Measuring the Effect of the Zero Lower Bound on Medium- and Longer-Term Interest Rates

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Abstract

The zero lower bound on nominal interest rates has constrained the Federal Reserve's setting of the overnight federal funds rate for over three years running. According to many macroeconomic models, such an extended period of being stuck at the zero bound has important implications for the effectiveness of monetary and fiscal policies. However, economic theory also implies that households' and firms' decisions depend on the entire path of expected future short-term interest rates, not just the current level of the overnight rate. Thus, interest rates with a year or more to maturity are arguably the most relevant for the private sector, and it is unclear to what extent the zero lower bound has affected those rates. In this paper, we propose a novel approach to measure when and to what extent the zero lower bound affects interest rates of any maturity. We compare the sensitivity of interest rates of various maturities to macroeconomic news during periods when short-term interest rates are very low to that during normal times. We find that yields on Treasury securities with six months or less to maturity have been strongly affected by the zero bound during most or all of the period when the federal funds rate was near zero. In stark contrast to this finding, yields with more than two years to maturity have responded to economic news during the past three years in their usual way. One- and two-year Treasury yields represent an intermediate case, being partially constrained by the zero bound over part of the period when the funds rate was near zero. We provide two explanations for these results. First, market participants have consistently expected the zero bound to constrain policy for only about a year into the future, minimizing its effect on longer-term yields. Second, the Federal Reserve's unconventional policy actions may be offsetting the effects of the zero bound on longer-term yields.

Keywords: monetary policy, zero lower bound, fiscal policy

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1 Introduction

The zero lower bound on nominal interest rates has clearly constrained the federal funds rate—the Federal Reserve's traditional monetary policy instrument—since December 2008, when it was lowered to a floor of essentially zero. However, standard textbook macroeconomic models (e.g., Clarida, Galí, and Gertler 1999, Woodford 2003) imply that monetary policy affects the economy through its effects on *longer*-term interest rates, not just the current level of the overnight rate, and it is not clear whether the zero lower bound has substantially constrained the Fed's ability to affect these longer-term interest rates. Theoretically, if a central bank has the ability to commit to future values of the policy rate, it can work around the zero bound constraint by promising monetary accommodation in the future once the zero bound ceases to bind (Reifschneider and Williams 2000, Eggertsson and Woodford 2003). Empirically, Gürkaynak, Sack, and Swanson (2005b) found that the effects of Federal Reserve policy announcements on asset prices are driven primarily by the Federal Open Market Committee (FOMC) statement's effects on financial market expectations of *future* monetary policy, rather than changes in the current federal funds rate target. And Figure 1 shows that yields on U.S. Treasury securities with a year or more to maturity remained well above zero throughout much of 2008–11, suggesting that those yields were not *directly* constrained by the zero bound during this period. Indeed, on several occasions, the Federal Reserve was able to generate a decline in medium- and longer-term Treasury yields of as much as 20 basis points by managing monetary policy expectations and by asset purchases.[1] These actions and their effects suggest that monetary policy still had room to affect the economy, despite the constraint on the current level of short-term interest rates.

In addition to monetary policy considerations, the extent to which the zero lower bound affects interest rates of different maturities has important implications for fiscal policy. Numerous authors have emphasized that the macroeconomic effects of fiscal policy are much larger when the zero lower bound is binding, because in that case interest rates do not rise in response to higher output, and private investment is not "crowded out" (e.g., Christiano, Eichenbaum, and Rebelo

[1] For example, on August 9, 2011, the FOMC stated, "The Committee currently anticipates that economic conditions. . . are likely to warrant exceptionally low levels for the federal funds rate at least through mid-2013." In response to this announcement, the 2-year Treasury yield fell 8 basis points (bp), while the 5- and 10-year Treasury yields each fell by 20 bp. Note that, in normal times, it would take a surprise change in the federal funds rate of about 100 bp to generate a fall of 8 to 20 bp in intermediate-maturity yields (Gürkaynak et al. 2005a).

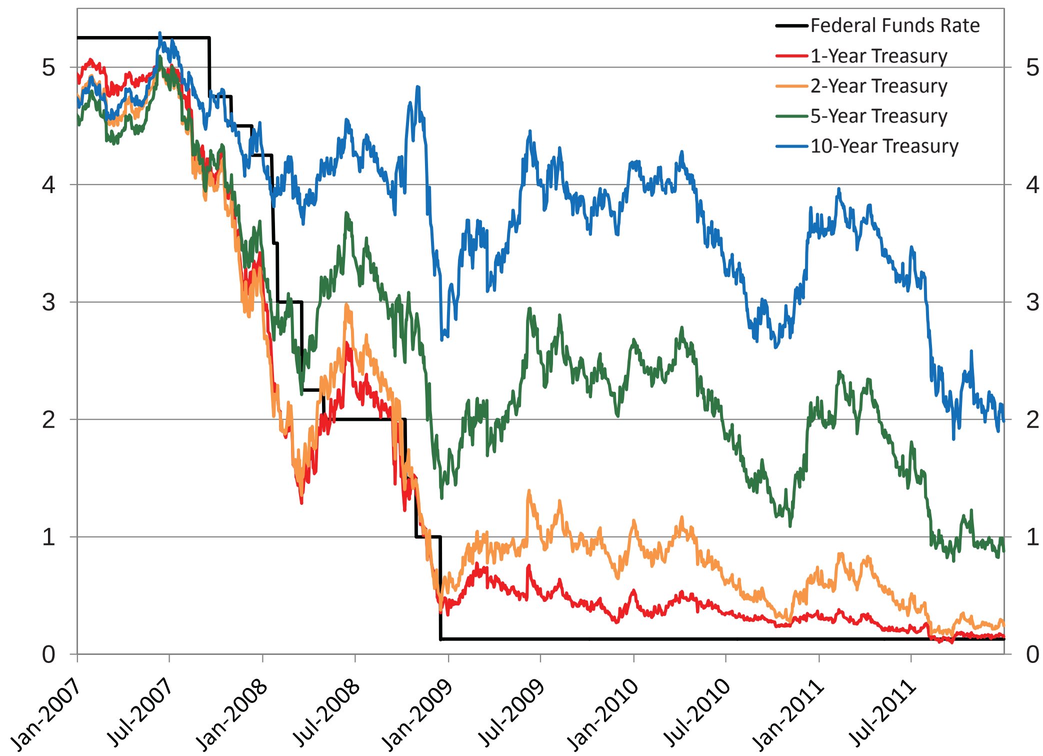

Figure 1. Federal funds rate target and 1-, 2-, 5-, and 10-year zero-coupon Treasury yields from January 2007 through December 2011.

2011, Erceg and Lindé 2010, Eggertsson and Krugman 2011). However, standard macroeconomic theory implies that private-sector spending is determined by the future path of short-term interest rates and not just the current level of the overnight rate. As emphasized by Christiano et al. (2011) and Erceg and Lindé (2010), the fact that the one-period interest rate is at the zero lower bound is largely irrelevant for measuring the fiscal multiplier. Instead, the extent to which private spending is crowded out by fiscal stimulus depends on the *length of time* that monetary policy is constrained by the zero lower bound. In other words, the fiscal multiplier depends on the extent to which medium- and longer-term yields are affected by the zero bound.

In this paper, we propose a novel method of measuring the extent to which interest rates of any maturity—and hence monetary policy, more broadly defined—are constrained by the zero lower bound. In particular, we estimate the time-varying sensitivity of yields to macroeconomic announcements using high-frequency data and compare that sensitivity to a benchmark period in which those yields were unconstrained by the zero bound (taken to be 1990–2000). In periods in which the yield is about as sensitive to news as the benchmark sample, we say that the yield is unaffected by the zero bound. In periods when the yield responds very little or not at all to news, we say that the yield is completely constrained. Intermediate cases are measured by the degree of the yield's sensitivity to news relative to the benchmark period, and the severity and statistical significance of the effects can be assessed using standard econometric techniques. This is the first method to our knowledge that sheds light on how relevant the zero bound constraint has been for intermediate- and longer-maturity yields, and thus to what extent the zero bound has hindered the effectiveness of monetary policy, and to what extent crowding out has reduced the effectiveness of fiscal policy.

We emphasize that the level of a yield alone is not a useful measure of whether that yield is constrained by the zero lower bound, for three reasons. First, there is no way to quantify the severity of the zero bound constraint or its statistical significance using the level of the yield alone. For example, if the one-year Treasury yield is 50 basis points (bp), there is no clear way to determine whether that yield is severely constrained, mildly constrained, or even unconstrained. By contrast, the method we propose in this paper provides an econometrically precise answer to this question.

Second, the lower bound on nominal interest rates may be above zero for institutional reasons, and this "effective" lower bound may vary across countries or over time.[2] For example, the Federal Reserve has held the funds rate at a floor of 0 to 25 bp from December 2008 through at least the end of 2011, but the Bank of England has maintained a floor of 50 bp for its policy rate over the same period while conducting unconventional monetary policy on a similar scale to the Federal Reserve. Thus, the effective floor on nominal rates in the U.K. appears to be 50 bp, rather than zero. As a result, a 50 or even 100 bp gilt yield in the U.K. might be substantially constrained by the effective U.K. lower bound of 50 bp, while a similar 50–100 bp yield in the U.S. might be only mildly constrained or unconstrained.[3] The approach in this paper relies on the sensitivity of interest rates to news rather than the level of rates, and thus can accommodate effective lower bounds that may be appreciably greater than zero or change over time.

[2]See Bernanke and Reinhart (2004) for a discussion of the institutional barriers to lowering the policy rate all the way to zero.

[3]As another example, in 2003, the Federal Reserve lowered the funds rate to 1 percent, at which point it began to use forward guidance, such as the phrase "policy accommodation can be maintained for a considerable period," to try to lower longer-term interest rates without cutting the funds rate any further (see, e.g., Bernanke and Reinhart 2004; the quotation is from the FOMC statement dated August 12, 2003). Thus, one can make a good case that the effective lower bound on the funds rate in 2003–04 was 100 bp rather than zero.

Third, the sensitivity of interest rates to news is more relevant than the level of yields for the fiscal multiplier. As discussed in Christiano et al. (2011) and others, what is crucial for the fiscal multiplier is whether or not interest rates respond to the government spending shock; the level of yields is largely irrelevant. Although the zero lower bound motivates the analysis in those studies, their results are all derived in a "constant interest rate" environment in which nominal interest rates can be regarded as being fixed at any absolute level. If we estimate that the interest rates relevant for private-sector spending are half as sensitive to news as in "normal" times, that would suggest a fiscal multiplier that is roughly halfway between the normal value of 1 or a little less estimated by Christiano et al. (2011), for example, and the much larger, constant-interest-rate multiplier estimated by those authors.

To preview our results, we find that Treasury yields with six months or less to maturity were severely constrained by the zero lower bound from the spring of 2009 through the end of 2011. In contrast, Treasury yields with two years or more to maturity were substantially unaffected by the zero bound over this same period, with only the two-year Treasury yield becoming partially constrained in the second half of 2011. One-year Treasury yields represent an intermediate case, with damped sensitivity to news from the beginning of 2010 through mid-2011, and almost complete insensitivity to news thereafter. Importantly, our method provides a quantitative measure of the *degree* to which the zero bound affects each yield, as well as the periods during which it was affected.

We provide two explanations for these results. First, up until August 2011, market participants consistently expected the zero bound to constrain policy for only about a year into the future, minimizing the zero bound's effects on longer-term yields. Second, the Federal Reserve's unconventional policy actions may be offsetting the effects of the zero bound on longer-term yields.

The remainder of the paper proceeds as follows. Section 2 lays out a simple New Keynesian model that illustrates some of the observations we will use in our empirical analysis. Section 3 describes our empirical framework. Our main results are reported in Section 4. Section 5 considers various extensions, additional results, and discussion related to our main findings. Section 6 concludes.

