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ABSTRACT

We measure monetary policy shocks as changes in the Fed funds target rate that surprise bond markets in daily data. These shock series avoid the omitted variable, time-varying parameter, and orthogonalization problem of monthly VARs, and do not impose the expectations hypothesis. We find surprisingly large and persistent responses of bond yields to these shocks. 10 year rates rise as much as 8/10 of a percent to a one percent target shock. The usual view that monetary policy only temporarily raises long term rates and influences inflation would lead one to predict a negative long rate response.

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The Fed and Interest Rates – a High-Frequency Identification

John H. Cochrane and Monika Piazzesi*

This paper studies monetary policy shocks, defined from Fed Funds target movements relative to daily interest rate data. These shocks are nearly ideal measures of unexpected movements in monetary policy. Market expectations can summarize the vast amount of information used by the Fed in setting policy, and used by Fed watchers in guessing the Fed’s actions, thus surmounting the omitted variables problem in estimated policy rules. Interest rate forecasts can adapt to changes in the Fed’s reactions to the rest of the economy – the time-varying parameter problem. If in one year the Fed worries about inflation, but in another year it places more weight on unemployment, market forecasts will adapt, but VAR regressions may not, and incorrectly interpret anticipated actions to be shocks.

Finally, high frequency data surmount painlessly the pervasive orthogonalization problem. Interest rates all move together. Does this movement reflect Fed reaction to interest rates, or interest rate reactions to the Fed? Neither recursive identification is plausible for monthly data. Fed officials obviously look at interest rates just before the FOMC meeting, and just as obviously, interest rates react immediately to any change in funds target. By contrast, the one-day correlation between a target change and interest rate changes is obviously not a Fed reaction to intra-day interest rate news.

Orthogonalization matters a lot in monthly data. If one orthogonalizes the funds rate before other interest rates, one estimates that policy shocks have a strong, “level” effect on other interest rates. If one orthogonalizes with the funds rate after other interest rates, one recovers an idiosyncratic funds rate movement that does not affect other rates. The effect of the funds shock on long term interest rates is *entirely* determined by the orthogonalization.

Following this attractive intuition, Glenn Rudebusch (1998) and others have used Fed funds futures data and the expectations hypothesis that the futures rate is equal to the expected future spot rate to define an expected fed funds target, and thus a shock. Alas, the institutional details of the funds rate and its futures market make this approach more complex than it seems. Also, the expectations hypothesis is currently most famous for the failure of the forward-spot spread to forecast interest rate changes. Finally, this approach is limited to a sample since Fed funds futures were introduced in 1988.

With these thoughts in mind, we follow Monika Piazzesi (2001) in defining shocks from interest rates more generally, and without imposing the expectations hypothesis. We use two approaches. First, we run a regression of target rate changes on interest rates just before the target change. Second, we define the shock as the change in the 1 month Eurodollar rate from just before to just after the target change. Both measures use the fact that there has been a target rate change; they omit from the shocks all dates on which the funds rate might have been expected to change, but it did not. Throwing out shocks need not bias responses, and we suspect that the response to unexpected target changes is different from the response to target changes expected by some (usually overparameterized) regression that did not happen.

We are especially interested in the effect of target changes on interest rates. Target changes seem to be accompanied by large changes in long-term interest rates, and many estimates support this correlation (Our own estimates include John Cochrane 1989 and Piazzesi 2001, Figure 3). This effect is puzzling. Why do 30 year bond yields not *decline* on funds rate shocks? Tight monetary policy should lead to lower inflation, which should lower long-term bond yields. Can the Fed really raise the real short rate 1% for 5 years or more, without leading to 1% lower inflation that would cancel any effect on longer yields?

Charles Evans and David Marshall (1998) look at interest rate responses to the shocks identified by Lawrence Christiano, Martin Eichenbaum, and Charles Evans (1996). These shocks are residuals in a carefully orthogonalized monthly VAR. They find that these CEE shocks only have “slope” effects on interest rates, and do not move long rates much. Since “level” shocks dominate the variance of long rates, their view implies that the bulk of interest rate movements is explained by the systematic component of policy. Evans and Marshall impose that interest rates do not forecast the Federal funds rate either at lags or contemporaneously. Thus, their responses are the same as regressions of interest rates on unmodified CEE shocks. One of our prime questions is whether allowing interest rates to forecast the funds target changes their conclusions.

