Some Tests for the Existence of "Open Mouth Operations"

Garett Jones
Southern Illinois University Edwardsville
March 2001

Abstract

Does the Federal Reserve control the federal funds rate by controlling reserve supply? Evidence presented in this paper indicates that the answer is: No, total reserves and nonborrowed reserves are generally unchanged on the days and weeks following a change in the federal funds rate target, even though the rate quickly moves to its new target within a day or two. The results from Hamilton (1997, 1998) and Jones (2000) indicate that the Federal Reserve is able to control the federal funds rate on a daily basis via changes in reserve supply; nonetheless, the Fed is able to make large, persistent changes in the rate without such supply shocks. Competing explanations for this phenomenon are discussed.

I would like to thank Valerie Ramey, Garey Ramey, and Daniel Thornton for helpful comments. I would especially like to thank James D. Hamilton for many very helpful discussions. All remaining errors are my own. Contact Information: Department of Economics and Finance, Southern Illinois University, Edwardsville, IL 62026-1102. e-mail: garjone@siue.edu.

The federal funds rate is the interest rate on one-day, overnight loans of reserves between banks. It is an entirely private-sector rate, negotiated by the banks who choose to lend and borrow reserves. That the Federal Reserve exerts control over this rate is beyond question; the question of interest is, just how does the Fed control this rate? Is it mostly via changes in each period's supply of total reserves, as in the models of Coleman, Gilles and Labadie (1996)? Or does the Federal Reserve change the ratio of nonborrowed to total reserves, as Strongin (1996) has argued?

Another possibility is that the Fed controls the fed funds rate by what appears to be a self-fulfilling prophecy: It announces a target for the fed funds rate, and banks immediately begin trading at (or quite close to) the new funds rate target, with no change in the level or composition of today's reserves. This theoretical possibility has been explored in the context of New Zealand's central banking system by Guthrie and Wright (1998), and in the American setting by Thornton (1999) and Taylor (2000). Surprisingly, the officials who implement the bulk of U.S. monetary policy--at the Trading Desk of the Federal Reserve Bank of New York—indicate that this theoretical possibility appears to be the case in practice. One could imagine a number of theoretical explanations for this kind of apparent self-fulfilling prophecy: Multiple equilibria leap to mind as one possibility. Another possible explanation would be the concept that a target change announcement represents a change in future reserve policy: today's fed funds rate might rationally be a function of expected future reserve

policy, not just a function of today's reserve levels. Taylor (2000) finds support for this latter possibility via simulations of a simple rational expectations model, and Demiralp and Jorda (1999) find empirical support for this idea using biweekly data. The latter authors find that prior to 1989, a rise (fall) in the federal funds rate target led to an immediate fall (rise) in the ratio of nonborrowed to borrowed reserves, while after 1989, there is no relationship between reserves and target changes.

In this paper, we use econometric evidence at higher frequencies than that used by Demiralp and Jorda to see how the Fed implements a typical change in the federal funds target. We use daily data from 1989 to 1994 along with biweekly data from 1984 to 1999 to observe the relationship among reserve levels, the fed funds target, and the actual fed funds rate on the days just before and after a change in the fed funds rate target. Our identifying assumption is that the exact day of the target change is itself uncorrelated with other supply and demand shocks in the financial system; surely the Fed chooses its rate target to respond to ongoing developments in the economy, but the decision to implement a target change on one particular day rather than another is largely a function of when the Federal Open Market Committee has previously scheduled a meeting, which would appear to be uncorrelated with other events in the economy (cf. Hamilton and Jorda, 1999).

To preview our findings, it appears that during the 1989-94 period, the fed funds rate quickly moved to its new target within a day of the target change announcement; however, reserves—both total reserves and nonborrowed reserves—do not appear to change at all on days $t-1$ through $t+1$ in response to a day t change in the

target. If the Desk did sometimes implement target changes by way of shifts in reserve supply, they did so only occasionally, too rarely to yield either large coefficients or small standard errors. A similar picture emerges when we look at the biweekly data from 1984 to 1999. In our discussion, we will discuss how the results from these daily and biweekly results can be integrated into the rest of the liquidity effect literature.

Daily Reserves and the Federal Funds Rate: 1989-1994

In this section, we look at the days immediately surrounding a change in the rate target, and provide answers to the following three questions: Does the federal funds rate move to its new target? Are target changes accompanied by reserve changes within a day or so? And, do changes in daily reserves change the fed funds rate? We use data from April 26, 1989 through November 27, 1991 and from January 2, 1992 through December 31, 1994, and use ordinary least squares estimation methods. The data were originally provided to James D. Hamilton by the Federal Reserve Bank of New York; the time periods were selected because of data availability. The measure of the day *t* federal funds rate that we use is a volume-weighted average of the interest rates for all federal funds transactions falling on day *t* (Figure 1).

Table 1 answers the first question. We regress the one-day change in the federal funds rate on a set of calendar dummy variables employed by Hamilton (1996,

1997, 1998) as well as two additional calendar dummies explained below, along with lags +1 through –1 of the change in the fed funds target.

The fourteen calendar dummies used by Hamilton consist of one dummy for each day of the ten business-day reserve maintenance period (beginning every other Thursday, and ending on the Wednesday two weeks later), as well as one dummy each for the days before and after a one-day or three-day holiday. These calendar dummies are important because of the way reserve requirements are met in the U.S.: Banks do not meet their reserve requirements each day; rather, they have to meet them on average over the two-week reserve maintenance period. The deadline day is referred to as settlement Wednesday. Hamilton (1996) demonstrated that there is a consistent pattern to the fed funds rate over the maintenance period, falling over the course of the maintenance period, but then spiking upward in the last two days; the rate also tends to fall on Friday and rise on Monday, and there are significant effects just before and after holidays. These calendar effects on the fed funds rate are so pronounced that they are transmitted to the overnight Eurodollar market, as Lee (1999) has shown.

In addition to Hamilton's fourteen dummies, we also include two additional dummies for the first and last days of each quarter, since these are recognized as days of unusual volatility, with consistent spikes in interest rates as businesses adjust their balance sheets for financial reports.

The target change variable has a value of zero for all but 30 of the 1432 observations; when it does not have a zero value, it ranges from +0.75 to –0.5 (Figure 1). Since the Federal Reserve Board generally makes its decision late in the day on

day *t-1* for a target change on day *t*, it is possible that the financial markets (or the Operations Desk in New York) acquire information about the target change and move the rate on day *t-1*. Another possibility is that markets strongly anticipate that the target will move on day *t,* and so market participants push the rate in that direction on day *t-1*, correctly anticipating that the Desk will not intervene to stop the move.

Another minor complication arises from the fact that our measure of the fed funds rate is a trade-weighted average: If the Desk implements the target change slowly over the course of day *t*, or implements it on day *t* via a mid-day move in the reserve markets, then early-morning fed funds transactions will not reflect the change in the rate; therefore, in order to see the full effect of a target change, we will have to look at the change in the fed funds rate on the day after a change in the target.