2 An Illustrative Model

In this section, we use a simple macroeconomic model to illustrate the effects of the zero lower bound on the responsiveness of yields to economic news. In particular, we use the model to illustrate three important points that we will employ in our empirical analysis, below. First, we show that when short-term interest rates are constrained by the zero lower bound, then yields of all maturities respond less to economic announcements than if the zero bound were not present; moreover, the reduction in the responsiveness of yields to news is greatest at short maturities and is smaller for longer-term yields. Second, the effects of the zero bound on the sensitivity of yields to news is essentially *symmetric*—that is, the responsiveness of yields to both positive and negative announcements falls by about the same amount when the zero bound is strongly binding on short-term rates. And third, the zero bound dampens the sensitivity of yields to news by roughly similar amounts for different types of shocks, so long as the persistence of those shocks are not too different.

To conduct this analysis, we use a simple, textbook New Keynesian model consisting of three equations that describe the evolution over time t of the output gap, y_t, the inflation rate, π_t, and the one-period risk-free nominal interest rate, i_t. The purpose of this theoretical exercise is to illustrate qualitatively how the zero lower bound may affect the sensitivity of bond yields and forward interest rates to news. The model is purposefully simplistic and not intended to capture the quantitative effects we estimate below.

The equation for the output gap is based on the consumption Euler equation, relating the current level of the output gap to the difference between the current ex ante real interest rate, $i_t - E_t\pi_{t+1}$, and the natural rate of interest, r_t^*, and the expected level of the output gap next period:

$$y_t = -\alpha(i_t - E_t\pi_{t+1} - r_t^*) + E_t y_{t+1}. \tag{1}$$

Solving this equation forward, we have:

$$y_t \;=\; -\alpha\, E_t \sum_{j=0}^{\infty} \{i_{t+j} - \pi_{t+j+1} - r_{t+j}^*\}. \tag{2}$$

This equation makes clear that the current level of the output gap depends on the expected future path of short-term interest rates, as well as expected inflation and the natural rate of interest. As emphasized by many authors (e.g., Clarida, Galí, and Gertler 1999, Woodford 2003), the expectations hypothesis of the term structure implies that the quantity $E_t \sum_{j=0}^{\infty} i_{t+j}$ is closely related to the nominal long-term interest rate in the economy.

We model shocks to output as shocks to the natural interest rate, r_t^*. We assume that the natural interest rate follows a stationary AR(1) process,

$$r_t^* \;=\; (1-\rho)\bar{r}^* + \rho r_{t-1}^* + e_t, \tag{3}$$

where $\rho \in (-1, 1)$ and $\bar{r}^*$ denotes the unconditional mean of the natural rate of interest.

The equation for inflation is based on a standard textbook model of Calvo price adjustment and is given by:

$$\pi_t \;=\; \gamma y_t + \beta E_t \pi_{t+1} + \mu_t, \tag{4}$$

where μ_t can be thought of as a markup shock, assumed to follow a mean-zero stationary AR(1) process:

$$\mu_t \;=\; \delta \mu_{t-1} + v_t, \tag{5}$$

where $\delta \in (-1, 1)$.

We assume that the central bank sets the one-period risk-free rate, i_t, according to a version of the Taylor Rule (Taylor 1993), subject to the constraint that i_t must be nonnegative:

$$i_t \;=\; \max\{\, 0,\; \pi_t + r_t^* + 0.5(\pi_t - \bar{\pi}) + 0.5 y_t \}, \tag{6}$$

where $\bar{\pi}$ denotes the central bank's inflation target, assumed to equal 2.

Note that monetary policy is assumed to respond to the current level of the natural interest rate. This implies that, absent the zero lower bound, monetary policy would perfectly offset the effects of shocks to the natural rate of interest on the output gap and inflation. Of course, the presence of the zero lower bound implies that, in certain circumstances, monetary policy will be unable to offset such shocks.

Consistent with the log-linearized structure of the economy implicit in equation (1)–(5), we assume that long-term bond yields in the model are determined by the expectations hypothesis. Thus, the M-period yield to maturity on a zero-coupon nominal bond, i_t^M, is given by:

$$i_t^M \;=\; E_t \sum_{j=0}^{M-1} i_{t+j} \;+\; \phi^M, \tag{7}$$

where ϕ^M denotes an exogenous term premium that may vary with maturity M but is constant over time.

We solve for the impulse response functions of the model under two scenarios: first, a scenario in which the initial value of r_t^* is substantially greater than zero, so that the zero lower bound is not a binding constraint on the setting of the short-term interest rate. And second, in a scenario in which the initial value of r_t^* is -4, which is sufficient for the zero bound to bind the short-term nominal rate i_t for several periods. In the latter case, we solve the model using a perfect foresight algorithm, as in Reifschneider and Williams (2000), which solves for the impulse response functions of the model to an output or inflation shock under the assumption that the private sector assumes that realized values of all future innovations will be zero.

We set the model parameters $\alpha = 1.5924$ and $\gamma = 0.0960$, based on Woodford (2003). For the simulations, we set the shock persistence parameters $\rho = 0.85$ and $\delta = 0.5$. The choice of the shock persistence parameters is somewhat arbitrary, but it allows us to examine the effects of the persistence of the shock on the sensitivity of yields to news under the zero bound. We calibrate the magnitude of the shocks so that they each generate a 5 basis point response of the one-period interest rate i_t on impact, assuming the zero lower bound is not binding. This calibration is consistent with the finding that any given macroeconomic news surprise typically moves shorter-term yields by a few basis points (as discussed along with our empirical results below).

The top panels of Figure 2 report the impulse response functions of the one-period nominal interest rate, i_t, to a shock to output (the natural rate of interest) and a shock to inflation (the markup), respectively. In each of these panels, the solid black line depicts the impulse response function—computed as a difference from the baseline path of the economy absent the shock—to a positive shock to output or inflation in the case where the zero lower bound is not binding. Thus, the solid black lines correspond to the standard impulse response functions to an output or inflation shock in a standard textbook New Keynesian model. The dashed red line in each panel depicts the impulse response function for i_t to the same shock when the zero lower bound is binding—that is, when the initial value of r_t^* is set equal to -4 percent. In each case, the impulse responses are computed relative to a baseline in which r_t^* begins at -4 percent but is returning toward $\bar{r}^*$, so that the zero bound ceases to bind the short-term interest rate i_t in three periods.

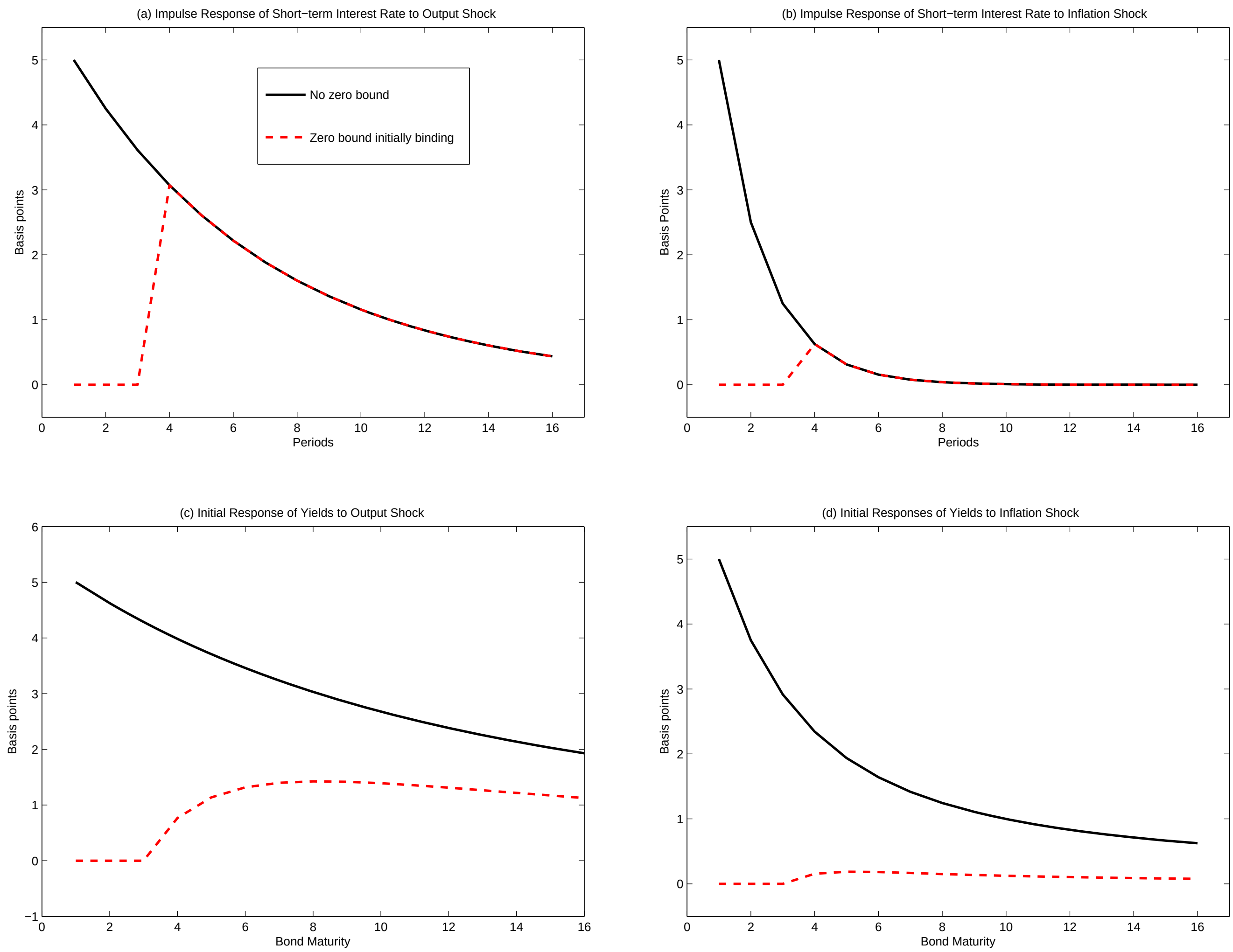

Figure 2. Response of short-term interest rate and the yield curve to output and inflation shocks in a simple New Keynesian model, with and without the zero bound constraint on monetary policy. Shocks are normalized to produce a 5 basis point effect on the one-period nominal interest rate on impact. (a) impulse response function of one-period interest rate to an output shock and (b) an inflation shock. (c) initial response in period 1 of the yield curve to an output shock and (d) an inflation shock; x-axis in the bottom panels denotes bond yield maturity rather than periods after the shock. See text for details.

Note that, once the zero bound ceases to bind in Figure 2, the behavior of the interest rate i_t is identical to what would occur absent the zero bound—that is, the red and black lines in the top panels of Figure 2 are identical. This is because output and inflation in this particular model are purely forward-looking. More generally, in models with some intrinsic output or inflation inertia, the zero bound affects the entire paths of those variables, which, in turn, have lasting effects on interest rates.

The bottom panels of Figure 2 depict the responses on impact of the yield curve to an output or inflation shock in period 1, the period when the shock hits. Thus, the bottom panels of Figure 2 are not impulse response functions, but rather plot the instantaneous response of the entire yield curve at a single point in time.

The first main observation to take away from Figure 2 is that the response of the yield curve to shocks is attenuated when the zero bound constrains policy, and the degree of attenuation declines with the maturity of the bond. This can be seen clearly in the bottom panels of Figure 2. For the shortest maturities, there is a total lack of responsiveness of the yield curve to an output or inflation shock when the zero bound is binding, whereas for the longest-maturity bonds, the response of the yield curve to an output or inflation shock becomes closer to the normal, unconstrained response. Intermediate-maturity bonds are constrained by the zero bound to an intermediate extent. The intuition for these results is very clear and holds for models that are more general than the simple New Keynesian model we have used as an illustrative example in this section.

