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The Daily Liquidity Effect

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Abstract

Motivated, on the one hand, by the belief that the Fed controls the short-term rate through open market operations, and on the other, by "the lack of convincing proof that this is what happens," Hamilton (1997) suggested that more convincing evidence of the liquidity effect could be obtained with the use of high-frequency (daily) data. Thornton's (2001a) detailed analysis of Hamilton's results and evidence using both Hamilton's and an alternative methodology indicates a quantitatively unimportant daily liquidity effect. Recently, Carpenter and Demiralp (2006) report "clear evidence" of a daily liquidity effect using a more comprehensive reserve-supply-shock measure than that used by Hamilton. This paper investigates the daily liquidity effect using Carpenter and Demiralp's new measure.

JEL Classification: E40, E52
Key words: federal funds rate target, monetary policy, operating procedure, FOMC

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It is generally conceded that the Fed uses open market operations to control the federal funds rate through the "liquidity effect." Open market purchases of government securities drive the funds rate down; open market sales push the funds rate up. The liquidity effect must exist if the demand for reserves is negatively sloped in the funds rate because, in this case, an exogenous change in the supply of reserves will generate a change in the federal funds rate in the opposite direction. Despite the liquidity effect's axiomatic quality, Hamilton (1997) (hereafter, Hamilton) notes that "it is very difficult to find convincing proof that this is indeed what happens."[1] A negatively sloped demand curve is sufficient for the liquidity effect's existence; it does not guarantee that it is large and economically meaningful.

Noting that most attempts at identifying a liquidity effect have used low-frequency (monthly or quarterly) data, Hamilton suggests that the lack of success in isolating the liquidity effect is due to the fact that, of necessity, low-frequency data mixes together the effect of policy on economic variables with the effect of economic variables on policy. To avoid this problem, Hamilton sought to develop "a more convincing measure of the liquidity effect."[2] Rather than attempting to identify the effect of monetary policy over a month or quarter, Hamilton investigated the effect of an exogenous shock to the supply of reserves on the funds rate at the daily frequency. Reasoning that a reserve supply shock is analogous to an exogenous open market operation, a significant response of the funds rate to a reserve supply shock is prima facie evidence that the Fed can generate changes in the funds rate through open market operations. The existence of a statistically significant and qualitatively important daily

[1] Hamilton (1997), p. 80.
[2] Hamilton (1997), p. 80.

liquidity effect would suggest the relevance of the liquidity effect at lower frequencies where it is much more difficult to isolate. Of course, the converse is true. Finding a weak and qualitatively unimportant daily liquidity effect casts doubt on its importance at frequencies more relevant for monetary policy. Hence, the existence and magnitude of the daily liquidity effect has important implications for monetary policy.

Noting several shortcomings in Hamilton's methodology, Thornton (2001a) found that Hamilton's result was the consequence of a few days when there were uncharacteristically large changes in the federal funds rate. Using Hamilton's procedure, he also found no evidence of a liquidity effect for sample periods before and after Hamilton's. Furthermore, reasoning that if the Fed changed the funds rate through open market operation then the supply of nonborrowed reserves should change significantly when the Fed changes the target for the federal funds rate, Thornton (2001a) found "little support for the conventional view that the Fed controls the funds rate using open market operations."[3] This finding has been confirmed recently by a detailed analysis of open market operations conducted by the Fed over the period 1984 – 1996 (see Thornton 2006a).

Recently, Carpenter and Demiralp (2006) (hereafter, C&D) find "clear evidence of a liquidity effect at the daily frequency."[4] Moreover, they find that the estimated size of the liquidity effect is economically meaningful. Unlike Hamilton, who used one component of autonomous factors that affect supply and estimated the supply shock, C&D have all of the autonomous factors that affect reserve supply and have the actual error made by the staff of the Board of Governors in forecasting these factors. They

[3] Thornton (2001a), p. 76.
[4] C&D, p. 16.

argue that their reserve-supply-shock measure is both more comprehensive than Hamilton's and represents the actual shocks to reserves that occurred in carrying out open market operations.

Given the importance of the liquidity effect and the uncertainty about its importance empirically, I investigate the daily liquidity effect using C&D's measure. In so doing, I point out that (a) this measure does not necessarily reflect the reserve supply shocks made by the Fed in the conduct of open market operations, and (b) this measure does not mitigate the other criticisms of Hamilton's methodology and, hence, of C&D's.

The remainder of the paper is structured as follows. Section 2 briefly reviews the evidence on the daily liquidity effect prior to C&D. Section 3 presents C&D's analysis and shows why it does not overcome the concerns raised by Thornton (2001a). A detailed analysis of the daily liquidity effect using C&D's reserve-supply-shock measure is presented in Section 4. The conclusions and implications are presented in Section 5.

2.0 The Daily Liquidity Effect

Each day the Trading Desk of the Federal Reserve Bank of New York (hereafter, the Desk) estimates the quantity of reserves that banks will demand over a two-week maintenance period, conditional on the target for the federal funds rate and the quantity of reserves that will be supplied if the Desk conducts no open market operations that day.[5] If the former exceeds the latter, the operation procedure suggests that the Desk add reserves through an open market purchase. If the former is smaller than the latter, the procedure suggests that reserves be drained through an open market sale.

[5] A more detailed analysis of the Desk's operating procedure can be found in Feinman (1993) and Thornton (2001b, 2006a).

An important ingredient to the operating procedure is the estimate of the supply of reserves due to autonomous factors that affect supply—the float, currency in circulation, the Treasury's balance at the Fed, etc. If autonomous factors on the day turn out to be larger than estimated, there is a positive reserve supply shock. If they are smaller than expected, the shock is negative. As Hamilton noted, a supply shock is analogous to an exogenous open market purchase of an equal magnitude. Hence, evidence of a statistically significant and economically important response of the funds rate to a reserve supply shocks is evidence that the Desk can move the funds rate through open market operations.

Because errors in forecasting the Treasury's balance are an important source of the error in forecasting autonomous factors affecting the supply of reserves, Hamilton approximated the errors made in forecasting the Treasury's balance. Specifically, using daily data on the Treasury's balance with the Fed over the period April 6, 1989 – November 27, 1991, he estimated an exponential GARCH (EGARCH) model of the Treasury's balance. Hamilton then found a negative (i.e., an unexpected increase in the Treasury balance reduces reserves) and statistically significant coefficient on his reserve shock measure in an EGARCH model of nonborrowed reserves, suggesting that he had correctly identified a reserve supply shock analogous to the shock made by the Fed in conducting open market operations. Finally, he found a positive and statistically significant coefficient on his supply shock measure in an EGARCH model of the daily change in the federal funds rate—i.e., a daily liquidity effect. However, the daily liquidity effect was statistically significant only on the last day of the two-week maintenance period, known as *settlement Wednesday*.

Thornton (2001a) noted three shortcomings of Hamilton's analysis. First, he observed that the estimated coefficient on Hamilton's reserve-supply-shock variable in his nonborrowed reserves equation was -0.42, significantly different from its theoretical value of -1.0.[6] Hence, Hamilton's estimates differed significantly from the true forecast errors the Desk makes each day in conducting open market operations.[7]

Second, Thornton (2001a) noted that there is a two-day lag in the "contemporaneous" accounting system that the Fed introduced in March 1984. Specifically, banks satisfy their reserve requirements by holding reserves over a two-week maintenance period ending Wednesday, while banks' reserve requirements are based on deposit balances that banks hold over a two-week period ending two days earlier—the second Monday of the maintenance period. Thornton (2001a) argued that because of this two-day lag, the demand for reserves is perfectly interest inelastic on the last two days of the maintenance period. Consequently, he suggested it is impossible to estimate the slope of the demand curve (the essence of the liquidity effect) on settlement Tuesday or settlement Wednesday.

Analyses by Clouse and Dow (2002) and Bartolini, Bertola, and Prati (2002) show that Thornton's implication need not hold if individual banks behave optimally with respect to the reserve carryover provision. If banks follow such procedures, it would be possible to estimate the slope of the demand curve on the last two days of the maintenance period. These models ignore the costs of operating such a procedure which are likely to be large relative to the cost satisfying a reserve shortfall at the end of the

[6] See Thornton (2001b) for an explanation of why -1.0 is the correct theoretical value of the coefficient.
[7] This implication is confirmed by Thornton (2004).

maintenance period.[8] Consequently, it is not clear that such intense reserve management—though technically feasible—is economically viable. It seems safe to conclude only that the nature of reserve demand on the last two days of the maintenance period is uncertain. How the funds rate responds to reserve supply shocks on these days is an empirical issue that will be addressed.

Third, Thornton (2001a) noted that reserve requirements are based on the averaged holdings reserves over the fourteen days of the two-week maintenance period. The large changes in the funds rate that tend to occur on settlement Wednesdays are due to an imbalance between the aggregate reserves demanded by all banks, on average over the maintenance period, and the aggregate amount of reserves supplied by the Fed over the period. Consequently, shocks to reserves will cause large changes in the funds rate only if they are large enough to create an imbalance between the aggregate reserve supply and aggregate reserve demand. Since a one-day shock to the Treasury's balance contributes only one-fourteenth to the weekly-average imbalance, Thornton (2001a) suggested that it would take a very large shock to the Treasury's balance on the last day of the maintenance period to generate a large maintenance-period-average reserve imbalance. The implication is that the statistically significant response of the funds rate that Hamilton finds on settlement-Wednesday is due either to relatively large shocks to the Treasury's balance on settlement Wednesdays or it is spurious—the consequence of a few relatively large settlement-Wednesday changes in the funds rate.