A final complication arises from a surprise change in reserve requirements (from 12% to 10% for many types of deposits) that occurred during our sample period. In order to see if the statistical relationships are consistent, we run all regressions in this section twice, once with the full sample, and again while excluding the first 10 weeks after the surprise announcement of this fall in reserve requirements (i.e., observations from Wednesday December 12, 1990 through Thursday, March 7, 1991). Three of our 30 target changes fell during this period. The 10-week period was chosen because daily reserve levels appeared to stabilize considerably after this time (see Figure 2).

The results from Table 1 indicate that the fed funds rate moves quickly to its new target. In both the full and the restricted samples, the daily fed funds rate move

over 70% of the way to its new target by the day after a target change; F-tests readily accept the restriction that the three target change coefficients sum to 100% in both samples. Also, note that the day *t* effect of a target change on the rate is larger in the full sample than in the restricted sample; while the difference is not statistically significant, this result may help to explain some of our later results.

The second question is whether target changes are typically accompanied by changes in reserves; accordingly, we begin by regressing the one-day change in total reserves, and separately, the one-day change in non-borrowed reserves, on the same three target-change variables used to answer question one. Over this time period, banks generally became much more reluctant to borrow from the discount window, and so moves in nonborrowed reserves are almost identical to moves in total reserves. As such, we focus our discussion on the broader measure of total reserves, since there is never a substantive difference in results.

We also include dummies for the day of the maintenance period, since there is a strong pattern to reserves over the 14-day reserve maintenance period, with reserves generally rising by a few billion dollars in the last few days of the period. Finally, we include dummies for the days before and after holidays, since there are strong, well-known trends to reserves on these days. We also include dummies for the next-to-last, last, and first days of a quarter, since the Desk routinely adds reserves to counteract the quarterly spikes in interest rates noted earlier.

The results are reported in Table 2 (and nonborrowed reserve results are reported in Table 3). Again, we report the same two sets of results for each time

period. The results indicate a noisy relationship, at best, between reserves and the fed funds target. None of the target change variables rise to conventional significance levels, although the coefficient sizes appear plausible, if somewhat small: If we look only at the day *t* coefficient, then a typical 25 basis-point rise in the rate would be accompanied by fall in reserves of between 500 and 640 million dollars.

According to the coefficient estimates in Jones (2000), a half billion dollars in reserves, removed at the beginning of a maintenance period and kept out for the entire period, would lead to a rise in the federal funds rate of about five basis points. We hypothesized in that paper that within a given maintenance period, if a reserve loss is expected to be more persistent, then it will have a greater impact on today's fed funds rate. We also uncovered evidence consistent with this hypothesis. If the small reserve changes reported in Table 2 actually do persist into future maintenance periods, then that could explain these small reserve supply shock coefficients.

As a check on the results in the current paper, we choose to detrend reserves by using the level of reserves (rather than the change) as the dependent variable, and by including four lags of reserves in the regression. The weak negative relationship between reserves and the target vanishes when these lags are included. Whether the four lags are the first through fourth, or (to avoid a possible correlation between lagged reserves and the target change) the third through the sixth, the coefficients tend to have the wrong sign, and the only coefficient bordering on statistical significance itself has the incorrect sign; these results are reported in Tables 4 and 5. It appears

that, as Fed officials indicate, there is no systematic relationship between reserves and changes in the target on the days immediately surrounding a target change.

Our third question is whether changes in the rate are associated with changes in reserves. While there appears to be no systematic relationship between target changes and reserves, it could be the case that the rate moves especially quickly on a few occasions when the Desk intervenes in the markets following a change in the target. To answer this question, we regress the one-day change in the fed funds rate (between days *t* and *t-1*) on the same calendar dummies used in the previous regressions as well as three new variables: the one-day change in reserves (between days *t* and *t-1*) multiplied by one of three dummy variables, which have a value of one if and only if there is a change in the funds target on days *t+1*, *t*, or *t-1*. This allows us to see whether reserves are changing on the day before, the day of, or the day after a change in the target, respectively. The results are reported in Table 6 and Table 7. Compared to our first question, these econometric results appear much more sensitive to the sample period: if we exclude the period of falling reserve requirements, it appears that there is no significant relationship between daily reserves and the daily fed funds rate--anomalously, the largest and most statistically significant effect is on the day *before* the target change. However, if we include the period of falling reserve requirements, then our result reverses: a 25 basis point fall in the rate (the modal target change in this sample) is concurrent with a $5B rise in that day's reserve levels. Since the average daily reserve level in this sample was only $30B, these reserve changes appear quite large. However, the liquidity effect measured here, of five basis points per billion

dollars, is roughly in line with the small daily liquidity effects due to transitory, one-day reserve shocks, as documented by Hamilton (1997, 1998) and Jones (2000).

Why the difference between these two samples? Clearly, the reserve/fed funds rate relationship is showing up strongest during the period of falling reserve requirements; we hypothesize that this is because during this time of extreme uncertainty, the Desk leads the market by the hand, as it were, implementing the target declines by way of a generous reserve policy.

To confirm this hypothesis, we look only at the three months following the cut in reserve requirements. Here we find an even stronger relationship: The three rate cuts during this period appear to be implemented via increases in reserves, averaging $900 million for each of the three 25 basis point rate cuts. It would seem that since reserve levels were naturally plummeting as bank discovered their new optimal reserve levels, the Desk wanted to make a move to counteract the steep decline in reserve levels in order to ensure that rates moved in the Fed's desired direction.

The more interesting result, of course, is from the regression that excludes this unusual period, and focuses instead on the other 27 target changes; this result, combined with our answer to the first question, presents something of a surprise: The rate moves to its new target (on average), but reserves are not changing (on average). This result supports the accounts of Desk officials that target changes are often self-fulfilling, and do not require immediate changes in reserve policy.

As a check on these results, we choose to detrend total reserves, removing both an autoregressive and a seasonal component. As noted above, there is a strong pattern

to reserves over the 14-day reserve maintenance period, with reserves generally rising by a few billion dollars in the last few days of the period. The econometric assumption underlying the estimate in Table 2 is that the exact date of a target change will be uncorrelated with these reserve fluctuations, so that any systematic change in reserves will be due solely to the change in the target; since the announcement dates in this sample did vary over the course of the week, this seems to be a reasonable assumption. However with only 30 target changes in our sample, it seems prudent to take account of the trend and seasonal components; one could imagine that the these components could understate or overstate the relationship between reserves and the fed funds rate.