The second main point to take away from the model is that the responses of yields to shocks are essentially symmetric to positive and negative shocks. Figure 2 plots the response of the model to small positive shocks, but the results for small negative-signed shocks of the same size are exactly the same in absolute value. This symmetry holds perfectly as long as the number of periods that policy is constrained at the zero bound does not change, which is the case for small shocks.

Even for larger shocks, the responses of yields are essentially symmetric. Figure 3 plots the absolute value of the impulse responses of the model to a positive (dashed red line) and negative (solid blue line) output shock that are each ten times larger than in Figure 2, for the case where the zero bound is binding. The two lines in the first panel are almost identical, except that the dashed red line lifts off from the zero bound one period sooner than the blue line, because the positive

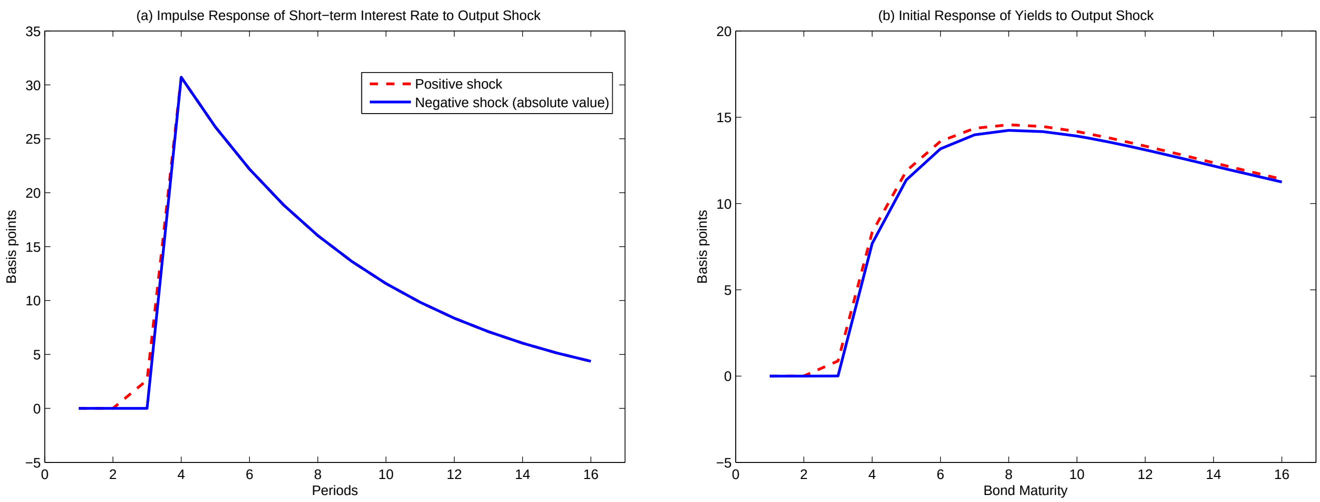

Figure 3. Absolute value of responses of short-term interest rate and yield curve to large positive and negative output shocks in the simple New Keynesian model when the zero bound is binding. Shocks are normalized to produce a 50 bp effect on the one-period nominal interest rate on impact, ten times as large as in Figure 2. (a) impulse response function of one-period interest rate to the output shock; (b) initial response of the yield curve to an output shock. See text for details.

shock increases policymakers' desired interest rate above the zero bound in that period. Once the zero bound ceases to bind in period 4 and beyond, both lines are identical for the same reasons as in Figure 2. The second panel of Figure 3 plots the absolute value of the yield curve response in period 1 to the positive and negative output shocks underlying the first panel.

The fact that the zero bound causes the yield curve to be damped almost symmetrically to positive and negative announcements can be counterintuitive at first, since the zero bound is a one-sided constraint. Nevertheless, the intuition is very clear and holds much more generally than in just the simple model of this section: When the zero bound is a severe constraint on policy—that is, policymakers would like to set the one-period nominal interest rate far below zero for several periods—then short-term yields are completely unresponsive to *both* positive and negative shocks, as long as those positive shocks are not large enough to bring short-term rates above the zero bound. Similarly, medium-term yields are about equally damped in response to positive and negative shocks, because: (a) medium-term yields are an average of current and expected future short-term rates, (b) current short-term rates do not respond to either positive or negative shocks when the zero bound is binding, and (c) expected future short-term rates respond symmetrically to positive and negative shocks in periods in which the zero bound is not binding. There are very few periods in which expected future short-term rates are unconstrained by the zero bound for the positive shock but still constrained for the negative shock, and even in those periods the interest rate differential between the two cases is typically very small. These small differences are negligible compared to the response of the yield curve as a whole, so the result is almost perfectly symmetric.

The third and final point to take away from the model is that the dampening effects of the zero bound on the sensitivity of yields is qualitatively the same regardless of the specific nature of the shock. However, the quantitative effects of the zero bound do depend on the persistence of the shock. That is, the dampening of the sensitivity of yields is greater for short-lived shocks that have their main effects on the short-term interest rate during the period that the zero bound is a binding constraint, as in the case of the inflation shock in Figure 2. The more persistent output shock continues to have large effects on interest rates in periods when the zero bound is not binding. As a result, there is less dampening of the sensitivity of longer-term yields in response to those shocks.

Note that this difference across the two shocks is not because of the type of shock, but because of the difference in persistence. If the degree of persistence in the two shock processes were the same, then the attenuation across maturities would be essentially identical for the output and inflation shocks. In models with more complicated dynamics, the effects of the zero bound would differ more substantially across the two types of shocks, but even in those models it remains true that the degree of attenuation across maturities is determined primarily by the length of time the zero lower bound is expected to bind, and not by the type of shock.

For the sake of parsimony in our empirical work below, we assume that the dampening effects of the zero bound on the sensitivity of the yield curve to news is the same for all shocks. In our theoretical model, this would only be exactly valid if all of the shocks have similar persistence characteristics in terms of their effects on short-term interest rates. We view this assumption as a testable approximation, which we will test in our empirical analysis.

3 Empirical Framework

We now seek to identify empirically the extent to which Treasury securities of different maturities have been more or less sensitive to macroeconomic announcements over time. We do this in three steps: First, we identify the surprise component of major U.S. macroeconomic announcements. Second, we estimate the average sensitivity of Treasury securities of each maturity to those announcements over a benchmark sample, 1990–2000, during which the zero bound was not a constraint on yields. Third, we compute the sensitivity of each Treasury yield in subsequent periods and compare it to the benchmark sample to determine when and to what extent each yield was affected by the presence of the zero lower bound. Periods in which the zero bound was a significant constraint on a given Treasury yield should appear in this analysis as periods of unusually low sensitivity of that security to macroeconomic news. We describe the details of each of these three basic steps in turn.

3.1 The Surprise Component of Macroeconomic Announcements

Financial markets are forward-looking, so the expected component of macroeconomic data releases should have essentially no effect on interest rates.[4] To measure the effects of these announcements on interest rates, then, we must first compute the unexpected, or surprise, component of each release.

As in Gürkaynak, Sack, and Swanson (2005a), we compute the surprise component of each announcement as the difference between the realized value of the macroeconomic data release on the day of the announcement less the financial markets' expectation for that realized value. We obtain data on financial market expectations of major macroeconomic data releases from two sources: Money Market Services (MMS) and Bloomberg Financial Services. Both MMS and Bloomberg conduct surveys of financial market institutions and professional forecasters regarding their expectations for upcoming major data releases, and we use the median survey response as our measure of the financial market expectation. Anderson et al. (2003) and other authors have verified that these data pass standard tests of forecast rationality and provide a reasonable measure of ex ante expectations of the data release, which we have verified over our sample as well.

Data from MMS for some macroeconomic series are available back to the mid-1980s, but are only consistently available for a wider variety of series starting around mid-1989, so we begin our sample on January 1, 1990. Bloomberg survey data begin in the mid-1990s but are available to

[4]Kuttner (2001) tests and confirms this hypothesis for the case of monetary policy announcements.

us more recently. When the two survey series overlap, they agree very closely, since they are surveying essentially the same set of financial institutions and professional forecasters. Additional details regarding these data are provided in Gürkaynak, Sack, and Swanson (2005a) and Gürkaynak, Levin, and Swanson (2010).

3.2 The Sensitivity of Treasury Yields to Macro Announcements

In normal times—when the presence of the zero bound is not affecting a given Treasury yield—that yield will respond to macroeconomic news. To measure this responsiveness, Gürkaynak et al. (2005a) estimate daily-frequency regressions of the form

$$\Delta y_t = \alpha + \beta X_t + \varepsilon_t \,, \tag{8}$$

where t indexes days, Δy_t denotes the one-day change in the Treasury yield over the day, X_t is a vector of surprise components of macroeconomic data releases that took place that day, and ε_t is a residual representing the influence of other news and other factors on the Treasury yield. Note that most macroeconomic data series, such as nonfarm payrolls or the consumer price index, have data releases only once per month, so on days for which there is no news about a particular macroeconomic series, we set the corresponding element of X_t equal to zero.[5]

Table 1 reports estimates of regression (8) for the 3-month, 1-year, and 10-year Treasury yields from January 1990 to December 2000, a period in which we assume the zero lower bound did not constrain these Treasury yields. We exclude days on which no major macroeconomic data releases occurred, although the results are very similar whether or not these non-announcement days are included. To facilitate interpretation of the coefficients in Table 1, each macroeconomic data release surprise is normalized by its historical standard deviation, so that each coefficient in the table is in units of basis points per standard-deviation surprise in the announcement.

The first column of Table 1 reports results for the 3-month Treasury yield. Positive surprises in output or inflation cause the 3-month Treasury yield to rise, on average, consistent with a Taylor-type reaction function for monetary policy, while positive surprises in the unemployment rate or initial jobless claims (which are countercyclical economic indicators) cause the 3-month

[5] Thus, if we write X as a matrix with columns corresponding to macroeconomic series and rows corresponding to time t, each column of X will be a vector consisting mostly of zeros, with one nonzero value per month corresponding to dates on which news about the corresponding macroeconomic series was released.

	Treasury yield maturity					
	3-month		1-year		10-year	
Capacity Utilization	1.67	(2.90)	1.50	(3.50)	1.48	(2.52)
Consumer Confidence	0.29	(0.60)	1.96	(4.65)	2.70	(5.39)
Core CPI	0.81	(2.58)	1.96	(4.62)	1.73	(3.38)
GDP (advance)	0.35	(0.74)	0.22	(0.30)	−0.69	(−0.62)
Initial Claims	−0.29	(−1.36)	−0.54	(−2.49)	−0.40	(−1.44)
ISM Manufacturing	0.98	(1.45)	2.80	(6.87)	2.64	(4.98)
Leading Indicators	0.80	(1.57)	1.29	(3.29)	0.69	(1.09)
New Home Sales	1.49	(3.57)	1.66	(4.69)	2.09	(4.30)
Nonfarm Payrolls	2.47	(4.40)	3.93	(7.27)	2.90	(4.03)
Core PPI	0.52	(1.39)	0.53	(1.35)	1.34	(2.60)
Retail Sales ex. autos	1.20	(3.34)	1.69	(3.08)	1.19	(1.82)
Unemployment rate	−1.53	(−2.19)	−2.03	(−2.94)	−0.96	(−1.22)
# Observations	1303		1303		1303	
R^2	.07		.20		.09	
$H_0 : \beta = 0$, p-value	$< 10^{-8}$		$< 10^{-16}$		$< 10^{-16}$	

Table 1. Coefficient estimates β from nonlinear regression $\Delta y_t = \alpha + \beta X_t + \varepsilon_t$ at daily frequency on days of announcements from Jan. 1990 to Dec. 2000. Change in yields Δy_t is in basis points; surprise component of macroeconomic announcements X_t are normalized by their historical standard errors; coefficients represent a basis point per standard deviation response. Heteroskedasticity-consistent t-statistics in parentheses. $H_0 : \beta = 0$ p-value is for the test that all elements of β are zero. See text for details.

