existing literature:

First, focusing on how much yields change as the sole metric of the “success” or “impact” of quantitative easing is flawed. To the extent that Fed policies succeed in boosting investor expectations for future inflation and growth, that will tend to increase bond yields. A proper measure of the effectiveness of balance sheet policies needs to control for such effects.

Second, as readily acknowledged by their authors, event studies are constrained by key supporting assumptions: first, that non-policy factors were (on average) not material during the selected windows; and, second, that the impact of unconventional policies either before or after the selected windows were also (on average) not material. The second assumption is particularly
questionable, since financial market participants both seek to anticipate policy innovations before they occur and to elaborate their full implications after the fact.

Finally, existing studies generally have not fully tapped information from multiple asset markets to shed light on some identification problems attendant to the analysis of risk-free yields. There are a few studies that seek to measure the impact of QE on risk markets. For example, Swanson (2015) seeks to isolate the forward guidance and asset purchase elements of Fed policy announcements via principal components analysis, and then link them to moves in equity and currency markets. Mamaysky (2018) uses an event study methodology with flexible windows to identify periods of unusual market performance in equity and equity volatility markets that may be attributable to the lagged impacts of quantitative easing. Such studies do not, however, seek to use cross-market price movements in the other analytical direction: namely, to shed light on the drivers of changes in forward rates or bond yields.

The methodology proposed in this paper seeks to fill these gaps by proposing a new framework for measuring the impact of unconventional policies that focuses on the market’s expectations for the central bank’s future policy reaction function. Attention to the future interest rate path is nothing new—indeed that is the focus of the “signaling” channel explored by Bauer and Rudebusch (2014), and concepts such as the “Odyssean” commitment to low rates described by Campbell et. al. (2012). But previous studies have generally conceptualized this as a commitment to some particular rate path, whereby an accommodative signal from the Fed “pushes out” some pre-set hiking/normalization of interest rates further off into the future.

To my knowledge, there are no existing studies that seek to model market expectations of the future policy reaction function—that is, how the market thinks the central bank will set rates in relation to future inflation and output dynamics.

This absence is remarkable given that the dominant framework for analyzing monetary policy for the last three decades has been the policy reaction function known as the Taylor Rule. Taylor (1993) showed that Federal Reserve policy in the Greenspan era could be effectively represented by calculating the central bank’s selected policy rate as a function of the deviation of inflation from target and the output gap. Subsequent studies (Judd and Rudebusch 1998; Clarida, Gali, and Gertler 1998, 2000; Taylor 1999) used the framework of Taylor’s original work to identify distinct regimes of monetary policy by demonstrating that there were statistically significant changes in the coefficient values for the estimated Taylor Rule for different periods and countries. Later authors went even further. Rather than estimating Taylor Rules for periods pre-identified by the scholar, Duffy and Engle-Warnick (2006) applied new econometric methods for detecting multiple structural breaks in a time series (Bai and Perron 1998, 2003) to identify regime shifts in the Taylor Rule coefficients based solely on the statistical properties of the data.

This study builds upon this diverse literature, for the first time extending the techniques used to analyze actual monetary policy to market expectations about future monetary policy. Where previous scholars found structural breaks in actual Taylor Rule coefficients coinciding with events like changes in the Fed Chair, this study finds structural breaks in the market’s expected Taylor Rule coefficients coinciding with innovations in balance sheet policies. This suggests a powerful vector for the effect of unconventional policies was via their impact on market perceptions of the Fed’s future policy reaction function.
SECTION 2 – ANALYTICAL FRAMEWORK

Revisiting the Taylor Rule

Taylor (1993) has been the foundational framework for analyzing monetary policy for the last quarter century. The Taylor Rule explains the central bank’s policy rate as a function of inflation and the output gap, defined as the deviation of actual GDP from potential GDP. There are alternative ways of specifying the Taylor Rule, but one such specification is:

\[ \text{Nominal Policy Rate} = \alpha + \beta (\text{Inflation}) + \gamma (\text{Output Gap}) \]

where \( \beta \) reflects sensitivity to changes in inflation and \( \gamma \) reflects sensitivity to changes in the output gap. In this specification, \( \alpha \) is a variable that scales the central bank’s implicit nominal anchoring rate—defined as the nominal policy rate that would be selected by the central bank when inflation is at target and output gap is zero. The implicit nominal anchoring rate is equal to \( \alpha + \beta (\text{Inflation Target}) \). For example, if \( \alpha = 0 \), \( \beta = 1.5 \), \( \gamma = 0.5 \), and the inflation target is 2 percent, then central bank would be acting upon an implicit nominal anchoring rate = 0 + 1.5(2) + 0.5(0) = 3 percent.\(^2\)

The Taylor Rule can be depicted as a three-dimensional policy reaction surface, where the nominal policy rate (z-axis) is a function of the inflation rate (x-axis) and output gap (y-axis). For example, using the function defined above, if inflation were 1.5 percent and the output gap were −2 percent (below potential), then the nominal policy rate could be located at 1.25 percent on the policy reaction surface, as shown in FIGURE 1.

Note that any regime shift in the central bank’s overall policy stance would be reflected in changes in the parameter \( \alpha \) specifically, since \( \alpha \) scales the selected policy rate at every

\(^2\) In the long-run steady state equilibrium, the implicit nominal anchoring rate should be equal to the neutral nominal interest rate. In the short run, however, the central bank might opt to deviate from this, centering its policy around an implicit nominal anchoring rate that is either higher (more restrictive) or lower (more accommodative) than the neutral rate.
combination of inflation and the output gap. If the value of $\alpha$ increases, the selected policy rate would be higher at every given combination of inflation and the output gap—reflecting a more restrictive (hawkish) shift in policy. If the value of $\alpha$ decreases, the selected policy rate would be lower at every combination of inflation and the output gap—reflecting a more accommodative (dovish) shift in policy. Figure 2 illustrates these regime shifts in terms of the three-dimensional policy reaction surface. Restrictive shifts in policy associated with an increase in $\alpha$ move the surface up, while accommodative shifts associated with a decrease in $\alpha$ move the surface down.\(^3\)

We can also visualize this in fewer dimensions, focusing on the central bank’s reaction to changes in inflation alone. By holding the output gap constant (e.g., at $-2$ percent), we can take a vertical slice of the policy reaction surface per Figure 3 to show a policy reaction line depicting the central bank’s selected policy rate at different inflation rates. Restrictive and accommodative changes in the policy stance then appear as shifts up and down, respectively, of the policy reaction line. Figure 4 illustrates this, showing restrictive and accommodative shifts applied to the previous scenario. The Taylor policy rate—which is initially 1.25 percent at 1.5 percent inflation and $-2$ percent output gap—shifts to 2.25 percent in the restrictive regime and 0.25 percent in the accommodative regime when inflation and the output gap values are unchanged.

**Identifying the Market’s Expectation of the Future Policy Reaction Function**

The key contribution of this paper is to apply this Taylor Rule framework to measure the market’s expectations about the central bank’s future policy reaction function. By combining

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\(^3\) In this specification, the observed value of $\alpha$ could change suddenly for three reasons. For instance, a decline in $\alpha$ could reflect: (1) a decrease in the implicit real anchoring rate targeted by the central bank relative to the neutral real interest rate; (2) an increase in the central bank’s inflation target; and (3) a decrease in the neutral real interest rate assumed by the central bank. Decreases in $\alpha$ for the first two reasons are hallmarks of an accommodative stance in that they imply greater central bank comfort with higher inflation and faster GDP growth. The third reason is accommodative in a diagnostic sense in that it reflects an updated central bank view that the economy can run at lower interest rates without generating inflation. Note also that if outside observers like financial markets do not know when the central bank revises its internal estimates of potential GDP, a sudden increase in the central bank’s estimate of potential GDP that makes the output gap more negative (and thus further away from generating inflation) would also produce an apparent decline in $\alpha$ to outside observers that would appear as an accommodative shift.
price data on market instruments across several asset classes, we can identify how the market expected future policy rates to be related to future inflation and output at various points in time. This sub-section describes the sources for this data.

1. **Expected Future Policy Rates**

Market expectations for future U.S. policy rates are embedded in Eurodollar futures contracts. A Eurodollar future enables a party to “lock in” a short-term U.S. dollar interest rate for a particular three-month period in the future, either as a borrower or lender.4

One of the most widely traded futures contracts in the world, Eurodollar futures are not only a preeminent hedging vehicle, but are also the main instrument used by large asset managers for implementing directional (speculative) views on future short-term U.S. dollar rates. Thus, the prevailing market rate for a Eurodollar future of a particular maturity date reflects the average (market-clearing) expectation for what short-term U.S. dollar rates be on that date. Eurodollar futures are a superior proxy for future U.S. short-term rates than Fed Funds futures, because they are much more widely traded, much more liquid, and are available in considerably longer tenors.5

In this study, we will focus on the 12th Eurodollar future (ED12) which proxies the market’s expectation for what the Fed policy rate will be three years (12 quarters) in the future.6

2. **Inflation Expectations**

Information about average market expectations for inflation are embedded in inflation swaps, an over-the-counter derivative used both to hedge and to implement speculative trading views on future inflation. Inflation swaps enable a party to “lock in” a prediction on inflation to a particular date, with one side of the transaction profiting if actual inflation is above that

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4 The terminal value of a particular Eurodollar futures contract is a function of the difference between the rate agreed when the contract was first created (original traded price) versus the actual fixing value of the 3-month U.S. Dollar London Interbank Offer Rate (LIBOR) at the chosen maturity date. The buyer of a Eurodollar future profits when the actual LIBOR fix is lower than the traded price, and a seller profits when the fix is higher than the traded price. If the LIBOR matches the traded price, then the value of the contract at settlement is zero.

5 The most liquid Fed Funds futures are 12 months or less in maturity, with the longest generic contract with historical pricing data on Bloomberg is just over two years (25 months) and not liquid. In contrast, Eurodollar futures are highly liquid for the first three years (known as the white, red, and green packs), with liquidity diminishing in the fourth and fifth years (blue and gold packs).

6 Because LIBOR is an offshore U.S. dollar rate with 3-month maturity, in contrast to the onshore, overnight Fed Funds rate, it typically trades at a spread (or “basis”) to the Fed Funds rate. During the financial crisis in 2008-9, the basis increased to more than 300 basis points, reflecting extreme illiquidity in offshore funding markets and concerns about counterparty insolvency. As stability was restored to financial markets, this spread largely normalized. This was also the case in the futures market, as measured by the basis between Eurodollar and Fed Funds futures of matched tenor. For example, during the period of this study (2010-2018), the basis between 2-year forward Eurodollar and Fed Funds futures generally fluctuated between 25 to 40 basis points. The only significant exception was in late 2011, when shortages of offshore dollar liquidity connected with concerns about the Eurozone sovereign crisis pushed the basis as high as 60 basis points, before stabilizing following the Federal Reserve’s November 28, 2011 decision to extend its U.S. dollar swap lines with the European Central Bank. Bottom line: the basis between Eurodollar futures and Fed Funds futures between 2010 and 2018 was sufficiently stable such that Eurodollar futures can be used as an accurate proxy for market expectations of future Fed policy.
prediction and other side profiting if actual inflation is below that prediction. Thus, the prevailing inflation swap rate reflects the market-clearing balance of views on expected average inflation for a given future period.

Historical prices for inflation swaps are highly correlated with “breakeven inflation” calculated from the difference between the nominal yields on regular Treasury bonds and the real yields of Treasury Inflation-Protected Securities (TIPS) of comparable maturities. However, inflation swaps are a more flexible measure because they are available at constant maturities, versus TIPS breakevens which are only available for maturities at which TIPS have been issued.

Historical data on the market prices of inflation swaps of constant maturities (1yr, 2y, 3yr, etc.) are available on Bloomberg. Expected inflation for a specific future period can be calculated (“bootstrapped”) from this constant-maturity inflation swap curve. In this study, we calculate the trailing (12-month) inflation rate that the market expects to prevail three years in the future using the 3yr and 2yr constant-maturity inflation swap rates.

3. Future Output Gap

In the absence of a derivative for the output gap, a compelling proxy for market expectations of future GDP growth can be constructed from credit spreads, defined as the difference in yield between corporate bonds with credit risk and Treasury bonds without credit risk.