Thornton (2001a) finds that Hamilton's settlement-Wednesday effect is due to just six of the sixty-nine settlement Wednesdays in his sample period. When these

[8] The one-day cost of paying a one-percentage-point premium on a $100 million dollar reserve shortfall is $2,739.73.

observations are accounted for, there is no statistically significant liquidity effect on settlement Wednesday or any other day of the maintenance period. Moreover, using Hamilton's methodology, he found no statistically significant negative response of the funds rate to reserve supply shocks for sample periods before and after Hamilton's.

Thornton (2001a) then attempted to estimate the liquidity effect using an alternative methodology. Specifically, he estimated the reduced-from equation of nonborrowed reserves obtained from a structural model of the reserve market (Thornton, 2001b). If open market operations were responsible for changes in the funds rate, there should be a statistically significant change in nonborrowed reserves on days when it would have implemented changes in Fed's target for the funds rate. Thornton (2001a) found a statistically significant but quantitatively very small response before 1994 but not after. He concluded that there was "little support" for the daily liquidity effect.

3.0 The Daily Liquidity Effect à la Carpenter and Demiralp

C&D attempt to overcome some of the issues raised by Thornton (2001a) by using a more comprehensive measure of reserve supply shocks. Specifically, they use the actual forecast error for all of the autonomous factors made by the staff of the Board of Governors ($miss_t^{BOG}$). Using $miss_t^{BOG}$ mitigates, but does not eliminate, Thornton's (2001a) criticism. The reason is each day two estimates of autonomous factors are made—one by the Board's staff and another by the staff of the Federal Reserve Bank of New York. Indeed, for the most important component of autonomous factors—the Treasury's balance at the Fed—three estimates are made. The staff of the U.S. Treasury also makes an estimate. Thornton (2004) shows that the Desk uses a weighted average of the three estimates of the Treasury's balance in conducting daily open market operations.[9] How the Desk weights the remaining components is unclear. Nevertheless, Thornton's (2004) finding makes it clear that $miss_t^{BOG}$ is not the forecast error the Desk makes in the conducting open market operations.

Moreover, using $miss_t^{BOG}$ does nothing to alleviate Thornton's (2001a) other criticisms. Specifically, given the uncertainty about reserve demand on the last two days of the maintenance period, the extent to which the liquidity effect can be estimated on settlement Tuesdays or Wednesdays is in doubt. More specifically, the statistically significant coefficients that C&D obtain on settlement Tuesday and Wednesday are not necessarily evidence of "a daily frequency liquidity effect…the reciprocal of the partial derivative of the demand for balances with respect to the funds rate,"—i.e., $1/\beta$, where β is the slope of the demand curve for reserves—as C&D contend.[10]

Furthermore, it remains true that it takes a large settlement Wednesday shock to the Treasury's balance to generate an aggregate imbalance on settlement Wednesday. Because $miss_t^{BOG}$ is more comprehensive than the measure Hamilton used, it is reasonable to assume that large shocks will occur more frequently. The shocks range from - \$ 6.78 billion to \$ 9.34 billion, and the average absolute value of $miss_t^{BOG}$, \$ 0.79 billion, is fifty percent larger than the average absolute error in forecasting the Treasury's balance. However, one-day shock contributes only one-fourteenth to the aggregate maintenance period shock. Other things the same, the largest one-day shock is equivalent to a \$ 0.66 billion aggregate maintenance period shock. It seems likely that a shock of

[9] Thornton (2004) has also shown that these three estimates of the Treasury's balance are independent and weighted nearly equally in the optimal forecast.
[10] C&D, p. 13.

this magnitude could account for the large spikes in the funds rate that are associated with the close of the maintenance period.

Finally, unlike Hamilton (1997) and Thornton (2001a), who use the change in the effective federal funds rate (Δff_t), C&D use the spread between the effective federal funds rate and federal funds rate target $(ff_t - ff_t^*)$. A priori, Δff_t seems like the natural variable for measuring the impact of reserve supply shocks on the federal funds rate. Using $ff_t - ff_t^*$ rather than Δff_t could distort the relationship between the funds rate and reserve supply shocks if, for example, negative misses tend to occur more often when the funds rate is above than below the target.

4.0 The Daily Liquidity Effect

This section analyzes the relationship between $miss_t^{BOG}$ and Δff_t using daily data over the period January 2, 1986 – January 30, 2004. The data were supplied by the Board of Governors of the Federal Reserve. The sample period is longer than C&D's period, May 19, 1989, through January 30, 2004. The federal funds rate is the effective federal funds rate, which is a weighted average of federal funds transactions of a group of federal funds brokers who report daily to the Federal Reserve Bank of New York. Holidays are omitted, as are days when $miss_t^{BOG}$ is unavailable. With these days omitted, there are a total of 4499 daily observations during the sample period.[11]

[11] There was also an enormous reserve supply shock of more than $30 billion on September 13, 2001. Hence, this observation was also deleted. The last two days of 1986, when there were extremely large "window dressing" increases in the funds rate, were also deleted.

Figure 1 presents a simple scatter plot of Δff_t and $miss_t^{BOG}$. While it is not obvious from Figure 1, there is a weak but sample-period-robust negative correlation between Δff_t and $miss_t^{BOG}$. The correlation is -0.092.[12]

4.1 *EGARCH Estimates of the Liquidity Effect*

The analysis employs an EGARCH (1, 1) model similar to that estimated by C&D. The EGARCH model, which is in the class of autoregressive conditional heteroskedastic (ARCH) models developed by Engle (1982), was introduced by Nelson (1991). C&D's specification takes the general form

(1) $$\Delta ff_t = X_t \beta + \varepsilon_t, \quad t = 1, 2, ..., T$$

where X_t denotes a 1-by-k vector of k regressors and β denotes the corresponding k-by-1 vector of coefficients. The variance of ε_t, σ_t^2, is assumed to be conditionally heteroskedastic. Specifically,

(2) $$\log \sigma_t^2 = \xi + \gamma \left| \frac{\varepsilon_{t-1}}{\sigma_{t-1}} \right| + \psi \frac{\varepsilon_{t-1}}{\sigma_{t-1}} + \varsigma \log \sigma_{t-1}^2 + Z_t \delta + \omega_t ,$$

where Z_t is a 1-by-m vector of observable variables that determine the evolution of the variance and δ is a corresponding m-by-1 vector of coefficients. The coefficient ψ allows for the possibility of asymmetry in the response shocks to the funds rate.

Because ARCH models account for heteroskedasticity, they produce estimates of β that are generally more efficient than ordinary least squares (OLS). The ARCH model is designed to capture changes in the variance of the stochastic process that decay over time. Hence, ARCH models are useful when there are clusters of volatility, and

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[12] This is only slightly weaker than the correlation between $miss_t^{BOG}$ and $(ff_t - ff_t^*)$, which is -0.108. Analysis, not presented here, indicates that the results are qualitatively the same when $(ff_t - ff_t^*)$ is used.

particularly if one is interested in estimating and forecasting the variance of the dependent variable.

Figure 2 presents Δff_t in basis points over the sample period. While there are some volatility clusters, typical of ARCH, there is also a marked decline in volatility beginning in late 1999 and a further decline beginning in late 2001. Moreover, there is a relatively large number of volatility spikes, where the funds rate changed by a relatively large amount on one day and by a nearly equal but opposite amount the next. Some of these spikes are associated with well-known events, e.g., settlement Wednesday, the first and last days of the year, days before a holiday. Whatever their cause such shocks are difficult to predict.

To account for spikes in the funds rate associated with such events, dummy variables are used for each of the 10 maintenance period days (Di, $i = 1, 2, ..., 10$); for the first and last days of the month, quarter, and year ($bom, eom, boq, eoq, boy, eoy$); for the 15th day of the month (mom); for the day before and after holidays; for the day before and after changes in the funds rate target ($bh, ah, btar, atar$); for the month of December (dec); and for the first and second week of the maintenance period ($w1, w2$).[13] The period of increased volatility of Δff_t in late December 1990 through the early part of 1991 is associated with the Fed's very large and surprise reduction in reserve requirements.[14] Consequently, a dummy variable for the period of the reduction in

[13] If the 15th falls on a weekend or a holiday, mom takes on the value of 1 on the business day closest to the middle of the month.

[14] Effective December 13, 1990, the 3 percent reserve requirement on nontransaction liabilities was reduced to 1.5 percent for weekly reporters, and effective December 27, 1990, the 1.5 percent reserve requirement on nontransaction liabilities was reduced to zero for weekly reporters. The combined effect of these actions reduced required reserves by an estimated $13.2 billion.

reserve requirements in 1990 (Δrr) is also included.[15] As noted above, the variability of Δff_t declines in late 1999 and declines further in late 2001, hence, two dummy variables are used, one for the period November 1, 1999, through August 31, 2001 ($d1999$), and the other for the period after September 1, 2001 ($d2001$).