II. A revealing episode

Figure 1 presents Federal funds target changes, the 1 month Eurodollar rate, and long term treasury yields through 2001. (Our data are all taken from the New York Fed website, release H.15, and target data augmented by Glenn Rudebusch. Eurodollar rates are recorded at 9:30 am Eastern time, while the other data are recorded at the end of the day, so we assign the Eurodollar rates to the previous day.) The top panel of Figure 1 instantly suggests which target changes were anticipated and which were unanticipated. The changes on January 3, April 18 and September 17 all took the 1 month Eurodollar rate by surprise. In fact, on January 3 the 1 month rate fell *more* than the target. The market may have inferred that another cut was coming soon. On the other hand, the changes on Jan 31, May 15 and Aug 21 were completely and exactly anticipated by the one month rate. On Mar 20 and Jun 27, the 1 month rate actually *rose* slightly on the target cut. Apparently, markets expected a larger cut, so the “shock” was positive rather than negative. On Oct 2 and Nov 6, the market had anticipated a good part but not all of the change. We could read these as some

chance of a change, which then happened. In this graph, as in the larger sample, most target changes seem completely expected by bond markets, suggesting that many conventionally measured shocks (i.e. from monthly VARs) are anticipated.

The bottom panel of Figure 1 strongly suggests that unexpected target moves affect long term rates. For example, around the 50 bp target rate change on Jan 3, the 1 and 3 year rates fell 70 bp, and the 5 year rate about 50. The natural interpretation is that the cut signaled a change of direction; in the place of further tightening, there would be further rate cuts. If the *average* shock has a smaller impact on long term rates (as found by Evans and Marshall 1998, for example), the average shock must be more transitory, or anticipated but misclassified as a shock in a monthly regression.

The response of yields to shocks is quite consistent over maturities. When the 1 month rate in the top half of the figure is surprised, so are the long rates in the bottom half, and conversely when the 1 month rate is not surprised, neither are the long rates.

September 17 is a particularly interesting target change. The terrorist attack was on Tuesday Sept 11. Bond markets reopened Thursday Sept 13. The one and three year rates dropped 50 bp. The natural interpretation is that the markets correctly anticipated that on Monday Sept 17, the Fed would lower the target 50 bp. That is exactly what the Fed did, and yields did not move on that news. Now, is this a shock, or an expected movement? A monthly VAR would count it as a shock. But the target move was clearly taken in response to events, and to a threat that output will otherwise decline. It should not count as a shock, and our measure does not do so.

III. Shocks from daily data

Figure 1 naturally suggests that we use the change in the 1 month Eurodollar rate surrounding the target change to measure its unexpected component. Detailed inspection

of some of the target changes shows interest rate movements the day before target rate changes, which may reflect dating errors. For this reason, we define the interest rate move corresponding to the shock as the move from 2 days before to one day after the change, and our regression forecast of target changes uses data 2 days before the change.

Table 1 presents regressions of interest rates on these target shocks. The relation between interest rates and unexpected target changes is clearly much stronger and more consistent than the relation between interest rates and raw target changes. The size of the coefficients is particularly startling. A 1% unexpected target change affects Treasury yields by 60-70 bp all the way out to 5 years, and 52 bp at a 10 year maturity!

We also measure policy shocks from a more conventional target forecasting regression. We started with a regression of target changes on all yields, but with many similar coefficients and small t-statistics, we iteratively eliminated the variables with the smallest t-statistics to end up with the simpler and more interpretable form given in the table. The R^2 only declines from 0.66 to 0.64 as we exclude yields. Table 2 presents our final regression.

