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The views expressed and analysis in this paper are the author's and should not be interpreted as the Congressional Budget Office's.

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1. Introduction

When the Federal Reserve changes the target for the federal funds rate, longer-term rates, to varying degrees (and with varying sign) respond as well. That response depends on the net effect of several (sometimes opposing) factors. In particular, in response to a change in the funds rate target (and since 1994, in response to accompanying statements by Federal Open Market Committee (FOMC)) bond market participants have to assess what those changes mean for the path of future short-term rates, expected inflation, and the term premium. It is therefore not surprising that previous researchers have found the relationship between changes in the federal funds rate and changes in longer-term rates to be unstable over time[1] (e.g. Ellingsen and Söderström 2001).

This paper re-examines the relationship between changes in the federal funds rate and longer-term Treasury rates. We take the view that the Federal Reserve's move toward greater transparency since the mid-1990s provides a natural experiment with which to isolate the factors described above. We hypothesize that in the pre-transparency period, increases in the federal funds rate were more likely to reveal information about the Federal Reserve's view of future inflation and therefore were more likely to result in a steepening of the yield curve. This hypothesis is consistent with the work of Romer and Romer (2000) who found that long-term interest rates tend to rise when the Fed increases the federal funds rate target because bond market participants interpret rate hikes as an indication that the Fed expects inflation to increase in the future. Romer and Romer further argue that the reason market participants interpret rate hikes as signaling inflation is that the Fed has historically been better than the private sector at forecasting inflation. Recent research however shows that the Fed's forecasting superiority has diminished since the early 1990s, possibly because of their own efforts to increase transparency (Gamber and Smith 2009). In the post-transparency period, the Federal Reserve's inflation forecasting accuracy diminishes and we would therefore expect to see increased transparency on the part of the Federal Reserve starting in 1994 to result in a more muted response of long-term interest rates to changes in the federal funds rate.

We test this hypothesis by estimating a vector error correction model (VECM) with the federal funds rate or shadow federal funds rate, and measures of the level, slope and curvature (corresponding to the first three principal components) of the yield curve. We examine three samples: early Great Moderation (1984 - 1993), Great Moderation and greater transparency (1994 - 2007), and Financial Crisis-Great Recession and recovery (2008 - 2019).

Our findings are broadly consistent with our hypothesis. In particular, we find that in the pre-transparency sample, the slope of the yield curve responded positively to increases in the federal funds rate. In the post-transparency period, the estimated response is smaller or not significantly different from zero.[2] Therefore, our results are consistent with the hypothesis that greater transparency by the Federal Reserve has resulted in less knowledge transmission about future inflation and hence smaller changes in the slope of the yield curve.

2. Previous Literature

[1] Section 2 fully discusses the changes in the relationship between the fed funds rate and long-term interest rates found by researchers over the past 30 years.

[2] Our most recent sub-sample, 2008-2019, overlaps with the period during which the federal funds rate was at the zero lower bound (ZLB). For the ZLB period (January 2009 through November 2015), we substitute the shadow federal funds rate (Wu and Xia 2016).

Our work is most closely related to the large literature on the relationship between changes in monetary policy and changes in long-term interest rates. Cook and Hahn (1989) is often cited as the start of this line of work. They examined the response of longer-term yields to changes in the federal funds rate. Their focus was on explaining the response of long-term interest rates to changes in the federal funds rate during the 1970s. They found that changes in the federal funds rate do have significant impacts on Treasury yields along the entire yield curve (over that sample). There are smaller effects on long-term rates yet they are still significant.

Roley and Sellon (1995) also examined the response of long-term rates to changes in the federal funds rate using a regression approach. Similar to Cook and Hahn they examine the response of long term rates to changes in monetary policy over fairly short (one or two day) windows. They also investigated whether there are anticipatory effects by looking at changes in long-term rates prior to anticipated changes in monetary policy. They found that the anticipatory effects on long-term rates are much larger than the contemporaneous effects. In addition, Skinner and Zettelmeyer (1995) examined the cross-country evidence on the response of long-term interest rates to changes in monetary policy. They found that monetary tightening led to increases in rates (on average) and monetary loosening led to decreases in interest rates (on average).

Kuttner (2001) measured the response of long-term rates to anticipated and unanticipated changes in monetary policy. He found that that long-term rates did not change in response to anticipated monetary policy (derived from fed funds futures) changes but responded (economically and statistically) significantly to unanticipated changes in monetary policy. Ellingsen and Söderström (2001) showed how the response of long term rates to changes in the federal funds rate depend on the expected path of short rates and whether the central bank reveals information about the future state of the economy when it changes the federal funds rate. Their paper was an effort to reconcile conflicting empirical evidence previously found.

Berument and Froyen (2006) empirically investigate the response of long-term rates to changes in monetary policy across monetary policy regimes. Their main interest is in the pre- and post-1979 response of long-term interest rates to changes in the federal funds rate. They found that the response of long-term rates to changes in the federal funds rate was smaller and less persistent after 1979. Kozicki and Sellon (2005) decomposed changes the yield curve slope into various components and found that a key factor explaining the (at that time) recent movements in the yield curve was the decline in the term premium. Wright (2012) examined the response of long-term rates to changes in monetary policy but his focus was on the effects of the quantitative easing programs implemented by the Federal Reserve in the aftermath of the Great Recession.