C&D include a variable for the expected change in the funds rate target on the day before a target change and the unexpected target change on the day of a target change. The expectations are implied from the federal funds futures market using the procedure suggested by Kuttner (2001). The federal funds futures contract was introduced in October 1988 and, hence, these variables would not be available for the entire sample period and are not used in this analysis. Because the coefficient on Δff_t^* summarizes the effect of an unexpected target change, the change in the funds rate target (Δff_t^*) is used.[16]

Table 1 reports the estimates of the coefficients of (1) and (2) along with the marginal significance level in the adjacent column. There are three sets of estimates corresponding to three different specifications of the model. The first two sets are for EGARCH models that differ solely in that one assumes that the errors are normally distributed while the other assumes that the errors are distributed as Student's t. The third set is OLS, where the standard errors are obtained using White's (1980) heteroskedastic-consistent estimates. The specification of Z_t is the same as C&D's, except that Δrr, $d1999$, and $d2001$ are included.

[15] Δrr takes on the value 1 from the first settlement Wednesday affected by the changes, December 26, 1990, until the settlement period ending March 05, 1991, and zero elsewhere.
[16] These variables were included for a shorter sample period corresponding to C&D's. The coefficients on the maintenance-period partitions of $miss_t^{BOG}$ were insensitive to whether these variables were included.

The estimates of the parameters of (2) are broadly similar to those reported by C&D. As expected, the coefficient on Δrr is positive and significant for both the normal and Student's t specifications. Likewise, as expected, the coefficients on $d1999$ and $d2001$ are negative, with the absolute value of the coefficient of the former being smaller than that of the latter.

$miss_t^{BOG}$ is partitioned by the day of the maintenance period. For the EGARCH–normal specification, six of the coefficients are statistically significant at the 5 percent level and, of these, five are negative. For the Student's t specification, six of the ten coefficients are statistically significant and all of these are negative. Moreover, the estimate of the degrees of freedom parameter (dof) is about 3, suggesting a strong departure from normality, which is consistent with evidence on financial data more generally.

A comparison of the parameters of interest from the two EGARCH specifications reveals that the estimates of the day-of-the-maintenance-period coefficients are sensitive to the distributional assumption. For example, the coefficient on $miss^{BOG}$ x $D9$ is relatively large and statistically significant for the normal specification, but small and statistically insignificant for the Student's t specification. The reverse is true for the coefficient on $miss^{BOG}$ x $D6$. Somewhat more troubling is the fact that the coefficient on $miss^{BOG}$ x $D5$ is positive and statistically significant for the normal specification and negative and statistically significant for the Student's t specification. These sharp differences stem from the fact that two EGARCH specifications weight the individual observations very differently.

The estimated coefficients for the White (1980) heteroskedasticity-consistent, OLS specification are negative for all but one day, but are statistically significant for only four of the ten days during the maintenance period. Also, the estimated coefficients for the OLS specification are much larger in absolute value than the corresponding EGARCH estimates. This is due to the fact that OLS is influenced by the extreme observations, while EGARCH tends to down-weight these observations.

All three of the estimates of β in Table 1 are consistent, and all three procedures generate consistent estimates of the variances. Hence, asymptotic theory provides no basis for preferring one set of estimates over another. While the sample size is very large—4499 observations—the number of observations on each day of the maintenance period is much smaller. Moreover, with the exception of the last two days of the maintenance period, there is no particular reason to expect the response to be different on average for a particular day in the maintenance period. Given this fact, together with the sensitivity of the EGARCH estimates to the distribution assumption and the marked difference between the OLS and EGARCH estimates noted in Table 1, it seems reasonable to estimate the response for a group of days rather than each day of the maintenance period separately. Consequently, the days of the maintenance period are partitioned into the last two days (L2D) and the other eight days (NL2D).

Also, any effect of a supply shock on the funds rate will be distorted on days when the funds rate target is changed. Consequently, the sample is partitioned by days when the funds rate target is changed ($d\Delta ff_t^*$) and days when it is not ($dn\Delta ff_t^*$).

Finally, C&D found that the coefficients on $miss_t^{BOG}$ were statistically significant only for large shocks, i.e., $miss_t^{BOG} \geq$ \$1 billion. Consequently, $miss_t^{BOG}$ is partitioned into large ($miss_{\lg}^{BOG}$) and small ($miss_{sm}^{BOG}$) shocks.

Estimates for the three specifications are reported in Table 2. A comparison of Tables 1 and 2 reveals that most of the other parameters in the model are relatively unaffected by the alternative partitioning of $miss_t^{BOG}$. Consistent with C&D's findings, small misses do not have a statistically significant impact on the funds rate. Also, the coefficients on $miss_{\lg}^{BOG}$ on days when the target was changed are either the wrong sign or statistically insignificant.

The results for $miss_{\lg}^{BOG}$ on days when the target was not changed on the last two days of the maintenance period are somewhat mixed. The coefficients are relatively large and statistically significant for both the EGARCH–normal and OLS specifications, but small and not statistically significant for the EGARCH–Student's t specification. There is clear evidence of a statistically significant response on the other eight days of the maintenance period; however, the size of the response differs greatly between the two EGARCH specifications and, of course, between either of the EGARCH specifications and OLS. Indeed, for the EGARCH–normal specification, the estimated response appears to be statistically significant, but economically unimportant.

4.2 *The Impact of Outliers*

Thornton (2001a) found Hamilton's results to be sensitive to six observations when there were large changes in the funds rate that happened to occur on days when there were unusually large shocks to Hamilton's reserve-supply-shock measure. Three of the six observations occurred during the turbulent period following the surprise reductions in reserve requirements in December 1990. Using Thornton's (2001a) criterion of a change in the funds rate of 80 basis points or larger, there were 33 days when $|\Delta ff_t| \geq 80$ basis points and $|miss_t^{BOG}| \geq$ \$1 billion, in the direction consistent with the liquidity effect. These observations are presented in Table 3. A priori, there is no reason to single out days when there are unusually large changes in the funds rate. However, eight of these (shaded in Table 3) are associated with the December 1990 surprise reduction in reserve requirements. Most of the others occurred on the last two days of the maintenance period, the first or last day of a month, year, quarter, or the middle of the month—days when there tend to be large temporary spikes in the funds rate.

In any event, the sensitivity of the estimated parameters to these "outliers" is investigated by partitioning $miss_{\mathrm{lg}}^{BOG}$ into these days and all other days. Sixteen of the 33 outliers occurred on settlement Tuesday or Wednesday. Hence, $miss_{\mathrm{lg}}^{BOG}$ on the last two days of the maintenance period is partitioned into these 16 days and the remaining 280 days. Seventeen of the outliers occurred on the other days of the maintenance period. Hence, $miss_{\mathrm{lg}}^{BOG}$ on all other days is partitioned into these 17 outliers and the remaining 1038 days.

The results are summarized in Table 4. To conserve space, only the estimates for the various partitions of $miss_t^{BOG}$ are presented along with the corresponding marginal significance levels. These results indicate that the statistically significant effect of large shocks on the last two days of the maintenance period in the OLS specification, reported in Table 2, is due entirely to these outliers. The coefficient on the outliers is -15.892 and is statistically significant at the 5 percent level. The coefficient on the remaining days is -0.157 and not statistically significant at even the 20 percent level. The EGARCH-estimated coefficient for large shocks on the last two days of the maintenance period was not statistically significant for the Student's t distribution in Table 2 and remains so when the shocks are partitioned. The estimates for both outliers and non-outliers are negative and statistically significant for the normal distribution; however, the estimate is nearly 23 times larger for the 16 outliers (-32.938 versus -1.457).

Estimates for other than the last two days of the maintenance period are also affected by outliers. For the OLS estimates both coefficients are statistically significant; however, the estimate for the 17 outlier observations is -23.677 compared with -0.754 for the remaining observations.

The estimates for other than the last two days of the maintenance period are likewise sensitive for the EGARCH models. The estimates for the EGARCH–Student's t specification are -32.998 and -0.701 for the outlier and other observations, respectively. Both estimates are statistically significant. The corresponding estimates for the normal distribution are -20.232 and -0.143, with the latter coefficient being not statistically significant at even the 10 percent level.

The results for the OLS or EGARCH–Student's t specification suggest that there is no statistically significant response of the funds rate to supply shocks on the last two days of the maintenance period when outliers are accounted for. For the remaining eight days of the maintenance period, with the exception of the 17 outliers, large shocks to the supply of reserves have a relatively small, although statistically significant, effect on the funds rate. Indeed, the estimates from the OLS and EGARCH–Student's t specifications are remarkably similar, -0.754 and -0.701, respectively. For the EGARCH–normal specification, the estimated liquidity effect is much smaller and not statistically significant.

4.3 The Temporal Stability of the Estimated Liquidity Effect

If the statistically significant reaction of the funds rate to supply shocks is a true liquidity effect, it should be stable over time, as there is no particular reason to believe that the funds rate should respond to reserve supply shocks during some periods but not others. On the other hand, because the response of the funds rate on the last two days of the maintenance period depends on the reserve market conditions at the time of the shock, one might expect this response to vary significantly over time. On settlement days when there is a surfeit of reserves, a large negative supply shock will have little or no effect on the funds rate. On days when reserves are particularly scarce, the same shock might generate a relatively large response in the funds rate. Also, recall also that it takes a relatively large reserve shock to have much of an affect on the aggregate reserve imbalance. For both of these reasons, one might expect to see considerable temporal variation in the response of the funds rate on the last two days of the maintenance period.