Table 2 gives a strong and appealing message. First, there is some slow mean reversion, shown in the coefficient on the target. Second, and interestingly given the visual appeal of Figure 1, the long-term rates are far more important than the short-term rates in forecasting Fed moves. (In the regression with all yields, the 1 month Eurodollar had a coefficient of -0.06 and a t-statistic of -0.8.) This finding contradicts expectations hypothesis logic, which suggests that the shortest possible interest rate should be the best forecaster of target changes. It suggests instead that interest rates forecast target moves because the Fed *responds* to expected inflation information embodied in long rates, as suggested by Taylor rules, especially as specified by Richard Clarida, Jordi Gali and Mark Gertler (2000). Third, the *spread* between the 2 and 5 year rate is the most important target forecasting variable

of all. This spread is a potent forecaster of real activity, which naturally suggests the output component of a Taylor rule. However, as in Piazzesi (2001), these interest rate regressions far outperform conventional Taylor rules in forecasting the target.

IV. Monthly shocks and responses

To construct monthly impulse-response functions, we sum up the daily shock series. For comparison purposes, we construct monthly CEE shocks. The VAR consists of nonfarm employment, the cpi, the commodity price index, and the fed funds rate. We orthogonalize shocks recursively in that order, and estimate the VAR with 6 monthly lags.

Our shock series is zero in a month with no target changes, and many target changes are almost completely anticipated. As a result, and especially in the latter half of the sample, we see few shocks. Inference from VAR shocks after about 1990 is dominated by expected movements that don't happen, rather than by unexpected movements that do. The two high-frequency measures also see the early 1990s rate declines and the recovery after 1994 as largely positive shocks, while the CEE measure shows positive and negative shocks.

To calculate the impulse response for horizon j , we run single regressions of the changes in variables on the policy shocks, $y_{t+j} - y_t$ on ε_{t+1} . We follow this procedure since we cannot include all the state variables (interest rates on the day before a target change) in the autoregressive representation of the VAR. It also has a very nice intuition. The impulse response function is after all a summary of the experience of the target variable following a shock. This procedure is consistent, and gives results quite similar to the autoregressive simulation when applied to the CEE VAR.

Figure 2 contrasts responses of output and CPI to our shocks and to CEE VAR shocks. Our shocks show employment *rising* following a target shock, while employment declines slowly following a CEE shock. The difference results from a different interpretation of interest

rate movements as expected vs. unexpected, and thus a different view of output episodes. CEE shocks count months around the 1987 stock market crash as much larger negative shocks than the daily measures. and the daily measures see larger negative shocks in early 1991. Alas, neither set of responses is statistically significant, as found by CEE in this sample. This is unfortunate – all of our information about the output effects of monetary policy comes from interpretation of the 1979-1982 experience.

The two high-frequency shocks give quite different answers about inflation. The one month Eurodollar shock agrees with the CEE shock that monetary policy has nearly no effect on inflation. The regression shock shows a large, though dubiously significant, *increase* in inflation following a shock. However, the standard errors are large enough that we basically conclude that there is no inflation response. This is also troubling. Fed funds shocks should lower inflation, but as in larger samples, there is no evidence that they do so.

Figure 3 plots the instantaneous (one month) responses of yields to the target shock. Both high frequency shocks produce flatter yield curve responses, and notably larger changes at the long end of the yield curve. As we found in the daily data, the measure based on the one month Euro rates produces a very large response. The 10 year rate rises by 0.8 percentage points when the funds target rises one percent, in contrast to 0.2 percentage points for the CEE shock. The fact that funds shocks do not lower inflation, and in fact seem to raise inflation, is consistent with the finding that funds shocks raise long-term rates.

Figure 4 presents the dynamic responses of yields to the regression shock and the CEE shock. (The Eurodollar shock produces results quite similar to the regression shock.) Here too, the high frequency shocks produce quite different response functions. After a blip at 6 months, all interest rates keep rising following a shock. By contrast, the CEE VAR shock produces a quite short lived response.

VI. Concluding remarks

We construct measures of monetary policy shocks from target rate changes that surprise bond markets in daily data. The “rule” we estimate is sensible: the Fed responds to long term interest rates, perhaps embodying inflation expectations, and to the slope of the term structure, which forecasts real activity. Short-term interest rates do not help to forecast target changes, suggesting that interest rate forecasts of target changes occur because the Fed *reacts* to interest rates.