More recently, Hanson and Stein (2015) measured the response of long-term interest rates to changes in monetary policy. They separately identified changes in the expected path of policy and changes in the term premium and found that most of the change in long-term rates in response to monetary policy changes is due to changes in the term premium. Our paper contributes to these discussions by examining how transparency affects the relationship between changes in the federal funds rate and long-term rates.

3. Theory

In this section we present an illustrative model of the yield curve based on the expectations hypothesis of the term structure. Our hypothesis is that during periods when the federal funds rate conveys new "private" information about the course of inflation, the level and slope of the yield curve will respond by more to such changes. As we argued above, previous research findings suggest that the amount of private information about inflation contained in changes in the federal funds rate has diminished as the Federal Reserve has moved toward greater transparency. Thus, we expect the level and slope of the yield curve to respond by less over time, especially after 1994, when the Federal Reserve began undertaking a number of measures to improve its transparency and signal the future course of monetary policy.[3] In other words, we hypothesize that the transmission from changes in the federal funds rate to changes in the level and slope of the yield curve has weakened over time.

We assume that long-term interest rates are determined according to the expectations hypothesis plus a time-varying term premium:[4]

$$i_t^{(n)} = E_t\left(\frac{\sum_{j=0}^{n-1}(r_{t+i}^{(1)} + \pi_{t+i}^{(1)})}{n}\right) + TP_t^n, \tag{1}$$

where $i_t^{(n)}$ is the (nominal) yield on an n-period bond at time t, $r_{t+i}^{(1)}$ is the real yield on a 1-period bond in time period $t+i$, $\pi_{t+i}^{(1)}$ is the 1-period inflation rate in period $t+i$, and TP_t^n is the n-period term premium at time t; E_t denotes expectations conditional on time t information. The yield curve slope (difference between yields on an n-period bond and 1 period bond) can therefore be expressed as:

$$i_t^{(n)} - i_t^{(1)} = E_t\left(\frac{\sum_{j=0}^{n-1}\left(r_{t+i}^{(1)} + \pi_{t+i}^{(1)}\right)}{n}\right) - r_t^{(1)} - \pi_t^{(1)} + TP_t^n \tag{2}$$

$$S_t^{(n)} = i_t^{(n)} - i_t^{(1)} = E_t\left(\frac{\sum_{j=1}^{n-1} r_{t+i}^{(1)} - (n-1)r_t^{(1)}}{n}\right) + E_t\left(\frac{\sum_{j=1}^{n-1} \pi_{t+i}^{(1)} - (n-1)\pi_t^{(1)}}{n}\right) + TP_t^n \tag{3}$$

We further assume that when the Fed raises short-term rates $\Delta i_t^{(1)}$ the current 1-period inflation rate is fixed so $\Delta\pi_t^{(1)} = 0$ so the real rate rises by the full amount of the nominal fed funds rate change: $\Delta r_t^{(1)} = \Delta i_t^{(1)}$. Finally, we assume that the term premium remains unchanged: ΔTP_t^n=0.

To isolate the various changes in the yield curve slope that might occur in response to changes in the federal funds rate we consider several cases.

Case 1: an increase in the federal funds rate $\Delta r_t^{(1)}$ does not cause a change in the expected inflation rate:

$$E_t\left(\frac{\sum_{j=1}^{n-1} \Delta\pi_{t+i}^{(1)}}{n}\right) = 0 \tag{4}$$

It follows that the change in the slope will equal

$$\Delta S_t^{(n)} = E_t\left(\frac{\sum_{j=1}^{n-1} \Delta r_{t+i}^{(1)} - (n-1)\Delta r_t^{(1)}}{n}\right) \tag{5}$$

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[3] See https://www.reuters.com/article/us-usa-fed-communications/timeline-federal-reserves-transparency-steps-idUSTRE80O2QQ20120125 for details about the Fed's move toward greater transparency.

[4]The finance literature typically expresses the expectations hypothesis in terms of log yields. The log yield on an n-period discount bond can be represented as $y_t^n \equiv -\frac{1}{n}p_t^n$ where p_t^n is the log price of an n-period discount bond. Equation (1) is a reasonable approximation for the purposes of illustrating our hypothesis.

In general the sign on this term depends on the expected path of future federal funds rate change. We consider two polar extreme cases.

Case 1a. Suppose the ***change*** in the federal funds rate is a random walk:

$$\Delta r_{t+i}^{(1)}=\Delta r_{t+i-1}^{(1)} \qquad (6)$$

This process for the federal funds rate implies that a 25 basis point rate hike today is expected to be followed by 25 basis point rate hikes each period so that the expression for the change in the slope would reduce to:

$$\Delta S_t^{(n)} = E_t\left(\frac{(n-1)\Delta r_t^{(1)} - (n-1)\Delta r_t^{(1)}}{n}\right) = 0 \qquad (7)$$

In other words, the slope would remain constant, but the level of the yield curve would shift upward by the change in the federal funds rate $\Delta r_t^{(1)}$.

Case 1b. Anything less than this extreme case, that is if financial market participants expect the change in the federal funds rate to persist for m periods where m < n-1, and the expected inflation rate is unaffected by the change in the federal funds rate, then

$$\Delta S_t^{(n)} < 0 \qquad (8)$$

which implies a flattening of the yield curve in response to an increase in the federal funds rate.