Because of the likely sensitivity of the response to shocks on the last two days of the maintenance period and to investigate the temporal robustness of the funds rate to supply shocks on other days in the maintenance period, the OLS and EGARCH–Student's t model are estimated with rolling regressions of 600 observations.[17] The

[17] The EGARCH–normal specification was also estimated, but, to conserve space, not presented here. The results are generally similar to the OLS estimates. However, coefficient for the last two days of the

nearly 30-month window should be sufficiently long to yield relatively precise estimates of the parameters as well as capture any significant time variation in the effect of reserve supply on the funds rate.

Estimates of the response of the funds rate to small shocks on days when the target was not changed for the OLS and EGARCH–Student's t models are presented in Figures 3 and 4, respectively. The estimated coefficients are represented by the solid line, and dashed lines represent plus or minus two standard errors. The estimates are plotted on the last day of the sample period. As before, the standard errors for the OLS estimates are obtained using White's heteroskedastic-consistent procedure. These figures show that the conclusion from Table 2—the response of the funds rate to small supply shocks is not statistically significant—is robust to the sample period. The estimated coefficients range from negative to positive values for both specifications and are rarely statistically significant at the 5 percent level.

Figures 5 and 6 present the OLS and EGARCH estimates, respectively, for large shocks on the last two days of the maintenance period for days when there were no outliers. The effect of these 16 outliers on the OLS estimates is demonstrated by presenting the estimates (shown in red) with these observations included. The EGARCH–Student's t estimates including the outliers is not presented because the estimates were relatively insensitive to the presence or absence of these observations.

Consistent with the findings of the previous section, with the exception of a brief period in the late 1990s, the estimated coefficients for the OLS specification are not statistically significant. Moreover, as expected, the effect of the 16 outliers is dramatic.

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maintenance period exhibits extreme volatility, at times switching quickly from large positive to large negative values.

When these observations are not excluded, the estimated response becomes larger, particularly so during the period following the surprise reduction in reserve requirements. While the estimated coefficient is most often negative, it is statistically significant only for a brief period in the late 1990s.

Like the OLS estimates, the EGARCH estimates suggest that the effect of supply shocks on the last two days of the maintenance period is temporally unstable. Indeed, there is an abrupt change in the estimated coefficient in early 1994. Unlike the OLS estimates, however, there are three periods where the response is statistically significant.

The estimated coefficients on all but the last two days of the maintenance period are presented in Figures 7 and 8. The OLS estimates are more often than not negative, but are statistically significant only for a brief period in the late 1990s. Again, the OLS estimates are very sensitive to the 17 outliers. The response is much larger when these observations are included.

The parameter estimates for the EGARCH estimates follow a pattern similar to, but somewhat more stable than, the OLS estimates. Moreover, the estimated coefficients are generally statistically significant since the late 1990s, but not before.

The results presented here suggest three conclusions. First, C&D's finding that the funds rate responds only to large shocks is robust—only large reserve supply shocks matter.

Second, the response of the funds rate to large shocks on settlement Tuesdays and Wednesdays appears to be the consequence of unusually large changes in the funds rate that sometimes occur on those days. This conclusion is strongly supported by the OLS estimates, but less so by the EGARCH estimates.

Third, once the effect of settlement Tuesdays and Wednesdays and unusually large changes in the funds rate are accounted for, the response of the funds rate to large reserve supply shocks appears to statistically significant sometime after the mid-1990s but not before.

To further investigate these conclusions, the three models were estimated separately for the period January 2, 1986 – August 31, 1995, and the period September 1, 1995 – January 30, 2004. The break was chosen by the change from statistical insignificance to statistical significance in Figure 8, allowing for the fact that the data are plotted on the last day of the sample of 600 observations. The results are presented in Table 5. Again, to conserve space only the estimates for the various partitions of $miss_t^{BOG}$ are presented along with the corresponding marginal significance levels. Large forecast errors on days when there were no changes in the funds rate target are partitioned into the 33 days where there are outliers (O) and all other days (NO).[18]

All three conclusions are strongly supported by these estimates. First, consistent with the results presented in Figure 3 and 4, the effect of small shocks to reserves is not statistically significant in either period for any of the three specifications.

Second, with the exception of days identified as outliers, the federal funds rate did not respond significantly to large shocks that occurred on the last two days of the maintenance period during either sub-period. Hence, the relatively large settlement Tuesday and Wednesday response reported by C&D appears to be due to a few observations when there were unusually large changes in the federal funds rate that are likely caused by other events.

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[18] That is, O is a dummy variable that takes on the value 1 on the 33 days listed in Table 3 and zero otherwise. NO is 1 when O is zero and is zero when O is 1.

Finally, with the exception of the few outliers, there is no statistically significant response of the funds rate to large shocks on the other days of the maintenance period before September 1995. This result is robust across specifications. The response is statistically significant after August 1995; however, the estimated magnitude of the response on days when there are no outliers is small, ranging from about a third of a basis point for the EGARCH–normal specification to just over a basis point for OLS. There is a large, statistically significant response of the funds rate on days identified as outliers; however, because these observations occur when there are unusually large changes in the funds rate, it is questionable whether these responses should be considered as evidence of a liquidity effect. The liquidity effect should occur on all days and not merely on days when there are unusually large changes in the funds rate for other reasons.

5.0 Summary and Conclusions

The daily liquidity effect was first investigated by Hamilton (1997) and subsequently by Thornton (2001a). The evidence suggests a weak and economically unimportant liquidity effect at the daily frequency. Carpenter and Demiralp (2006) have reopened the issue using a reserve-supply-shock measure that is both more comprehensive than that used by Hamilton and Thornton and more closely approximates the errors that the Fed actually made in carrying out open market operations. This paper investigates the daily liquidity effect using this measure over an extended sample period. The evidence indicates that once the effect of changes in the funds rate target, the last two days of the maintenance period, and a few extreme observations are taken into consideration, there is a small but statistically significant response of the federal funds rate to this reserve-supply-shock measure after August 1995 but not before.

This is encouraging but not convincing evidence of a daily liquidity effect for two reasons. First, because this measure only approximates the true reserve supply shock from open market operations, the estimates suffer from the usual stochastic regressor problems. While the effect of this problem on the magnitude of the response cannot be determined without additional information, generally speaking, the effect on the standard error is to overstate, to some undetermined degree, the precision of the estimate. Consequently, we cannot be certain that the estimated response of the funds rate reported here is a measure of the true daily liquidity effect.

Second, even if the estimates are indicative of the true daily liquidity effect, it is very small. Taking the midpoint of the range of estimates of approximately 0.7 basis points, it would take a reserve supply shock (or correspondingly an open market operation) of nearly $36 billion to generate a 25-basis-point change in the federal funds rate. Hence, it would take a very large open market operation to generate a 25-basis-point change in the funds rate. The largest daily open market operation in the period January 3, 2000, through January 30, 2004, was $21.5 billion.[19] Hence, while the estimates are statistically significant, the practical economic significance is less obvious. Indeed, the fact that the response is not statistically significant before mid-1995 and that the magnitude of the effect is small thereafter may account for why, in Hamilton's (1997) words, "it is very difficult to find convincing proof that this [the liquidity effect] is indeed what happens."[20]

This lack of a daily liquidity effect may not seem all that remarkable nowadays because many analysts (e.g., Friedman, 1999, 2000; Goodhart, 2000; Guthrie and Wright,

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[19] See Thornton (2006a) for the size of open market operations for the period 1983-1996.
[20] Hamilton (1997), p. 80.

2000; Taylor 2001; and Woodford, 2000) suggest that central banks control the overnight rate through what Guthrie and Wright (2000) have called *open mouth operations*, or Goodhart (2000) has termed *open mouth policy*. As long as market participants believe the Fed can control the federal funds rate through open market operations, such operations are unnecessary.

These results are remarkable for the period before the Fed began announcing its target for the funds rate, however. Not only was the funds rate target not announced, but Thornton (2006b) shows that the FOMC concealed the fact that it was targeting the funds rate. Consequently, the Fed could not have controlled the funds rate through open mouth operations during this period—a liquidity effect was essential. Consequently, the results presented here raise important questions about why the funds rate is so close to the funds rate target during this period.

One possibility for the confluence of relatively modest open market operations and large and persistent changes in the funds rate is the possibility that most target changes are endogenous—the Fed adjusts its target whenever the equilibrium short-term rate changes. Woodford (2000) and Friedman (2000) consider this explanation "implausible"; however, they offer no empirical or documentary evidence to support their skepticism.

Nevertheless, the evidence presented here supports Friedman's (2000) and Woodford's (2000) suggestion that it would take very large open market operations to defend a target rate that differed significantly from the equilibrium rate should market participants come to doubt the Fed's ability to defend its rate objective. As Friedman (2000) suggests, in this event "the market would cease to do the central bank's work for it."[21] Evidence that the Fed has not controlled the funds rate through open market operations, and that it would take open market operations much larger than any heretofore taken, might cause a breach in the market's confidence of what the Fed is willing or able to do. Were this to happen, the Fed would have to engage in much larger transactions than it has ever done before, give up its overnight interest rate instrument, or keep its target for the overnight rate close to the equilibrium level—if, in fact, it has not always essentially done so.

[21] Friedman (2000), p. 271.