As often happens, the purer the shock, the more unusual the response. Interest rates move in the same direction as policy shocks, and by surprisingly large amounts. It is natural to presume that policy shocks should *lower* long rates. Ellingsen and Söderström (2001) do find such a negative response in a narrative classification, but at the cost that their shocks must become predictable. Output and price responses are poorly measured, but there is no evidence that inflation declines following a surprise increase in the target.

It is tempting to interpret these responses by the “price puzzle” logic. Output might rise following a tightening, if the Fed is tightening to offset a foreseen output rise. However, the Fed cannot systematically fool the markets, so this is a difficult interpretation. One must believe that the Fed has a consistent information advantage over the private sector, which is a difficult case to make. This puzzle and the Sept 17 episode challenge our notions of a shock. The Fed *always* explains its actions as a response to economic events. It never says “we added another half percent just for the heck of it.” Perhaps there are no shocks.

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Footnote

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	Euro		Treasury			
	1m	3m	3m	1y	3y	10y
	Yield change on target change					
b	0.52	0.46	0.37	0.37	0.29	0.19
t	9.1	8.0	7.6	6.7	5.0	3.5
R ²	0.39	0.32	0.28	0.24	0.15	0.08
	Yield change on 1m Euro change					
b		0.91	0.62	0.72	0.67	0.52
t		22.1	6.8	10.8	8.8	5.2
R ²		0.87	0.54	0.63	0.55	0.39

Table 1. The left hand variable is the change in yield from 2 days before a target rate change to 1 day after the change. The right hand variable is, in the top panel, the target rate change itself, and in the bottom panel, the change in the one month Eurodollar rate.

	const	target	3 mo	2 yr	5 yr	10 yr
b	0.29	-0.037	0.12	0.87	-0.87	0.24
t	3.1	-3.7	2.0	6.7	-3.5	1.57

Table 2. Forecast regression of target rate changes. The left hand variable is the change in the federal funds rate target. The right hand variables are the target, and interest rate spreads over the target two days before the change. The regression is only run on dates where there are target changes. The R^2 is 0.64. Sample 1984-2001.