Under normal market conditions, that yield difference between corporate bonds and Treasury bonds is primarily compensation for the risk of default on corporate bonds. Of particular interest is the average option-adjusted spread (OAS) on bonds issued by BBB-rated U.S. corporate borrowers. BBB-rated issuance constitutes the largest proportion of the U.S. credit market, accounting for approximately 40 percent of outstanding issuance.

Because the ability of companies to service debt is tightly linked to corporate profit growth, credit spreads serve as a proxy for market expectations for future GDP growth. The probability of default is strongly correlated with the business cycle, as shown on Figure 5. Because BBB-rated companies are near the borderline between investment-grade and high-yield ratings, they are particularly sensitive to changes in the economic outlook. These facts help explain why BBB credit spreads are empirically correlated with the output gap realized four quarters in the future, as depicted in Figure 6.

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7 In an inflation swap, the buyer of inflation effectively receives floating payments equal to the realized Consumer Price Index (CPI) and pays fixed payments equal to the traded price of the swap. The value of the contract reflects the difference between these two payment streams, and which are in practice settled in a single payment at maturity. A buyer of inflation profits from higher realized CPI, while a seller profits from lower realized CPI.
8 The difference between nominal and real yields—known as the TIPS breakeven inflation rate—represents the average rate of inflation that would make the returns on nominal and inflation-protected bonds equivalent over the time period corresponding to the maturity of those securities.
9 A credit spread is the difference in yield between a bond with credit risk (such as a bond issued by a company) and a risk-free bond (U.S. Treasury). It is typically expressed in basis points (hundredths of a percentage point). “Option-adjusted” spreads account for the value of options embedded the bond contract, typically a call option that gives the issuer the right to pre-pay the obligation at par before the maturity date.
In this study, we use the Merrill Lynch BBB Option-Adjusted Spreads Index as the data source for credit spreads, which is available through the St. Louis FRED database.

A Glimpse of the Framework in Action: QE2

To motivate the discussion to come and build intuition helpful for interpreting the model presented in the next section, let’s look at an example that brings these market data together. Each dot in Figure 7 represents a single day in the market over a few months in 2010: specifically, the combination of values extracted from Eurodollar futures and inflation swaps representing the expected future short-term interest rate (vertical axis) and the expected future inflation rate (horizontal axis). The blue dots represent days during summer 2010, and the orange dots represent days from fall 2010.

Each set of points independently appears to trace out an implicit relationship, resembling the policy reaction lines discussed previously: as the market expects lower inflation in the future, it also expects lower future policy rates. And there is an interesting change in the lines between the two periods. The move from the blue line to the orange line resembles the signature of an accommodative policy shift discussed previously and illustrated conceptually in Figure 4: at the same values for expected inflation, the expected policy rate is lower for the orange points than for the blue points.
The timing is intriguing. On August 27, 2010, Federal Reserve Chairman Bernanke gave a famous speech at Jackson Hole previewing the FOMC’s readiness to engage in a second major round of asset purchases that came to be known as QE2. Can the Jackson Hole speech—and the following September 21, 2010, FOMC statement declaring the Fed was “prepared to provide additional accommodation”—explain the apparent shift in the market’s expectation of the Fed’s future policy reaction function illustrated in Figure 7? If so, was it because these events revealed new information about the weakness in the economy (“Delphic” effect) or signaled something new about the Fed’s commitment to a different future policy path (“Odyssean” effect)?

To answer these questions, we need to incorporate that additional piece of data we introduced—namely credit spreads, our proxy for market expectations of the future output gap.

It turns out that by consulting the information implicit in credit spreads, we can rule out the “Delphic” interpretation of Bernanke’s QE2 speech: credit spreads decreased between the summer and fall of 2010, indicating that market participants’ expectations for economic prospects improved over this period. Thus, the downward shift in the policy reaction line in Figure 7 cannot be explained by deteriorating market expectations of the growth outlook.

This is highly suggestive that Bernanke’s Jackson Hole speech may have shifted the market’s expectation of the Federal Reserve’s future policy reaction function. In order to move beyond “suggestive” to a stronger conclusion requires that we model these dynamics systematically. That is the focus of the next section.

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10 See Campbell et. al. (2012).
SECTION 3 – ESTIMATING THE MARKET-EXPECTED POLICY REACTION FUNCTION

The model introduced in this paper describes the market-expected future policy rate as a function of future expected inflation and credit spreads (proxy for the future output gap):

\[ \text{Rate3yr} = \alpha + \beta (\text{Inf3yr}) + \gamma (\text{OAS}) \]

where \( \text{Rate3yr} \) is the short-term rate three years forward (12th Eurodollar futures contract), \( \text{Inf3yr} \) is expected trailing inflation three years forward (bootstrapped from the 3yr and 2yr constant-maturity inflation swaps), and \( \text{OAS} \) is the credit spread (Merrill Lynch BBB Option-Adjusted Spread Index). Historical graphs for all these variables are in the Appendix (FIGURES A1-A3).\(^{11}\)

Pre-Crisis Model

The model is first estimated for the pre-crisis period using daily data from January 2003 through January 2007.\(^{12}\) The regression results are reported in Column (0) of TABLE 1.

The model has significant explanatory power \((R^2 = 0.42)\). Coefficients have the expected signs, positive (+) for expected inflation and negative (−) for OAS. The inflation coefficient is statistically significant at the 0.05 level. The coefficients also have reasonable magnitudes. The inflation coefficient \((1.04)\) is greater than one, indicating the expected increases in the real rate when inflation rises, though the magnitude is lower than many conventionally recommended values. The coefficient on OAS is more difficult to interpret directly, but we can put it into Taylor Rule “language” using the empirical relationship between credit spreads and the output gap depicted in FIGURE 6. That figure shows that a 100bp OAS increase is correlated with \(-2.07\) percentage point decline in the output gap four quarters in the future. Thus a \(-0.11\) coefficient on the OAS variable implies \(-0.11 \times -2.07 = +0.23\) coefficient on the output gap, which is also of reasonable magnitude though not statistically significant.

It is worth emphasizing again that these coefficients represent the model’s estimation of the market’s expectation for the Fed’s reaction function, which may or may not reflect the Fed’s actual reaction function during this time period. This is important to bear in mind for all the analysis in this section. The object of study is not the Fed’s actual reaction function, but the market’s expectation for what the Fed’s reaction function will be in the future. It is those market expectations of the Fed’s future reaction function that underlie investor decisions about portfolio construction and capital allocation.

\(^{11}\) Continuous historical pricing data for inflation swaps on Bloomberg is only available beginning in November 2004. Therefore, missing 3yr forward trailing inflation for January 2003 through November 2004 is imputed from available data on 5yr U.S. Treasury breakeven inflation for that period using a simple regression model.

\(^{12}\) Two seminal events mark February 2007 as the “beginning” of the subprime crisis. During that month, HSBC became the first major global bank to announce significant write-downs from losses on subprime securities, and Freddie Mac announced it would stop purchasing large categories of subprime securities. The latter is the first event logged in the chronology of the financial crisis compiled by the Federal Reserve Bank of St. Louis (see https://fraser.stlouisfed.org/timeline/financial-crisis).
TABLE 1. MARKET-EXPECTED FUTURE POLICY REACTION FUNCTION – MODEL ESTIMATION

<table>
<thead>
<tr>
<th></th>
<th>(0) PRE-CRISIS MODEL (Jan 2003-Jan 2007)</th>
<th>(1) PRE-IDENTIFIED POLICY DATE MODEL (April 2010-Dec 2018)</th>
<th>(2) PARTIAL STRUCTURAL CHANGE MODEL (April 2010-Dec 2018)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>2.04</td>
<td>1.47 *</td>
<td>1.29 *</td>
</tr>
<tr>
<td></td>
<td>(1.72)</td>
<td>(0.85)</td>
<td>(0.76)</td>
</tr>
<tr>
<td>Expected Inflation (Inf3yr)</td>
<td>1.04 **</td>
<td>0.82 ***</td>
<td>0.81 ***</td>
</tr>
<tr>
<td></td>
<td>(0.53)</td>
<td>(0.24)</td>
<td>(0.23)</td>
</tr>
<tr>
<td>Credit Spreads (OAS)</td>
<td>-0.11</td>
<td>-0.16</td>
<td>-0.19</td>
</tr>
<tr>
<td></td>
<td>(0.31)</td>
<td>(0.17)</td>
<td>(0.13)</td>
</tr>
<tr>
<td>QE2 (QE2) 8/27/10</td>
<td></td>
<td>-0.45 *</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.24)</td>
<td></td>
</tr>
<tr>
<td>Forward Guidance/Twist (FGTwist) 8/9/11</td>
<td></td>
<td>-1.10 ***</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.26)</td>
<td></td>
</tr>
<tr>
<td>QE3 (QE3) 8/31/12</td>
<td></td>
<td>-0.70 ***</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.19)</td>
<td></td>
</tr>
<tr>
<td>Taper (Taper) 5/22/13</td>
<td></td>
<td>1.50 ***</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.16)</td>
<td></td>
</tr>
<tr>
<td>Balance Sheet Reduction (Reduce) 9/20/17</td>
<td></td>
<td>0.50 ***</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.18)</td>
<td></td>
</tr>
<tr>
<td>Structural Break #1 7/6/11</td>
<td></td>
<td>-1.14 ***</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.22)</td>
<td></td>
</tr>
<tr>
<td>Structural Break #2 6/13/12</td>
<td></td>
<td>-0.76 ***</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.15)</td>
<td></td>
</tr>
<tr>
<td>Structural Break #3 6/10/13</td>
<td></td>
<td>1.41 ***</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.15)</td>
<td></td>
</tr>
<tr>
<td>Structural Break #4 1/18/18</td>
<td></td>
<td>0.62 ***</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.09)</td>
<td></td>
</tr>
<tr>
<td>R-Squared</td>
<td>0.42</td>
<td>0.79</td>
<td>0.83</td>
</tr>
<tr>
<td>No. Observations</td>
<td>1021</td>
<td>2185</td>
<td>2185</td>
</tr>
</tbody>
</table>

Newey-West standard errors corrected for heteroskedasticity and autocorrelation in parentheses. *, **, *** indicate significance at the 90%, 95%, and 99% levels, respectively.
Pre-Identified Policy Date Model

We now turn to the analysis of the post-crisis period. By adding dummy variables for specific periods of unconventional policies, we can check for level changes to $\alpha$ (vertical shifts in the market-expected policy reaction surface) associated with successive phases of Fed policy. We are testing the hypothesis that negative coefficients on dummies correspond to expansionary policy innovations and positive coefficients correspond to restrictive policy innovations.

The analysis is conducted using daily data from April 2010 (the day after QE1 ended) through the end of 2018. QE1 is deliberately excluded from the analysis because dislocations in markets during the crisis and QE1 period are too extreme to generate interpretable results from this model. All model variables (Eurodollar futures, inflation swaps, and credit spreads) were swinging wildly due to causes separate from Taylor Rule policy reaction function factors, including LIBOR-OIS basis, extreme illiquidity, and impairment in the basic functioning of markets. Our analysis will thus focus on balance sheet policies from the end of QE1 onward.

Our post-crisis model is specified as follows:

$$Rate_{3yr} = \alpha + \beta (Inf_{3yr}) + \gamma (OAS) + \varphi_1 (QE2) + \varphi_2 (FGTwist) + \varphi_3 (QE3) + \varphi_4 (Taper) + \varphi_5 (Reduce)$$

where $Rate_{3yr}$, $Inf_{3yr}$, and $OAS$ are as previously described. $QE2$, $FGTwist$, $QE3$, $Taper$, and $Reduce$ are all dummy variables equal to 0 before the following dates and equal to 1 on and after the following critical dates when unconventional policy innovations were revealed:

- **QE2** – Bernanke’s 2010 Jackson Hole Speech (August 27, 2010)\(^{13}\)
- **Forward Guidance/Operation Twist (FGTwist)** – FOMC (August 9, 2011)\(^{14}\)
- **QE3** – Bernanke’s 2012 Jackson Hole Speech (August 31, 2012)\(^{15}\)

\(^{13}\) “Fed Ready to Dig Deeper to Aid Growth, Chief Says,” *New York Times*, August 27, 2010. (https://www.nytimes.com/2010/08/28/business/economy/28fed.html). Bernanke’s speech at Jackson Hole laying out the rationale for additional monetary stimulus was followed by an FOMC statement on September 21, 2010 indicating readiness to “provide additional accommodation” and by the November 3, 2010 FOMC decision to initiate $600 billion in additional purchases of longer-term Treasury securities (QE2).