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Table 1: Estimate of the Response of the Federal Funds Rate to Reserve Supply Shocks: January 2, 1986 – January 30, 2004						
Variable	Normal		Student's t		OLS—White	
Δff_{t-1} x $w1$	-0.157	0.000	-0.112	0.000	-0.366	0.000
Δff_{t-1} x $w2$	-0.062	0.010	-0.020	0.384	-0.168	0.080
$D1$	2.569	0.000	1.908	0.000	-1.346	0.294
$D2$	-6.129	0.000	-5.514	0.000	-14.057	0.000
$D3$	4.998	0.000	5.119	0.000	2.204	0.038
$D4$	-3.800	0.000	-3.242	0.000	-5.095	0.000
$D5$	-1.530	0.000	-1.013	0.000	-5.605	0.000
$D6$	3.221	0.000	2.987	0.000	0.408	0.684
$D7$	-2.808	0.000	-2.675	0.000	-9.981	0.000
$D8$	6.145	0.000	6.299	0.000	7.529	0.000
$D9$	-5.053	0.000	-5.231	0.000	-7.871	0.000
$D10$	7.852	0.000	5.271	0.000	11.155	0.000
eom	7.418	0.000	6.583	0.000	16.851	0.000
bom	-2.181	0.000	-1.831	0.003	-0.979	0.628
eoq	12.479	0.007	4.760	0.253	24.262	0.000
boq	-1.841	0.498	-4.692	0.058	-4.466	0.564
eoy	-31.764	0.144	-17.929	0.193	-78.114	0.000
boy	23.441	0.069	17.241	0.029	32.736	0.044
mom	7.932	0.000	7.040	0.000	12.516	0.000
bh	-1.960	0.005	-2.392	0.000	-3.130	0.195
ah	14.276	0.000	14.172	0.000	19.517	0.000
Δrr	-3.903	0.436	-6.348	0.185	-0.163	0.989
Δff_t^*	0.426	0.000	0.426	0.000	0.437	0.000
ff_t^*	-0.138	0.003	-0.140	0.000	-0.001	0.991
dec	-1.239	0.003	-0.928	0.020	0.859	0.562
$miss^{BOG}$ x $atar$	2.785	0.024	4.000	0.000	4.659	0.203
$miss^{BOG}$ x $D1$	0.500	0.363	-0.275	0.582	-1.207	0.395
$miss^{BOG}$ x $D2$	-1.041	0.002	-0.911	0.000	-1.609	0.324
$miss^{BOG}$ x $D3$	-0.610	0.021	-0.898	0.000	-2.453	0.003
$miss^{BOG}$ x $D4$	0.143	0.524	-0.121	0.600	-1.568	0.011
$miss^{BOG}$ x $D5$	0.310	0.014	-0.434	0.017	-1.489	0.013
$miss^{BOG}$ x $D6$	-0.292	0.315	-0.606	0.025	-1.035	0.163
$miss^{BOG}$ x $D7$	0.262	0.304	0.155	0.536	-1.170	0.245
$miss^{BOG}$ x $D8$	-1.165	0.012	-1.018	0.013	0.245	0.867
$miss^{BOG}$ x $D9$	-1.439	0.001	-0.293	0.511	-1.150	0.335
$miss^{BOG}$ x $D10$	-3.188	0.000	-2.477	0.000	-6.922	0.003
Variance Estimates						

const.	0.835	0.000	0.909	0.000	--	--
$\lvert \frac{\varepsilon_{t-1}}{\sigma_{t-1}} \rvert$	0.623	0.000	0.714	0.000	--	--
$\frac{\varepsilon_{t-1}}{\sigma_{t-1}}$	0.149	0.000	0.216	0.000	--	--
$\log \sigma_{t-1}^2$	0.672	0.000	0.678	0.000	--	--
$D1+D2+D3$	1.160	0.000	1.005	0.000	--	--
$D2$	-0.528	0.000	-0.641	0.000	--	--
$D7$	0.058	0.234	-0.080	0.418	--	--
$btar$	0.468	0.000	0.510	0.006	--	--
$atar$	0.781	0.000	0.578	0.001	--	--
bh	0.549	0.000	0.410	0.004	--	--
ah	1.168	0.000	1.062	0.000	--	--
eoq	2.522	0.000	2.221	0.000	--	--
dec	0.301	0.000	0.201	0.000	--	--
eom	0.881	0.000	0.967	0.000	--	--
Δrr	0.744	0.000	0.896	0.000	--	--
$d1999$	-0.385	0.000	-0.369	0.000	--	--
$d2001$	-0.553	0.000	-0.561	0.000		
dof	--	--	3.208	0.000	--	--

Table 2: Estimate of the Response of the Federal Funds Rate to Large and Small Reserve Supply Shocks: January 2, 1986 – January 30, 2004						
Variable	Normal		Student's t		OLS—White	
Δff_{t-1} x $w1$	-0.158	0.000	-0.113	0.000	-0.365	0.000
Δff_{t-1} x $w2$	-0.070	0.004	-0.019	0.398	-0.163	0.092
$D1$	2.381	0.000	1.939	0.000	-1.212	0.346
$D2$	-6.059	0.000	-5.363	0.000	-13.823	0.000
$D3$	5.304	0.000	5.186	0.000	2.635	0.017
$D4$	-3.811	0.000	-3.114	0.000	-4.960	0.000
$D5$	-1.692	0.000	-0.955	0.001	-5.364	0.000
$D6$	3.250	0.000	3.011	0.000	0.475	0.637
$D7$	-2.882	0.000	-2.513	0.000	-9.830	0.000
$D8$	6.234	0.000	6.313	0.000	7.732	0.000
$D9$	-5.026	0.000	-5.158	0.000	-7.665	0.000
$D10$	8.086	0.000	5.310	0.000	11.540	0.000
eom	7.985	0.000	6.634	0.000	16.933	0.000
bom	-2.125	0.000	-1.811	0.004	-1.417	0.486
eoq	12.573	0.009	4.691	0.260	24.626	0.000
boq	-1.720	0.538	-4.420	0.074	-3.692	0.635
eoy	-33.521	0.134	-18.235	0.174	-78.397	0.000
boy	23.244	0.071	18.035	0.020	32.439	0.045
mom	7.316	0.000	7.010	0.000	12.455	0.000
bh	-1.703	0.015	-2.317	0.000	-3.195	0.185
ah	15.302	0.000	13.910	0.000	19.628	0.000
Δff_t^*	0.418	0.000	0.431	0.000	0.437	0.000
ff_t^*	-0.136	0.002	-0.148	0.000	-0.034	0.798
dec	-1.132	0.010	-0.961	0.017	0.780	0.595
$miss_{sm}^{BOG}$ x $d\Delta ff_t^*$	0.103	0.968	4.389	0.065	2.047	0.646
$miss_{sm}^{BOG}$ x $dn\Delta ff_t^*$	-0.043	0.859	-0.257	0.213	-0.258	0.682
$miss_{\lg}^{BOG}$ x $d\Delta ff_t^*$	2.831	0.003	2.525	0.000	-0.636	0.865
$miss_{\lg}^{BOG}$ x $dn\Delta ff_t^*$ xL2D	-2.439	0.000	-0.502	0.215	-2.714	0.040
$miss_{\lg}^{BOG}$ x $dn\Delta ff_t^*$ xNL2D	-0.197	0.022	-0.706	0.000	-1.837	0.000
Variance Estimates						
const.	0.841	0.000	0.926	0.000	--	--
$\lvert \frac{\varepsilon_{t-1}}{\sigma_{t-1}} \rvert$	0.623	0.000	0.717	0.000	--	--
$\frac{\varepsilon_{t-1}}{\sigma_{t-1}}$	0.154	0.000	0.221	0.000	--	--
$\log \sigma_{t-1}^2$	0.668	0.000	0.676	0.000	--	--

$D1+D2+D3$	1.175	0.000	1.010	0.000	--	--
$D2$	-0.490	0.000	-0.655	0.000	--	--
$D7$	0.092	0.062	-0.075	0.453	--	--
$btar$	0.549	0.000	0.431	0.020	--	--
$atar$	0.793	0.000	0.601	0.001	--	--
bh	0.534	0.000	0.411	0.004	--	--
ah	1.175	0.000	1.059	0.000	--	--
eoq	2.516	0.000	2.179	0.000	--	--
dec	0.302	0.000	0.204	0.000	--	--
eom	0.901	0.000	1.003	0.000	--	--
Δrr	0.771	0.000	0.941	0.000	--	--
$d1999$	-0.379	0.000	-0.361	0.000	--	--
$d2001$	-0.537	0.000	-0.561	0.000		
dof	--	--	3.170	0.000	--	--

Table 3: Thirty-Three Days When There Were Unusually Large Changes in the Federal Funds Rate and Large Reserve Shocks Were Consistent with the Liquidity Effect		
	Δff	*miss*
9/30/1986	87	-1.453
1/2/1987	-192	1.311
12/16/1987*	-99	1.711
4/19/1989*	100	-1.661
9/5/1990*	114	-2.321
9/6/1990	-111	1.241
10/31/1990*	168	-1.377
12/26/1990*	241	-1.359
12/28/1990	-111	3.685
1/2/1991	232	-2.150
1/22/1991**	166	-1.530
1/23/1991*	283	-2.944
1/24/1991	-270	1.958
1/31/1991	122	-1.174
2/1/1991	-188	1.266
4/1/1991	95	-1.069
6/28/1991	83	-1.492
2/18/1992**	81	-1.057
9/16/1992*	128	-3.459
9/30/1992*	121	-3.377
3/17/1993*	86	-1.709
1/20/1994	-100	2.666
7/5/1995*	152	-1.205
12/20/1995*	111	-2.320
1/2/1996**	133	-4.863
7/31/1996*	142	-1.135
9/30/1996	88	-1.628
3/31/1997	155	-3.028
4/1/1997	-89	1.264
6/30/1998**	137	-1.462
1/4/1999	97	-3.826
1/2/2001	126	-2.036
9/17/2001	-100	1.913