We do so by creating two one-day forecasts of total reserves, using a reserve model similar to that used by Hamilton (1998) for nonborrowed reserves; one includes the full sample and the second excludes (as elsewhere) the first three months after the change in reserve requirements. We model reserves as an autoregressive process of order four; we also add in dummy variables for the days of the reserve maintenance period because of the aforementioned trend in reserves within each reserve maintenance period. We also include dummies for the days before and after holidays, and for the beginning and end of the quarter. As the coefficients from this particular regression are not of interest, these results are not reported. The residuals from this regression are used as estimates of the shock to reserves, uncorrelated with calendar or autoregressive effects. We use these residuals (rather the one-day change in reserves), and otherwise run the same regressions as in Table 6; the results are reported in Table

8. The modest signs of a liquidity effect from Table 6 weaken considerably. In the restricted sample, there is no sign of a liquidity effect. When we include all the observations, the coefficients imply that any move in the reserve markets on the day of a target change is largely symbolic: either it is undoing a move in the previous direction the day before the target change (as in the full sample), or the move is entirely undone the next day (as in the omitted observations). Overall, the days immediately surrounding a change in the fed funds target provide little evidence that target changes are implemented via reserve changes.

Are cumulative reserves the variable that matters?

The previous section looked at changes on the days immediately after a change in the fed funds target. However, Jones (2000) showed that the Fed funds rate is affected not only by daily reserves, but also by expected cumulative reserves within the maintenance period. If banks believe that the Desk is going to increase reserves in the next few days before settlement Wednesday, then those expected reserves could push the rate down: banks would expect to comfortably meet their reserve requirements, and so would bid down today's fed funds rate. In this section, we check to see whether the strong observed relationship between the fed funds rate and the fed funds rate target can be explained by this mechanism.

To measure the surprise to reserves within the maintenance period, we use the cumulative total reserve forecast created and tested in Jones (2000); this is a least-squares day *t* forecast of settlement Wednesday's cumulative reserves, conditioned on

information arriving on day *t* and earlier. This forecast does not make use of the fed funds rate; it only makes use of a combination of calendar dummies, lagged daily reserves, and lagged cumulative reserves. We choose day *t* to be the day *before* a change in the fed funds target, before the information on a target change arrives (and before reserves could be altered to implement the target change).

Our identifying assumption is that the errors from this simple forecast will be highly correlated with the shock to reserves that market participants will expect once they learn about the change in the fed funds target. If there turns out to be a correlation between these forecast errors and changes in the fed funds rate, then this would imply that the shock to cumulative reserves caused the change in the rate.

The measure of the fed funds rate we use is the change in the average fed funds rate prevailing on the days within the maintenance period following a change in the target (To avoid the unusual volatility on settlement Wednesday, we exclude all fed funds rate measurements and target changes which fall on this day). This means that if the target is changed on the 6^{th} day of the 10-day maintenance period, then we take the average rate over days 6 through 9 of this period, and subtract the average rate over days 6 through 9 of the previous reserve maintenance period. This inter-period differencing is necessary because of the strong within-period trend in the fed funds rate. All results from this section are in Table 9.

As a check on our previous results, we regressed the change in the fed funds rate on the change in the target and a constant; the coefficient on the target change is .93 with a standard error of .08. The rate is quickly moving to the new target.

By contrast, there is no apparent negative correlation between cumulative reserve shocks and the fed funds rate: when we regress the 24 relevant changes in the fed funds rate on the 24 forecast shocks, we actually find a coefficient that is fairly large, statistically significant, and positive. This could reflect the difficulty of creating an accurate forecast of cumulative reserves, or it could reflect a Fed policy of overcompensating for any negatively-correlated reserve supply shocks which the Desk might use as a signal on the day of a target change. Alternately, these results could be driven by outliers: to check this possibility, I drop the two largest observations with the "wrong" signs--the only candidates for genuine outliers--and rerun the regressions (One outlier occurs just after the drop in reserve requirements, so reserves are falling even though the rate is being cut; the second occurs just before Thanksgiving in 1994, when the Desk was probably adding reserves in preparation for the holidays despite a 75 basis-point rise in the target. In both cases, the actual fed funds rate quickly moved to its new target). The sign becomes negative, but it is much smaller in absolute value and statistically insignificant. Rerunning these regressions with the (simpler) first difference of cumulative reserves between maintenance periods as the explanatory variable (rather than the forecast errors) does not change these results. Within-period cumulative reserve shocks do not appear to be driving the fed funds rate after a target change in this sample.

Adjusted Reserves and the Federal Funds Rate: 1984-1999

Another way to see if target changes are implemented by changes in reserve supply is to look at the maintenance periods immediately before and after a change in the target. Again, we can ask the same questions: Does the rate move to its new target? Are target changes accompanied by reserve changes? And, do changes in reserves change the rate?

If we look at maintenance-period level data, then we can use the longer public datasets available from the FRED database at the Federal Reserve Bank of St. Louis. We choose to use their measure of adjusted reserves per maintenance period, described in Anderson and Rasche (1996). This reserve measure is seasonally adjusted; further, an adjustment is made following any change in reserve requirements to eliminate discrete jumps in the reserve level. Since these adjustments are designed to remove medium- and low-frequency fluctuations, they should be uncorrelated with the relatively high-frequency issues we are examining here; at the same time, we will no longer need to worry about the econometric complications that arise from seasonal fluctuations and intercept shifts. As before, we report separate results coefficients for nonborrowed reserves and total reserves, but, as before, find the same results regardless of the reserve measure used.

We use maintenance-period level (biweekly) data running from March 14, 1984 through July 14, 1999 (The nonborrowed reserve series begins January 1, 1986). We end the sample in mid-1999 because of the sharp rise in reserves later in the year due to issues surrounding Y2K. The final sample includes 401 maintenance periods and 91 target changes. The only obvious outlier in the series occurs at the end of

1986, when the average fed funds rate was 200 basis points above its target. We include dummies for this maintenance period in all regressions.

Our goal in using this longer-run data is to look at the change in reserves *between* maintenance periods and *after* a change in the target. Accordingly, if a rate change occurs in period *p*, we look at the relevant variable's change between periods *p-1* and *p+1*. Since we are interested in observing the effect of period *p*'s target change by itself, we omit all observations where a rate change also occurred in periods *p-1* or *p+1*. Since target changes were frequent in the early years of this sample, this reduces our number of observations to 49; however, our results do not change in any economically or statistically significant manner if all 91 target changes are included.

The regressions in this section include the two-period changes of the three variables of interest (the target, the average rate, and the level of adjusted reserves), a dummy for the last maintenance period of 1986, and a constant. As in the previous section, we only include observations in which there has been a target change in period *p*. Over this sample period, if there is a target change during maintenance period *p*, the rate moves 90% of the way to its new target between periods *p-1* and *p+1* (Table 11). An F-test accepts the restriction that the rate moves 100% of the way.

It appears that target changes are not systematically accompanied by changes in total reserves by period *p+1*, as Table 10 indicates. If we took the coefficient at face value, it would mean that a typical 25 basis point decline in the target is accompanied by a $40M increase in total reserves; this is similar to Hamilton's (1997) estimate of the within-period liquidity effect, but since the standard error is twice the size of the

coefficient, we should place little faith in this magnitude. A more cogent interpretation of the large standard error and small coefficient is that some target changes are accompanied by increases in reserves, but most are not.