\(^{14}\) “Its Forecast Dim, Fed Vows to Keep RatesNear Zero,” *New York Times*, August 9, 2011. (https://www.nytimes.com/2011/08/10/business/economy/fed-to-keep-rates-exceptionally-low-through-mid-2013.html) In addition to stating that economic conditions were “likely to warrant exceptionally low levels for the federal funds rate at least through mid-2013,” the FOMC statement on August 9, 2011 indicated that the Fed was “prepared to employ” a range of policy tools as appropriate to promote a stronger recovery. On September 21, 2011, the FOMC deployed one such tool by announcing a program to purchase $400 billion in longer-term Treasury securities (with maturities of 6 to 30 years) against sales of short-term Treasury securities (less than 3 year maturity). This program—known formally as the Maturity Extension Program, and informally as Operation Twist—was extended and expanded by approximately $267 billion at the FOMC on June 20, 2012.

\(^{15}\) “Fed Chairman Makes Case, in Strong Terms, for New Action,” *New York Times*, August 31, 2012. (https://www.nytimes.com/2012/09/01/business/economy/fed-chairman-pushes-hard-for-new-steps-to-spur-growth.html). Bernanke’s Jackson Hole speech was followed by an FOMC decision on September 13, 2012 to initiate open-ended purchases of $40 billion in mortgage-backed securities per month. The December 12, 2012 FOMC statement announced the expansion of the purchase program to include $45 billion in longer-term Treasury securities, bringing total monthly purchases to $85 billion per month. The program known as QE3 was colloquially called QE Infinity by some market participants, emphasizing its indeterminate length.
This specification recognizes that the impact of policy innovations accumulates—a new policy innovation does not obviate the effect of previous ones, but rather adds or subtracts from them.

Regression results for the post-crisis model are reported in Column (1) of TABLE 1.18

The model has significant explanatory power ($R^2 = 0.79$). Coefficients have the expected signs, positive (+) for expected inflation and negative (−) for OAS. Expected inflation is statistically significant at the 0.01 level. They also have reasonable magnitudes: the values are lower but broadly similar to those estimated in the pre-crisis regression, increasing confidence in the model specification. The intercept term is substantially lower (1.47 post-crisis vs. 2.04 pre-crisis), a result that is consistent with either a falling neutral rate19, the lingering effects of QE1, or a combination of both.

The most important results relate to the dummy variables. All the policy dummy variables have the expected signs, positive (+) for restrictive policy innovations and negative (−) for expansionary innovations. Four of the dummy variables ($FGTwist, QE3, Taper, and Reduce$) are statistically significant at the 0.01 level, while $QE2$ is significant at the 0.10 level ($p=0.057$).

Column (1) of TABLE 2 summarizes the effect each policy innovation on the market’s expectation of the Fed’s policy reaction function, as estimated by the post-crisis model. $QE2$ is estimated to have shifted the market expectation of the Fed’s policy reaction function three years in the future downward by −45 basis points, Forward Guidance and Operation Twist by −110 basis points, and $QE3$ by −70 basis points—a cumulative effect of 225 basis points for all three interventions. Bernanke’s comments in May 2013 on tapering asset purchases inaugurated a period in which the market-expected future Fed reaction function was shifted up by +150 basis points, followed by another +50 basis point increase following the Fed’s announcement that it would begin balance sheet reduction in October 2017.

16 “Dollar Advances as Bernanke Says Fed May Taper Soon,” Bloomberg, May 22, 2013. (https://www.bloomberg.com/news/articles/2013-05-21/dollar-lower-after-two-day-drop-versus-euro-before-bernanke) In testimony before Congress on May 22, 2013, Bernanke indicated that the Federal Reserve was prepared to “take a step down in our pace of purchases” if the Fed believed the momentum of the recovery would be sustained, previewing an eventual end of the Fed’s stimulus efforts. The subsequent FOMC statement of June 19, 2013 cited improvements in economic indicators. The FOMC then went on to surprise the market by not announcing a tapering of asset purchases at the September 2013 FOMC meeting, waiting instead to announce a phased reduction of purchases at the December 2013 FOMC. The official end of $QE3$ purchases was announced at the September 17, 2014 FOMC and the program terminated in October 2014.


18 Actual and predicted values for the Pre-Identified Policy Date model are presented in the Appendix (Figure A4).

19 For example, see Holston, Laubach, and Williams (2017) and Rachel and Summers (2019).
TABLE 2. ESTIMATED SHIFTS IN MARKET-EXPECTED FED FUTURE POLICY REACTION FUNCTION

<table>
<thead>
<tr>
<th>Pre-Identified Policy Dates</th>
<th>Partial Structural Change</th>
<th>Full Structural Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010 8/27/10 QE2 Jackson Hole -45bps</td>
<td>-</td>
<td>9/21/10 QE2 Signal FOMC (same day) -63bps</td>
</tr>
<tr>
<td>2011 8/9/11 Forward Guidance FOMC -110bps</td>
<td>7/8/11 Forward Guidance (-32 days) -114bps</td>
<td>8/10/11 Forward Guidance (+1 day) -124bps</td>
</tr>
<tr>
<td>2012 8/31/12 QE3 Jackson Hole -70bps</td>
<td>6/13/12 Twist Expanded FOMC (~7 days) -76bps</td>
<td>-</td>
</tr>
<tr>
<td>2013 5/22/13 Taper +150bps</td>
<td>6/10/13 Taper (+19 days) +141bps</td>
<td>6/3/13 Taper (+12 days) +115bps</td>
</tr>
<tr>
<td>2016</td>
<td>-</td>
<td>3/18/16 Dot Plot Surprise FOMC(+2 days) -25bps</td>
</tr>
<tr>
<td>2017 9/20/17 Reduction FOMC +50bps</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>2018</td>
<td>1/18/18 Powell Sworn In (-18 days) +62bps</td>
<td>1/18/18 Powell Sworn In (-18 days) +51bps</td>
</tr>
</tbody>
</table>

Results of the estimated Pre-Identified Policy Date model can be summarized as follows: expansionary and restrictive changes in Fed balance sheet policies were strongly associated with substantial shifts in market expectations for future Fed interest rate policy, after controlling for changing expectations about future inflation and growth dynamics.

Partial Structural Change Model

To assess the robustness of these findings, we now approach the analysis from a different angle. Rather than pre-specifying important policy dates, we instead use established econometric methods to test for structural breaks in the time series. Such an approach does not import any prior information about balance sheet policy innovations into the model. Rather, it simply “lets the data speak for itself” to identify dates where the estimated parameters of the market-expected policy reaction function exhibited a statistically significant break.

How should we then interpret the dates identified through such a structural break approach? As discussed previously, because markets both anticipate Fed policy changes ahead of time and digest them after the fact, it is possible (indeed likely) that the identified structural break dates will deviate to some extent from the specific policy announcement dates—even when those policy announcement dates are consequential in validating or shaping market expectations. But the greater that deviation, then the greater should be our skepticism that Fed
policy was a determinative factor. That is, if the structural break dates identified bears no evident relationship to the dates of significant Fed policy innovations, then we should suspect that the findings of the Pre-Identified Policy Date Model are spurious. On the other hand, if the dates identified via the policy-blind, data-only structural break method are proximate to significant monetary policy actions, it would increase our confidence that balance sheet policy innovations were indeed consequential in shaping market expectations of the future Fed reaction function.

The methodology for identifying multiple structural breaks was pioneered by Bai and Perron (1998, 2003), and full technical details can be found therein. Simply stated, the method employs an algorithm to iteratively re-estimate the chosen model for multiple combinations of possible break dates and select the break date combination that minimizes the sum of squared residuals. The residual-minimizing model for given number of break dates can then be compared to the null hypothesis of no break dates (ℓ breaks vs. none) and to the null hypothesis of a simpler model with fewer break dates (ℓ +1 breaks vs. ℓ) using an F-type test. The approach allows for the estimation of a partial structural break model (where some parameters are allowed to change at the break dates, while others are estimated for the entire dataset) and full structural break model (all parameters subject to change at the break dates).20

The initial model we estimate is a Partial Structural Change Model, in which the constant term is permitted to vary across break dates, while the single values for the coefficients for expected inflation (Inf3yr) and credit spreads (OAS) are estimated using the entire dataset. Note that this is analogous to the Pre-Identified Policy Date Model, in which the dummy variables enable the constant term to vary across different periods, while single values for the coefficients for expected inflation and credit spreads are estimated using the entire dataset. In short, the only variations permitted are the vertical shifts in the policy reaction function described in Section 2.

Column (1) of TABLE 3 summarizes the results for the Partial Structural Change Model. The test statistics identify four structural breaks in the regression model at the following dates: July 8, 2011; June 13, 2012; June 10, 2013; and January 18, 2018. Note the proximity of these break dates to important policy dates in the Pre-Identified Policy Date Model: July 8, 2011 was one month before the FOMC announcing Forward Guidance, and June 13, 2012 was less than three weeks after Bernanke’s comments on tapering asset purchases. The other two break dates are also associated with significant monetary policy developments: June 13, 2012 was one week before the Fed announced that it was expanding and extending Operation Twist, and January 18, 2018.

20 To elaborate, in this study we use the Bai-Perron procedure to estimate models with as many as five break dates. The procedure identifies the residual-minimizing model for each of those numbers of break dates (0, 1, 2, 3, 4, 5). We then ask “Is there at least one break date?” Bai and Perron (1998, 2003) propose a double maximum test to answer that question, defining two test statistics (UD max and WD max) that compare the null hypothesis of no structural breaks (model 0) to the hypothesis of at least one structural break up to a maximum of five (models 1, 2, 3, 4, or 5). If UD max and WD max exceed the published critical values, we reject the null hypothesis and establish that at least one structural break exists. Having answered the first question in the affirmative, we then ask “How many break dates are there?” To answer this question, Bai and Perron (2003) recommend iteratively comparing each model to the model with one additional break (1 vs. 2, 2 vs. 3, 3 vs. 4, 4 vs. 5), to test whether the increase in explanatory power is statistically significant, in a test referred to by Bai and Perron (2003) as the supF1(ℓ+1|ℓ) test with global minimizers. When no models with a larger number of breaks fail to reject the null hypothesis, we conclude the smaller model contains the appropriate number of breaks.
Table 3. Structural Break Tests (Bai-Perron 1998 and 2003 Method)

<table>
<thead>
<tr>
<th></th>
<th>(1) Partial Structural Change Model</th>
<th>(2) Full Structural Change Model</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>BREAKING VARIABLES</strong></td>
<td>Constant</td>
<td>Constant, Expected Inflation (Inf3yr), Credit Spreads (OAS)</td>
</tr>
<tr>
<td><strong>NON-BREAKING VARIABLES</strong></td>
<td>Expected Inflation (Inf3yr), Credit Spreads (OAS)</td>
<td>-</td>
</tr>
<tr>
<td><strong>NUMBER OF BREAKS IDENTIFIED</strong></td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td><strong>BREAK DATES</strong></td>
<td>July 8, 2011</td>
<td>September 21, 2010</td>
</tr>
<tr>
<td></td>
<td>June 13, 2012</td>
<td>August 10, 2011</td>
</tr>
<tr>
<td></td>
<td>June 10, 2013</td>
<td>June 3, 2013</td>
</tr>
<tr>
<td></td>
<td>January 18, 2018</td>
<td>March 18, 2016</td>
</tr>
<tr>
<td></td>
<td></td>
<td>January 18, 2018</td>
</tr>
<tr>
<td><strong>BAI-PERRON TEST STATISTICS</strong></td>
<td><strong>UD max</strong> 66.92**</td>
<td><strong>UD max</strong> 242.31**</td>
</tr>
<tr>
<td></td>
<td><strong>WD max (5%)</strong> 89.39**</td>
<td><strong>WD max (5%)</strong> 334.02**</td>
</tr>
<tr>
<td></td>
<td>**supF(2</td>
<td>1)** 14.47**</td>
</tr>
<tr>
<td></td>
<td>**supF(4</td>
<td>3)** 37.66**</td>
</tr>
<tr>
<td></td>
<td>**supF(5</td>
<td>4)** 36.42**</td>
</tr>
<tr>
<td></td>
<td><strong>Breaking Dates</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td>July 8, 2011</td>
<td>September 21, 2010</td>
</tr>
<tr>
<td></td>
<td>June 13, 2012</td>
<td>August 10, 2011</td>
</tr>
<tr>
<td></td>
<td>June 10, 2013</td>
<td>June 3, 2013</td>
</tr>
<tr>
<td></td>
<td>January 18, 2018</td>
<td>March 18, 2016</td>
</tr>
<tr>
<td></td>
<td></td>
<td>January 18, 2018</td>
</tr>
</tbody>
</table>

Both models estimated using least squares method with Newey-West standard errors corrected for heteroskedasticity and autocorrelation. For both models, Bai-Perron parameters are M = 5 (maximum breaks) and ε = 0.05 (h = 110 minimum observations per segment). The procedure recommended for empirical applications in Bai and Perron (2003) is employed to select the number of breaks: if UD max and WD max statistics exceed critical values to indicate presence of at least one structural break, then the number of breaks is identified by examining supF(ℓ+1|ℓ) tests until any larger number of breaks is rejected. ** indicates significance at the 95% level. 