Treasury yield to fall. The data release that has the largest effect on 3-month Treasury yields is nonfarm payrolls, for which a one-standard-deviation surprise causes yields to move by about 2.5 bp on average, with a t-statistic of about 4.5. Capacity utilization, unemployment, and new home sales have the next strongest effects, about 1.5 bp per standard deviation, with t-statistics around 3.[6] Taken together, the twelve data releases in Table 1 have an extremely significant effect on the 3-month Treasury yield, with a joint F-statistic above 5 and a p-value of less than 10^{-8}. The results for the 1-year and 10-year Treasury yields in the second and third columns are similar, with joint statistical significance levels that are even higher than for the 3-month yield. Thus, the high-frequency regressions in Table 1 provide measures of the sensitivity of Treasury yields to news that are highly statistically significant.

Although the magnitudes of the coefficients in Table 1 are only a few basis points per standard deviation, and thus might seem small at first glance, they are in fact not surprising given the

[6] Although GDP is not statistically significant over this sample, it will be significant when we extend the estimation to the full sample, below. For this reason, we include it in our analysis.

relatively low signal-to-noise ratio of any single monthly data release for the true underlying state of economic activity and inflation. Likewise, the regression R^2 are each 0.2 or less, implying that even on the 1303 days when we know the major economic news that day, the regression explains less than one-fifth of the variation in short-term yields. The main reason for this is that our surprise data cover only the headline component of each release, while the full releases are typically much richer: for example, the employment report includes not just nonfarm payrolls and the unemployment rate, but also how much of the change in payrolls is due to government hiring and how much of the change in unemployment is due to workers dropping out of the labor force.[7] Nevertheless, the extraordinary statistical significance of the regressions implies that they are extremely informative about the sensitivity of Treasury yields to economic news.

3.3 Measuring the Time-Varying Sensitivity of Treasury Yields

We now measure to what extent the sensitivity of Treasury yields to news has varied over time. In principle, one can measure this time-varying sensitivity by running regressions of the form (8) over one-year rolling windows. However, this approach suffers from small-sample problems because most macroeconomic series have data releases only once per month, providing just twelve observations per year with which to identify each element of the vector β.

We overcome this small-sample problem by imposing that the *relative* sizes of the elements of β are constant over time, so that only the overall magnitude of β varies as the yield in question becomes more influenced by the presence of the zero lower bound. Intuitively, if a Treasury security's responsiveness to news is reduced because its yield is affected by the zero bound, then we expect that security's responsiveness to all macroeconomic data releases to be damped by a roughly proportionate amount. This assumption is supported by the illustrative model in Section 2 and by empirical tests we conduct below.

Thus, for each given Treasury yield, we generalize regression (8) to a nonlinear least squares

[7] Details such as these often have a substantial effect on the markets' overall interpretation of a release. Similarly, the CPI release includes not just the top-line inflation numbers, but also a detailed breakdown of inflation by product category, and markets may respond differently to a given headline number depending on the underlying detail of the release and whether that detail suggests the news in the release is transitory or more permanent. The situation is very similar for all of the other releases in Table 1.

specification of the form:

$$\Delta y_t = \gamma^{\tau_i} + \delta^{\tau_i}\beta X_t + \varepsilon_t, \tag{9}$$

where the parameters γ^{τ_i} and δ^{τ_i} are allowed to take on different values in each calendar year τ_i, $i = 1990, 1991, \ldots, 2011$. The use of annual dummies in (9) is deliberately atheoretical in order to "let the data speak" at this stage; we will consider more structural specifications for the time-varying sensitivity coefficients δ in Section 5, below. Note that regression (9) lessens the small-sample problem associated with allowing every element of β to vary across years, because in (9) there are about 140 observations of βX_t per year with which to estimate each δ^{τ_i}. We formally test the restriction that β is constant over time in (9) by comparing the results to a regression in which every element of β is permitted to vary across calendar years. Finally, regression (9) brings roughly twice as much data to bear in the estimation of β relative to the 1990–2000 sample considered in Table 1.

We need to choose a normalization to separately identify the coefficients β and δ^{τ_i} in (9), since one can multiply the δ^{τ_i} by any constant k and divide β by the same factor to achieve the same fit. We normalize the δ^{τ_i} so that they have an average value of unity from 1990–2000, since that benchmark represents the "normal" or unconstrained behavior of Treasury yields in our analysis. Thus, an estimated value of δ^{τ_i} close to unity corresponds to a year in which the Treasury yield was behaving normally, while an estimated value of δ^{τ_i} close to zero would correspond to a period in which the Treasury yield was completely insensitive to news. Intermediate values of $\hat{\delta}^{\tau_i}$, to the extent that they are statistically greater than zero but less than unity, represent a year in which the Treasury yield was partially constrained.

Finally, we define a "generic surprise" regressor $\hat{X}_t \equiv \hat{\beta}X_t$, where $\hat{\beta}$ denotes the estimated value of β from (9). We use this generic surprise regressor to estimate daily rolling regressions of the form

$$\Delta y_t = \gamma^{\tau} + \delta^{\tau}\hat{X}_t + \varepsilon_t^{\tau}, \tag{10}$$

where (10) is estimated over a one-year window centered around each business day τ from January 1990 through December 2011.[8] When τ corresponds to the midpoint of a given calendar year

[8]Toward either end of our sample, the regression window gets truncated and thus becomes smaller and less centered, approaching a six-month leading window in January 1990 and a six-month trailing window in December 2011.

	Treasury yield maturity					
	3-month		1-year		10-year	
Capacity Utilization	0.72	(1.50)	1.24	(2.10)	0.84	(2.48)
Consumer Confidence	0.75	(2.88)	1.38	(4.28)	0.88	(2.42)
Core CPI	0.41	(1.92)	1.64	(4.84)	1.29	(3.84)
GDP (advance)	0.95	(3.20)	1.41	(2.85)	0.97	(1.66)
Initial Claims	−0.30	(−1.81)	−0.93	(−4.95)	−0.98	(−5.03)
ISM Manufacturing	1.24	(3.21)	2.26	(6.32)	2.07	(6.05)
Leading Indicators	0.21	(0.62)	0.45	(1.30)	0.24	(0.84)
New Home Sales	0.84	(2.62)	0.66	(2.06)	0.52	(1.94)
Nonfarm Payrolls	3.07	(7.67)	4.13	(9.75)	2.93	(6.67)
Core PPI	0.21	(0.77)	0.33	(0.93)	0.82	(2.97)
Retail Sales ex. autos	0.84	(3.77)	1.68	(4.90)	1.65	(4.23)
Unemployment rate	−1.23	(−3.50)	−1.33	(−3.33)	−0.39	(−0.98)
# Observations	2707		2707		2707	
R^2	.08		.18		.10	
$H_0 : \beta$ constant, p-value	.929		.103		.183	
$H_0 : \delta$ constant, p-value	$< 10^{-16}$		$< 10^{-16}$		.012	

Table 2. Coefficient estimates β for nonlinear regression $\Delta y_t = \gamma^{\tau_i} + \delta^{\tau_i}\beta X_t + \varepsilon_t$ at daily frequency from Jan. 1990 to Dec. 2011. Coefficients indexed τ_i may take on different values in different calendar years. Δy_t and X_t are as in Table 1. Heteroskedasticity-consistent t-statistics in parentheses. $H_0 : \beta$ constant p-value is for the test that β is fixed over time and only the δ^{τ_i} vary. $H_0 : \delta$ constant p-value is for the test that $\delta^{\tau_i} = 1$ for all years τ_i. See text for details.

$i \in \{1990, 1991, \ldots, 2011\}$, the estimated value of δ^τ agrees with δ^{τ_i} from regression (9). But we can also estimate (10) for any business day τ in our sample, and graph δ^τ as a function of τ to provide a finer estimate of the periods during which the Treasury yield was more constrained. When we plot the standard errors in regression (10) around the point estimates for δ^τ, we account for the two-stage sampling uncertainty by using the estimated standard errors of the δ^{τ_i} from regression (9) as benchmarks and interpolating between them using the standard errors estimated in (10).

4 Main Results

Table 2 reports nonlinear least squares estimates for β in regression (9) for the 3-month, 1-year, and 10-year Treasury yields for the sample 1990–2011. The results in Table 2 are generally similar to those in Table 1, with differences in any given coefficient across the two tables within the range of sampling variability. The number of observations in Table 2 is about twice as large as in Table 1, owing to the longer sample.

At the bottom of Table 2, we report results for two specification tests. First, we test the hypothesis that β in (9) is constant, against an alternative in which every element of β is permitted to vary independently across calendar years, that is:

$$\Delta y_t = \gamma^{\tau_i} + \beta^{\tau_i} X_t + \varepsilon_t. \tag{11}$$

As can be seen in Table 2, this hypothesis is not rejected at conventional levels of significance for any of the yields. The restrictions implicit in regression specification (9) thus appear to be consistent with the data.

In the final row of Table 2, we test the hypothesis that the time-varying sensitivity coefficients δ^{τ_i} in (9) are fixed over time. That is, we test whether $\delta^{\tau_i} = 1$ for each calendar year τ_i, $i = 1990, \ldots, 2011$. In contrast to the assumption of a constant β, the data overwhelmingly reject the restriction that δ is constant over time for the 3-month and 1-year Treasury yields, with p-values less than 10^{-16}. Clearly, the sensitivity of these two yields to macroeconomic news has varied substantially over time. In contrast, the constant-δ restriction for the 10-year yield is rejected much less strongly. Although the sensitivity of the 10-year Treasury yield to macroeconomic news does appear to have varied over time, the assumption of a constant sensitivity coefficient δ for this yield is not nearly as inconsistent with the data as for the shorter-maturity yields.

Figure 4 plots the time-varying sensitivity coefficients δ^{τ} from regression (9) as a function of time τ, interpolating between the annual midpoints τ_i using the daily regression specification (10). The six panels of the figure depict results for the 3-month, 6-month, and 1-, 2-, 5-, and 10-year Treasury yields. The solid blue line in each panel plots the estimated value of δ^{τ} at each date τ, while the dotted gray lines depict heteroskedasticity-consistent ± 2-standard-error bands. In each panel, horizontal black lines are drawn at values of 0 and 1 as benchmarks for comparison, corresponding to the cases of complete insensitivity to news and normal sensitivity to news, respectively.