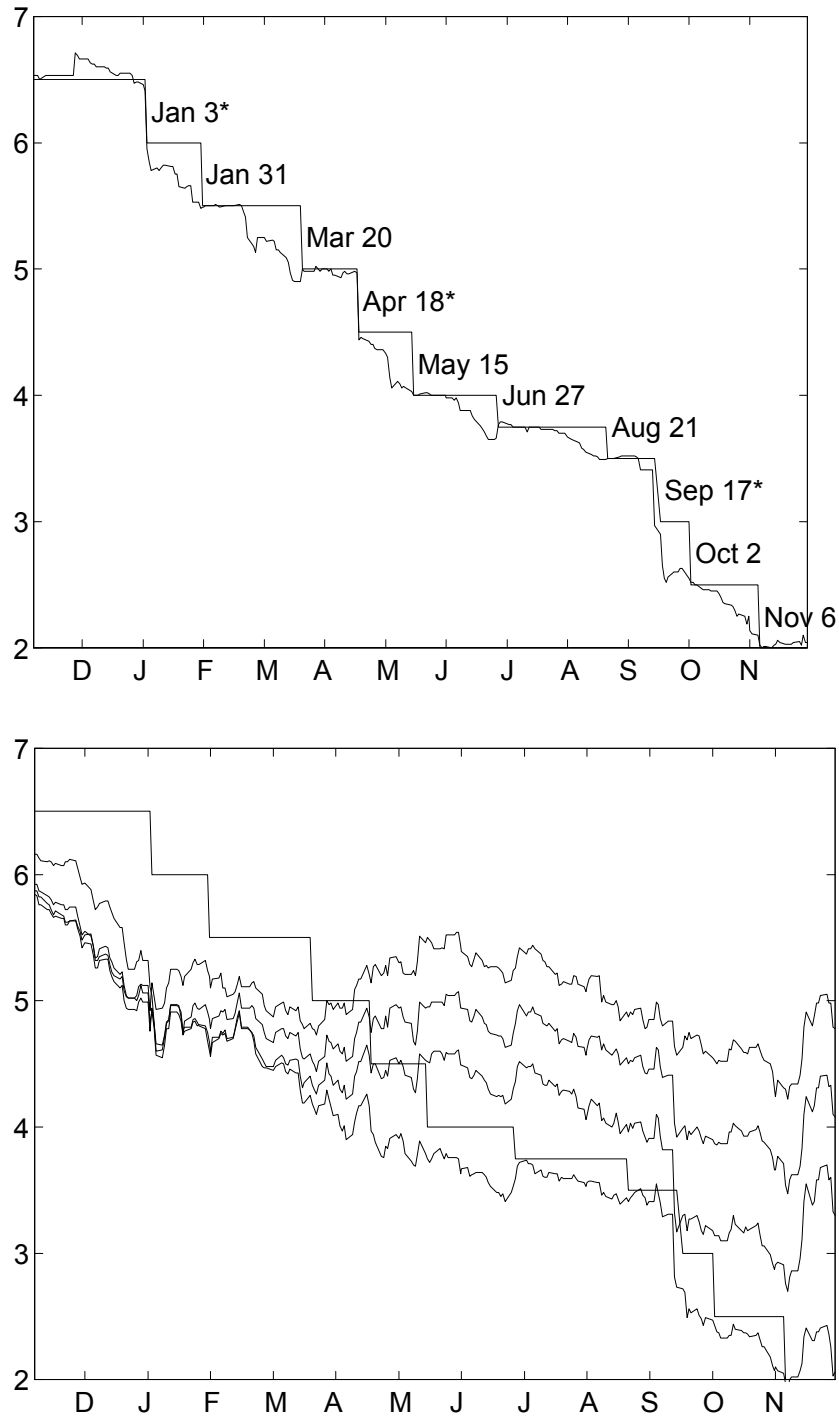


Figure 1. Interest rates and Federal funds target in 2001. Top panel: target and one month Eurodollar rate. Bottom panel: target and 1, 3, 5, and 10 year treasury yields. Changes outside regular FOMC meetings are marked with a *.