2018 was less than three weeks before Jerome Powell was sworn in as new Federal Reserve Chair, replacing Janet Yellen. Those events also coincide within a few months of the start of QE3 and balance sheet reduction, respectively.

With these dates identified, we can estimate the model associated with those break dates. These results are presented back in Column (2) of Table 1.

As the table shows, the results of the Partial Structural Change Model in Column (2) are quite similar to the results for the Pre-Identified Policy Date Model in Column (1). The model has significant explanatory power (R² = 0.83). Coefficients have the expected signs, positive (+) for expected inflation and negative (−) for OAS, with expected inflation statistically significant at the 0.01 level. Those coefficients are also of similar magnitude to the previous model.

The magnitudes for the coefficients for the structural break dates are similar to the magnitudes of proximate dates for the dummies in the Pre-Identified Policy Date Model. This can also be seen by comparing Column (1) and Column (2) of Table 2, which translates the dummy coefficient estimates in the model to basis points of vertical shift in the market-expected policy reaction function. Finally, the coefficients on the dummy variables for the break dates are all highly statistically significant at the 0.01 level.
**Full Structural Change Model**

The final model permits all of the model parameters to vary across the breaks—the constant, expected inflation, and credit spreads—estimating entirely separate models for each period.

Column (2) of TABLE 3 shows the break dates and Bai-Perron test statistics resulting from this Full Structural Change Model. In this model, the test statistics identify five structural breaks in the regression model at the following dates: September 21, 2010; August 10, 2011; June 3, 2013; March 18, 2016; and January 18, 2018.

The proximity of these break dates to important policy dates in the Pre-Identified Policy Date Model is even more striking than with the partial model: September 21, 2010 was the same day as that the FOMC declared it was “prepared to provide additional accommodation,” validating Bernanke’s QE2 preview at Jackson Hole a few weeks earlier; August 10, 2011 was one day after the FOMC announced Forward Guidance; and June 3, 2013 was less than two weeks after Bernanke’s comments on tapering asset purchases. We have also seen the January 18, 2018 date before in the partial model, as it was proximate to Powell’s swearing in.  

What about the new date: March 18, 2016? Is that an example of a spurious break date? No, as it turns out. That date was two days after an FOMC meeting at which there was an accompanying release of the “dot plot” showing the rate path expected by FOMC members. The dot plot surprised the market by envisaging fewer rate hikes than previously expected based upon the December 2015 dot plot. And in point of fact, after initiating the rate hike cycle in December 2015, the FOMC did not raise rates again until December 2016. The fact that this policy-blind, data-only structural break approach identified such a date with monetary policy significance validates the interpretive insight generated by this approach.

The full model estimation for the Full Structural Change Model is presented in the Appendix in TABLE A1. The explanatory power is high ($R^2 = 0.92$), reflecting the dramatically larger number of degrees of freedom included in the model (18 in the full model versus 7 in the partial model). Most of the variables are statistically significant. However, unlike the previous two models for the post-crisis period, the coefficient estimates for the Full Structural Change Model are difficult to interpret directly. The values swing widely from period to period. At face, it is difficult to discern whether a particular array of changes in the coefficients reflect an accommodative or restrictive change in the market’s expectation of the Fed’s future policy reaction function.

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21 It is notable that both the Partial and Full Structural Break Models identify a structural break proximate to Powell’s swearing in. This appears to suggest that the turning point for the balance sheet reduction policy innovation may be more strongly linked to the February 2018 transition in Federal Reserve leadership than the September 2017 announcement that balance sheet reduction would commence. Once reason for this may be that the leadership transition coincided with an acceleration in the pace of balance sheet reduction: the Fed’s balance sheet contracted by roughly $15 billion per month from mid-October 2017 through the end of January 2018, while the pace of reduction increased to approximately $30 billion per month from February 2018 through the end of 2018.

A way to disentangle the net effect reflected in the model is as follows: for a given period, compare the predicted rate expectation using the model coefficients for that period, and compare that to what the market would have predicted using the model coefficients for the “baseline” period before the inauguration of QE2. For example, for each of the 222 days in the period between September 21, 2010 and August 10, 2011, calculate what the rate expectation using the actual model estimate for that period \((12.03 - 0.73(3yrInf) - 3.81(OAS))\), subtract the rate expectation that would have applied to that period’s daily data using the estimated coefficients for the baseline period \((1.24 + 1.30(3yrInf) - 0.50(OAS))\), and calculate the average difference. For accommodative policy innovations, we would those numbers to become more negative on average; for restrictive policy innovations, we would expect those numbers to become more positive on average. Those calculations are presented in Column (5) of TABLE A1. The difference from the previous period is presented in Column (6) of TABLE A.

Again, the pattern is quite clear: break periods that start proximate to expansionary policy innovations are associated with lower model-predicted expected future policy rates, while break periods that start proximate to restrictive policy innovations are associated with higher model-predicted expected future rates. This result obtains from the data itself, without importing any prior knowledge of policy into the model.

Discussion of the Model Results

One way of comparing the output of the three different models is to compare Columns (1)-(3) of TABLE 2, which tabulate the estimates of Pre-Identified Policy Date Model, Partial Structural Change Model, the Full Structural Change Model.

Another way to compare them is presented in FIGURE 8, which shows the cumulative shifts in the market-expected future policy reaction function estimated by each of the models. It is evident that all three models exhibit broadly the same pattern, in terms of both the magnitudes and periodicities of the shifts.

In short, three distinct econometric approaches provide support for the importance of balance sheet policy innovations in shifting market expectations of the Fed’s future policy reaction function. That should give us confidence in the robustness of these findings.

Which of the three models presented in this section is “best”? Different observers may have different views. The Pre-Identified Policy Date Model has the virtues of simplicity and intuitiveness. It avoids overfitting the data by specifying priors in advance. It doesn’t aspire to identify precisely when the market “turned” to either anticipate a policy change \textit{ex ante} or fully digest its implications \textit{ex post}. Rather it assumes that high-profile policy dates are the right focal points, on average, for calculating these effects.\textsuperscript{23} Sometimes policy actions may validate market expectations, in which case structural change models may identify break dates in advance of key events. At other times, policy actions may shock market expectations, in which case break dates may occur afterwards as market participants digest the full implications of a policy change.

\textsuperscript{23} Such a view is consistent with the idea that specific events populate “representativeness heuristics” that anchor market participants’ diagnoses of ongoing developments, as argued by Gennaioli and Shleifer (2018)
For these reasons, the Pre-Identified Policy Date Model may be a good choice if only one must be chosen. But the ability to use policy-blind/data-only approaches to stress-test the robustness of a policy-aware model strengthens our confidence in the results of that model.

**Assessing Plausibility in Historical Context**

Stepping back, are the overall magnitudes of the estimated impact of quantitative easing in this analysis plausible? As shown in Figure 8, at their peak in 2012, the analysis here suggests the cumulative impact of such policies on market expectations of the Fed’s future reaction function was in the range of 187-225 basis points. That is quite large. Does it make sense in light of historical experience?

Table 4 provides a prism for assessing that question. It compares three dates: January 31, 2003, amid the wake of the bursting of the tech bubble, 2001 recession, and corporate accounting scandals that combined to produce a deflation scare; July 1, 2010, in the aftermath of the global financial crisis, after the end of QE1 but before the announcement of additional quantitative easing; and August 31, 2012, the day that Bernanke delivered his Jackson Hole speech previewing QE3.

As shown in the table, these three dates are comparable in terms of what the market expected for future inflation (2.00 to 2.17 percent) and prevailing credit spreads (between 240 and 264 basis points). Yet, look at the differences in the expected policy rates. The market expected three-year forward rates of 4.22 percent and 2.58 percent in 2003 and 2010. In 2012,
Table 4. A Tale of Three Dates

<table>
<thead>
<tr>
<th>Date</th>
<th>Expected 3yr Forward Inflation</th>
<th>Credit Spreads (OAS)</th>
<th>Expected 3yr Forward Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>January 31, 2003</td>
<td>2.10%</td>
<td>251 basis points</td>
<td>4.22%</td>
</tr>
<tr>
<td>July 1, 2010</td>
<td>2.00%</td>
<td>264 basis points</td>
<td>2.58%</td>
</tr>
<tr>
<td>August 31, 2012</td>
<td>2.17%</td>
<td>240 basis points</td>
<td>0.69%</td>
</tr>
</tbody>
</table>

The market’s expectation was for future rates of just 0.69 percent! This is despite the fact that in 2012, expected inflation was slightly higher and credit spreads slightly more optimistic than the other dates, which if anything should have implied slightly higher future rate expectations.

The evidence presented in this section suggests that the explanation for this historical anomaly of exceptionally low forward rates priced into money market futures can be found in the sequence of aggressive unconventional policies by the Federal Reserve that meaningfully and measurably shaped the market’s expectation of the Fed’s future policy reaction function.

SECTION 4 – IMPACT ON 10-YEAR U.S. TREASURY YIELDS

Most studies of the effectiveness of quantitative easing have focused on impact of the policy on benchmark 10-year U.S. Treasury yields. How can we translate the quantitative findings of the above analysis of the future policy reaction function into terms that enable a comparison with previous studies?

Indirect Calculation of Impact on 10-Year Yields

Answering this question using the findings of the previous section requires harnessing the relationship between the 3-year forward Eurodollar rate and 10-year Treasury yields.

For intuition on the relationship, remember that the 10-year Treasury yield can be decomposed into a series of short-term forward rates. If a change in the 3-year forward rate were matched by parallel changes in the forward rates along the entire Treasury yield curve, then the change in the 3-year rate would exactly equal the change in the 10-year yield. But this is unlikely to be the case in reality. For one, after the crisis, forward rates less than 3 years could not shift down as much as the 3-year forward rate, because they were already close to the zero bound. For rates further out than 3 years forward, these would have a tendency to move less than the 3-year forward rate if the market believed that the Fed would normalize policy rates at some point in the future. For both of these reasons, we would expect the “beta” of 10-year Treasury yields to 3-year forward Eurodollars to be less than one.

Indeed, using weekly data for the post-crisis model period (April 2010 through December 2018), we find that the empirical relationship, on average, shows that a 100 basis point change in 3-year forward Eurodollar rate was correlated \( R^2 = 0.75 \) with a 64 basis point change in the same direction for the 10-year Treasury yield. This is illustrated in Figure 9.
FIGURE 9.

Using this simple relationship, we can translate the level shifts in the market’s expected 3-year forward policy reaction function into 10-year U.S. Treasury equivalents, simply by multiplying the former values by 0.64. This produces an estimate of the “true” underlying impact of each Federal Reserve policy innovation on 10-year Treasury yields that is catalyzed by the shift in the market’s expectation for the Fed’s future policy reaction function, as estimated by the Pre-Identified Policy Data Model.

These calculations—summarized in Columns (1) and (2) of TABLE 5—estimate that QE2, Forward Guidance/Operation Twist, and QE3 reduced 10-year Treasury yields by −29 bps, −70 bps, and −45 bps respectively. That implies a peak impact of −144 bps basis points on 10-year yields from these interventions alone (i.e., excluding any impact from QE1, which is beyond the scope of this study). As policy support was withdrawn, this analysis suggests that Bernanke’s Taper comments in May 2013 and the initiation of balance sheet reduction in October 2017 had the “true” underlying impact of increasing 10-year yields by +96 bps and +32 bps respectively.