Finally, we answer our third question: Are changes in the rate caused by changes in reserves? Here, the answer is clearly no (Tables 11). In order to compare the relative importance of the target change versus the reserve change in determining the rate, we run a final regression, including both as independent variables, while using the change in the rate as the dependent variable. Reserves again have no explanatory power when the target change is included in the regression. These results confirm our results in the previous sections: The federal funds rate generally moves to its new target without a change in reserve levels.

Discussion

The results presented here are something of a puzzle, at first glance. Within a given maintenance period in the 1989-1994 period, there appears to be a negative relationship between reserves and the target that is noisy at best; similarly with the relationship between the reserves and the fed funds rate. Meanwhile, the rate moves quickly toward its new target. When we look at biweekly data from 1984 to 1997, we confirm the observation that the rate moves quickly toward its new target, and find even less of a link between reserves and the fed funds rate. If reserve levels are not changing, then why does the rate move?

The first place to look for an explanation is the influential article by Strongin (1996): According to his understanding of the U.S. banking system, reserve demand is almost infinitely inelastic within a given month. Banks cannot quickly adjust their demand for required and excess reserves. Accordingly, the Fed tightens and looses reserves not by changing the supply of total reserves, but instead by changing the mix between borrowed and non-borrowed reserves. Banks strongly dislike going to the Fed's discount window (the only source of borrowed reserves), but since total reserve demand is inelastic, a reduction in the percentage of non-borrowed reserves forces banks to the discount window. This is equivalent to a tightening of reserve policy, because only at a higher equilibrium federal funds rate are banks willing to borrow reserves from the unappealing discount window. According to Strongin's model, then, we would not expect total reserves to fall when the Fed raises the target: we would instead expect non-borrowed reserves to fall, and borrowed reserves to rise by an equal amount. Our results have provided little evidence that either nonborrowed reserves or borrowed reserves have large, persistent changes within four weeks of a typical target change. The one exception is that there may sometimes by a shift in reserves on the day of a target change, but this relationship, while economically large, is statistically insignificant.

The results from Hamilton (1997, 1998) and Jones (2000) further reason to have doubts about Strongin's explanation, at least in the short time horizons we analyze. Their work indicated that although large shocks to total reserve supply did affect the fed funds rate, short-run reserve demand was elastic enough for the Fed to

realistically change the rate via changes to total reserve supply. Jones's results, for example, indicate that a $2B increase in total reserves, if kept in for an entire maintenance period, would push the rate down by 25 basis points (for additional evidence of the finite short-run elasticity of reserve demand, see Leeper, Sims, and Zha (1996)). It appears that the Fed is able to control the fed funds rate via short-run changes to total reserve supply, but it chooses not to do so.

This leaves expected reserves as the strongest available explanation for how the Fed might implement target changes via reserves. This result has some support in the vector autoregression literature on the liquidity effect: Christiano, Eichenbaum and Evans (1996) show that a positive federal funds policy shock of about 75 basis points leads to a decline in total reserves two quarters later; this decline lasts at least five more quarters, and is equal to a persistent fall of about 1/3 of one percent of total reserves. The semi-elasticity of reserve demand implied by this result is over an order of magnitude higher than that implied by Jones's (2000) single-maintenance-period results: Persistent expected reserve losses appear to be much more important that single-period reserve losses.

Could expected reserve policy be the force pushing the current fed funds rate to its new target? Jones's (2000) empirical results indicate that within a given maintenance period, today's fed funds rate depends on both today's reserve supply, and on expected reserve policy for the rest of the period; he showed that small, persistent changes in expected reserves can change today's rate much more than large changes in today's reserve level could. If this idea applies between periods, then this could

explain how the Fed is able to control the rate with no discernable change in current reserve policy: It simply changes the path of expected reserve supply.

However, we should note again that Demiralp and Jorda find that at least since 1989, target changes do not lead to shifts in the future path of reserves. If their empirical results and the results presented here are robust, than there is strong evidence that the Federal Reserve controls interest rates largely through announcement effects, a mechanism that Guthrie and Wright appropriately refer to as "open mouth operations."

Table 1

Dependent Variable: One-day change in the federal funds rate on day *t*

	Full Sample		Restricted Sample	
Variable	**Coeff**	**SE**	**Coeff**	**SE**
Δtar_{t+1}	0.11	0.17	0.29	0.15
Δtar_{t}	0.45	0.17	0.12	0.15
Δtar_{t-1}	0.23	0.17	0.33	0.15
$\Psi_{1,t}$	-0.15	0.02	-0.14	0.02
$\Psi_{2,t}$	-0.11	0.02	-0.10	0.02
$\Psi_{3,t}$	0.05	0.03	0.06	0.02
$\Psi_{4,t}$	-0.07	0.02	-0.06	0.02
$\Psi_{5,t}$	-0.02	0.02	-0.04	0.02
$\Psi_{6,t}$	0.02	0.02	0.02	0.02
$\Psi_{7,t}$	-0.09	0.03	-0.07	0.02
$\Psi_{8,t}$	0.11	0.03	0.13	0.02
$\Psi_{9,t}$	-0.09	0.03	-0.09	0.02
$\Psi_{10,t}$	0.25	0.02	0.21	0.02
$\xi_{1,t}$	-0.17	0.09	0.13	0.08
$\xi_{1,t-1}$	0.34	0.09	-0.05	0.08
$\xi_{3,t}$	-0.13	0.05	-0.15	0.04
$\xi_{3,t-1}$	0.43	0.05	0.40	0.04
α_t	0.01	0.05	-0.13	0.05
ω_t	0.10	0.05	0.23	0.04
	R^2		R^2	
	0.18		0.22	

Δtar_t is the one-day change in the federal funds rate target on day *t*; it has a non-zero value in 30 of the 1440 observations.
Δtar_{t+1} and Δtar_{t-1} are the one-day changes in the federal funds rate target occuring tomorrow and yesterday, respectively.

$\Psi_{i,t}$ is a dummy variable for day i of the maintenance period.

$\xi_{i,t}$ is a dummy varible indicating that day t occurs immediately before an i-day holiday.

$\xi_{i,t-1}$ is a dummy variable for the day after an i-day holiday.

α_t and ω_t are dummy variables for the first and last day of a quarter.