* denotes a settlement Wednesday
** denotes a settlement Tuesday

Table 4: Estimate of the Response of the Federal Funds Rate to Large and Small Reserve Supply Shocks: January 2, 1986 – January 30, 2004						
Variable	Normal		Student's t		OLS—White	
$miss_{sm}^{BOG}$ x $d\Delta ff_t^*$	0.127	0.962	4.343	0.073	1.889	0.712
$miss_{sm}^{BOG}$ x $dn\Delta ff_t^*$	-0.046	0.853	-0.265	0.201	-0.343	0.632
$miss_{\mathrm{lg}}^{BOG}$ x $d\Delta ff_t^*$	3.121	0.000	2.454	0.001	-0.659	0.739
$miss_{\mathrm{lg}}^{BOG}$ x $dn\Delta ff_t^*$ xL2Dx O	-32.938	0.000	3.166	0.635	-15.892	0.000
$miss_{\mathrm{lg}}^{BOG}$ x $dn\Delta ff_t^*$ xL2Dx NO	-1.457	0.001	-0.333	0.416	-0.157	0.820
$miss_{\mathrm{lg}}^{BOG}$ x $dn\Delta ff_t^*$ xNL2Dx O	-20.232	0.000	-32.998	0.000	-23.677	0.000
$miss_{\mathrm{lg}}^{BOG}$ x $dn\Delta ff_t^*$ xNL2Dx NO	-0.143	0.103	-0.701	0.000	-0.754	0.015

Table 5: Estimate of the Response of the Federal Funds Rate to Large and Small Reserve Supply Shocks: January 2, 1986 – August 31, 1995 and September 1, 1995 - January 30, 2004

Variables	January 2, 1986 – August 31, 1995					
$miss_{sm}^{BOG}$ x $d\Delta ff_t^*$	4.399	0.036	7.142	0.000	3.799	0.495
$miss_{sm}^{BOG}$ x $dn\Delta ff_t^*$	0.039	0.910	0.034	0.934	-0.880	0.367
$miss_{lg}^{BOG}$ x $d\Delta ff_t^*$	2.352	0.000	1.071	0.357	-0.739	0.851
$miss_{lg}^{BOG}$ x $dn\Delta ff_t^*$ xL2Dx O	-0.996	0.210	-3.600	0.000	7.180	0.779
$miss_{lg}^{BOG}$ x $dn\Delta ff_t^*$ xL2Dx NO	20.458	0.081	5.965	0.458	-0.048	0.973
$miss_{lg}^{BOG}$ x $dn\Delta ff_t^*$ xNL2Dx O	-35.104	0.000	-28.756	0.000	-32.453	0.002
$miss_{lg}^{BOG}$ x $dn\Delta ff_t^*$ xNL2Dx NO	-0.231	0.193	-0.030	0.874	-0.346	0.491
Variables	September 1, 1995 – January 30, 2004					
$miss_{sm}^{BOG}$ x $d\Delta ff_t^*$	-1.45	0.83	-3.88	0.70	-7.164	0.258
$miss_{sm}^{BOG}$ x $dn\Delta ff_t^*$	-0.32	0.21	-0.18	0.58	0.376	0.618
$miss_{lg}^{BOG}$ x $d\Delta ff_t^*$	-1.98	0.56	-1.69	0.60	-3.478	0.696
$miss_{lg}^{BOG}$ x $dn\Delta ff_t^*$ xL2Dx O	-0.32	0.39	-0.28	0.51	-21.882	0.002
$miss_{lg}^{BOG}$ x $dn\Delta ff_t^*$ xL2Dx NO	-20.35	0.10	-8.93	0.60	0.228	0.888
$miss_{lg}^{BOG}$ x $dn\Delta ff_t^*$ xNL2Dx O	-40.49	0.00	-40.04	0.00	-21.093	0.021
$miss_{lg}^{BOG}$ x $dn\Delta ff_t^*$ xNL2Dx NO	-0.69	0.00	-0.33	0.02	-1.136	0.035