**TABLE 5. TRANSLATING SHIFT OF REACTION FUNCTION INTO 10-YEAR TREASURY YIELD IMPACT**

<table>
<thead>
<tr>
<th></th>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
<th>(4)</th>
<th>(5)</th>
<th>(6)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Impact on 3yr Forward Rate</td>
<td>“True” Impact on 10yr Yields</td>
<td>Change in Expected Inflation</td>
<td>Change in Credit Spreads</td>
<td>Reflation/Disinflation Factor</td>
<td>“Apparent” Impact on 10yr Yields</td>
</tr>
<tr>
<td>QE2</td>
<td>−45</td>
<td>−29 bps</td>
<td>+11</td>
<td>−27</td>
<td>+9</td>
<td>−20 bps</td>
</tr>
<tr>
<td>FG/Twist</td>
<td>−110</td>
<td>−70 bps</td>
<td>−6</td>
<td>+66</td>
<td>No mitigating factor</td>
<td></td>
</tr>
<tr>
<td>QE3</td>
<td>−70</td>
<td>−45 bps</td>
<td>+33</td>
<td>−70</td>
<td>+24</td>
<td>−21 bps</td>
</tr>
<tr>
<td>Taper</td>
<td>+150</td>
<td>+96 bps</td>
<td>−54</td>
<td>−17</td>
<td>−26</td>
<td>+70 bps</td>
</tr>
<tr>
<td>Reduction</td>
<td>+50</td>
<td>+32 bps</td>
<td>+27</td>
<td>−42</td>
<td>No mitigating factor</td>
<td></td>
</tr>
</tbody>
</table>
Note the use of the term “true” underlying impact. This is because, as described in the opening paragraphs of this paper, some of the impact of quantitative easing on observed yields is mitigated by the impact of Fed policies in generating reflationary expectations. This positive shock to expectations for higher inflation and higher growth might stimulate consumption and investment, while at the same time putting upward pressure on yields and making Fed policy appear less impactful than it actually was. This could help explain why bond yields increased during some implementation periods cited by QE skeptics like Cochrane (2017).

For an illustration of how Fed policy announcements did in fact influence market expectations for reflation and disinflation during this time period, observe the data presented in Figure 10. It shows the evolution of inflation expectations and credit spreads around three key events: Bernanke’s QE2 Jackson Hole speech on August 27, 2010; Bernanke’s QE3 Jackson Hole speech on August 31, 2012; and the FOMC statement on September 17, 2014 announcing the end of QE3. Note the distinct impact on inflation expectations in each episodes, where the expansionary implications of QE2 and QE3 inaugurate a turn to rising inflation expectations while the end of QE3 depresses inflation expectations. Credit spreads decline after the announcements of QE2 and QE3, while rising notably after the end of QE3.

**Figure 10. Changes in Inflation Expectations & Credit Spreads Around QE2/QE3**
To measure the magnitude of potential mitigating effects of changing reflationary expectations on observed yields, we can measure what happened to 3-year expected future inflation and to credit spreads during each successive period of balance sheet policies, and then trace through their imputed shadow impact on nominal 10-year Treasury yields.

Columns (3) and (4) of Table 5 above show the change in average inflation expectations and average credit spreads for each period versus the preceding period. For example, in the QE3 period, average expected inflation increased +33 basis points while credit spreads fell by −70 basis points, indicating a reflationary shift in market expectations for future inflation and growth. To translate this into the impact of 10-year Treasury yields, we multiply each of these by the respective coefficients estimated in the Pre-Identified Policy Date Model (for QE3: 0.82 (33) − 0.16 (−70) = 38) and multiply that by the beta of 0.64 (for QE3: 0.64 (38) = 24) to calculate the reflation/disinflation factor for 10-year yields listed in Column (5).

We can see that failure to factor in the reflationary or disinflationary expectations effect can have large consequences estimates of the Fed’s impact. The “true” impact of QE3 on 10-year yields (−45 bps) was more than double the “apparent” impact (−21 bps) that does not account for the upward pressure on yields from rising reflationary expectations in the QE3 period. Similarly, the “true” impacts of Taper and QE2 were approximately 40 percent greater than the “apparent” impacts—e.g., disinflationary expectations induced by Bernanke’s Taper remarks masked the full extent of the underlying upward pressure on yields generated by those comments.

**Direct Calculation of Impact on 10-Year Yields**

To validate these indirect estimates, we can also use the methods introduced in this paper to calculate a direct estimate of the impact of balance sheet policies on 10-year Treasury yields. We start by specifying the model:

\[
UST10yr = \alpha + \beta (Breakeven10yr) + \gamma (OAS) + \\
\varphi_1 (QE2) + \varphi_2 (FGTwist) + \varphi_3 (QE3) + \varphi_4 (Taper) + \varphi_5 (Reduce)
\]

where \(UST10yr\) is the 10-year Treasury yield and \(Breakeven10yr\) is 10-year breakeven inflation rate (reflecting the market’s expectation for average inflation over the next 10 years). The rest of the variables \(OAS, QE2, FGTwist, QE3, Taper,\) and \(Reduce\) are all as previously described.

Note the symmetry to the model for the market-expected future policy reaction function. Here we are essentially conceptualizing the 10-year Treasury yield as the series of short-term rates over the next ten years, and hypothesizing that the market’s expectation for that short-term rate trajectory is a function of inflation expectations (Breakeven 10yr), output gap expectations

---

24 Two comments on this approach: (1) For estimating the “true” impact of Fed policy described here, it does not matter whether the changes in expectations from period to period were caused by the Fed or by other developments. The goal is simply to subtract out the change in 10-year yields attributable to identifiable changes in inflation and output expectations, whatever their causes. (2) In some instances (Forward Guidance/ Operation Twist and Reduce), there was no mitigation factor because the changes in expected inflation and credit credits reinforced the directional move rather than mitigating it. This could have been due to “Delphic” effects from policy announcements or because any reflationary impact of Fed policy on expectations was more than offset by changes in the perceptions of market participants attributable to other factors, such as incoming data and other macroeconomic indicators.
### Table 6. Direct Impact on 10-Year Treasury Yields – Model Estimation

<table>
<thead>
<tr>
<th>10-Year UST Yield Policy Date Model (April 2010-Dec 2018)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Constant</strong></td>
<td>0.27 (0.73)</td>
</tr>
<tr>
<td>10-Year Breakeven Inflation <em>(Breakeven10yr)</em></td>
<td>1.24 *** (0.20)</td>
</tr>
<tr>
<td>Credit Spreads <em>(OAS)</em></td>
<td>0.24 (0.17)</td>
</tr>
<tr>
<td><strong>QE2 (QE2) 8/27/10</strong></td>
<td>−0.48 *** (0.11)</td>
</tr>
<tr>
<td><strong>Forward Guidance/Twist (FGTwist) 8/9/11</strong></td>
<td>−1.15 *** (0.24)</td>
</tr>
<tr>
<td><strong>QE3 (QE3) 8/31/12</strong></td>
<td>−0.40 ** (0.18)</td>
</tr>
<tr>
<td><strong>Taper (Taper) 5/22/13</strong></td>
<td>1.26 *** (0.16)</td>
</tr>
<tr>
<td>Balance Sheet Reduction <em>(Reduce)</em> 9/20/17</td>
<td>0.40 *** (0.15)</td>
</tr>
</tbody>
</table>

R-Squared: 0.85
No. Observations: 2185

Newey-West standard errors corrected for heteroskedasticity and autocorrelation in parentheses. *, **, *** indicate significance at the 90%, 95%, and 99% levels, respectively.

(proxied by OAS), and Fed balance sheet policy innovations *(QE2, FG/Twist, QE3, Taper, and Reduce)*. Implicitly, it is ten years of market-policy reaction functions rolled into one.25

Regression results for the 10-year yield model are reported in Table 6.26 The model has significant explanatory power (R² = 0.85). Coefficients on breakeven inflation have the expected sign (+), a reasonable magnitude, and statistical significance at the 0.01 level. The coefficient for credit spreads does not have the expected sign (it is + rather than −), though it is not statistically significant.27 All the policy dummy variables have the expected signs, positive (+) for restrictive policy innovations and negative (−) for expansionary innovations. Four of the dummy variables *(QE2, FG/Twist, Taper, and Reduce)* are statistically significant at the 0.01 level, while QE3 is significant at the 0.05 level.

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25 This interpretation puts to the side the fact that the forward curve for the 10-year yield also incorporates a term premium in addition to the “pure” expectation for future rates. We discuss this issue in detail later.
26 Actual and predicted values for the 10-Year UST Policy Date model are presented in the Appendix (Figure A5).
27 One possible reason for the positive coefficient on OAS in this regression is discussed later.


**Table 7. Direct vs. Indirect Estimates of Policy Impact on 10-Year Treasury Yields**

<table>
<thead>
<tr>
<th></th>
<th>(1)</th>
<th>(2)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Indirect Method</td>
<td>Direct Method</td>
</tr>
<tr>
<td>QE2</td>
<td>−29 bps</td>
<td>−48 bps</td>
</tr>
<tr>
<td>FG/Twist</td>
<td>−70 bps</td>
<td>−115 bps</td>
</tr>
<tr>
<td>QE3</td>
<td>−45 bps</td>
<td>−40 bps</td>
</tr>
<tr>
<td>Taper</td>
<td>+96 bps</td>
<td>+126 bps</td>
</tr>
<tr>
<td>Reduction</td>
<td>+32 bps</td>
<td>+40 bps</td>
</tr>
</tbody>
</table>

The coefficients on the policy dummies represent estimates of the impact of each policy innovation on 10-year Treasury yields, reported in Column (2) of Table 7 to enable a comparison of the policy impact computed via the indirect and direct methods. As is evident from the table, the estimates are highly correlated ($R^2=0.99$). They are broadly similar in magnitude, though in general the direct method generates larger estimated impacts, with the sole exception of QE3. At peak, the direct method implies that the cumulative effect of QE2, Forward Guidance/Operation Twist, and QE3 was to decrease 10-year Treasury yields by −203 basis points (versus −144 basis points for the indirect method).²⁸

*Testing for Structural Breaks in 10-Year Yields*

We can again examine whether the regression results obtained by pre-specifying the policy dates are spurious by analyzing structural breaks. Once more, this gives the opportunity for the “data to speak for itself” and identify the dates where there were statistically significant shifts in the relationship between 10-year Treasury yields (dependent variable) and inflation expectations and credit spreads (explanatory variables). The results are presented in Table 8. The Bai-Perron test statistics identify five structural breaks in the regression model at the following dates: September 7, 2010; August 10, 2011; May 18, 2012; May 31, 2013; and February 2, 2018.

The proximity of these purely data-selected break dates in the 10-year yield regression model to important policy dates is remarkable. They are arguably even closer than in the 3-year future policy reaction function models: September 7, 2010 was 11 days after Bernanke’s QE2 preview at Jackson Hole; August 10, 2011 was 1 day after the FOMC announced Forward Guidance; May 18, 2012 was one month before Operation Twist was expanded by the FOMC; May 31, 2013 was 9 days after Bernanke’s comments on tapering asset purchases; and February 2, 2018 was 3 days before Powell was sworn in as Fed Chair.

It is worth emphasizing this key finding: the purely statistical properties of the 10-year yield time series reveal structural breaks that are strongly indicative of the importance of innovations in the Fed’s unconventional policies in explaining 10-year Treasury yields.