Case 1 suggests that the baseline for thinking about the response of the yield curve slope to a change in the federal funds rate is that the slope will flatten. To the extent that we observe the yield curve steepening in response to a change in the federal funds rate, it must be the case that some combination of expected future inflation and/or the term premium respond enough to offset the negative effect described in case 1.

Case 2: maintaining the assumption that current inflation does not respond to the federal funds rate change, that is, $\Delta\pi_t^{(1)} = 0$, we again consider the extreme case in which the change in the real rate is a random walk; if an increase in the federal funds rate today causes people to raise their expectations of inflation (the Romer and Romer hypothesis) then

$$\Delta S_t^{(n)} = E_t\left(\frac{\sum_{j=1}^{n-1}\Delta\pi_{t+i}^{(1)}}{n}\right) > 0 \qquad (9)$$

If we relax the assumption of a random walk for the federal funds rate and maintain the assumption that the term premium remains unchanged, it is clear that in order to observe a steepening of the yield curve in response to an increase in the federal funds rate, the term described by equation (9) must be large enough to offset the downward pressure on the yield curve slope described in case 1b.

Our hypothesis is that the Federal Reserve's movement towards transparency and the accompanying erosion of their advantage in forecasting inflation (as documented by Gamber and Smith, 2009) suggests that the yield curve slope would rise by less (or perhaps even flatten) in response to a fed funds rate hike because the term described by equation (9) (the sum of expected inflation) would respond less to fed funds rate hikes.

$$\Delta S_{t,post-transparency}^{(n)} < \Delta S_{t,pre-transparency}^{(n)} \qquad (10)$$

It is worth emphasizing that the main result of our analysis – that the yield curve slope will respond positively to fed funds increases when expected inflation rises – does not rely on the assumption that the federal funds rate is a random walk. The random walk assumption is sufficient but not necessary in this case. When the federal funds rate is not a random walk, as in case 1b, the slope will decline unless it is offset by a positive change in expected inflation.[5] The fact that we observed a positive yield curve response to fed fund changes in the pre-transparency period suggests that the increase in expected inflation was in fact large enough to offset the effect described by 1b.

In the empirical application that follows, we separate changes in the slope from changes in the level and changes in the curvature of the yield curve. We do so to isolate the effect on slope and therefore directly test the hypothesis given by equation (10).

Although our focus is on the response of the yield curve slope to changes in the federal funds rate, we need to additionally address the effects of greater transparency on the response of the level to changes in the federal funds rate as well. As noted in Case 1a above, a change in the federal funds rate which persists indefinitely (the random walk assumption) and does not elicit a change in the path of expected inflation will result in an upward shift in the yield curve and no change in the slope.

The change in the level of the yield curve is described by $\Delta i_t^{(n)}$ for all n.

$$\Delta i_t^{(n)} = i_t'^{(n)} - i_t^{(n)} = E_t\left(\frac{\sum_{j=0}^{n-1}\left(r_{t+i}'^{(1)} - r_{t+i}^{(1)} + \pi_{t+i}'^{(1)} - \pi_{t+i}^{(1)}\right)}{n}\right) + \left(TP_t^n - TP_t'^n\right) \quad (11)$$

For simplicity, and given the fact that we control for changes in the term premium in the empirical application below, we assume that $(TP_t^n - TP_t'^n) = 0$. The level effect is therefore isolated by imposing the condition that $\Delta i_t^{(n)} = \Delta i_t^{(n-1)}$

$$E_t\left(\frac{\sum_{j=0}^{n-1}\left(r_{t+i}'^{(1)} - r_{t+i}^{(1)} + \pi_{t+i}'^{(1)} - \pi_{t+i}^{(1)}\right)}{n}\right) = E_t\left(\frac{\sum_{j=0}^{n-2}\left(r_{t+i}'^{(1)} - r_{t+i}^{(1)} + \pi_{t+i}'^{(1)} - \pi_{t+i}^{(1)}\right)}{n-1}\right) \quad (12)$$

Or more simply, the level effect implies $r_t'^{(1)} - r_t^{(1)} + \pi_t'^{(1)} - \pi_t^{(1)} = r_{t+j}'^{(1)} - r_{t+j}^{(1)} + \pi_{t+j}'^{(1)} - \pi_{t+j}^{(1)}$ for all j. Again, assume that when the Fed raises short-term rates $\Delta i_t^{(1)}$ the current 1-period inflation rate is fixed so $\Delta\pi_t^{(1)} = 0$ so the real rate rises by the full amount of the nominal fed funds rate change: $\Delta r_t^{(1)} = \Delta i_t^{(1)}$. The level-effect is therefore the part of the change in the current real rate that persists across all forward rates. In other words, changes in the level of the yield curve reflect changes in the long-run neutral policy rate (r-star). By including changes in the level of the yield curve in the empirical application below, we isolate the effects of changes in the neutral policy rate.

4. Data

Our data are non-seasonally adjusted monthly, beginning in 1984 and ending in August 2019. We generated the synthetic yield curve for Treasury securities using the parameters from Gürkaynak et al. (2007) for monthly maturities (*m*=1 to 120). We then decomposed the yields into level, slope and curvature using principal components (additional details in the following section).