Table 2

Dependent Variable: One day change in total reserve levels in billions on day *t*

	Full Sample		Restricted Sample	
Variable	**Coeff**	**SE**	**Coeff**	**SE**
Δtar_{t+1}	0.34	1.77	0.78	1.85
Δtar_{t}	-2.54	1.77	-2.05	1.85
Δtar_{t-1}	0.76	1.77	-0.11	1.85
$\Psi_{1,t}$	-2.81	0.26	-2.80	0.26
$\Psi_{2,t}$	-0.01	0.26	-0.21	0.26
$\Psi_{3,t}$	0.38	0.26	0.33	0.26
$\Psi_{4,t}$	-0.15	0.26	-0.18	0.26
$\Psi_{5,t}$	-0.16	0.25	0.00	0.25
$\Psi_{6,t}$	0.00	0.26	-0.03	0.26
$\Psi_{7,t}$	0.83	0.27	0.75	0.27
$\Psi_{8,t}$	0.54	0.28	0.55	0.28
$\Psi_{9,t}$	-0.04	0.27	0.05	0.27
$\Psi_{10,t}$	1.88	0.26	1.81	0.26
$\xi_{1,t}$	-1.52	0.89	-1.71	0.95
$\xi_{1,t-1}$	-3.90	0.89	-2.28	0.95
$\xi_{3,t}$	0.05	0.54	0.11	0.54
$\xi_{3,t-1}$	0.69	0.54	0.85	0.54
α_t	-0.02	0.54	0.98	0.56
ω_{t+1}	-0.10	0.53	-0.89	0.55
ω_t	-1.46	0.53	-1.55	0.55
	R^2		R^2	
	0.14		0.14	

Δtar_t is the one-day change in the federal funds rate target on day *t*; it has a non-zero value in 30 of the 1440 observations.
Δtar_{t+1} and Δtar_{t-1} are the one-day changes in the federal funds rate target occuring tomorrow and yesterday, respectively.

$\Psi_{i,t}$ is a dummy variable for day i of the maintenance period.

$\xi_{i,t}$ is a dummy varible indicating that day t occurs immediately before an i-day holiday.

$\xi_{i,t-1}$ is a dummy variable for the day after an i-day holiday.

α_t, ω_{t+1}, and ω_t are dummy variables for the first, penultimate, and last days of a quarter.

Table 3

Dependent Variable: One day change in nonborrowed reserve levels in billions on day *t*

	Full Sample		Restricted Sample	
Variable	**Coeff**	**SE**	**Coeff**	**SE**
Δtar_{t+1}	0.04	1.80	0.36	1.90
Δtar_{t}	-2.52	1.79	-1.98	1.87
Δtar_{t-1}	1.17	1.79	0.33	1.87
$\Psi_{1,t}$	-2.30	0.26	-2.34	0.26
$\Psi_{2,t}$	0.04	0.26	-0.17	0.26
$\Psi_{3,t}$	0.37	0.27	0.31	0.27
$\Psi_{4,t}$	-0.12	0.26	-0.16	0.26
$\Psi_{5,t}$	-0.14	0.26	0.01	0.26
$\Psi_{6,t}$	-0.01	0.26	-0.04	0.26
$\Psi_{7,t}$	0.86	0.27	0.76	0.27
$\Psi_{8,t}$	0.50	0.28	0.51	0.28
$\Psi_{9,t}$	-0.05	0.27	0.06	0.27
$\Psi_{10,t}$	1.41	0.26	1.35	0.26
$\xi_{1,t}$	-1.42	0.91	-1.65	0.97
$\xi_{1,t-1}$	-4.32	0.91	-2.25	0.97
$\xi_{3,t}$	-0.02	0.55	0.06	0.55
$\xi_{3,t-1}$	0.57	0.55	0.84	0.55
α_t	-0.04	0.54	-0.81	0.56
ω_{t+1}	-1.74	0.54	-1.86	0.56
ω_t	0.20	0.54	1.23	0.57
	R^2		R^2	
	0.10		0.10	

Δtar_t is the one-day change in the federal funds rate target on day *t*; it has a non-zero value in 30 of the 1440 observations. Δtar_{t+1} and Δtar_{t-1} are the one-day changes in the federal funds rate target occuring tomorrow and yesterday, respectively.

$\Psi_{i,t}$ is a dummy variable for day i of the maintenance period.
$\xi_{i,t}$ is a dummy varible indicating that day t occurs immediately before an i-day holiday.

$\xi_{i,t-1}$ is a dummy variable for the day after an i-day holiday.

$\alpha_{t,}$ ω_{t+1}, and ω_t are dummy variables for the first, penultimate, and last days of a quarter.

Table 4

Dependent Variable: Total reserve level in billions on day *t:* (R_t)

	Full Sample		Restricted Sample	
Variable	**Coeff**	**SE**	**Coeff**	**SE**
Δtar_{t+1}	1.56	1.56	1.35	1.63
Δtar_t	-0.38	1.55	-0.24	1.62
Δtar_{t-1}	1.04	1.55	0.26	1.62
TR_{t-1}	0.52	0.03	0.52	0.03
TR_{t-2}	0.02	0.03	0.02	0.03
TR_{t-3}	0.17	0.03	0.15	0.03
TR_{t-4}	0.20	0.03	0.21	0.03
	R^2		**R^2**	
	0.72		0.68	

Dependent Variable: Total reserve level in billions on day *t:* (R_t)

	Full Sample		Restricted Sample	
Variable	**Coeff**	**SE**	**Coeff**	**SE**
Δtar_{t+1}	3.18	1.73	1.74	1.79
Δtar_t	0.87	1.72	0.36	1.78
Δtar_{t-1}	0.83	1.72	0.01	1.78
TR_{t-3}	0.26	0.03	0.23	0.03
TR_{t-4}	0.21	0.03	0.20	0.03
TR_{t-5}	0.21	0.03	0.21	0.03
TR_{t-6}	0.21	0.03	0.22	0.03
	R^2		**R^2**	
	0.65		0.62	

Coefficients for calendar dummies are not reported.

Δtar_t is the one-day change in the federal funds rate target on day *t*; it has a non-zero value in 30 of the 1440 observations.

Table 5

Dependent Variable: Nonborrowed reserve level in billions on day *t:* (R_t)

	Full Sample		Restricted Sample	
Variable	**Coeff**	**SE**	**Coeff**	**SE**
Δtar_{t+1}	1.38	1.59	1.15	1.67
Δtar_t	-0.33	1.58	-0.16	1.64
Δtar_{t-1}	1.49	1.58	0.75	1.64
NBR_{t-1}	0.53	0.03	0.52	0.03
NBR_{t-2}	0.01	0.03	0.01	0.03
NBR_{t-3}	0.17	0.03	0.16	0.03
NBR_{t-4}	0.20	0.03	0.20	0.03
	R^2		**R^2**	
	0.70		0.67	

Dependent Variable: Nonborrowed reserve level in billions on day *t:* (R_t)

	Full Sample		Restricted Sample	
Variable	**Coeff**	**SE**	**Coeff**	**SE**
Δtar_{t+1}	3.00	1.76	1.94	1.84
Δtar_t	0.90	1.75	0.42	1.81
Δtar_{t-1}	1.17	1.75	0.41	1.81
NBR_{t-3}	0.26	0.03	0.24	0.03
NBR_{t-4}	0.20	0.03	0.19	0.03
NBR_{t-5}	0.21	0.03	0.21	0.03
NBR_{t-6}	0.21	0.03	0.22	0.03
	R^2		**R^2**	
	0.63		0.60	

Coefficients for calendar dummies are not reported.

Δtar_t is the one-day change in the federal funds rate target on day *t*; it has a non-zero value in 30 of the 1440 observations.