In each panel, the yellow shaded regions denote periods during which the estimated value of δ^{τ} is significantly less than unity at the one percent level. We use a conservative threshold here so that the shaded regions represent periods in which the yield was clearly less sensitive to news than normal. In addition, if the hypothesis $\delta^{\tau} = 0$ cannot be rejected, then the region is shaded red.[9] Thus, red shaded regions correspond to periods in which the Treasury yield was

[9] We use a standard five percent threshold here, which is again conservative—the lower the significance level, the

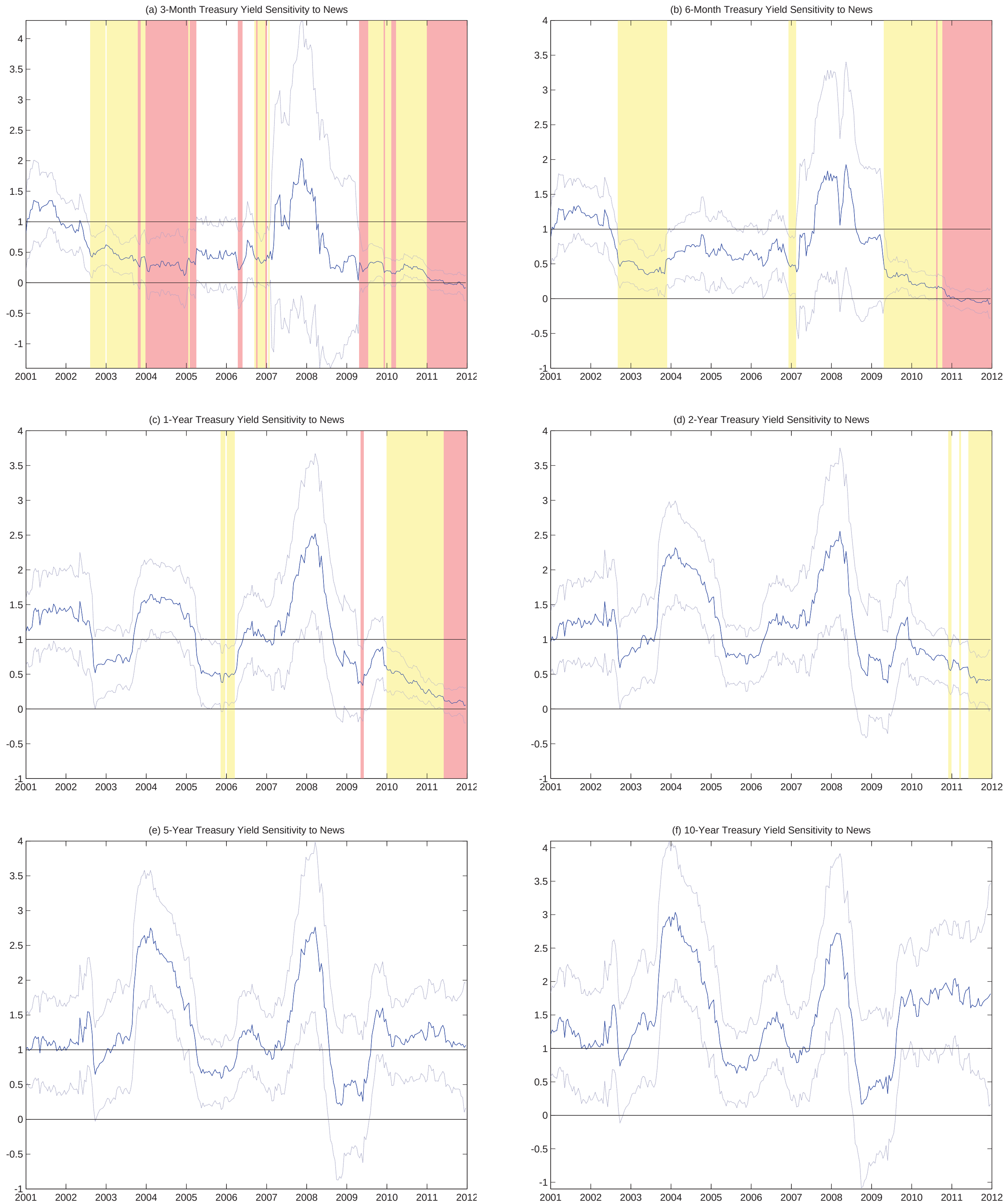

Figure 4. Time-varying sensitivity coefficients δ^τ from regression (10) for (a) 3-month, (b) 6-month, (c) 1-year, (d) 2-year, (e) 5-year, and (f) 10-year Treasury yields. Dotted gray lines depict heteroskedasticity-consistent $\pm$2-standard-error bands, adjusted for first-stage sampling uncertainty in (10). $\delta^\tau = 1$ corresponds to normal Treasury sensitivity to news; $\delta^\tau = 0$ to complete insensitivity. Yellow shaded regions denote δ^τ significantly less than 1; red shaded regions denote δ^τ significantly less than 1 and not significantly different from 0. See text for details.

essentially insensitive to news, while yellow shaded regions correspond to periods in which the yield was partially—but not completely—unresponsive to news.

Panel (a) of Figure 4 shows that the sensitivity of the 3-month Treasury yield to macroeconomic news has varied between about 0 and 2 from 2001 through 2011. From the spring of 2009 through the end of 2011, the 3-month Treasury yield has been either partially or completely insensitive to news, as characterized by the yellow and red shaded regions in the figure. It is natural to interpret this insensitivity to news as being driven by the zero lower bound constraint, since the federal funds rate and 3-month Treasury yields were both essentially zero from December 2008 through the end of 2011. At the shortest end of the yield curve, at least, Treasury yields appear to have been substantially constrained by the zero bound from the spring of 2009 onward.

What is more surprising in the first panel of Figure 4 is that the 3-month Treasury yield was also partially or completely insensitive to news throughout 2003 and 2004, a period during which the federal funds rate target and 3-month Treasury yield never fell below 1 percent. However, the Fed had recently lowered the funds rate to 1.25 percent in November 2002 and again to 1 percent in June 2003, and at the time, a level of the funds rate below 1 percent was regarded as costly for institutional reasons (Bernanke and Reinhart, 2004). Rather than try to lower the funds rate below 1 percent, the FOMC opted instead to switch to a policy of managing monetary policy expectations, using phrases such as "policy accommodation can be maintained for a considerable period."[10] Thus, even though the funds rate was not constrained by a floor of zero in 2003 and 2004, our results show that the 3-month Treasury yield behaved exactly *as if* it had been completely constrained by a rigid floor of 1 percent. The fact that our empirical method can detect the constraints faced by monetary policy in 2003–04, and the potential absence of crowding out of fiscal policy over the same period, is an important advantage of our approach.

Results for the 6-month Treasury yield in panel (b) of Figure 4 are generally similar to those for the 3-month yield: the sensitivity of the yield to macroeconomic news ranges between 0 and 2, and from the spring of 2009 through the end of 2011, the 6-month yield was either partially or

easier it is to reject that $\delta^\tau = 0$ and the less likely we are to conclude that interest rates are completely insensitive to news.

[10]The "considerable period" language was introduced into the FOMC statement on August 12, 2003, and continued until the end of January 2004, at which point it was replaced with the phrase, "the Committee believes that it can be patient in removing its policy accommodation." The funds rate was finally raised on June 30, 2004.

completely unresponsive to news. In contrast to the 3-month yield, however, the 6-month yield was much less constrained in 2003–04. Thus, to the extent that the effective lower bound of 1 percent was a substantial constraint on monetary policy in 2003–04, that constraint did not appear to extend out beyond 3 months in 2004.

The sensitivity of 1- and especially 2-year Treasury yields to news is less attenuated than that of 3- and 6-month yields throughout our sample. Results for these yields are reported in the middle two panels of Figure 4. For example, both the 1- and 2-year yields behaved close to normally throughout 2003–04, implying that they were relatively unaffected by the zero bound during this period. Thus, to the extent that crowding out is determined by yields with a year or more to maturity, we find that crowding out in 2003–04 would have been essentially no different from normal. Similarly, to the extent that the Federal Reserve can influence monetary policy expectations at a horizon of a year or more, we find that monetary policy was relatively unconstrained by the zero bound during that period.

From 2008 to 2011, the zero lower bound was a greater constraint on 1- and 2-year Treasury yields, but by no means a complete constraint. The sensitivity of the 1-year Treasury yield to news was only significantly less than normal beginning in 2010, and only became completely insensitive to news in the second half of 2011. The 2-year Treasury yield's sensitivity to news was only significantly less than normal beginning around early 2011, and never became completely insensitive to news; even at the end of 2011, the 2-year Treasury remained about half as sensitive as normal. Thus, to the extent that the Federal Reserve can influence monetary policy expectations at a horizon of two years or more, we find that monetary policy was largely unconstrained by the zero bound until 2011, and even by the end of 2011 still had substantial ability to influence 2-year Treasury yields. Similarly, to the extent that crowding out is related to 2-year yields, we do not find any evidence that crowding out in 2008–2010 would have been less than normal. But in 2011, crowding out would have been about half as large as normal, assuming that 2-year Treasury yields are the interest rates most relevant for private-sector investment. (We apply our analysis to corporate bond yields in Section 5, below.)

Our final results on yields with maturities of five and ten years, reported in the last two panels of Figure 4, are also remarkable. There are no red or yellow shaded regions in these panels, because nowhere in the sample is their sensitivity to news significantly less than unity. Thus, even in late 2011, when Treasury yields of up to two years are clearly affected by the zero lower bound, the 5- and 10-year yields appear to be unaffected by the zero bound.

5 Discussion

The results of the previous section raise important questions that we now investigate in greater detail. First, we relate the results to private-sector expectations of the time of federal funds rate "liftoff" from the zero bound. Second, we provide evidence that the Federal Reserve can manage monetary policy expectations at horizons out to several quarters. Third, we discuss some of the implications of the Federal Reserve's large-scale purchases of long-term bonds for our results. Fourth, we investigate why the sensitivity of interest rates to news sometimes exceeds unity, and why that sensitivity varies over time even when monetary policy is far away from the zero bound. And finally, we investigate to what extent our results generalize to other longer-term interest rates, such as corporate bond yields, which may be more relevant for measuring the effects of monetary and fiscal policy on private-sector investment and output.

5.1 Private-Sector Expectations of Federal Funds Rate "Liftoff" from Zero

Our illustrative theoretical model implies that the sensitivity of medium- and longer-term Treasury yields to news is closely related to the length of time that the federal funds rate is expected to be at the zero lower bound. If the funds rate is expected to be at the zero bound for only a single quarter, then medium- and longer-term interest rates should be nearly unaffected by the zero bound. But if the federal funds rate is expected to be at the zero bound for several years, then one would expect even 10-year Treasury yields to be substantially affected.

Figure 5 plots the number of quarters that the private sector expected the federal funds rate to be maintained below 25 bp, as measured by the median, "consensus" response to the monthly Blue Chip survey of professional forecasters. Prior to December 2008, the Fed was not expected to lower the funds rate below 25 bp for any length of time. After the Fed cut the target funds rate to near zero in December 2008, the Blue Chip consensus expectation of the length of time until

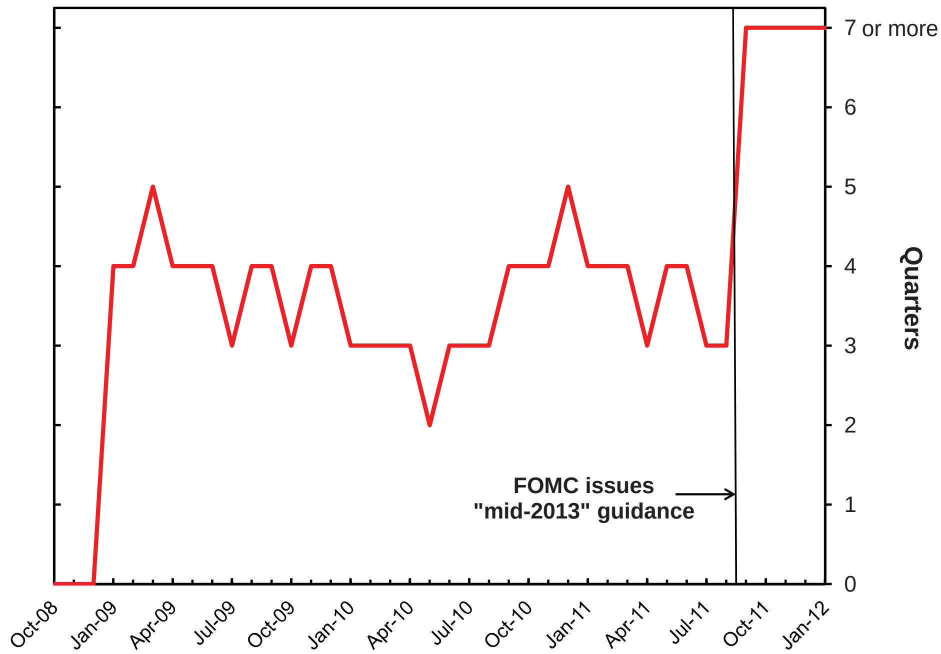

Figure 5. Expected number of quarters until the first federal funds rate increase above 25 bp, from the monthly Blue Chip survey of forecasters.

the first funds rate hike then fluctuated between two to five quarters until August 2011. After the FOMC announced that it expected to keep the funds rate at zero until at least "mid-2013," private expectations of the time until liftoff jumped to more than six quarters (the Blue Chip forecast horizon extends forward only six quarters).