Our main interest is the response of the federal funds rate to innovations in the yield curve components. We used monthly averages the effective federal funds rate for the samples 1984 through 2008 and December 2015 through August 2019. The period between 2009 and 2015

[5] Using quarterly data for the sample 1984 through 2018, the first order autoregressive coefficient for the federal funds rate .98, which suggests that shocks to the federal funds rate are highly persistent.

presents an obvious challenge. During that period the federal funds rate was arguably not an accurate measure of the stance of monetary policy. For the estimates presented below, we use monthly data on the effective federal funds rate, and for samples that covered the period January 2009 through November 2015, we used the shadow federal funds rate constructed by Wu and Xia (2016).[6] The shadow federal funds rate captures changes in the stance of monetary policy during the period when the Federal Reserve was constrained by the zero lower bound. Our measure of the term premium is based on the model of Adrian et al. (2013). They extract the estimated term premium from the predicted movements in observed one-period excess returns on Treasury securities. We use their term premium on the 10-year Treasury security which is available monthly from 1961-present.[7]

We break our sample at known times that there were transitions in the macroeconomy similar to an event study. Our first sample starts in 1984, which coincides with many estimates of the Great Moderation (see Kim and Nelson 1999, and McConnell and Perez-Quiros 2000). This time period is characterized by a reduction in the volatility of both inflation and real GDP growth. For our purposes, the reduced volatility in inflation has made inflation harder to forecast as noted by Stock and Watson (2007). The sample, which begins in 1994, coincides with the Fed moving toward greater transparency. The increased transparency was a gradual process that has continued through the end of our sample (see Swanson 2006)[8]. The final sample starts with the Financial Crisis, Great Recession and slow recovery period that includes unconventional monetary policy.

5. Method

Our hypothesis is that greater transparency on the part of the Fed should have reduced the responsiveness of the yield curve to fed funds innovations. We first decompose the yield curve into three orthogonal components representing level, slope and curvature. We then estimate the responses of those components to federal funds rate innovations in an error corrections framework.

5.1 Decomposing the Yield Curve into Level, Slope and Curvature

As noted above, following Cochrane and Piazzesi (2005) we characterize the yield curve by the first three principal components of the cross-section of yields at each point in time.[9]

The first three principal components roughly capture movements in the level, slope and curvature of the yield curve (see Diebold and Rudebusch, 2013). Figure 1 shows these estimates of the level (right axis), slope and curvature of the Treasury yield curve along with the nominal federal funds rate.

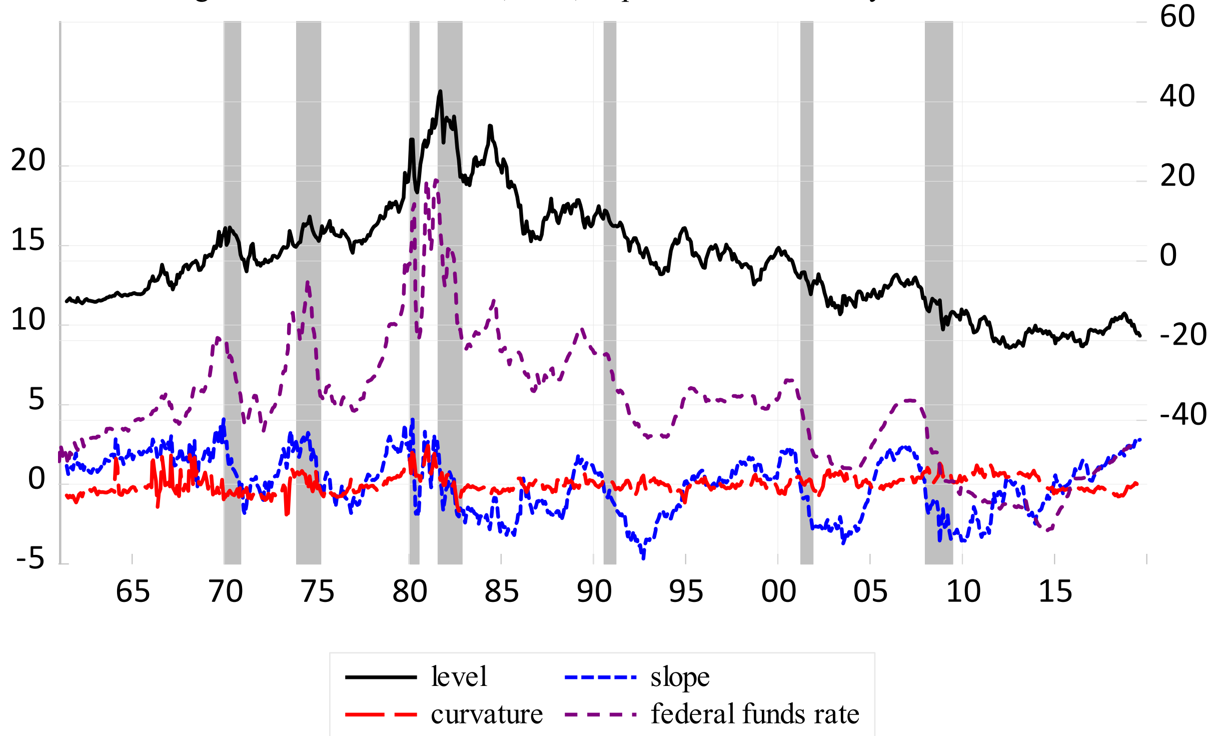
[6] See https://www.frbatlanta.org/cqer/research/shadow_rate.aspx?panel=1 for estimates of the shadow rate.