Figure 1: The Relationship Between Δff and $miss^{BOG}$

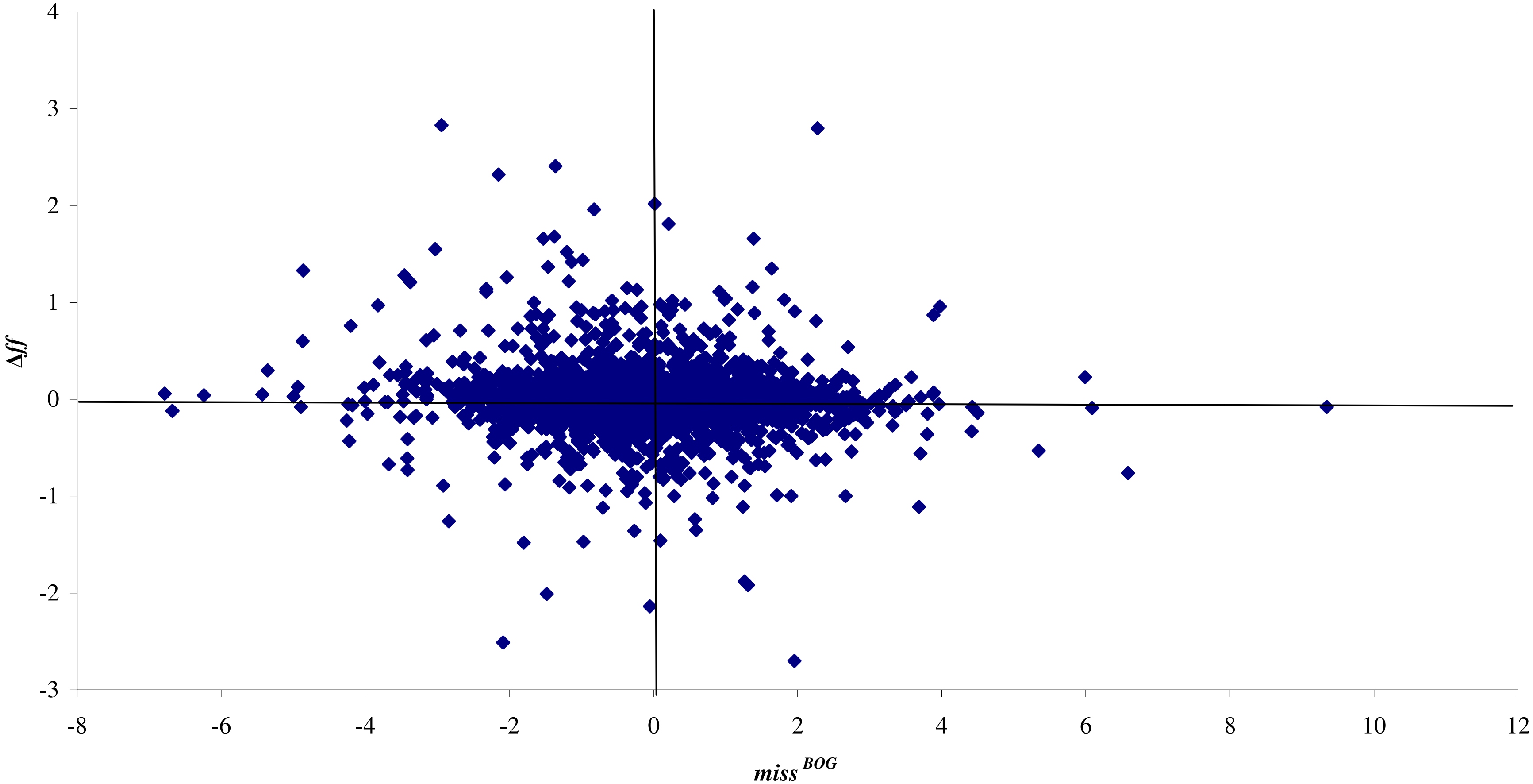

Figure 2: Δff : January 2, 1986 - January 30, 2004

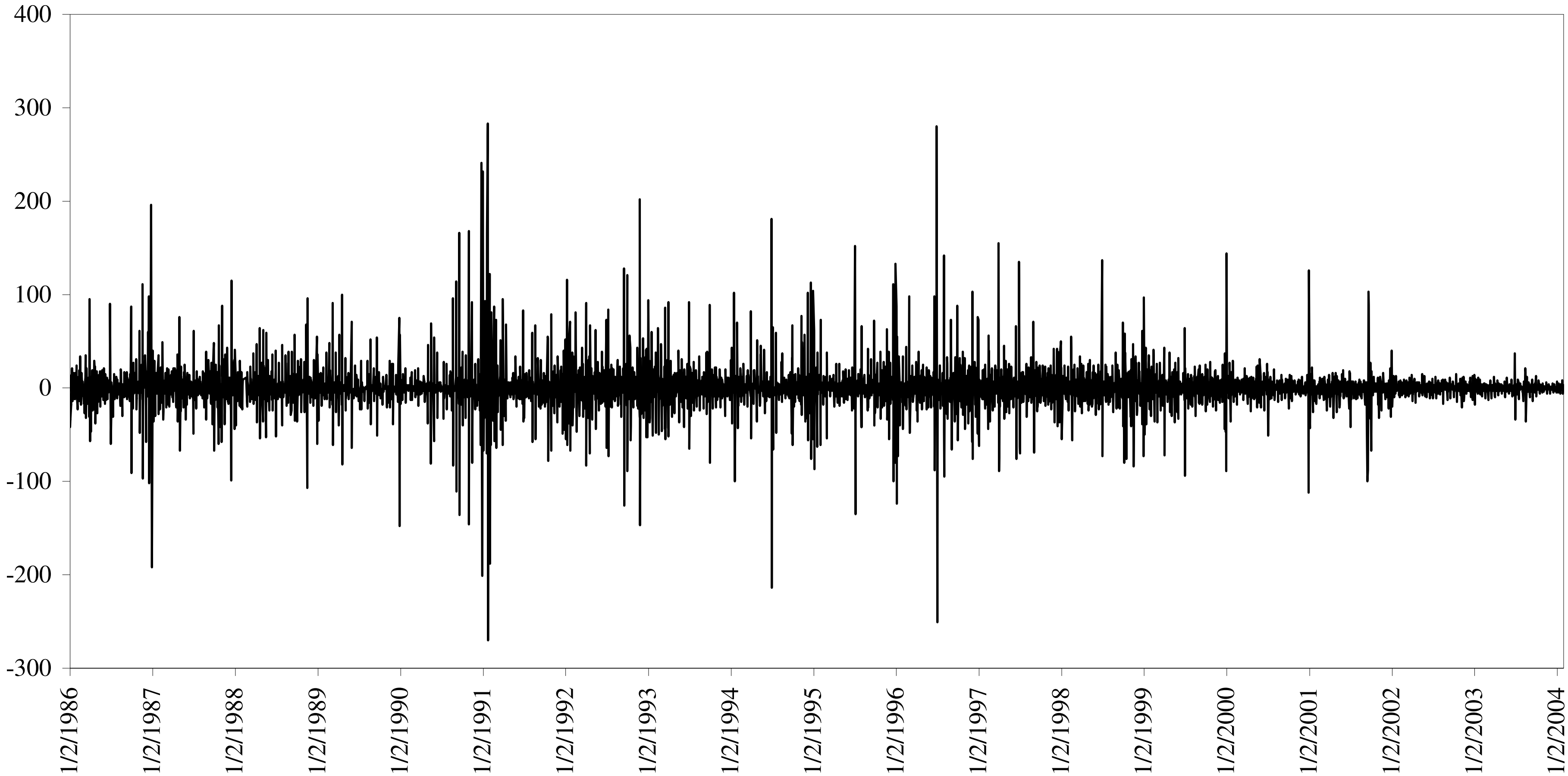

Figure 3: OLS Estimates of the Effect of Small Shocks on the Federal Funds Rate

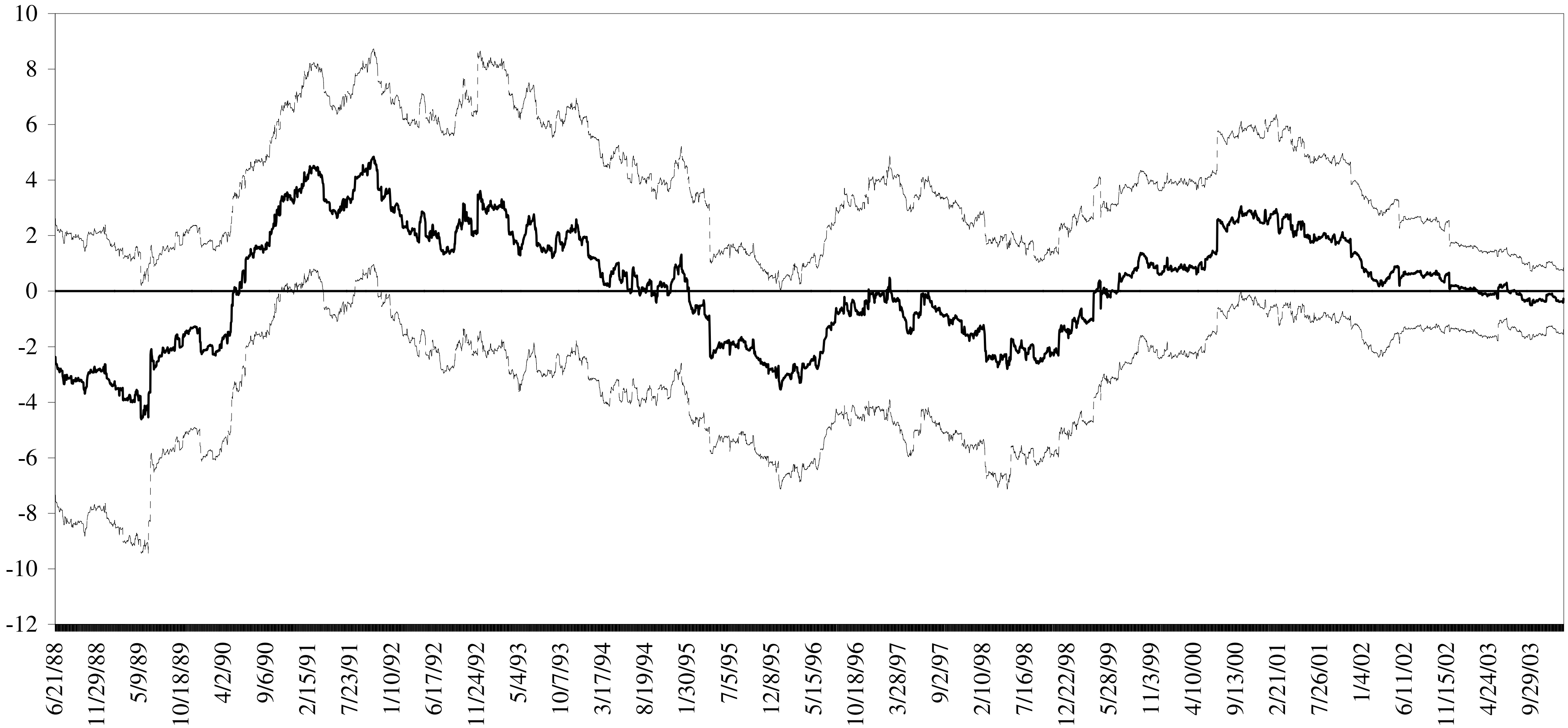

Figure 4: EGARCH Estimates of the Effect of Small Shocks on the Federal Funds Rate

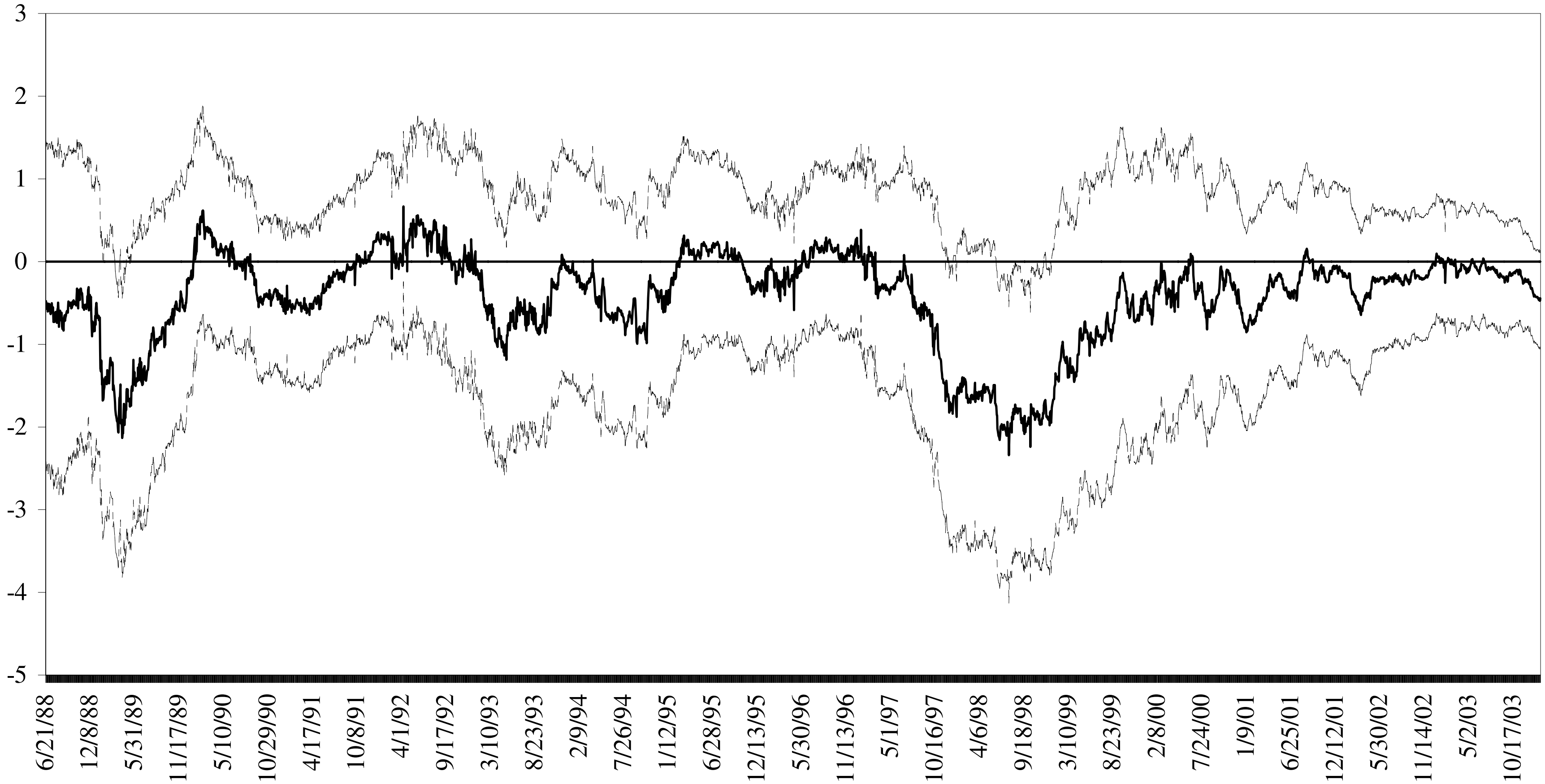

Figure 5: OLS Estimates of the Effect of Large Shocks on the Federal Funds Rate on the Last Two Days of the Maintenance Period