The implication of the forecasts underlying Figure 5 is that, from about December 2008 until August 2011, the sensitivity of yields for maturities of one year or less should have fallen to close to zero, while that for maturities of two years or more should have been partially dampened. And in fact this corresponds closely to what we found in our main results, above, at least for yields with maturities of two years or less.

Figure 6 provides an additional perspective on these results by applying regression (10) to Eurodollar futures rather than Treasury yields. Eurodollar futures are the most heavily traded, liquid futures contracts in the world, and settle at expiration based on the spot 3-month term Eurodollar deposit rate in London; thus, a Eurodollar future with one quarter to expiration is closely related to market expectations about the federal funds rate from 3 to 6 months ahead.[11] Similarly, a

[11]See Gürkaynak, Sack, and Swanson (2007) for additional details regarding Eurodollar futures. They compare the forecasting performance of Eurodollar futures to other market-based measures of monetary policy expectations and

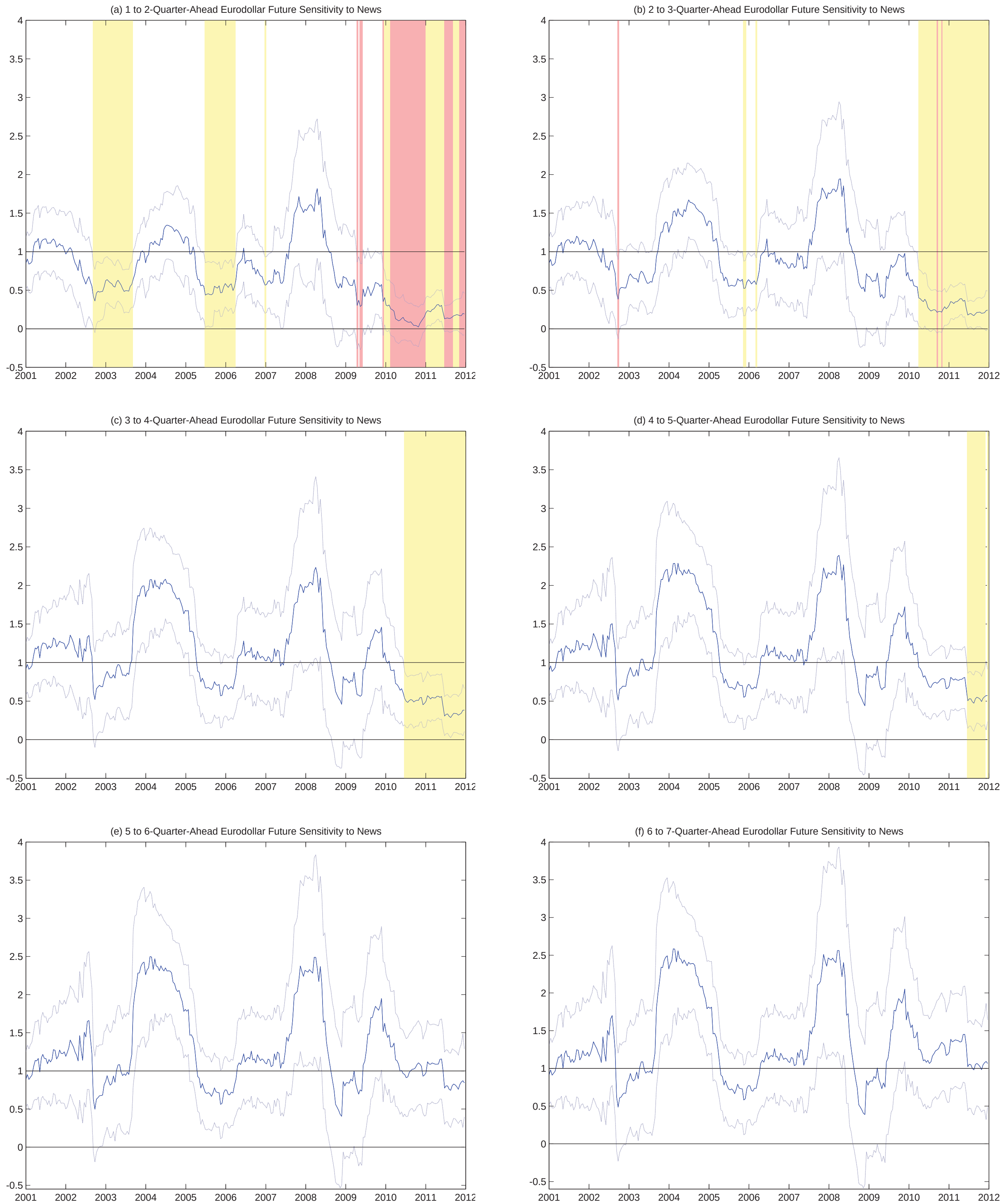

Figure 6. Time-varying sensitivity coefficients δ^{τ} from regression (10) for Eurodollar futures contracts with (a) 1–2 quarters, (b) 2–3 quarters, (c) 3–4 quarters, (d) 4–5 quarters, (e) 5–6 quarters, and (f) 6–7 quarters to expiration. Eurodollar futures settle based on the spot 3-month Eurodollar deposit rate at expiration, and thus correspond to forward interest rates beginning at expiration and ending 1 quarter after expiration. See notes to Figure 4 and text for details.

Eurodollar future with 3 quarters to expiration closely reflects market expectations about monetary policy from 9 to 12 months ahead. Thus, Eurodollar futures provide direct measures of *forward* interest rates beginning on the date of expiration of the futures contract. As a result, a Eurodollar future expiring in 3 quarters will behave somewhat differently than a 1-year Treasury, because the latter also includes market expectations of monetary policy from 0 to 9 months ahead, which are not included in the former.

The results in Figure 6 confirm those for Treasury yields in Figure 4. Just like 3- and 6-month Treasury yields, the sensitivity to news of Eurodollar futures with 1 to 3 quarters to expiration was dampened in 2003 and 2006, and fell to almost zero in 2010–11. And similar to the 1-year Treasury yield, the sensitivity to news of Eurodollar futures with 3 to 5 quarters to expiration remained close to normal until 2010, at which point they fell.

At horizons of 5 quarters or more, the sensitivity of Eurodollar futures to news remained near normal levels throughout the final three years of our sample. The point estimates of δ^τ are numerically close to unity and never differ significantly from unity. This result is somewhat stronger and clearer than for the 2-year Treasury yield in Figure 4 because the 5 to 6-quarter-ahead Eurodollar future is a forward rate that does not include monetary policy expectations from 0 to 15 months ahead, which are included in the 2-year Treasury yield.

5.2 Can the Fed Manage Monetary Policy Expectations?

The results in Figure 6 show that forward rates at horizons of five quarters or more were largely unaffected by the zero lower bound throughout our sample, including 2008–11. Even if the Federal Reserve had no ability to influence expectations of future monetary policy, this result would still have implications for fiscal policy and the degree to which fiscal stimulus crowded out private-sector investment over the 2008–11 period. The results are also relevant for monetary policy to the extent that the Fed can influence expectations of the federal funds rate five quarters or more into the future. In this section, we briefly review the evidence on the Federal Reserve's ability to influence

find that Eurodollar futures perform as well as or better than any other measure at horizons of six months or more, the horizon which is most interesting for our present analysis. Also note that Figure 6 lists the expiration of each contract as 1–2 quarters ahead, 2–3 quarters ahead, etc., because contracts expire in March, June, September, and December of each year; thus the number of quarters to expiration can lie anywhere between n and $n + 1$ quarters, depending on whether the current date t is closer to the beginning or the end of the current quarter.

these expectations by any means other than changes in the current level of the federal funds rate.

In theory, a central bank can influence private-sector expectations of future monetary policy if the bank has at least some ability to partially commit to its future policy actions. Schaumburg and Tambalotti (2007) and Debortoli and Nuñes (2010) define a continuum of partial commitment technologies that lie between perfect commitment and perfect discretion, in the sense of Kydland and Prescott (1977). Since perfect discretion is a limiting case along this continuum and implies no ability to commit whatsoever, it seems likely—or at least possible—that monetary policymakers would have some ability to influence private-sector expectations of future monetary policy actions at least a few periods into the future. Nevertheless, whether the Federal Reserve can effectively manipulate financial market expectations about future monetary policy several quarters into the future is ultimately an empirical question.

Empirically, there are several studies of the Federal Reserve's ability to influence longer-term interest rates through its communications, such as through the statements released by the FOMC after each monetary policy meeting. Gürkaynak, Sack, and Swanson (2005b) separately identify the impact of FOMC actions (that is, changes in the federal funds rate target) and statements, and find that FOMC statements have highly statistically significant effects on Treasury yields out to maturities of 10 years. In fact, more than half of the explainable variation in the response of two-year Treasury yields (and almost 90 percent of the variation in the response of 10-year yields) to FOMC announcements is attributable to the FOMC's statements, rather than to changes in the current federal funds rate target. The authors' interpretation of this finding is not that statements have some mysterious independent power over longer-term interest rates, but rather that statements affect longer-term yields by changing financial market expectations about the future path of the federal funds rate. Bernanke, Reinhart, and Sack (2004) review these results and come to very similar conclusions using slightly different methods.[12]

Table 3 highlights two important examples of this effect. From August 2003 until January 2004, the FOMC stated after each of its meetings that the accommodative stance of monetary policy "can be maintained for a considerable period." On January 28, 2004, in response to the

[12] Kohn and Sack (2004) also find that FOMC statements and Congressional testimony by the Fed Chairman have significant effects on longer-term interest rates, and present evidence that changes in monetary policy expectations are the primary driver of these changes.

	Treasury yields					
	3-month	6-month	1-year	2-year	5-year	10-year
FOMC drops "considerable period" language on Jan. 28, 2004						
Jan. 27, 2004	0.91	0.98	1.17	1.694	3.082	4.391
Jan. 28, 2004	0.94	1.00	1.295	1.86	3.221	4.494
change (bp)	3	2	12.5	16.6	13.9	10.3
FOMC projects zero funds rate "at least through mid-2013" on Aug. 9, 2011						
Aug. 8, 2011	0.05	0.07	0.173	0.271	1.133	2.591
Aug. 9, 2011	0.03	0.06	0.13	0.172	0.928	2.362
change (bp)	−2	−1	−4.3	−9.9	−20.5	−22.9

Table 3. Response of Treasury yields to significant changes in FOMC statements on Jan. 28, 2004, and Aug. 9, 2011. In both cases, there was no change in the current federal funds rate target, but the statement described a substantial change in the outlook for the funds rate relative to market expectations. See text for details.

strengthening economic outlook, the FOMC dropped this phrase from its statement and replaced it with the phrase "the Committee believes it can be patient in removing its policy accommodation."[13] Even though the funds rate target itself was unchanged on that date, the change in the statement was read by financial markets as indicating that the FOMC would begin raising the funds rate sooner than previously expected.[14] The result was that longer-term Treasury yields responded dramatically to the announcement, rising by about 10 to 16 bp at the 1- to 10-year maturities.

Similarly, on August 9, 2011, in response to the weakening economic outlook, the FOMC announced that "economic conditions... are likely to warrant exceptionally low levels for the federal funds rate at least through mid-2013." Because the federal funds rate was already at an effective lower bound of 0 to 25 bp, there was no change in the FOMC's current federal funds rate target. Analogous to the previous example, financial markets read the change in statement as signaling the FOMC would likely begin raising the funds rate later than previously expected.[15] As a result, longer-term Treasury yields fell substantially, between about 10 and 23 bp at the 2- to 10-year

[13]The statements released after each FOMC meeting are available from the Federal Reserve Board's public web site.