[7] See https://www.newyorkfed.org/research/data_indicators/term_premia.html for term premium data.

[8] Although there are measures of central bank transparency (e.g. Eijffinger and Geraats 2002) most do not cover our sample adequately to be used to determine break dates. See Board of Governors for information on current practices. https://www.federalreserve.gov/faqs/about_12798.htm.

[9] Diebold et al. (2006) estimate a VAR which incorporates the level, slope and curvature of the yield curve as measured by the first three principal components. Their purpose is different from ours. They are mainly focused on understanding whether the various dimensions of the yield curve are useful for forecasting future movements in the real economy and monetary policy.

Figure 1: federal funds rate, level, slope and curvature of yield curve



5.2 Empirical Specification

Our goal is to measure the response of the level, slope and curvature components of yield curve to federal funds rate innovations.[10] We begin by conducting a series of Granger causality, unit root and cointegration tests and then proceed to estimate an error correction model of the relationship between the federal funds rate and the various components of the yield curve.

Granger causality. We applied the Granger causality test to our 4 and 5-variable vector autoregressions:

$$X_t = A(L)X_{t-1} + \varepsilon_t \tag{13}$$

Where X_t contains either four or five variables

$$X_t = \begin{pmatrix} i_t \\ l_t \\ s_t \\ c_t \end{pmatrix}$$

[10] Gamber and Joutz (2005) also estimate the response of the slope the yield curve to changes in monetary policy. Their approach differs in that they impose contemporaneous restrictions to identify shocks to the yield curve slope (rather than measuring it directly using principal components).

$$X_t = \begin{pmatrix} i_t \\ l_t \\ s_t \\ c_t \\ tp_t \end{pmatrix}$$

i_t= nominal effective federal funds rate
l_t= level of the yield curve
s_t= slope of the yield curve
c_t=curvature of the yield curve
tp_t= term premium

We conducted the Granger causality test for our 3 subsamples: 1984-1993, 1994-2007 and 2008-2019 (July). The federal funds rate is replaced by the shadow rate for the period (January 2009 through November 2015). The level, slope and curvature of the yield curve are the first three principal components extracted from the monthly yield curves as described above. The five variable VAR includes an additional variable – the estimated term premium on the 10-year T-note. The term premium is from Adrian et al. (2013).[11] *A(L)* represents the matrix of polynomials in the lag operator. The lag length (for both the 4 and 5 variable specifications) was 2 which was chosen based upon minimizing the Akaike's information criteria (AIC) statistic.

Our reason for estimating the 5-variable VAR is to control for the effect described by Hanson and Stein (2015). They find that changes in monetary policy have an effect on the term premium. In the four-variable VAR, responses in the slope to yield curve innovations could result from changes in expected forward rates or changes in the term premium. In the five-variable VAR, we control for changes in the term premium so that all that is left of the change in the slope in response to an innovation in the federal funds rate are changes in the expected forward rates.

The Granger causality tests (available from the authors upon request) indicate that in the pre-transparency period, 1984 through 1993, changes in the federal funds rate Granger caused changes in the yield curve slope. After 1984, that result largely disappears, that is, changes in the federal funds rate do not Granger cause changes in the yield curve slope. The other Granger test results that is of interest to the main hypothesis of this paper is the relationship between the federal funds rate and the level of the yield curve. The heuristic model presented in section 3 above suggests the federal funds rate should Granger cause the level of the yield curve in the pre-transparency period. We failed to find Granger causality evidence in support of this hypothesis. That is, in each of the three sub-samples we examined, the federal funds rate failed to Granger cause the level of the yield curve. We note, however, that because of the presence of unit roots, as discussed in the next section, the Granger causality test results are possibly biased. Thus, below we present estimates of a vector error correction model in an effort to capture both the long-run relationships among the integrated variables as well as the short-term dynamics.

Unit roots Tests. We tested each of the five series in our VAR for the presence of a unit root using the Dicky-Fuller test. Each test was conducted over the full sample of monthly observations: 1984-2019 (July). The unit root test results are shown in Table 1 below.[12] Except

[12] The complete unit root test results are available upon request.

for the estimated curvature series (c_t) we fail to reject the unit root hypothesis for the variables in our 4 and 5 variable VARs.

Table 1: Unit Root Test Results

variable	Estimated root	Null hypothesis: unit root
i_t	0.99	fail to reject
l_t	0.99	fail to reject
s_t	0.98	fail to reject
c_t	0.88	reject
tp_t	0.99	fail to reject

Note: data are monthly, sample period: 1984.01-2019.07.

Cointegration and Error Correction. The unit root tests shown in Table 1 above suggest the possible presence of long-run relationships among the integrated variables in our model. We applied the Johansen cointegration test to our 4 and 5-variable VARs (full results available in the on-line supplemental materials). In the 4-variable VAR we found one cointegrating relationship:

$$i_t = 4.98 + 0.27^{**} \times l_t + 0.82^{**} \times s_t \qquad (14)$$

In the 5-variable VAR our tests indicated two cointegrating relationships:

$$i_t = -1.59 + 2.75^{**} \times s_t + 4.09^{**} \times TP_t \qquad (15a)$$

$$l_t = -24.8 + 7.22^{**} \times s_t + 15.4^{**} \times TP_t \qquad (15b)$$

The slope coefficients in the long-run relationships were all significant at the 0.01 level.
In the 4-variable VAR, the federal funds rate is positively related to the level and slope of the yield curve in the long-run. The results for the 5-variable VAR differ somewhat and offer some insight into the Granger-causality results presented above. Namely, the first long-run relationship is between the federal funds rate, the yield curve slope and the term premium, that is, the level of the yield curve is not contained in that relationship. The second long-run relationship suggests that the level is positively related to the slope and the term premium. Thus, our finding that the level of the yield curve is not Granger caused by the federal funds rate is consistent with equations (15) which say that the level of the yield curve and the federal funds rate are not cointegrated.