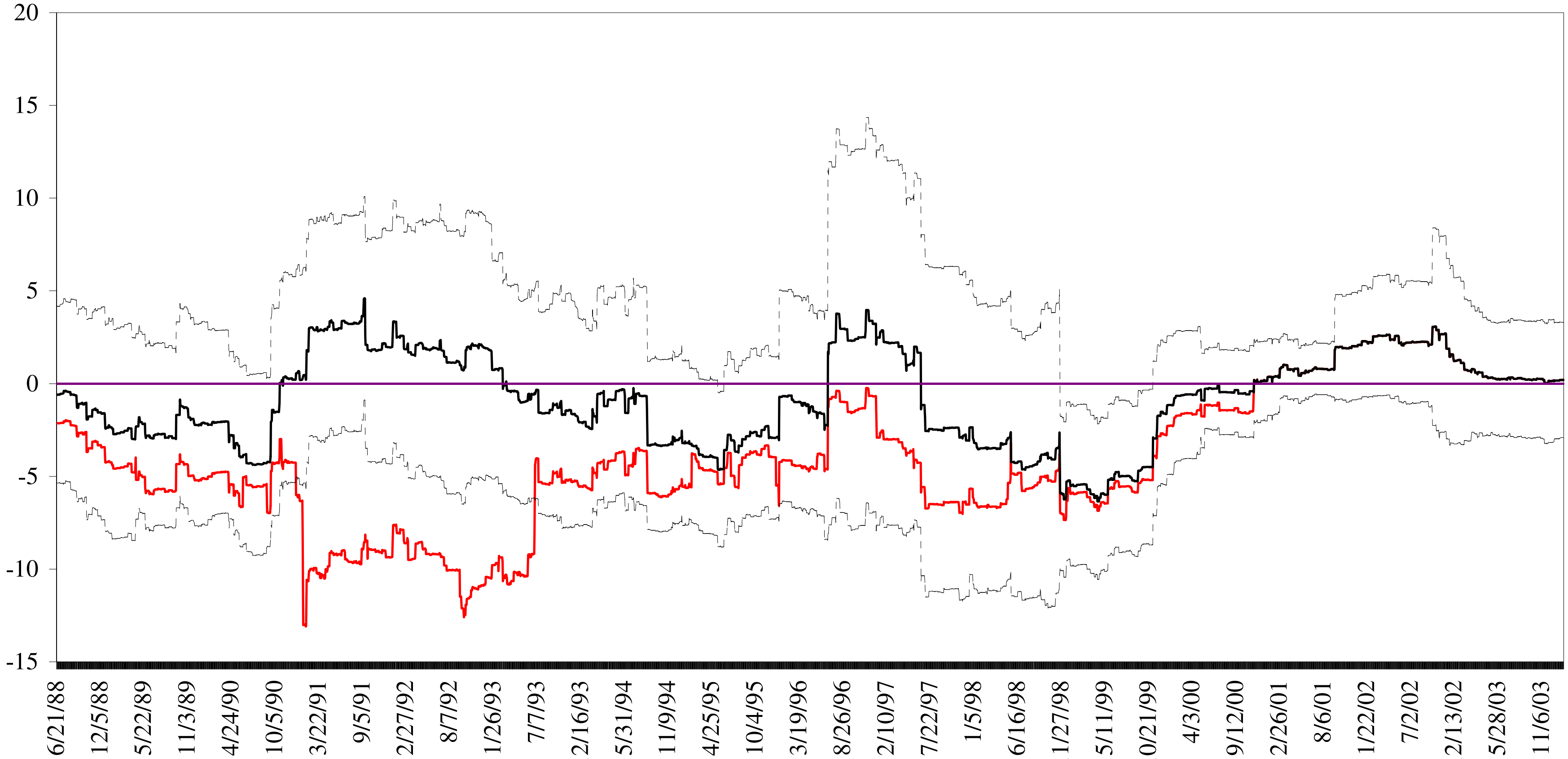

Figure 6: EGARCH Estimates of the Effect of Large Shocks on the Federal Funds Rate on the Last Two Days of the Maintenance Period

Figure 7: OLS Estimates of the Effect of Large Shocks on the Federal Funds Rate on All But the Last Two Days of the Maintenance Period

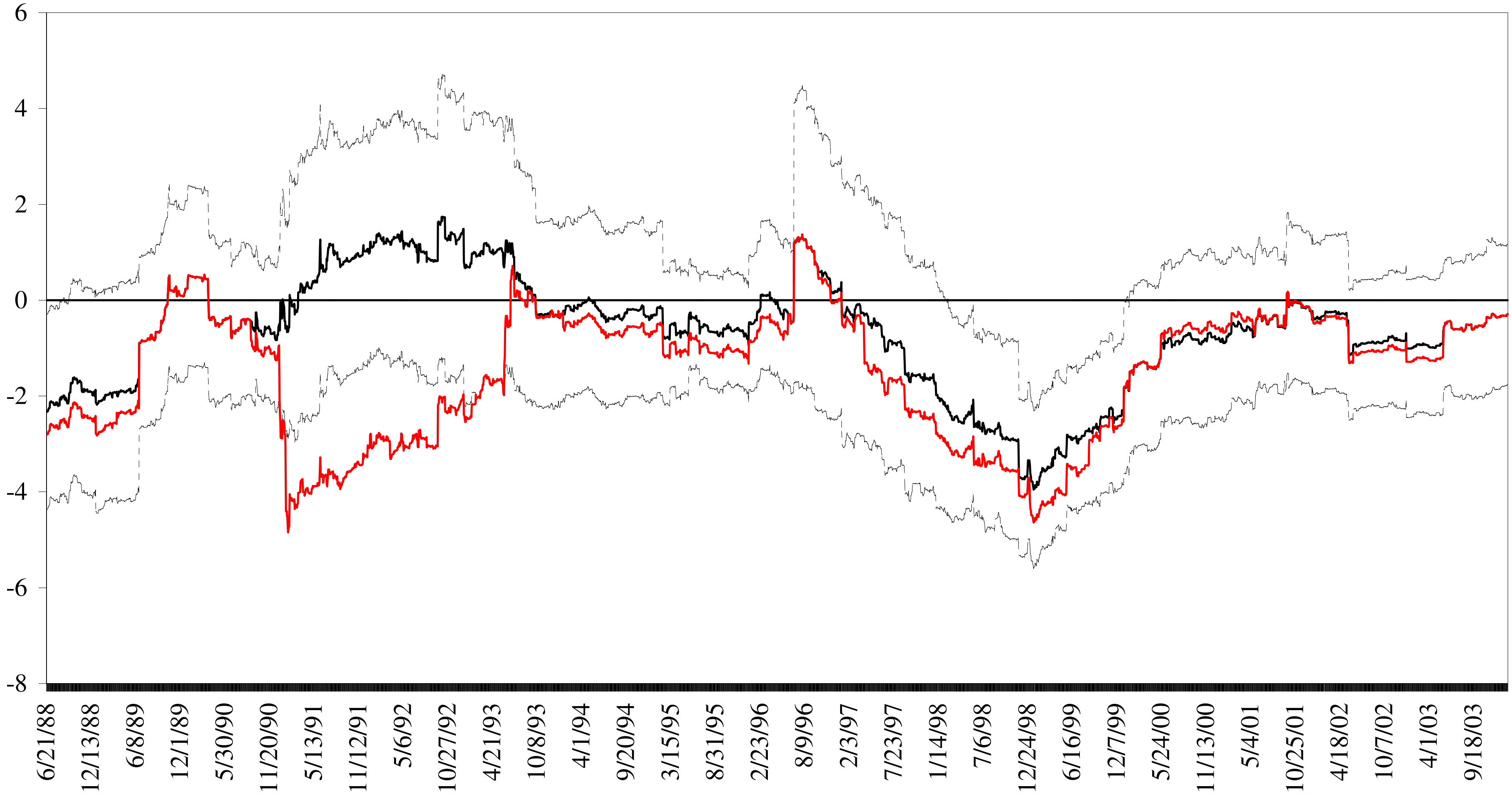

Figure 8: EGARCH Estimates of the Effect of Large Shocks on the Federal Funds Rate on All But the Last Two Days of the Maintenance Period