Table 6

Dependent Variable: One-day change in the federal funds rate on day *t*

	Full Sample		Restricted Sample		Omitted Observations	
Variable	**Coeff**	**SE**	**Coeff**	**SE**	**Coeff**	**SE**
$\varphi_{t+1}*\Delta TR_t$	0.00	0.02	0.00	0.02	0.03	0.13
$\varphi_t*\Delta TR_t$	-0.05	0.02	0.00	0.02	-0.27	0.14
$\varphi_{t-1}*\Delta TR_t$	0.01	0.02	0.01	0.01	0.08	0.16
$\Psi_{1,t}$	-0.15	0.02	-0.14	0.02	-0.27	0.28
$\Psi_{2,t}$	-0.12	0.02	-0.10	0.02	-0.28	0.28
$\Psi_{3,t}$	0.05	0.03	0.06	0.02	0.12	0.31
$\Psi_{4,t}$	-0.07	0.02	-0.06	0.02	-0.17	0.31
$\Psi_{5,t}$	-0.02	0.02	-0.04	0.02	-0.07	0.31
$\Psi_{6,t}$	0.02	0.02	0.01	0.02	0.23	0.29
$\Psi_{7,t}$	-0.10	0.03	-0.07	0.02	-0.44	0.40
$\Psi_{8,t}$	0.11	0.03	0.13	0.02	-0.02	0.48
$\Psi_{9,t}$	-0.09	0.03	-0.09	0.02	-0.31	0.41
$\Psi_{10,t}$	0.26	0.02	0.21	0.02	0.77	0.29
$\xi_{1,t}$	-0.17	0.09	0.13	0.08	-0.59	0.84
$\xi_{1,t-1}$	0.34	0.09	-0.05	0.08	1.64	0.75
$\xi_{3,t}$	-0.13	0.05	-0.15	0.04	-0.08	0.63
$\xi_{3,t-1}$	0.43	0.05	0.41	0.04	1.25	0.64
α_t	0.01	0.05	-0.14	0.05	0.38	0.54
ω_t	0.10	0.05	0.23	0.04	-0.77	0.57
	R^2		R^2		R^2	
	0.19		0.22		0.59	

φ_t is a dummy variable indicating a change in the federal funds rate target on day t.

ΔTR_t is the one-day change in total reserve levels, in billions, on day t.

$\Psi_{i,t}$ is a dummy variable for day i of the maintenance period.

$\xi_{i,t}$ is a dummy varible indicating that day t occurs immediately before an i-day holiday.
$\xi_{i,t-1}$ is a dummy variable for the day after an i-day holiday.

α_t and ω_t are dummy variables for the first and last day of a quarter.

Table 7

Dependent Variable: One-day change in the federal funds rate on day *t*

	Full Sample		Restricted Sample		Omitted Observations	
Variable	**Coeff**	**SE**	**Coeff**	**SE**	**Coeff**	**SE**
$\varphi_{t+1}*\Delta NBR_t$	-0.02	0.02	-0.03	0.02	0.10	0.21
$\varphi_t*\Delta NBR_t$	-0.05	0.02	-0.01	0.02	-0.27	0.14
$\varphi_{t-1}*\Delta NBR_t$	0.01	0.02	0.00	0.01	0.08	0.16
$\Psi_{1,t}$	-0.15	0.02	-0.14	0.02	-0.25	0.28
$\Psi_{2,t}$	-0.12	0.02	-0.10	0.02	-0.28	0.28
$\Psi_{3,t}$	0.05	0.03	0.06	0.02	0.12	0.31
$\Psi_{4,t}$	-0.07	0.02	-0.07	0.02	-0.17	0.31
$\Psi_{5,t}$	-0.02	0.02	-0.03	0.02	-0.07	0.31
$\Psi_{6,t}$	0.02	0.02	0.01	0.02	0.21	0.29
$\Psi_{7,t}$	-0.09	0.03	-0.07	0.02	-0.44	0.40
$\Psi_{8,t}$	0.11	0.03	0.13	0.02	-0.02	0.48
$\Psi_{9,t}$	-0.09	0.03	-0.09	0.02	-0.27	0.42
$\Psi_{10,t}$	0.26	0.02	0.21	0.02	0.76	0.28
$\xi_{1,t}$	-0.17	0.09	0.13	0.08	-0.59	0.84
$\xi_{1,t-1}$	0.34	0.09	-0.05	0.08	1.65	0.75
$\xi_{3,t}$	-0.13	0.05	-0.15	0.04	-0.08	0.63
$\xi_{3,t-1}$	0.43	0.05	0.41	0.04	1.21	0.64
α_t	0.10	0.05	0.23	0.04	-0.77	0.57
ω_t	0.01	0.05	-0.13	0.05	0.37	0.53
	R^2		R^2		R^2	
	0.19		0.22		0.60	

φ_t is a dummy variable indicating a change in the federal funds rate target on day t.
ΔNBR_t is the one-day change in nonborrowed reserve levels, in billions, on day t.

$\Psi_{i,t}$ is a dummy variable for day i of the maintenance period.

$\xi_{i,t}$ is a dummy varible indicating that day t occurs immediately before an i-day holiday.
$\xi_{i,t-1}$ is a dummy variable for the day after an i-day holiday.
α_t and ω_t are dummy variables for the first and last day of a quarter.

Table 8

Dependent Variable: One-day change in the federal funds rate on day *t*

	Full Sample		Restricted Sample		Omitted Observations	
Variable	**Coeff**	**SE**	**Coeff**	**SE**	**Coeff**	**SE**
$\varphi_{t+1}*\rho_t$	0.013	0.028	0.023	0.025	-0.260	0.573
$\varphi_t*\rho_t$	-0.014	0.021	0.005	0.018	-0.017	0.177
$\varphi_{t-1}*\rho_t$	0.008	0.018	0.000	0.016	0.473	0.289
$\Psi_{1,t}$	-0.149	0.025	-0.138	0.021	-0.418	0.286
$\Psi_{2,t}$	-0.117	0.025	-0.101	0.021	-0.280	0.288
$\Psi_{3,t}$	0.048	0.025	0.063	0.021	0.116	0.316
$\Psi_{4,t}$	-0.069	0.025	-0.066	0.021	-0.131	0.331
$\Psi_{5,t}$	-0.022	0.024	-0.038	0.021	-0.073	0.324
$\Psi_{6,t}$	0.022	0.025	0.014	0.021	0.177	0.294
$\Psi_{7,t}$	-0.099	0.026	-0.069	0.022	-0.821	0.367
$\Psi_{8,t}$	0.110	0.027	0.130	0.022	0.074	0.430
$\Psi_{9,t}$	-0.092	0.026	-0.091	0.022	-0.398	0.436
$\Psi_{10,t}$	0.249	0.025	0.207	0.021	0.703	0.303
$\xi_{1,t}$	-0.165	0.086	0.135	0.077	-0.684	0.826
$\xi_{1,t-1}$	0.343	0.086	-0.051	0.077	1.707	0.768
$\xi_{3,t}$	-0.127	0.052	-0.144	0.044	0.296	0.620
$\xi_{3,t-1}$	0.426	0.052	0.407	0.044	1.338	0.663
α_t	0.009	0.052	-0.139	0.045	0.343	0.549
ω_t	0.101	0.051	0.235	0.045	-0.721	0.566
	R^2		R^2		R^2	
	0.180		0.219		0.582	

φ_t is a dummy variable indicating a change in the federal funds rate target on day t.
ρ_t is the forecast error, in billions, from a one-day forecast of daily reserves, as described in the text.