[14]For example, the front page of *The Wall Street Journal* reported the following morning that "investors interpreted the omission of 'considerable period' as a signal that the Fed is closer to raising rates than many thought." ("Fed Clears Way for Future Rise in Interest Rates," *The Wall Street Journal,* Jan. 29, 2004, Greg Ip, p. A1.) Note that 10–15 bp is the typical response of 5- and 10-year Treasury yields to a 100-bp surprise change in the federal funds rate target (Gürkaynak et al. 2005b), so the changes in Table 3 are large.

[15]The front page of *The Wall Street Journal* the following morning noted that, in response to the FOMC statement, financial markets "lowered their expectations for when the Fed will start tightening policy." ("Markets Sink Then Soar after Fed Speaks," *The Wall Street Journal,* Aug. 10, 2011, Sudeep Reddy and Jonathan Cheng, p. A1.)

maturities.

These two examples are consistent with the more systematic evidence in Gürkaynak et al. (2005b), Kohn and Sack (2004), and Bernanke et al. (2004). Those authors all find statistically and economically significant effects of FOMC communications on longer-term bond yields, above and beyond any effects of changes in the current level of the federal funds rate. The evidence in Table 3 and the studies cited above strongly suggest that the FOMC has the ability to influence expectations of monetary policy for at least the next few years, and thereby affect longer-term interest rates.

5.3 The Federal Reserve's Purchases of Long-Term Bonds

In addition to managing monetary policy expectations, the Federal Reserve may be able to influence longer-term interest rates by withdrawing large quantities of longer-term bonds from the private sector through open-market purchases. Although standard representative-agent asset pricing models do not allow for the quantity of a security to have any effect on its price, Vayanos and Vila (2009) provide a modern, arbitrage-free foundation for the earlier "portfolio balance" and "preferred habitat" models of Tobin (1958) and Modigliani and Sutch (1966).[16] Intuitively, if private-sector investors have heterogeneous preferences for different bond maturities, and arbitrage across maturities is limited, then the supply of longer-term bonds in the market can affect longer-term bond yields.

Empirically, Bernanke, Reinhart, and Sack (2004), Krishnamurthy and Vissing-Jorgensen (2007), Gagnon et al. (2011), Swanson (2011), and others find that large changes in the supply of Treasury securities have had appreciable effects on the yields of those securities. Between 2008 and 2011, the FOMC announced several rounds of large-scale purchases of longer-term Treasury bonds and agency mortgage-backed securities and debt, amounting to over $2.3 trillion of securities in total.[17] These purchases represented a substantial fraction of the quantity of longer-term Trea-

[16] See also Hamilton and Wu (forthcoming), who relate the Vayanos-Vila model to a standard arbitrage-free affine term structure model to estimate quantity effects.

[17] On November 25, 2008, the FOMC announced that it would purchase $500 billion of mortgage-backed securities and $100 billion of debt directly issued by the housing-related government-sponsored enterprises (GSEs). On March 18, 2009, the FOMC announced it would purchase an additional $750 billion of mortgage-backed securities, an additional $100 billion of GSE debt, and $300 billion of longer-term Treasury securities. On November 3, 2010, the FOMC announced that it would purchase an additional $600 billion of longer-term Treasury securities. Moreover, on September 21, 2011, the FOMC announced it would exchange an additional $400 billion of short-term Treasury

sury bonds in the hands of the private sector (Gagnon et al. 2011), and thus would be expected to have appreciable effects on longer-term bond yields based on the findings of the studies cited above.

An interesting feature of our results in Figure 4 is that 5- and 10-year Treasury yields are no less sensitive to news during 2009–11 than in normal times. On one hand, a finding of relatively little dampening of the sensitivity of longer-term yields would not be surprising, given the relatively brief period that market participants expected short rates to be constrained by the zero bound. But the complete lack of dampening in sensitivity to news for longer-term Treasuries in Figure 4 is still somewhat surprising. For example, the simple model in Section 2 would predict that the sensitivity of 5-year Treasury yields to news would be at least slightly attenuated in 2011 given that the sensitivity of 2-year Treasury yields to news was only half as large as normal during that time.

One potential explanation for this finding is that the Federal Reserve's large-scale purchases of longer-term bonds may have played a role in offsetting the effect of the zero lower bound on the 5- and 10-year yields. Gagnon et al. (2011) find that the Fed's first asset purchase program led to a sizable reduction in longer-term yields, and that the primary channel by which the asset purchases lowered yields was by lowering the term premium. To the extent that market participants anticipated that the Fed would adjust its asset purchase programs in response to changing economic conditions, this expectation could work in the opposite direction of any dampening effect from the zero bound on longer-term Treasuries, and result in no net loss in sensitivity of those yields to macroeconomic news.

5.4 Why Are Interest Rates Sometimes More Sensitive to News?

Another interesting feature of Figures 4 and 6 is that the interest rate sensitivity coefficients δ^τ are sometimes estimated to be significantly *higher* than in normal times. For example, Treasury yields with two years or more to maturity and Eurodollar futures with three or more quarters to expiration were all more than twice as sensitive to news in 2004 and from mid-2007 to mid-2008 as in our benchmark sample from 1990–2000.

securities for an equal amount of long-term Treasury bonds, which did not increase the FOMC's total holdings of Treasury securities but substantially altered the composition of those holdings.

A natural explanation for why interest rates might have been more sensitive to news at those times is that financial markets may have been unusually uncertain about the outlook for monetary policy. In an environment of higher monetary policy uncertainty, each data release can have larger effects on financial market expectations of the future path of monetary policy; this would be the case, for example, if financial markets use methods similar to Kalman filtering to form expectations of future monetary policy. As a result, any given data surprise would tend to have a larger effect on medium- and longer-term interest rates, and our interest rate sensitivity regressions (9) and (10) would show a heightened sensitivity of those yields to news.

We investigate the importance of this effect by considering a more structural specification for the time-varying sensitivity coefficients δ^τ in regressions (9) and (10). In particular, we consider nonlinear regressions of the form

$$\Delta y_t = \gamma + f(Z_t)\beta X_t + \varepsilon_t, \tag{12}$$

where Z_t denotes a vector of explanatory variables for δ (including a measure of monetary policy uncertainty), and f denotes the nonlinear functional form

$$f(Z_t) = \max\{\, 0,\ \theta + \phi Z_t \,\}, \tag{13}$$

where θ and ϕ are parameters to be estimated along with γ and β in (12). The nonnegativity constraint in (13) reflects the view that, although an interest rate's sensitivity to news may rise and fall, it should never flip sign. (In practice, the estimated values of θ and ϕ almost never produce negative values for $f(Z_t)$, so the nonlinearity in (13) can essentially be ignored.) Thus, instead of estimating δ^{τ_i} or δ^τ in an unrestricted way in (9) or (10), with annual dummies or rolling regressions, regression (12) allows the sensitivity of Treasury yields to vary at daily frequency along with variations in Z_t.

We measure monetary policy uncertainty using Eurodollar options, which are the most liquid options available on a shorter-term interest rate, and thus represent the best measure of monetary policy uncertainty we have over the next several quarters. In particular, we use Eurodollar futures and Eurodollar options with about one year to expiration to estimate the distribution of the spot Eurodollar rate in one year's time; we then use the distance between the 95$^{\text{th}}$ and 5$^{\text{th}}$ percentiles of this distribution—a 90 percent confidence interval around the mean—as our measure of monetary

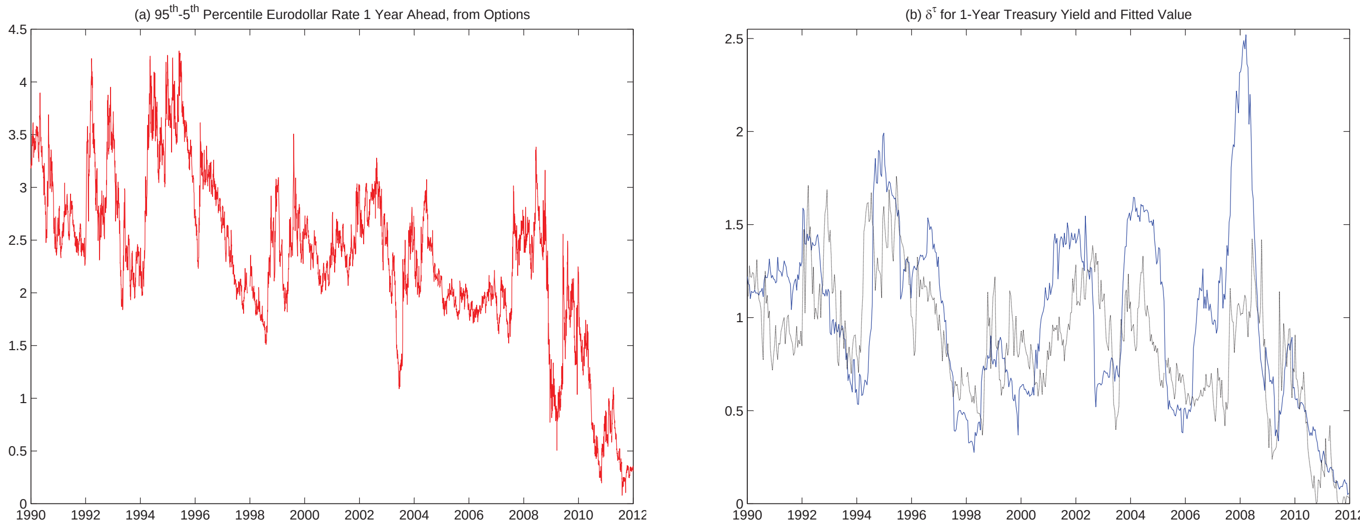

Figure 7. (a) Solid red line depicts the difference between the 95th and 5th percentiles of the one-year-ahead Eurodollar rate distribution, derived from Eurodollar futures and options. (b) Solid blue line depicts time-varying sensitivity coefficients δ^τ from regression (10) for the 1-year Treasury yield; dotted black line plots the fitted value $f(Z_t)$ from regression (12)–(13) where Z_t includes the width of the 90 percent confidence interval from panel (a). See text for details.

policy uncertainty.[18] We plot this series in the first panel of Figure 7. Note that the 90 percent confidence interval for the one-year-ahead Eurodollar rate is about 3.5 percentage points wide at the beginning of 1990, and falls over time to about 25 bp in 2011. There is a general downward trend in monetary policy uncertainty over time (discussed in more detail in Swanson, 2006), punctuated by increases in uncertainty in 1994 (when the Fed began to raise interest rates after the 1991 recession), 2002, 2004, and 2007–08.

Results for the coefficients ϕ in regression (12)–(13) for the 3-month, 1-year, and 10-year Treasury yields are reported in Table 4. In each regression, a constant θ is included and is normalized so that the average value of $f(Z_t)$ equals unity over the benchmark 1990–2000 sample, in order to ensure that θ, ϕ, and β are separately identified.

In Table 4, the coefficient on monetary policy uncertainty is positive for each yield, highly sta-

[18]This series is produced by staff at the Federal Reserve Board. The mean of the distribution is estimated using the Eurodollar futures rate, and the variance is estimated using Eurodollar options, assuming a lognormal distribution for the one-year-ahead spot Eurodollar rate. At the one-year-ahead horizon, the lognormal distribution is reasonable throughout our sample; for example, at the end of 2011, the estimated mean of the one-year-ahead spot Eurodollar rate is 57 bp, which is substantially above zero. Also note that, like Eurodollar futures, Eurodollar options settle based on the spot 3-month Eurodollar deposit rate; as a result, Eurodollar options with about 12 months to expiration capture uncertainty about monetary policy at a horizon of about 12 to 15 months. Swanson (2006) provides some additional details about Eurodollar options.