²⁸ The −203 basis point estimate via the direct method reflects a calculation of the underlying “true” impact of QE2, Forward Guidance and Operation Twist, and QE3. Observed yield declines would be less, due to the reflationary impact of Fed policies on expected inflation and GDP. As discussed previously, a reflationary adjustment is needed to estimate the impact on observed yields: $1.24 \text{(Breakeven10yr coefficient)} \times +49 \text{ bps (actual change in 10yr breakevens)} + 0.24 \text{(OAS coefficient)} \times -32 \text{ bps (change in credit spreads)} = +53 \text{ bps}$. Thus, “apparent” impact on 10-year Treasury yields via the direct method with the reflationary adjustment is $-203 + 53 = -150$ basis points.
Table 8. 10-Year Yield Structural Break Test (Bai-Perron 1998 and 2003 Method)

<table>
<thead>
<tr>
<th>10-Year UST Yield Model</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Breaking Variables</strong></td>
</tr>
<tr>
<td>Constant</td>
</tr>
<tr>
<td><strong>Non-Breaking Variables</strong></td>
</tr>
<tr>
<td>10-Year Breakeven Inflation (Breakeven10yr), Credit Spreads (OAS)</td>
</tr>
<tr>
<td><strong>Number of Breaks Identified</strong></td>
</tr>
<tr>
<td>5</td>
</tr>
<tr>
<td><strong>Break Dates</strong></td>
</tr>
<tr>
<td>September 7, 2010</td>
</tr>
<tr>
<td>August 10, 2011</td>
</tr>
<tr>
<td>May 18, 2012</td>
</tr>
<tr>
<td>May 31, 2013</td>
</tr>
<tr>
<td>February 2, 2018</td>
</tr>
<tr>
<td><strong>Bai-Perron Test Statistics</strong></td>
</tr>
<tr>
<td>$UD_{max}$</td>
</tr>
<tr>
<td>123.54**</td>
</tr>
<tr>
<td>$supF_t(3</td>
</tr>
<tr>
<td>17.43**</td>
</tr>
<tr>
<td>$WD_{max}$ (5%)</td>
</tr>
<tr>
<td>177.83**</td>
</tr>
<tr>
<td>$supF_t(4</td>
</tr>
<tr>
<td>9.18</td>
</tr>
<tr>
<td>$supF_t(2</td>
</tr>
<tr>
<td>9.11</td>
</tr>
<tr>
<td>$supF_t(5</td>
</tr>
<tr>
<td>15.87**</td>
</tr>
</tbody>
</table>

Both models estimated using least squares method with Newey-West standard errors corrected for heteroskedasticity and autocorrelation. Bai-Perron parameters are $M = 5$ (maximum breaks) and $\varepsilon = 0.05$ ($h = 110$ minimum observations per segment). The procedure recommended for empirical applications in Bai and Perron (2003) is employed to select the number of breaks: if $UD_{max}$ and $WD_{max}$ statistics exceed critical values to indicate presence of at least one structural break, then the number of breaks is identified by examining $supF_t(\ell + 1|\ell)$ tests until any larger number of breaks is rejected. ** indicates significance at the 95% level.

Discussion of the 10-Year Treasury Results

It is worth considering why the direct estimates differ from the indirect estimates—in particular, why the direct estimates appear to be higher.

One possible explanation involves the term premium. We consider two components of the term premium: first, compensation to investors for uncertainty around the future rate path; second, any market-clearing excess compensation for given securities driven by fluctuations in quantity supplied amid preferred habitats and market frictions (“portfolio rebalancing” channel).

Regarding the first component of compensation for uncertainty, all forward rates are associated with uncertainty regarding the future trajectory of policy rates. Forward rates at progressively longer tenors are typically associated with greater uncertainty. Longer term yields thus reflect not only the “pure” expectation of the trajectory of forward interest rates, but also a volatility premium associated with uncertainty around that expectation. The much longer tenor of the 10-year Treasury embeds uncertainty around a much longer forward rate curve than the 3-year Eurodollar future. To the extent that Fed actions affected both the “pure” expectation of the forward interest rate trajectory and the perceived uncertainty around that trajectory, rates have the potential to be doubly affected by policy innovations. Expansionary innovations tend to reduce the forward expected rate and the uncertainty premium, while restrictive innovations tend to increase the forward expected rate and the uncertainty premium. These effects would be
magnified for the 10-year Treasury compared to the 3-year Eurodollar future.

The term premium in the 10-year Treasury is also poised to be much more sensitive to the second component of the term premium to the extent that market-clearing premiums react to changes in the relative supply of securities. The Fed’s asset purchase programs (QE2, Operation Twist, and QE3) were all focused on longer-dated Treasury securities with maturities between 6 and 30 years, as well as mortgage-backed securities in the QE3 program. Any portfolio rebalancing impact on yields via the channel of relative scarcity would thus directly affect the 10-year Treasury yield in a way that it would not affect the 3-year Eurodollar future. Moreover, Operation Twist—which was announced in September 2011, expanded in June 2012, and implemented through December 2012—actually increased the supply of shorter-dated Treasury securities with maturities less than 3 years. If anything, portfolio rebalancing would have been expected to put upward pressure on the second component of the term premium for shorter-dated interest rates.

For these two reasons, the indirect estimate of the impact on 10-year yields (using the 0.64 beta to 3-year forward rates associated with policy innovations) might underestimate the impact those innovations systematically had on the term premium in 10-year Treasury yields.\(^29\)

In any case, the similar estimates of 10-year yield impact from the indirect and direct methods—combined with the structural break analysis results—offer strong evidence that the magnitudes are plausible and that the causal inference linking Fed policy innovations to changes in the 10-year U.S. Treasury yield is supported by multiple empirical approaches.

SECTION 5 – IMPACT OF QUANTITATIVE EASING ON RISK MARKETS

As shown in the previous section, successive innovations in Fed balance sheet policy between 2010 and 2018 were correlated with distinct and measurable shifts in investors’ expectations about the Federal Reserve’s future policy reaction function. Announcements on new asset purchase initiatives led market participants to expect that future Fed interest rate policy would react in a more accommodative fashion to future inflation and growth, while signals that balance sheet activities would be reduced led investors to expect more restrictive Fed interest rate responses to future inflation and output developments. Shifts in the market-expected future policy reaction function in turn affected longer-term bonds, such as 10-year U.S. Treasury yields.

But that is not where the potential effects on asset markets end.

Imagine that you are an investor. The Federal Reserve has announced a new program of asset purchases, underscoring its determination to reflate the U.S. economy. Market prices are now anticipating a more accommodative future interest rate policy reaction function—i.e., that the Federal Reserve will embrace a lower future interest rate path even against higher future inflation and growth. What assets are attractive to purchase in such an environment?

\(^29\) Since credit spreads are also positively correlated with volatility, the relationship between expected volatility and the term premium also might help explain why the 10-year yield model estimate produces a positive coefficient on the OAS variable.
Impact of Quantitative Easing on Equities and Credit

Two asset classes that fit the bill are equities and corporate bonds. In a reflationary environment, corporate profits would be expected to rise, which makes equities more valuable, improves the capacity of companies to service their debt, and reduces the probability of default in a manner that increases the attractiveness of corporate bonds. The risk of this investment strategy is that a reflationary environment might become excessively inflationary in a manner that induces the central bank to raise interest rates and “order the punch bowl removed just when the party was really warming up.”

But that is where the future Fed reaction function becomes important. To the extent that the market believes that the Fed will be more quiescent in face of future inflationary pressures, the risk that the punch bowl will be removed diminishes and prospects for a boisterous party increase. The market’s expectation for the Fed’s future policy reaction thus affects the attractiveness of a wide range of financial assets, not just U.S. Treasury bonds.

It is worth emphasizing this point, since investment committees around the world were focusing intensively on Federal Reserve policy during the post-crisis period. The interest of investors in new policy announcements was not limited to the technical dimensions of particular initiative. Rather, market participants were looking for what these announcements revealed about the character of the central bank. Was the Federal Reserve willing to do “whatever it takes” to secure a recovery and clip the tail risk of a deflation scenario? If so, portfolio managers would have a “green light” for investing in riskier assets that would benefit from a reflationary scenario. Each additional policy innovation provided more information about the Fed’s attitudes.

Many market participants found it reasonable to conclude that part of the Federal Reserve’s strategy during this period involved underwriting a substantial measure of risk-taking by financial markets. After all, financial conditions, such as credit spreads, were critical to achieving the Fed’s goal of reducing the cost of credit to firms and households as a way of supporting economic activity and avoiding deflation (McCulley and Toloui 2008). Bernanke’s own earlier academic work elaborated the manner in which financial conditions amplified macroeconomic fluctuations (Bernanke, Gertler, and Gilchrist 1996). By signaling an intention to embrace a more accommodative policy reaction in the future, unconventional policies could help sustain the recovery by catalyzing an improvement in overall financial conditions.

If this reasoning is correct, we would expect to see a relationship between the prices of equities and credit spreads, on the one hand, and innovations in Fed balance sheet policy. Figures 11 and 12 show the historical data on both for the period from the end of QE1 until the end of QE3. On casual inspection, there seems to be some link between balance sheet announcements and changes in risk asset prices. Periods of balance sheet expansion and associated policy innovations appear to coincide with gains in equities and declines in credit spreads, whereas the removal of balance sheet policies and restrictive signals coincide with declines in equities and increases in credit spreads.

30 Or more precisely with respect to the latter: a long position in corporate bonds versus a short position in U.S. Treasury bonds, as such a portfolio gains in value when credit spreads decline.
31 William McChesney Martin, speech before the Investment Bankers Association of America, October 19, 1955.
**Figure 11. S&P 500**

**Figure 12. Credit Spreads**
We can analyze this more systematically by examining periods of unusual market performance between 2010 and 2018. Specifically, let us identify the following episodes:

- 5 largest quarterly gains in equities (S&P 500)
- 5 largest quarterly losses in equities (S&P 500)
- 5 largest quarterly rallies in credit spreads (BBB Option-Adjusted Spreads)
- 5 largest quarterly sell-offs in credit spreads (BBB Option-Adjusted Spreads)

We can then examine whether these unusual periods of over- and under-performance in risk markets bear any relationship with significant Fed balance sheet actions.

**Table 9. Largest Quarterly Changes in Equities (2010-2018)**

<table>
<thead>
<tr>
<th>Rank</th>
<th>Start</th>
<th>End</th>
<th>Change</th>
<th>Potential Catalyst</th>
<th>Proximity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>11/25/11</td>
<td>2/23/12</td>
<td>+17.7%</td>
<td><strong>Fed Swap Lines</strong>: Extended to Foreign Central Banks (11/28/11)</td>
<td>3 days</td>
</tr>
<tr>
<td>2</td>
<td>8/26/10</td>
<td>11/24/10</td>
<td>+14.4%</td>
<td><strong>QE2</strong>: Bernanke Speech at Jackson Hole (8/27/2010)</td>
<td>1 day</td>
</tr>
<tr>
<td>3</td>
<td>8/10/11</td>
<td>11/8/11</td>
<td>+13.8%</td>
<td><strong>Forward Guidance/Twist</strong>: FOMC Statement (8/9/10)</td>
<td>1 day</td>
</tr>
<tr>
<td>4</td>
<td>1/20/16</td>
<td>4/19/16</td>
<td>+13.0%</td>
<td><strong>China</strong>: Rebound from Volatility</td>
<td>-</td>
</tr>
<tr>
<td>5</td>
<td>11/30/10</td>
<td>2/28/11</td>
<td>+12.4%</td>
<td><strong>QE2</strong>: Purchases Begin (11/3/10)</td>
<td>27 days</td>
</tr>
</tbody>
</table>

**Largest Equity Losses**

<table>
<thead>
<tr>
<th>Rank</th>
<th>Start</th>
<th>End</th>
<th>Change</th>
<th>Potential Catalyst</th>
<th>Proximity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>9/25/18</td>
<td>12/24/18</td>
<td>−19.4%</td>
<td><strong>Fed Tightening</strong>: Market concerns about rate hikes and quantitative tightening</td>
<td>-</td>
</tr>
<tr>
<td>2</td>
<td>7/5/11</td>
<td>10/3/11</td>
<td>−17.8%</td>
<td><strong>QE2</strong>: End of Program (6/30/11)</td>
<td>5 days</td>
</tr>
<tr>
<td>3</td>
<td>4/6/10</td>
<td>7/2/10</td>
<td>−14.0%</td>
<td><strong>QE1</strong>: End of Program (3/31/10)</td>
<td>6 days</td>
</tr>
<tr>
<td>4</td>
<td>5/27/15</td>
<td>8/25/15</td>
<td>−12.0%</td>
<td><strong>China</strong>: Volatility &amp; currency de-peg</td>
<td>-</td>
</tr>
<tr>
<td>5</td>
<td>11/10/15</td>
<td>2/8/16</td>
<td>−11.0%</td>
<td><strong>China</strong>: Volatility &amp; devaluation concerns</td>
<td>-</td>
</tr>
</tbody>
</table>

The results of this analysis for equities are presented in Table 9, which notes the magnitude of the changes, the start and end dates of the episode, and the potential catalyst based upon proximity to the start date. The five largest equity rallies involved gains between +12.4 and

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32 This analysis identifies the largest gains and largest losses for *non-overlapping* 90-day periods (if the 90th calendar day falls on day that the market is closed, the closest preceding market day is used). “Non-overlapping” means that once an episode is identified, the days covered by that episode are not eligible for inclusion in another episode, to avoid double-counting.
As shown on the table, 60 percent of the ten largest equity moves were proximate to significant unconventional policy innovations announced in the 2010-2014 timeframe, with 50 percent of the largest equity moves starting within one week of such an announcement. Another 10 percent were proximate to subsequent concerns about Fed interest rate policy and quantitative tightening in the fall of 2018. The remaining 30 percent appear to have been linked to other developments, especially concerns about financial stability in China.