$\Psi_{i,t}$ is a dummy variable for day i of the maintenance period.

$\xi_{i,t}$ is a dummy varible indicating that day t occurs immediately before an i-day holiday.

$\xi_{i,t-1}$ is a dummy variable for the day after an i-day holiday.

α_t and ω_t are dummy variables for the first and last day of a quarter.

Table 9

Dependent Variable: Change in the average federal funds rate for the remainder of the maintenance period
(complete definition given in text)

	Full Sample			Full Sample			Omitting Two Outliers	
Variable	**Coeff**	**SE**		**Coeff**	**SE**		**Coeff**	**SE**
Δtar_p	0.926	0.081	ρ_p	0.011	0.006	ρ_p	-0.002	0.006
constant	-0.021	0.027	constant	-0.126	0.065	constant	-0.131	0.056
	R^2			**R^2**			**R^2**	
	0.851			0.153			0.007	
	n= 25			n= 24			n= 22	

Δtar_p is the change in the federal funds rate target between maintenance periods p-1 and p.
ρ_p is the forecast error for cumulative reserves in maintenance period p, conditioned on information arriving before the target change.
As discussed in the text, it reflects the predictable change in cumulative reserves, conditioned on the change in the fed funds target.

Table 10

Dependent Variable: Two-maintenance period change in adjusted reserves between periods p+1 and p-1

Variable	**Coeff**	**SE**
$tar_{p+1} - tar_{p-1}$	-0.17	0.31
ω_{86}	2.00	0.85
constant	0.33	0.13
	R^2	
	0.11	

This regression only includes observations where the federal funds rate target changed within period p,
and excludes observations where the target changed within periods p+1 or p-1

tar_p is the federal funds rate target in maintenance period p.

ω_{86} is a dummy variable for the last maintenance period of 1986.

Table 11

Dependent Variable: Two-maintenance period change in the federal funds rate between periods p+1 and p-1

Variable	**Coeff**	**SE**	**Coeff**	**SE**	**Coeff**	**SE**	0.
$tar_{p+1} - tar_{p-1}$	0.90	0.07	--	--	0.77	0.08	1.
$TR_{p+1} - TR_{p-1}$	--	--	-0.01	0.07	0.02	0.04	0.
ω_{86}	1.52	0.19	2.37	0.41	2.16	0.24	
constant	0.00	0.03	-0.06	0.06	-0.01	0.04	
	R^2		**R^2**		**R^2**		
	0.84		0.46		0.82		

This regression only includes observations where the federal funds rate target changed within period p, and excludes observations where the target changed within periods p+1 or p-1

tar_p is the federal funds rate target in maintenance period p.

TR_p is the level of total adjusted reserves in maintenance period p.

ω_{86} is a dummy variable for the last maintenance period of 1986.

Table 12

Dependent Variable: Two-maintenance period change in the federal funds rate between periods p+1 and p-1

Variable	**Coeff**	**SE**	**Coeff**	**SE**	**Coeff**	**SE**
$tar_{p+1} - tar_{p-1}$	0.90	0.07	--	--	1.02	0.05
$NBR_{p+1} - NBR_{p-1}$	--	--	-0.06	0.07	0.04	0.02
ω_{86}	1.52	0.19	1.78	0.40	1.47	0.12
constant	0.00	0.03	-0.04	0.06	-0.03	0.02
	R^2		**R^2**		**R^2**	
	0.84		0.33		0.94	

This regression only includes observations where the federal funds rate target changed within period p, and excludes observations where the target changed within periods p+1 or p-1

tar_p is the federal funds rate target in maintenance period p.

NBR_p is the level of nonborrowed adjusted reserves in maintenance period p.

ω_{86} is a dummy variable for the last maintenance period of 1986.

Figure 1: The daily federal funds rate and the rate target, 1989-1994
Lighter region represents observations (12/12/90-3/7/91) omitted in some regressions

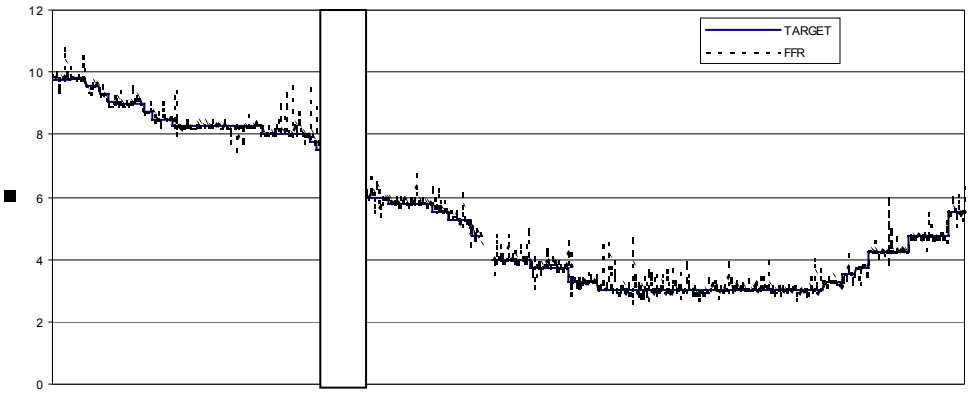


Figure 2: Daily Reserves, 1989-1994
Lighter region represents observations (12/12/90-3/7/91) omitted in some regressions