	Treasury yield maturity					
	3-month		1-year		10-year	
Monetary policy uncertainty	.404	(4.19)	.407	(8.65)	.177	(1.90)
# Observations	2709		2709		2709	
R^2	.08		.18		.10	

Table 4. Coefficient estimates ϕ from regression $\Delta y_t = \gamma + f(Z_t)\beta X_t + \varepsilon_t$, where $f(Z_t) = \max\{0, \theta + \phi Z_t\}$, at daily frequency from Jan. 1990 to Dec. 2011. Heteroskedasticity-consistent t-statistics in parentheses. See text for details.

tistically significant for the shorter-maturity yields, and marginally significant for the 10-year yield. The R^2 for each regression is essentially the same as in regression (9) with annual dummy variables, implying no change in fit from using the alternative specification (12)–(13). The coefficient point estimates of about 0.4 imply that, if the 90 percent confidence interval for the one-year-ahead Eurodollar rate widens by one percentage point, the Treasury yield's sensitivity to news increases by about 0.4, or 40 percent of the sensitivity during the benchmark 1990–2000 sample.

The coefficient estimate for the 10-year Treasury yield in Table 4 is smaller and less statistically significant than for the shorter-maturity yields because the 10-year yield's sensitivity to news does not decline in 2010–11 along with the uncertainty about monetary policy. As discussed in the previous section, a plausible explanation for this fact is that financial market uncertainty about longer-term yields has not fallen in line with shorter-term yields because of the Federal Reserve's large-scale purchases of longer-term Treasury bonds. Thus, even though uncertainty about monetary policy one year ahead has declined substantially, uncertainty about longer-term bond yields may not have declined at all.

Fitted values from regression (12)–(13) for the 1-year Treasury yield's sensitivity to news are reported in the second panel of Figure 7. The solid blue line in the figure depicts the time-varying sensitivity coefficient δ^τ from regression (10) for the 1-year Treasury yield, and the dotted black line plots the fitted values $f(Z_t)$ from regression (12)–(13). There is a close correspondence between the increases in monetary policy uncertainty in 1994, 2002, 2004, and 2007–08 with the increases in interest rate sensitivity over those same periods. Monetary policy uncertainty was also relatively low in 1993, 1997, and 2010–11, helping to explain the lower levels of interest rate sensitivity in those periods.

The results in Table 4 and Figure 7 suggest that one of the reasons medium- and longer-term Treasury yield sensitivity to news varies over time is because of uncertainty about the future path of monetary policy. However, the low level of monetary policy uncertainty in 2010–11 should not be interpreted as implying that the zero lower bound was not an important factor! Indeed, one of the main reasons monetary policy uncertainty fell to such low levels in 2010–11 is precisely because short-term interest rates were constrained by the zero bound! Moreover, it was the zero bound constraint itself that led the FOMC to declare its expectation that it would keep the federal funds rate at zero until "at least mid-2013," which reduced uncertainty about the path of monetary policy through mid-2013 even further.

Thus, one of the *channels* through which the zero lower bound affects Treasury yield sensitivity may be through a reduction in uncertainty about the future course of monetary policy, but this does not diminish the importance of the zero bound itself as the root cause of the fall in longer-term Treasury yield sensitivity.

5.5 Results for Corporate Bond Yields

When considering the effects of monetary or fiscal policy on private-sector investment, measures of private-sector borrowing costs are probably more relevant than Treasury yields. Here we consider the results of applying our high-frequency sensitivity regressions to corporate bond yields.

Figure 8 reports the results from applying regression (10) to indexes of corporate bond yields of various maturities produced by Bank of America Merrill Lynch. We consider BBB-rated bonds in four maturity bins: 1–3 years, 3–5 years, 5–7 years, and 7–10 years. The results in Figure 8 generally confirm those in Figure 4: BBB-rated corporate bonds with three or more years to maturity appear to have been largely unconstrained by the zero lower bound throughout our sample, with the one possible exception of the period 2008Q4–2009Q2, when corporate bond yields were essentially insensitive to macroeconomic news. This period in particular is very interesting for our methods. Between 2008Q4 and 2009Q2, BBB-rated bond yields were far above zero—in fact, they averaged about 9 percent—and those yields were highly volatile, but apparently were responding to factors other than news about the U.S. macroeconomy. Nevertheless, our high-frequency methodology identifies this period as one in which BBB corporate bond yields were unresponsive to news

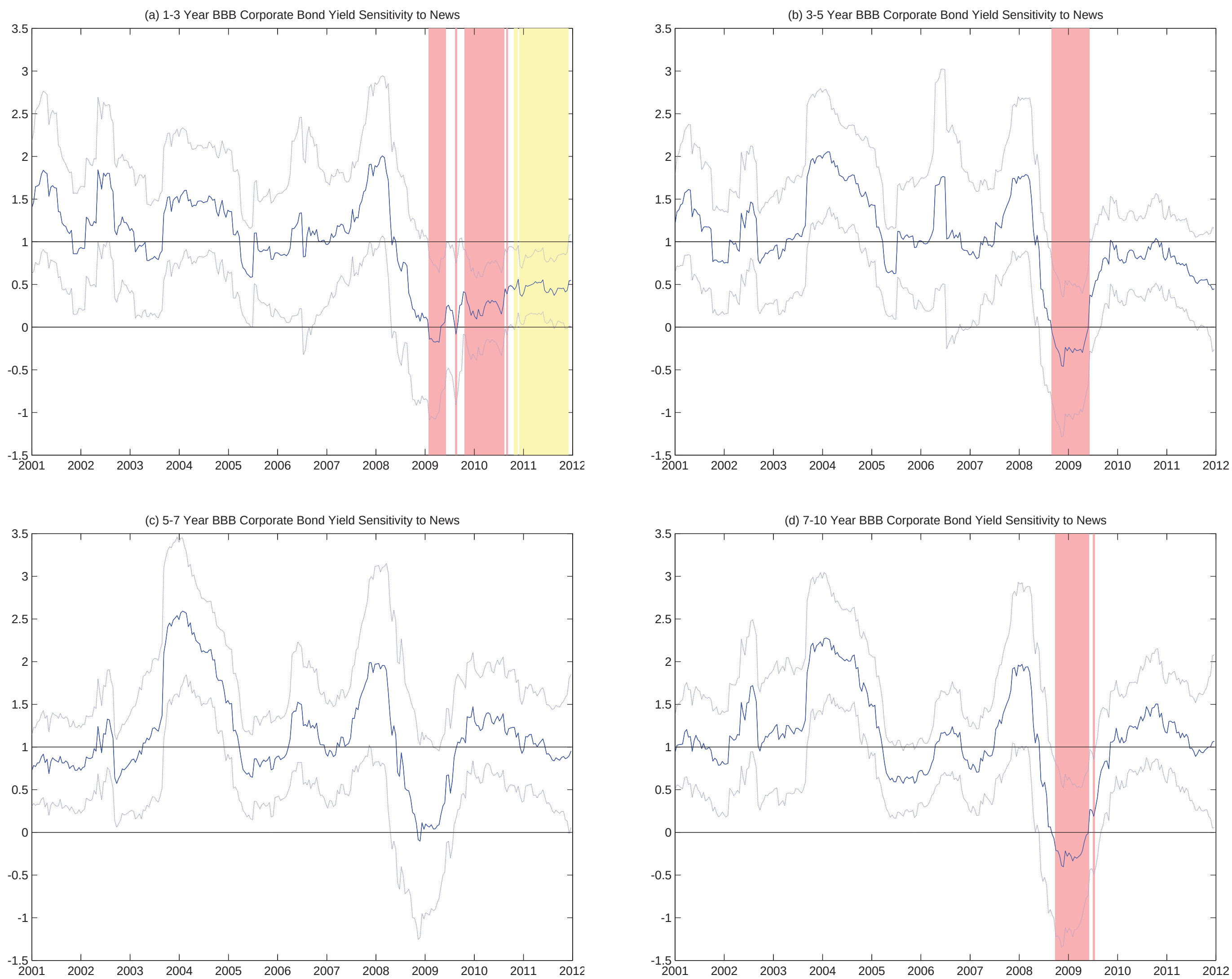

Figure 8. Time-varying sensitivity coefficients δ^{τ} from regression (10) for Merrill Lynch indexes of BBB-rated corporate bond yields with (a) 1–3 years, (b) 3–5 years, (c) 5–7 years, and (d) 7–10 years to maturity. Dotted gray lines depict heteroskedasticity-consistent ± 2-standard-error bands, adjusted for first-stage sampling uncertainty in (10). $\delta^{\tau} = 1$ corresponds to normal Treasury sensitivity to news; $\delta^{\tau} = 0$ to complete insensitivity. Yellow shaded regions denote δ^{τ} significantly less than 1; red shaded regions denote δ^{τ} significantly less than 1 and not significantly different from 0. See text for details.

about the aggregate U.S. economic outlook. We tentatively conclude from these results that BBB corporate bond yields at the time were likely to have been unresponsive to fiscal stimulus—which would imply *no* crowding out of private investment, and hence a larger fiscal multiplier, during that period.

After 2009Q2, however, the sensitivity of BBB-rated corporate bonds with 3 or more years to maturity was largely back to normal. From 2009Q3 through the end of 2011, then, we would expect the fiscal multiplier to be back to normal, to the extent that private-sector spending is related to yields with 3 years to maturity or more. Our results thus suggest that fiscal stimulus enacted after 2009Q2 could have been subject to a multiplier closer to the usual value of 1 or a little less estimated by Christiano et al. (2011), for example, rather than the larger, constant-interest-rate multiplier estimated by those authors.

However, to the extent that private-sector spending is related to BBB-rated yields with less than three years to maturity—an empirical question that we do not attempt to address in this paper—then crowding out from 2009Q3 to 2011 would have been less than in normal times; in fact, only about half as large. This would tend to suggest a fiscal multiplier about halfway between the normal and constant-interest-rate multipliers estimated by Christiano et al. (2011) and others.

6 Conclusions

In this paper, we have developed a new method to measure the degree to which interest rates of any maturity are affected by the presence of the zero lower bound. Our method uses the high-frequency sensitivity of yields to macroeconomic news to measure and statistically test the extent to which the zero bound affected any given yield's behavior. Importantly, our method provides a quantitative measure of the severity of the zero bound constraint on each yield as well as a statistical test for the periods during which each yield was affected.

We find that interest rates with six months or less to maturity were substantially constrained by the zero bound in 2008–11, but interest rates with more than two years to maturity were largely unaffected. One- and two-year Treasury yields represent an intermediate case, being only partly constrained for part of this period.

These results have important implications for both fiscal and monetary policy. To the extent that longer-term interest rates are more relevant than very short-term rates for private-sector spending, our findings imply that the fiscal multiplier would have been no larger than normal for much of the 2008–11 period. However, if private-sector spending is determined primarily by the shortest-maturity BBB-rated yields, then we estimate that crowding out in 2011 would have been about half as large as in normal times, implying a fiscal multiplier about halfway between the normal value and the larger, constant-interest-rate values estimated in the literature.

Our results also have important implications for monetary policy. Even when short-term interest rates are constrained by the zero lower bound, there may still be considerable scope for monetary policy to affect medium- and longer-term interest rates and, therefore, the economy. On several occasions since 2008, the Federal Reserve appears to have done exactly that, by managing private-sector expectations of future short-term interest rates and by conducting large-scale purchases of longer-term Treasury bonds and mortgage-backed securities.

Finally, the methods we have developed in this paper can be generalized beyond the United States and applied to any country for which financial markets are sufficiently well developed. In particular, it would be very interesting to see the results from applying our methods to other economies that have faced the zero lower bound in recent years, such as Japan, the U.K., Canada, Sweden, and the Euro area.

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