**TABLE 10. LARGEST QUARTERLY CHANGES IN CREDIT SPREADS (2010-2018)**

<table>
<thead>
<tr>
<th>Rank</th>
<th>Start</th>
<th>End</th>
<th>Change</th>
<th>Potential Catalyst</th>
<th>Proximity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2/11/16</td>
<td>5/11/16</td>
<td>−91 bps</td>
<td><strong>China</strong>: Rebound from Volatility</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>12/20/11</td>
<td>3/19/12</td>
<td>−71 bps</td>
<td><strong>Fed Swap Lines</strong>: Extended to Foreign Central Banks (11/28/11)</td>
<td>22 days</td>
</tr>
<tr>
<td>3</td>
<td>7/24/12</td>
<td>10/22/12</td>
<td>−66 bps</td>
<td><strong>Europe</strong>: Draghi Speech and OMT Program for Peripherals (7/24/12)</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>11/23/10</td>
<td>2/18/11</td>
<td>−37 bps</td>
<td><strong>QE2</strong>: Purchases Begin (11/3/10)</td>
<td>20 days</td>
</tr>
<tr>
<td>5</td>
<td>9/30/13</td>
<td>12/27/13</td>
<td>−35 bps</td>
<td><strong>No Taper</strong>: Surprise FOMC decision not to Taper (9/18/13)</td>
<td>12 days</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Rank</th>
<th>Start</th>
<th>End</th>
<th>Change</th>
<th>Potential Catalyst</th>
<th>Proximity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>7/7/11</td>
<td>10/5/11</td>
<td>+126bps</td>
<td><strong>QE2</strong>: End of Program (6/30/11)</td>
<td>7 days</td>
</tr>
<tr>
<td>2</td>
<td>11/13/15</td>
<td>2/11/16</td>
<td>+82 bps</td>
<td><strong>China</strong>: Volatility &amp; devaluation concerns</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>4/6/10</td>
<td>7/2/10</td>
<td>+63 bps</td>
<td><strong>QE1</strong>: End of Program (3/31/10)</td>
<td>6 days</td>
</tr>
<tr>
<td>4</td>
<td>10/3/18</td>
<td>12/31/18</td>
<td>+61 bps</td>
<td><strong>Fed Tightening</strong>: Market concerns on rate hikes and quantitative tightening</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>9/17/14</td>
<td>12/16/14</td>
<td>+58 bps</td>
<td><strong>QE3</strong>: End of Program Announced (9/17/14)</td>
<td>Same day</td>
</tr>
</tbody>
</table>

The results for credit spreads are presented in **TABLE 10**. The five largest credit rallies involved declines in risk spreads between −35 and −91 basis points, while the five largest sell-offs involved increases in spreads between +58 and +126 basis points. Again, 60 percent of the ten largest credit moves were proximate to significant balance sheet policy events in the 2010-2014 timeframe. Another 10 percent were proximate to subsequent concerns about Fed interest rate policy and quantitative tightening in the fall of 2018. The remaining 30 percent appear to have been linked to other developments, especially concerns about financial stability in China and the European sovereign crisis.

Particularly striking is the end of QE1, QE2, and QE3 were all correlated with large increases in risk spreads. Three of the five largest sell-offs in credit markets started within
one week of the ends of QE1, QE2, and QE3. The odds of that occurring randomly are less than 1 in 500,000 (p < 0.000002). It is more than two times more likely that you will be struck by lightning within the next five years.

Recall that we have not imposed any structure or prior knowledge into this analysis. Rather, we allow the “data to speak for itself” to identify the largest moves in both of these risk asset classes. It turns out that when the data speaks, it shouts: the largest moves in equities and credit spreads are correlated with the timing balance sheet policy innovations. This fact adds credence to the argument that the way in which balance sheet policies shifted the market’s expectations about the prospects for reflation and the Fed’s future policy reaction function significantly influenced price formation elsewhere in financial markets.

The Nexus Between Central Banks and Financial Markets

Central banks and financial markets are intertwined in profoundly interesting ways. As monetary policy committees deliberate on decisions regarding interest rates, asset purchases, and statement language, they not only consider ongoing developments in financial markets, but also carefully weigh the potential reactions of markets to various possible central bank actions. Policymakers ask themselves: What does the market expect us to do? What will be the impact of what we decide on bond, credit, and equity markets? These questions are important to central bankers because the answers directly affect the ability of the central bank to achieve its broader goals of managing inflation and output. Critical consumption and investment decisions are directly and indirectly affected by what happens in financial markets.

At the same time, financial markets are acutely interested in the decisionmaking processes within central banks. Investors ask themselves: What are the goals and biases of a particular Federal Reserve Chair and Board? Will they err on the side of maintaining expansionary policies, even if that means generating extra inflation, in order to avoid the risks of deflation? How will these preferences be manifest in their future policy reaction function? These questions are important to investors because the answers directly affect the absolute and relative returns of various assets in which they may deploy capital. Success as portfolio managers depends on making the right calls.

As described by McCulley and Toloui (2008), this produces a “You, Looking At Me, Looking at You” 33 effect: central bank decisionmaking is shaped by assumptions about the reaction function of markets, while simultaneously market decisionmaking is shaped by assumptions about the reaction function of the central bank (see Figure 13). In such a situation, it can be difficult to discern what is causing what, who is moving whom, which is the tail and which is the dog, and so forth. Notions of causality become complicated.

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For example, imagine that financial markets begin to anticipate that economic weakness will compel the central bank to cut interest rates. Asset prices in markets begin to reflect this anticipation, for example, through a decline in bond yields. Imagine further that when the central bank meets, its own reading of the underlying economic situation is more favorable than the economic view of financial markets, such that a rate cut on economic fundamentals is not warranted. However, the policymakers fear that because the market expects a rate cut, the failure of the central bank to validate that market expectation will generate an excessive and reactive sell-off in bond markets. And if that happens, they reason, the sudden increase in bond yields could squeeze consumption and investment, thereby causing economic weakness to materialize. Should the central bank cut rates in this situation? If so, did market expectations “cause” an interest rate cut that otherwise would not have occurred? If not, and in fact the bond market panics and the economy contracts, did the central bank “cause” the resulting recession? Who was “right” about economic fundamentals in each case?

When this interdependent system of expectations is in equilibrium, it is indeed difficult to discern what is causing what. The equilibrium is simply co-determined by its constituent parts. It is when the system is shoved out of equilibrium that a distinctive signature becomes apparent.

To see that signature most clearly, we must again look across different asset classes, in particular at forward short-term rates and credit spreads. Ceteris paribus, we would expect changes in forward interest rates and credit spreads to be negatively correlated. A stronger macroeconomic outlook would tend to increase forward rates (in anticipation of central bank tightening) and to decrease credit spreads (in anticipation of lower risk of default), while a weaker macroeconomic outlook would tend to decrease forward rates (in anticipation of central bank easing) and to increase credit spreads (in anticipation of higher risk of default).
When we look at the correlation coefficient between these two variables graphed in Figure 14, we see that it is indeed negative the vast majority of the time. It is when the correlation coefficient turns positive that something of obvious interest is happening. These mark episodes where rates and credit spreads were moving in the same direction, contrary to the normal expectation. Two episodes where they were simultaneously increasing are marked in red, while two episodes where they were simultaneously decreasing are marked in green.34

- **Rates and Credit Spreads Both Increasing.** The first instance was in the spring of 2007, accompanying statements by Federal Reserve Chair Bernanke in March and May that included the assessment that “troubles in the subprime sector...will likely be limited.” These comments punctured market expectations for monetary easing, causing forward rates to rise while also pushing up credit spreads, as investors feared a rising risk of recession in the absence of easier monetary conditions. The second was in the late spring and summer of 2013, when Bernanke’s comments on the tapering of asset purchases led the market to dramatically scale back its assumptions about future monetary accommodation and reflation, leading to both rising forward rates and rising credit spreads.

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34 The months following the bankruptcy of Lehman Brothers also featured positive correlations, reflecting the correlated breakdown of liquidity and spread of credit risk widely across financial markets.

• Rates and Credit Spreads Both Decreasing. The first instance was in the fall of 2010 after the announcement of QE2, which many market participants interpreted as a commitment to easy monetary policy that boosted inflationary prospects, leading to the combination of lower forward rates and lower credit spreads. The second was in the winter of 2011-12, following the Federal Reserve’s agreement to extend billions in swap line arrangements with foreign central banks to boost dollar liquidity in global markets amid concerns about the Eurozone.

These episodes offered vivid instantiations of how Fed decisions on interest rates and asset purchases affected financial markets. But what about all the rest of the times when the Fed acted and correlations behaved normally (i.e., remained negative)? Is there nothing to see there?

To the contrary, this discussion illustrates that “validating” or “not validating” market expectations is a consequential—yet subtle—aspect of central bank actions. We saw that in the spring of 2007, Bernanke’s comments dismissing the potential for the interest rate cut anticipated by markets produced the unusual configuration of rising forward rates alongside rising credit spreads. Figure 15 shows the 3-year forward rate before and after this episode. Beginning in the summer of 2006, the market started to anticipate that monetary conditions would need to be eased amid a contracting housing market. When Bernanke spoke in the spring of 2007 downplaying this idea, those expectations were punctured and forward rates increased sharply. Later in the summer, when subprime problems began interfering with normal money market functioning, leading the Fed to cut the discount rate in August, forward rates again fell dramatically and in fact the Fed began cutting the Federal Funds rate in September.

![Figure 15. 3yr Forward Rate in 2006-7](chart)

March & May 2007
Bernanke does not validate expectations, saying subprime impact “likely to limited” with no “significant spillovers”

August 2007
BNP fund failure & Fed cuts discount rate

Market begins to price monetary easing to combat housing collapse

Speculative path of forward rate if Bernanke remarks had validated market expectations

VALIDATION is easier to identify when it DOESN’T happen than when it DOES
Now imagine the counterfactual where Bernanke had instead declared that the problems in the housing market were serious and signaled an openness to easier monetary policy in spring 2007. It is likely that in such a scenario there would not have been a spike upward in forward rates (the red arrow); rather, depending upon the forcefulness of Bernanke’s hypothetical statement, forward rates might have continued to drift lower (as depicted in the imagined green arrow). Note that, in that hypothetical world, correlations between forward rates and credit spreads might have stayed in their normal state of negative. Note further that, in this hypothetical world, a structural break analysis of the counterfactual Figure 15 might not have even detected a break in spring 2007, but rather in summer 2006 when the market pricing for forward rates began to anticipate easing of monetary policy.

A hypothetical statement by Bernanke validating market expectations for monetary easing in the spring of 2007 would have been every bit as consequential as actual events, though it may not have registered the same obvious indicator flags. In this sense, actions that confirm market expectations are the financial equivalent of Sherlock Holmes’ dog that didn’t bark—meaningful but subtle, and more obvious when absent than present.36

Understanding these dynamics is important to drawing out the story being revealed by market data. Sometimes the story is easy to discern, such as when there are obvious anomalies in cross-asset correlations. Other times, the obvious anomalies may be absent. In those instances, the tools introduced in this paper—modelling the market-expected future policy reaction function, identifying structural breaks, and examining the timing of unusual periods of market performance—allow us assemble a picture of the underlying relationships.