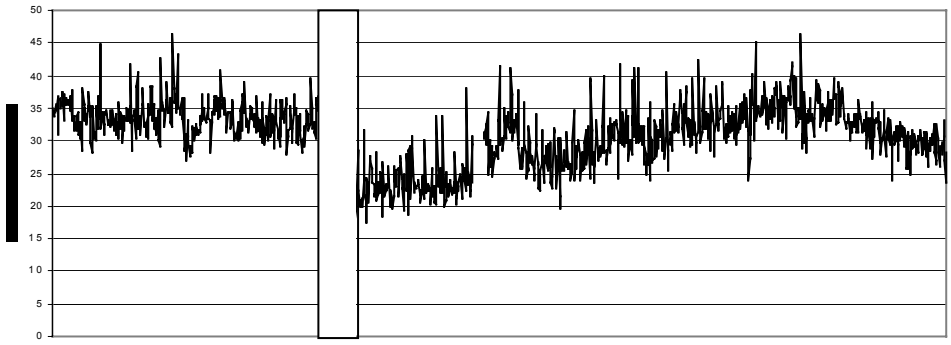


Figure 3: Target Changes and the Three-Day Change in the Fed Funds Rate

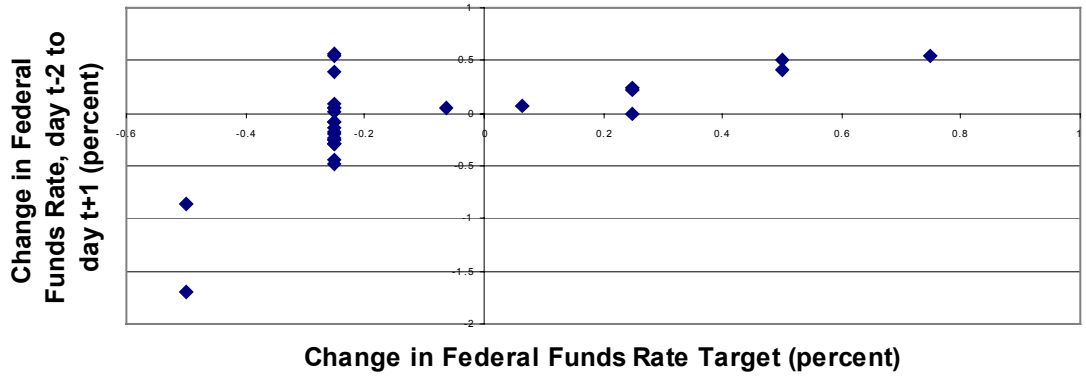
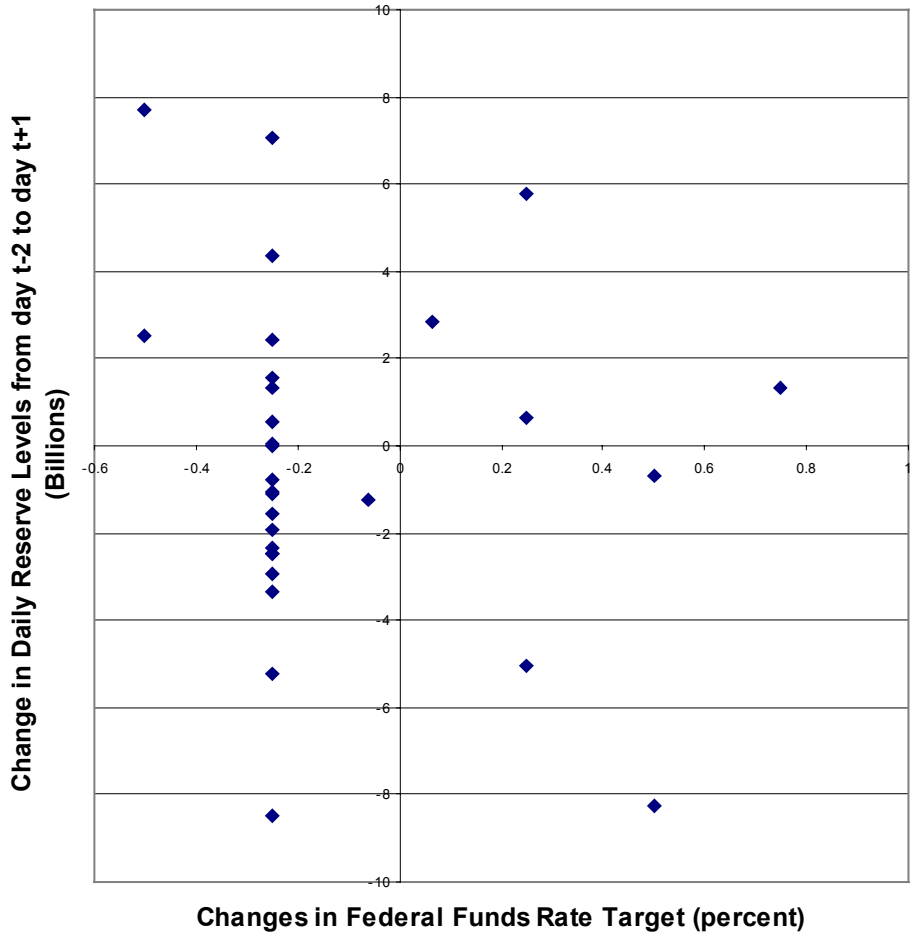


Figure 4: Three-day change in Reserves and Rate Target



Bibliography

Anderson, Richard G. and Robert H. Rasche. "A Revised Measure of the St. Louis Adjusted Monetary Base," *Federal Reserve Bank of St. Louis Review*, LXXVIII (1996), 1-36.

Christiano, Lawrence J,. Martin Eichenbaum, and Charles Evans. "Sticky Price and Limited Participation Models of Money: A Comparison," *European Economic Review*, XLI (1997), 1201-49.

Christiano, Lawrence J,. Martin Eichenbaum, and Charles Evans. "The Effects of Monetary Policy Shocks: Evidence from the Flow of Funds," *Review of Economics and Statistics*, LXXVIII (1996), 16-34.

Coleman, Wilbur John, II, Christian Gilles, and Pamela A. Labadie. "A Model of the Federal Funds Market," *Economic Theory*, VII (1996), 337-357.

Demiralp, Selva, and Oscar Jorda. "The Transmission of Monetary Policy via Announcement Effects," unpublished manuscript, University of California, Davis, (1999).

Guthrie, Graeme and Julian Wright. "Open Mouth Operations," *Journal of Monetary Economics*, XLVI (2000), 489-516.

Hamilton, James D. "The Daily Market for Federal Funds," *Journal of Political Economy*, CIV (1996), 26-56.

----------. "Measuring the Liquidity Effect," *American Economic Review*, LXXXVII (1997), 80-97.

----------. "The Supply and Demand for Federal Funds," *Carnegie-Rochester Conference Series on Public Policy*, IL (1998), 1-44.

Hamilton, James D. and Oscar Jorda. "A Model for the Federal Funds Rate Target," unpublished manuscript, University of California, San Diego, (1999).

Jones, Garett. "A Dynamic Model of the Daily Demand for Federal Funds," unpublished manuscript, University of California, San Diego, (2000).

Lee, Yungsook. "The Federal Funds Market and the Overnight Eurodollar Market," unpublished manuscript, University of California, San Diego, (1999).

Leeper, Eric, Christopher A. Sims and Tao Zha. "What Does Monetary Policy Do?" *Brookings Papers on Economic Activity*, II (1996), 1-63.

Strongin, Steven. "The Identification of Monetary Policy Disturbances: Explaining the Liquidity Puzzle," XXXV (1995), 463-497.

Taylor, John. "Expectations, Open Market Operations, and Changes in the Federal Funds Rate," http://www.stanford.edu/~johntayl, (2001).

Thornton, Daniel. "The Fed's Influence on the Federal Funds Rate: Is It Open Market or Open Mouth Operations?" working paper, Federal Reserve Bank of St. Louis,
(1999a).

Thornton, Daniel. "The Liquidity Effect at the Daily Frequency," working paper, Federal Reserve Bank of St. Louis, (1999b).