6. Results

As noted in the previous section, we estimated two VECM models. We chose the lag length that minimized the AIC statistic. The 4-variable VECM included one cointegrating relationship (14) and one lag of each of the differenced variables. We also included the curvature measure which our unit root tests indicated was stationary. The 5-variable VECM included two cointegrating relationship (15a and 15b) and one lag of each of the differenced variables. As in the 4-variable system, we also included the curvature measure in the system.

We present our main results in two sets of figures. Recall, we are examining how changes in the fed funds rate affects the level and slope of the yield curve as the transparency of the Fed has changed. Figures 2a to 2c show the results of the VECM without the term premium and Figures 3a to 3c show the results of the VECM with the term premium. We limit our presentation and discussion to those results that are economically interesting. All impulse responses are surrounded by 95 percent confidence intervals derived from 1000 bootstrap simulations.

Figures 2a through 2c display the impulse responses from the four variable VECM estimated over three sub-samples. The first sample spans the onset of the Great Moderation through the end of 1993 – the date that is generally associated with the start of increased transparency. The second sample spans from 1994 until the onset of the Great Recession and the third sample spans the Great Recession through 2019.

In our VECM, the graphs in all three figures show how the level and slope responds to a one standard deviation increase in the federal funds rate. The key result in this four-variable VECM is that the slope of the yield curve responds significantly to federal funds innovations in the pre-transparency sample (2a) and not at all in the period of greater Fed transparency (Figure 2b). In the sample that spans the Great Recession through 2019 the response of the yield curve slope to fed funds innovations is also zero (Figure 2c). Since over much of that sample the Fed maintained a funds rate target close to zero, we also estimate the VECM using the effective federal funds rate. The results are similar to those we present using the shadow rate constructed by Wu and Xia. Finally, as expected the level is not affected by increases in the federal funds rate once the Fed introduces greater transparency.[13]

In particular, the slope of the yield curve jumps and then increases slowly after the increase in the fed funds rate during the pre-transparency period. A one standard deviation innovation in the fed funds rate is 24 basis points. Therefore, a 24 basis point increase in the fed funds rate leads to an immediate 9 basis point increase in the slope and a long term 35 basis point increase in the slope. In contrast, there is little to no jump and no sustained increase in the slope in the two post-transparency time periods lending evidence to our hypothesis that greater transparency by the Fed has diminished the response of the yield curve to fed funds changes.

[13] Note that there does seem to be a positive response of the level (at least initially) to a positive fed funds innovation. This response is contained in a wide confidence interval so that it difficult to determine if the true response is positive or zero. Perhaps this level change is in response to changes in the term premium and therefore, our 5-varaible VECM can better address this issue.

Figure 2a: Response to One S.D. Innovations +/- 2 S.E.
VECM 4, sample: 1984-1993

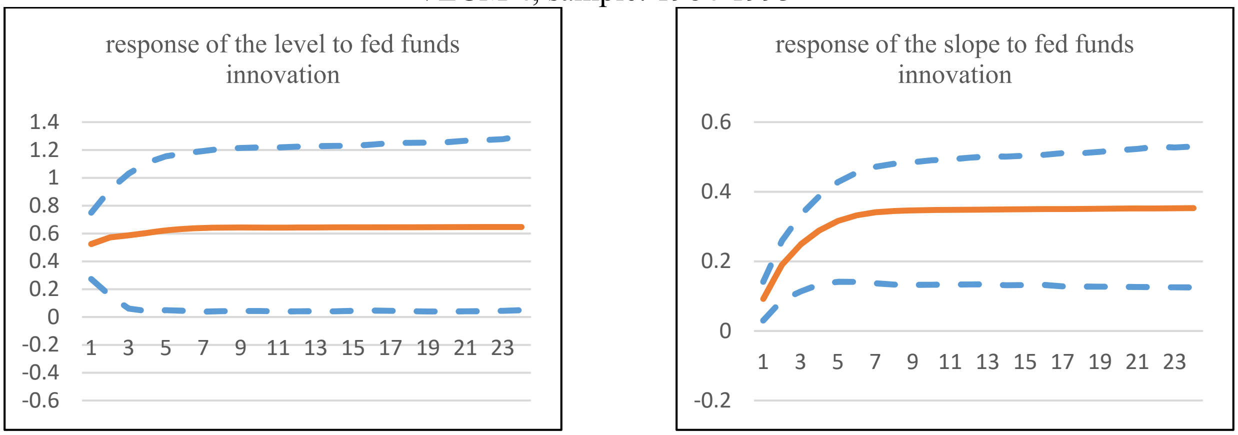
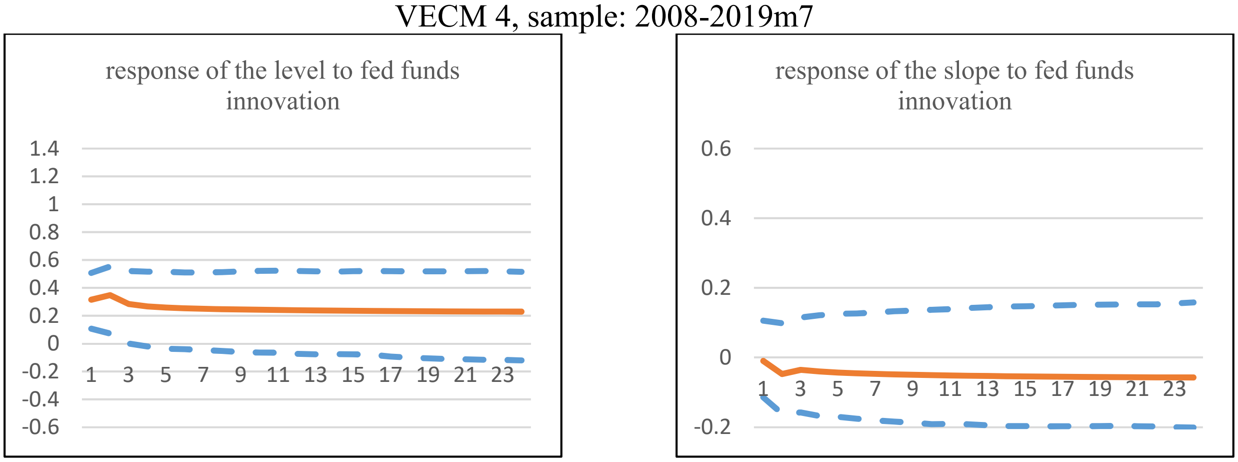