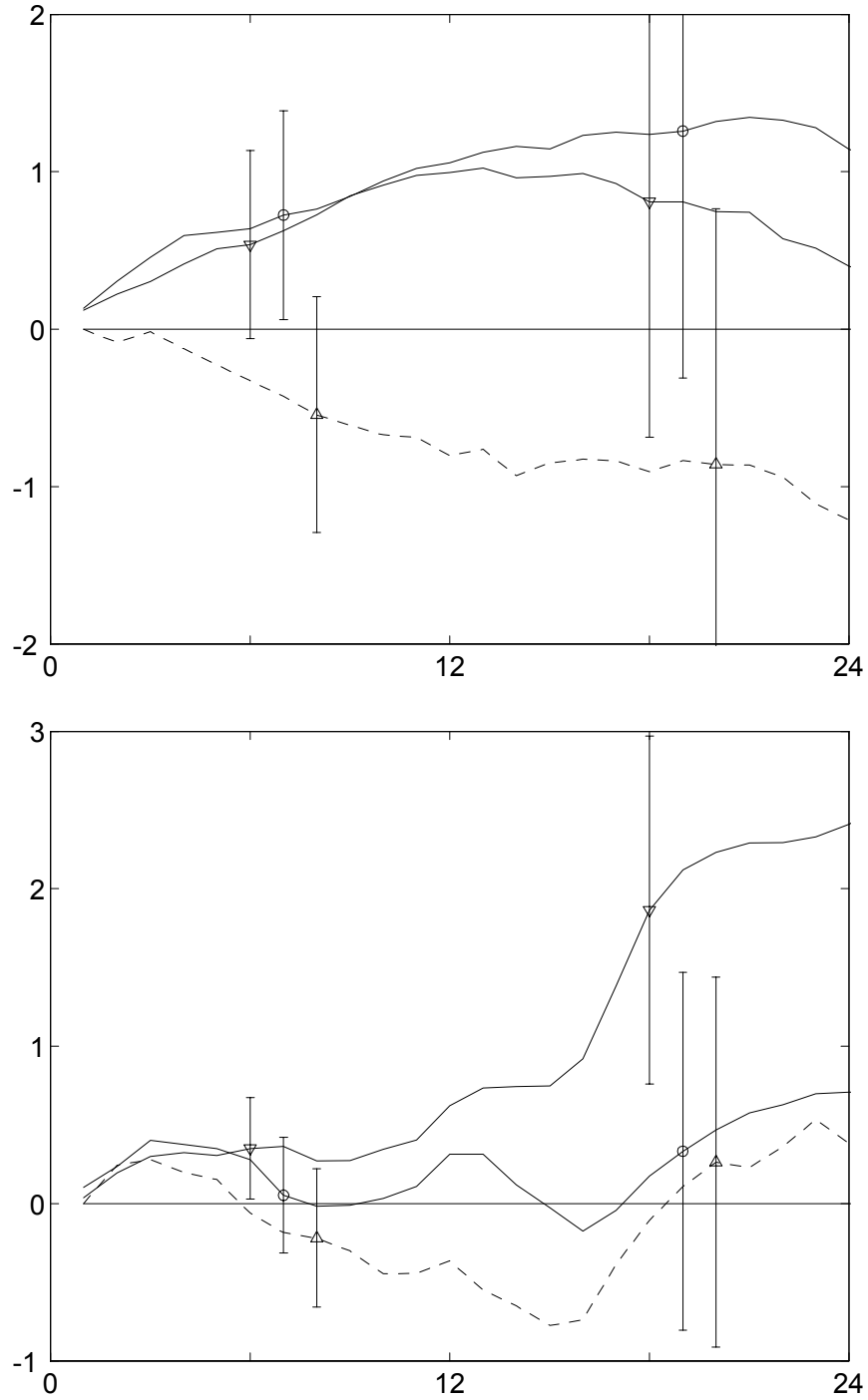


Figure 2. Response of employment (top) and CPI (bottom) to fed funds shocks. The solid lines give the response to our shocks, calculated from daily interest rates. The larger response in the bottom panel is to the regression shock. The dashed line gives the response to the VAR shock.

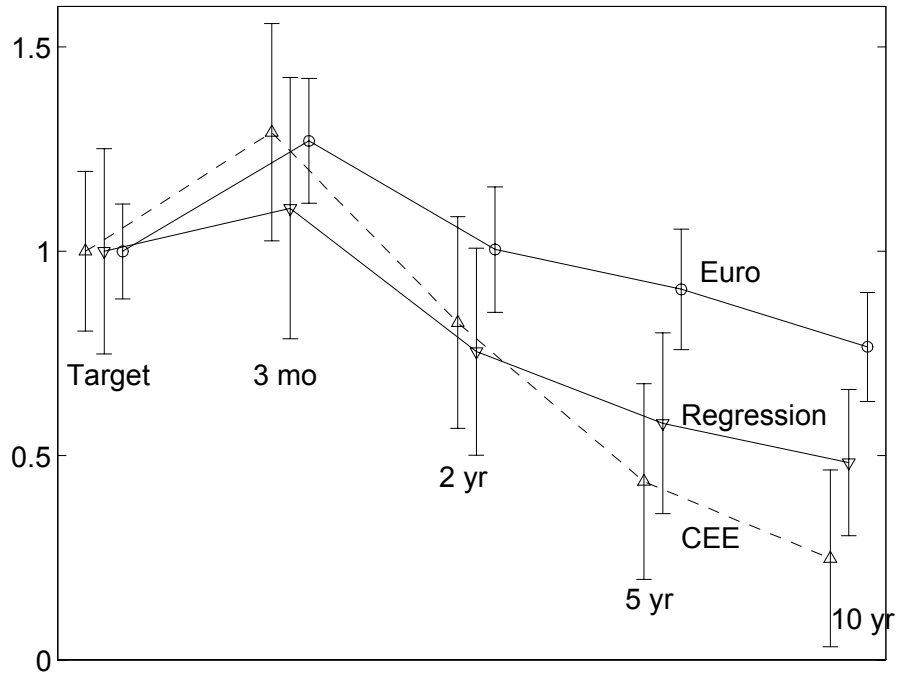


Figure 3. Impact (one month) response of yields to a funds target shock.