SECTION 6 – CONCLUSIONS

The key empirical findings of this paper can be summarized as follows:

1. Innovations in the Federal Reserve’s unconventional policies were associated with significant and measurable shifts in market expectations for the Fed’s future policy reaction function.

2. These effects were large and statistically significant—shifting the market’s expectation of the Fed’s future policy reaction function down by as much as 225 basis points—in addition to being robust to model specification using different empirical methods.

3. Shifts in the market-expected policy reaction function imply unconventional policies from 2010 on reduced 10-year Treasury yields by as much as 144 basis points via QE2 (−29 basis points), Forward Guidance/Operation Twist (−70 basis points), and QE3 (−45 basis points).

4. Indications that balance sheet support would be withdrawn were associated with investor expectations of a more restrictive Fed reaction function, implying higher 10-year Treasury yields accompanying Bernanke’s signal on the tapering asset purchases in 2013 (+96 basis points) and the beginning of balance sheet reduction in late 2017 (+32 basis points).

5. Direct estimates of the impact on 10-year Treasury yields confirm both the magnitude and timing of these effects. The direct estimates suggest an even larger cumulative impact (~203 basis points), while the close proximity of statistically determined break dates in 10-year yields to key policy innovations offers further support for the causal link to Fed actions.

6. Balance sheet policy innovations were typically accompanied by changes in market expectations for inflation and growth. The boost in reflationary expectations associated with expansionary policy innovations muted observed declines on 10-year U.S. Treasury yields during QE, while affecting prospective returns on risk assets such as equities and credit.

7. Periods of unusual performance in equity and credit markets were highly correlated with innovations in balance sheet policies. Half of the 10 largest quarterly rallies and sell-offs in equity markets began within one week of a major balance sheet announcement. Three of the five largest sell-offs in credit markets started within one week of the ends of QE1, QE2, and QE3. The probability that these events would coincide by chance is vanishingly low.

8. In sum, this study finds that the impact of Federal reserve policies on financial markets between 2010 and 2018 was large and pervasive. By altering market expectations of the Federal Reserve’s future policy reaction function, the Fed’s balance sheet policies influenced investor behavior and price formation across bond, credit, and equity markets.

Areas for Further Research

The methodologies introduced and empirical results presented in this paper suggest several areas for further research:

- The paper introduced a Taylor Rule-type framework for measuring the impact of unconventional central bank policies via shifts in the market’s expectations for the central bank’s future policy reaction function. This framework can be extended to other economies that have employed balance sheet policies, such as the Eurozone.

- This paper presented evidence that innovations in balance sheet policies were highly correlated with periods of unusual performance in equities and credit markets. Future work can build on this by developing methods to more precisely estimate the magnitude of these effects, elaborate causal channels, and extend the analysis to other asset classes.

- The consequences of interlocking expectations that central banks and markets have about one another’s behavior were also explored. These ideas can be formalized and incorporated into Dynamic Stochastic General Equilibrium (DSGE) models to more rigorously understand their complex properties; explore how policy rules for unconventional policies might achieve desired policy goals; and translate the impact of shifts in the market-expected policy reaction function into estimated effects on consumption, investment, growth, and employment.

- Evidence presented in this paper suggests the key role shifts in expectations played in mediating the effect of balance sheet policies, in particular market expectations about the future policy reaction function. How important are actual asset purchases (“putting money
where your mouth is”) to achieving such shifts, versus verbal commitments alone? What attributes of central bank actions catalyze shifts that reshape diagnostic expectations of the kind described by Gennaioli and Shleifer (2018) or narratives described by Shiller (2019)?

- This paper demonstrated the value of regression analysis with structural breaks to measure the significance of policy innovations and quantify their effects, especially when such effects are incorporated over time. Such methods may be relevant to a broader set of macrofinancial research questions, as an alternative to event study-based approaches.

- Finally, the evidence here suggests a “dashboard” of market indicators that gauge the central bank’s impact on markets should include not only include individual asset prices, but also cross-correlations and other measures that integrate multi-asset price movements. More work can be done to enumerate more cross-market indicators that would be useful in this regard.

Normative and Policy Considerations

The findings enumerated above are descriptive, not normative. They do not speak to whether it is good or bad that the Federal Reserve had such far-reaching effects on asset prices. Skeptics might argue that such effects represent a distortion in the allocation of capital in the economy. Should we want central banks to play such a role?

Answering that question requires considering the alternatives and the context. Between 2007 and 2009, the United States experienced by far the largest peak-to-trough contraction in six decades. GDP contracted by 4 percent at the trough, representing more than $600 billion in lost output. The shock to private demand was even more severe, falling 6.3 percent at its nadir. More than 8.7 million jobs were lost.

Policymakers responded with aggressive fiscal and monetary stimulus in 2008-09, which averted an even more severe contraction. Another Great Depression was avoided. But the road to recovery was arduous. Private demand had recovered less than half of its lost ground by the middle of 2010 and would only fully recover to its pre-crisis level in early 2012. Yet despite the still-fragile recovery, the policy support for the economy began to be unwound. While monetary policy rates remained near zero, the Federal Reserve ended its QE1 asset purchase program at the end of March 2010.

The withdrawal of fiscal support was even more dramatic. Figure 16 shows the trailing four-quarter contribution of government spending to GDP growth from the start of the 2007-09 recession in December 2007 in orange, in comparison to the average of the past three recessions (1982-83, 1990-91, and 2001) in blue. Not surprisingly, the peak fiscal response to the global financial crisis was larger than previous recessions, adding +0.8 percentage points of GDP growth in the four quarters ending in the first quarter of 2009. But the most striking aspect is rapid decline in the contribution of government spending to GDP growth, which turned negative in the third quarter of 2010. In the four quarters ending in the third quarter of 2011, declining government spending subtracted a peak of −0.8 percentage points from GDP growth.

37 In constant 2012 dollars, the current baseline for U.S. Government Bureau of Economic Analysis (BEA) statistics.
Such a sharp fiscal contraction so early in a recovery is historically anomalous. This is evident by comparing the orange 2007-09 recession line to the blue line showing the average government spending contribution to growth during the previous three recessions in Figure 16. It is also illustrated in Figure 17, which shows how far along the recovery in private demand had progressed when the government spending contribution turned negative. Following the 1982-83 and 2001 recessions, fiscal support was not withdrawn at all before the next recession. Following the 1990-91 recession, fiscal support first turned negative when private demand recovered to +2.1 percent above its pre-crisis peak. In contrast, following the 2007-09 crisis, falling government spending began to pull down GDP growth when private demand was still −3.5 percent below its pre-crisis peak.

With fiscal policy acting as a drag on a still-weak economy, monetary policy had to bear the burden of sustaining the recovery. Monetary policy was—to use the apt phrase of El-Erian (2017)—“the only game in town.” With policy rates already effectively at zero, central banks needed to develop new tools to play that game. The result was a set of novel policy initiatives—QE2, Forward Guidance, Operation Twist, and QE3. In fact, the period of implementation of those initiatives exactly coincides with the period during which fiscal spending was negatively contributing to GDP growth—from Bernanke’s QE2 Jackson Hole speech in the third quarter of 2010 through the announcement ending QE3 in the third quarter of 2014!

Against the backdrop of fiscal contraction, it was appropriate—indeed essential—for the Federal Reserve to embrace unconventional policies aimed at keeping the recovery going. Without the support to aggregate demand from such policies, the recovery would almost certainly have been slower (or stalled completely), fewer jobs would have been created, and wages for Americans across the income spectrum would have been lower.
At the same time, the findings in this paper suggest why a different policy mix—one that included stronger and more sustained fiscal support, with less reliance on monetary policy—could have been better for the U.S. economy and society. The novel balance sheet policies adopted by the Federal Reserve reached the broader economy via their impact on financial markets, a transmission mechanism with potential distributional consequences. The ownership of financial assets is highly concentrated; therefore, the benefits of rising returns and higher asset prices are distributed unequally across the socioeconomic spectrum. Indeed, measures of both income and wealth inequality increased in the years after the Great Recession (Wolff 2017; Piketty, Saez, and Zucman 2018).

While the net impact of unconventional policies on inequality remains subject to debate (see the recent survey by Colciago, Samarina, and de Haan 2019), the findings in this paper suggest that the impact on financial markets from Fed policies may have been larger and more pervasive than previously estimated. If that is the case, greater use of fiscal levers and lesser reliance on monetary policy—with its financial channel for reaching the broader economy—might have mitigated some of these distributional outcomes. In other words, a more balanced policy mix might have produced a more balanced recovery.

**Final Thoughts**

It is critical that we fully understand how the Federal Reserve’s balance sheet policies adopted in the wake of the global financial crisis worked, the scope of their effects, and the mechanisms through which they have operated. The experience of the Federal Reserve from 2010 through 2018 shows that unconventional policies play a powerful role in reshaping market expectations of the central bank’s future policy reaction function. These shifts in market expectations in turn have pervasive effects on asset markets and financial conditions.

Simply put, the evidence shows that balance sheet policies are a potent tool in the arsenal of emergency economic management. The best scenario, of course, is that such unconventional policies not be needed at all. The 2008-09 experience teaches us that better oversight and regulation of the financial system are essential to helping prevent the conditions that lead to systemic crises in the first place. And the contours of the post-crisis recovery suggest that when economic weakness does materialize, deploying more sustained fiscal support to aid the recovery is needed as part of a balanced policy response, so that less of the burden falls on exceptional monetary policies. This full suite of lessons is worth bearing in mind as policymakers prepare to navigate the economic challenges of the future.
APPENDIX

**Figure A1.**

3yr Forward Rate
(12th Eurodollar Futures Contract)

**Figure A2.**

3yr Expected Trailing Inflation Rate
(Bootstrapped from 2y and 3y Par Inflation Swap)

**Figure A3.**

Credit Spreads
(Merrill Lynch BBB Option-Adjusted Spreads Index)
Figure A4.  
*Market-Expected Policy Reaction Function*  
*Pre-Identified Policy Date Model*  
*Actual versus Predicted*  

Figure A5.  
*10-Year US Treasury Yield*  
*Pre-Identified Policy Date Model*  
*Actual versus Predicted*
### Table A1. Full Structural Change Model

<table>
<thead>
<tr>
<th>START DATE OF PERIOD</th>
<th>NO. OBS.</th>
<th>CONSTANT</th>
<th>EXPECTED INFLATION</th>
<th>OAS</th>
<th>AVERAGE PREDICTED VALUES: PERIOD VS. BASELINE MODELS: (CUMULATIVE)</th>
<th>DIFFERENCE VS. PREVIOUS PERIOD (INCREMENTAL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4/1/2010 (Baseline)</td>
<td>119</td>
<td>1.24 **</td>
<td>1.30 ***</td>
<td>-0.50 ***</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>9/21/10</td>
<td>222</td>
<td>(0.62)</td>
<td>(0.17)</td>
<td>(0.17)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8/10/11</td>
<td>451</td>
<td>1.09</td>
<td>-0.26</td>
<td>0.25 *</td>
<td>-1.88</td>
<td>-1.24</td>
</tr>
<tr>
<td>6/3/13</td>
<td>696</td>
<td>4.10 ***</td>
<td>-0.19</td>
<td>-0.82 ***</td>
<td>-0.73</td>
<td>1.15</td>
</tr>
<tr>
<td>3/18/16</td>
<td>459</td>
<td>-0.23</td>
<td>1.40 ***</td>
<td>-0.32 ***</td>
<td>-0.98</td>
<td>-0.25</td>
</tr>
<tr>
<td>1/18/18</td>
<td>238</td>
<td>0.72</td>
<td>0.95 **</td>
<td>0.06</td>
<td>-0.48</td>
<td>0.51</td>
</tr>
</tbody>
</table>

R-Squared 0.92  
Observations 2185

Least squares with Newey-West standard errors corrected for heteroskedasticity and autocorrelation. Bai-Perron parameters are $M = 5$ (maximum breaks) and $\varepsilon = 0.05$ ($h = 110$ minimum observations per segment). The procedure recommended for empirical applications in Bai and Perron (2003) is employed to select the number of breaks: if $UD \max$ and $WD \max$ statistics exceed critical values to indicate presence of at least one structural break, then the number of breaks is identified by examining $supF_t(t+1|t)$ tests in sequence until additional breaks are rejected. *, **, *** indicate significance at the 90%, 95%, and 99% levels.
REFERENCES