Figure 2b: Response to One S.D. Innovations +/- 2 S.E.
VECM 4, sample: 1994-2007

Figure 2c: Response to One S.D. Innovations +/- 2 S.E.
VECM 4, sample: 2008-2019m7



Figures 3a through 3c display the five variable VECM results estimated over the three sub-samples. In this VECM, the response of the yield curve slope is now orthogonal to the innovations in the term premium. The main result still holds – the slope responds significantly before greater Fed transparency but very little or not at all since. Once accounting for the term premium, the size of the increase in the slope due to fed funds increases is the same (10 basis points) immediately and smaller (26 basis points) after 6 months in the pre-transparency period (figure 3a). In the 1994 to 2007 period (figure 3b) in which transparency grew, the effect is small (9 basis points) but significant[14] and in the most recent period (figure 3c), the effect disappears (not statistically significant).

We also find similar results for the level; the level is not very responsive to fed funds rate increases. In our five variable VECM, it is not the pre-transparency period (figure 3a) where we find a significant response (except in the first two periods) but in the 2008 to 2019 period (figure 3c). We hypothesize that the level effect seen in figure 3c comes from the move away from the ZLB at the end of 2015. Future research is needed to better understand the effect on the yield curve when monetary policy moves away from the ZLB.

In addition in results not shown here, we find that the term premium responded negatively to federal funds rate innovations in the first two samples; this is somewhat inconsistent with the Romer and Romer hypothesis that the Fed revealed inflation information when they hiked rates. If that hypothesis were correct, we would expect that such revelations would lead to an increase in the term premium. The fact that the term premium declined suggests that Fed rate hikes at least partly reduced the fear of future inflation surprises. That response disappeared (became insignificant) in the 2008 to 2019 sample. The no-response result could be a consequence of more well-anchored inflation expectations as the Fed instituted an explicit inflation target in January 2012.

[14] Given that the Fed increased transparency slowly over this time period, it is possible that bond market participants adjusted their response gradually to these changes; therefore, we still find a significant response.