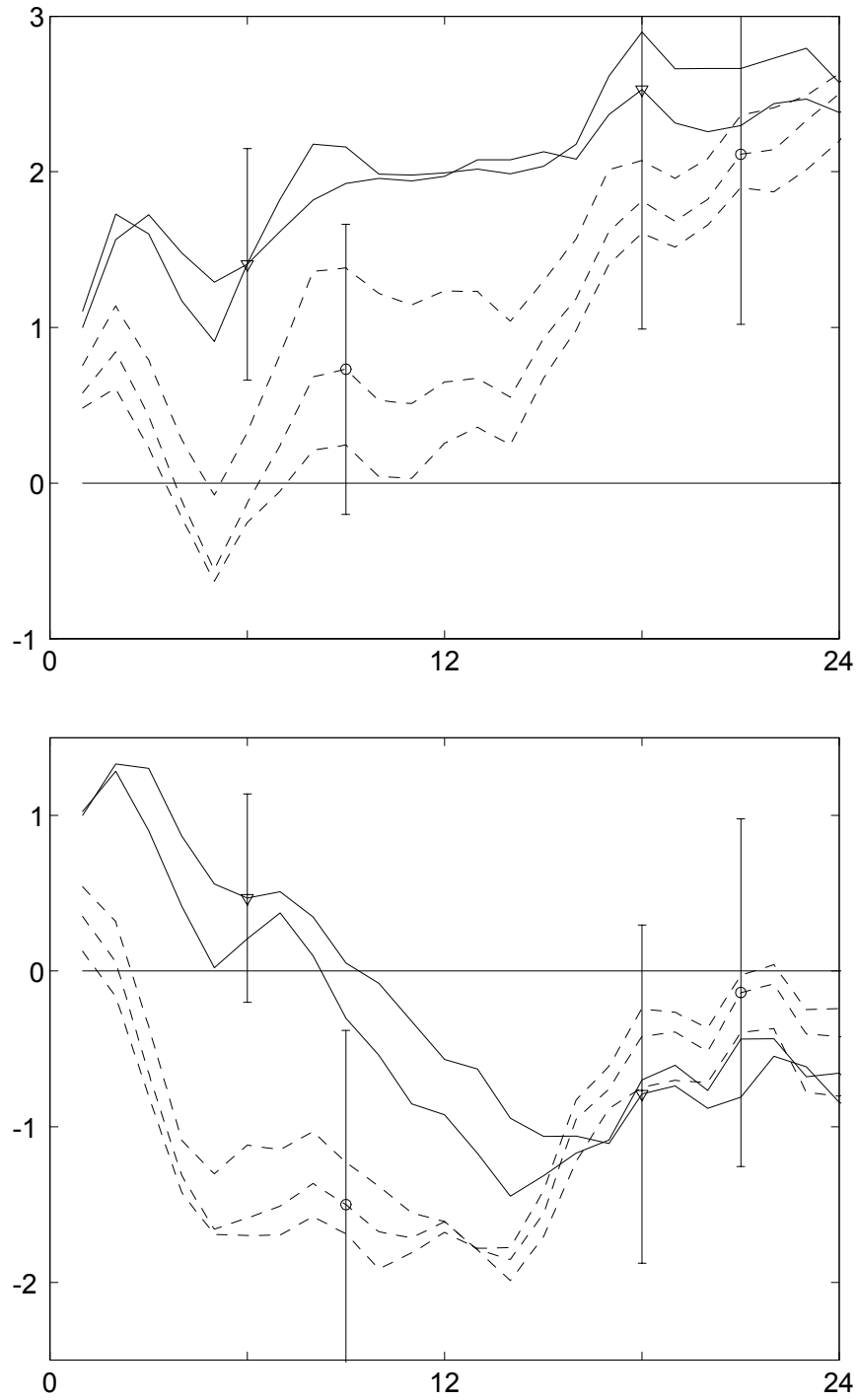


Figure 4. Dynamic response of yields to funds shocks. Top panel: response to daily regression shock. Bottom panel: response to CEE VAR shock. The solid lines are the target and 3 month Eurodollar yield. The dashed lines are the 2, 5, and 10 year Treasury yields.