Figure 3a: Response to One S.D. Innovations +/- 2 S.E.
VECM 5, sample: 1984-1993

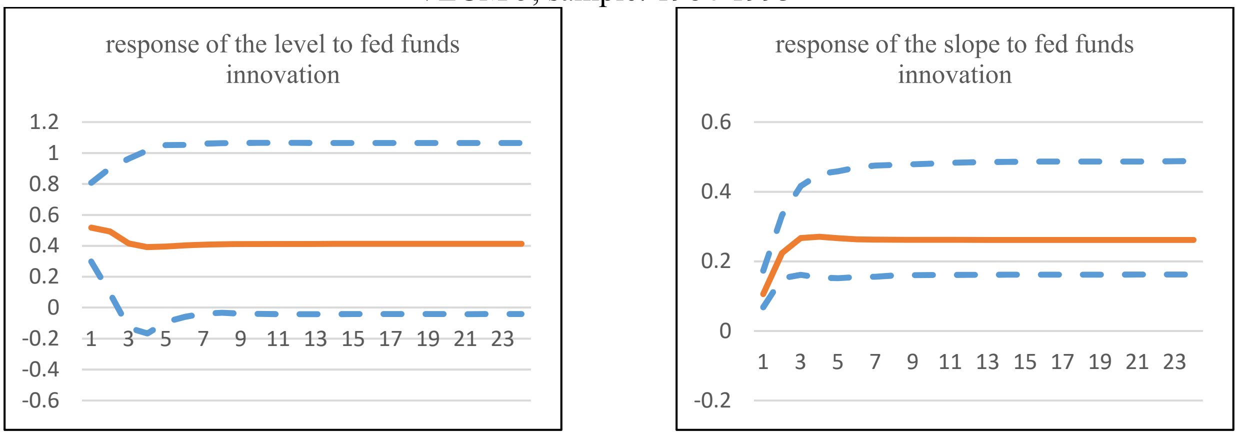


Figure 3b: Response to One S.D. Innovations +/- 2 S.E.
VECM 5, sample: 1994-2007

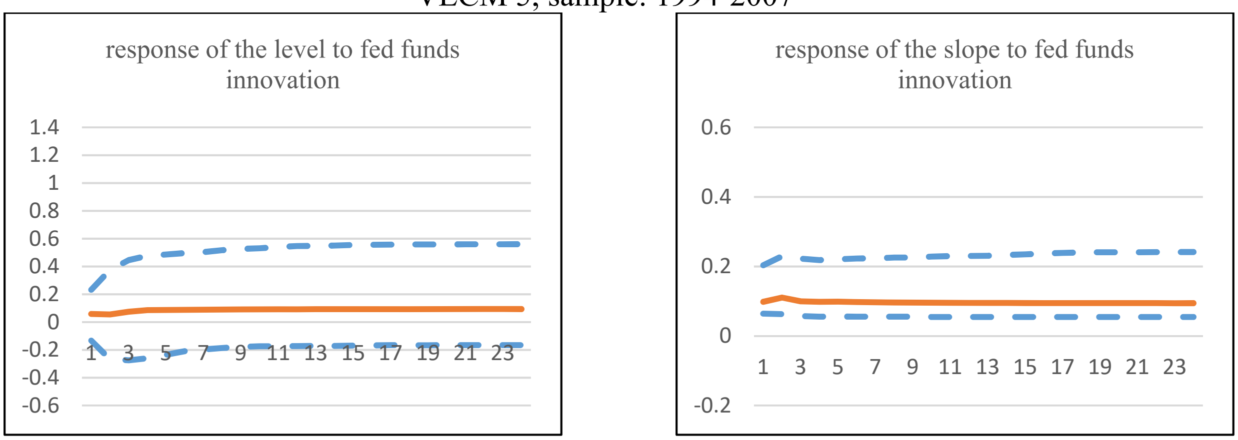
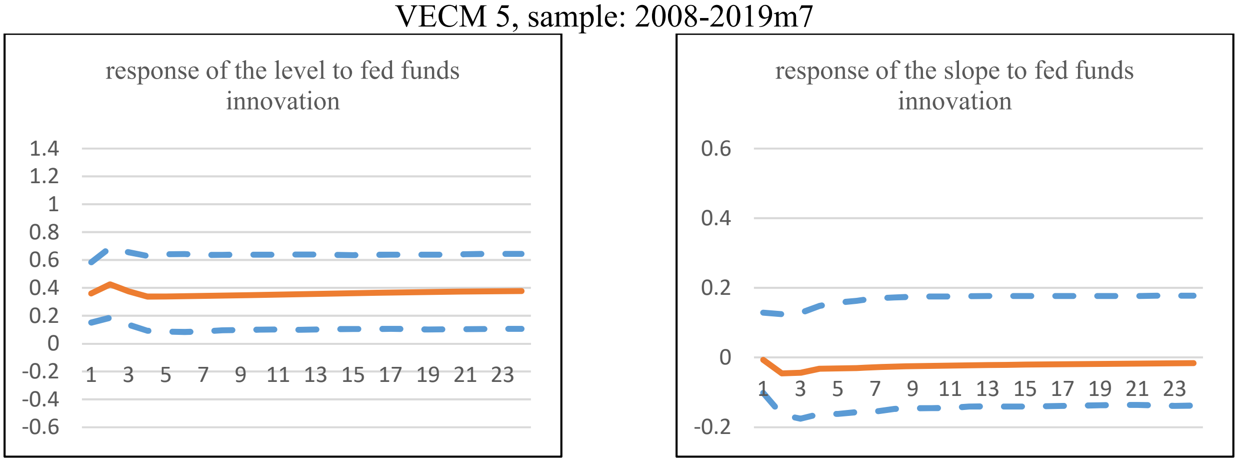


Figure 3c: Response to One S.D. Innovations +/- 2 S.E.
VECM 5, sample: 2008-2019m7



7. Conclusion

The results are consistent with our hypothesis. Greater transparency may be a reason for the disappearance of the response of the slope of the yield curve to fed funds innovations. There are other possible (related) explanations as well. At the same time that (and perhaps at least partly because of) the Fed's movement toward greater transparency, inflation expectations became more solidly anchored to the Fed's (implicit and after 2012 explicit) 2 percent inflation target. The anchoring of inflation expectations coincided with a decline in the term premium on long-term Treasury securities. Reduced risk of capital loss (because of lower risk of inflation surprises) increased the demand for long-term Treasuries.

And finally, our empirical strategy is based on a small set of summary measures derived from the yield curve—the level, slope, and curvature and term premium. It is possible that other macroeconomic factors could affect the federal funds rate and the yield curve. We have not included such factors in this analysis, partly for reasons of parsimony. But at a deeper level, our analysis maintains the so-called “spanning” hypothesis which says essentially that the information contained in the yield curve reflects all macroeconomic information relevant for understanding the movements in interest rates over time (see Bauer and Rudebusch 2017, and Bauer and Hamilton 2017.) We leave a full investigation of that matter to future research.

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