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Abstract

We analyze the impact of aggregate reserve levels on the intraday behavior of the federal funds rate over a sample period extending from 2002 to 2005. We study both how the reserve levels accumulated earlier in a maintenance period influence the morning level of the funds rate relative to the target set by the FOMC, and how same-day reserve levels as well as the reserve levels accumulated earlier affect intraday movements of the funds rate. The impact of recurring calendar events on the behavior of the federal funds rate is also explored. In general, we find a negative relationship between our measures of reserve levels and our two measures of federal funds rate behavior.

Key words: federal funds rate, open market operations, reserve requirements

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I. Introduction

In this study we examine the relationship between aggregate reserve levels held by depository institutions (banks) at the Federal Reserve (the Fed) and the behavior of the overnight federal funds rate. The federal funds rate refers to the interest rate a bank pays another bank on borrowings of reserve balances held at the Federal Reserve.[1] The vast majority of trades in this market settle on the trade date and mature the next business day. The Open Market Desk (the Desk) of the Federal Reserve Bank of New York (FRBNY) is directed by the Federal Open Market Committee (FOMC) to use open market operations—transactions between the Desk and securities dealers for the purchase or sale of government securities—to maintain the overnight federal funds rate on average around a target level set by the FOMC. Purchases by the Desk increase reserve supply and sales decrease reserves. Each day, the Desk estimates the aggregate level of reserve supply needed to maintain the federal funds rate around the target. When this estimate differs from its estimate of reserve supply, open market operations will be used to close the gap. Ceteris paribus, a higher (lower) supply of reserves is expected to be associated with lower (higher) rates in the federal funds market.

Earlier studies investigated the relationship between monetary aggregates, such as M1 or M2, and short-term interest rates, such as the rate on 3-month Treasury bills. These studies relied on quarterly or monthly data and found mixed evidence regarding the liquidity effect, a negative relationship between money supply and interest rates. More

[1] Descriptions of the federal funds market can be found in Board of Governors of the Federal Reserve System (2005), Bartolini et al. (2005), or Hilton (2005). For simplicity, institutions in the funds market are referred to as "banks" in this study, although several other types of institutions actively participate in this market.

recent studies have focused on the relationship between bank reserves and the federal funds rate using daily data.

There are two main innovations in this study. First, our specification allows for intra-day dynamics of the federal funds rate, albeit somewhat simplistically. Second, we employ actual reserve levels, instead of deviations of reserves from intended levels, in our analysis. And in so doing, our data also allow us to distinguish between the impact of same-day reserve levels and reserve levels already cumulated in a reserve maintenance period (defined below).

We first examine the relation between past reserve levels in a reserve maintenance period and a representative level of the federal funds rate in the morning (measured relative to the target rate). We find that cumulated reserves through the previous day in the maintenance period have a negative relationship with this spread, and that this relationship grows in magnitude and significance over the course of a two-week maintenance period. We then examine the relation between reserve levels and movements in the rate over the course of a day, measured by the difference between the average daily (effective) federal funds rate and the morning rate. We find that both daily excess reserve levels and cumulated excess reserves through the previous day have a negative relation with intra-day rate movements, which also tends to become more pronounced over the course of a maintenance period.

The paper is structured as follows. Section II contains background information on the federal funds market and open market operations. A literature review is found in Section III. Section IV contains a description of the data, and regression results can be found in Section V. Section VI concludes.

II. Background

In the segment of the federal funds market examined in this study, reserve balances in the accounts of commercial banks at the Fed are borrowed or loaned for one business day (overnight) and settle on the trade date. In volume, transactions with these characteristics account for the vast majority of all trading in the federal funds market. By convention, loans in this market are unsecured. Trading ends when Fedwire closes, scheduled for 6:30 pm.[2] Each morning, open market operations (OMOs) may be conducted by the Desk to adjust the expected aggregate supply of bank reserves in such a way as to foster conditions in the market consistent with the FOMC's policy directive for rates.

Determinants of Reserve Supply[3]

Using a simple balance sheet identity, the supply of reserve liabilities of the Federal Reserve may be viewed as being the residual of the level of domestic financial assets (less liabilities) held by the Fed, discount window loans outstanding, and the net value

[2] Fedwire is the wholesale electronic funds transfer network owned and operated by the Federal Reserve System. Fed funds transactions typically settle when the lending institution instructs the Fed via Fedwire to transfer reserves out of its account and into the account of the borrowing bank.

[3] In this study the term "reserves" is used to refer to the actual balances held by depository institutions at the Fed. As used in this study, the term does not include applied vault cash (which technically are reserves) and does include balances used to meet clearing balance requirements (which technically are not reserves).

(assets less liabilities) of all other factors on the Federal Reserve balance sheet—so-called "autonomous factors" over which the Desk has little or no control.

Federal Reserve notes in circulation (currency), which represent liabilities of the Fed, are by far the largest of these autonomous factors. The Fed debits the reserve accounts of banks in payment for the currency that it ships to banks. Therefore, an increase in currency demand by the public ultimately drains reserves when banks request more currency from the Fed to satisfy their depositors' demands. Although currency is the largest of these autonomous factors, other factors can be more volatile and have a less predictable impact on reserve supply.[4]

Open market operations—the purchase or sale of government securities by the Desk with securities dealers—are a discretionary tool that is used by the Desk to affect the supply of reserves. When the Desk purchases government securities, it pays for the securities it acquires by crediting the reserve balance of the dealer, or of the dealer's correspondent bank in cases where the dealer does not have a reserve account. This action increases the supply of reserves. Sales of securities that reduce domestic financial assets held by the Fed reduce reserve supply.

Reserve Accounting: Requirements, Penalties, and Carryover Privileges

Over each two-week reserve maintenance period, which begins every other Thursday, each bank is required to hold a quantity of reserves in proportion to the quantity of

[4] Weekly averages of the main autonomous factors and other items on the Fed's balance sheet are published each Thursday by the Federal Reserve, in Publication H.4.1.

transactions deposit liabilities on its balance sheet taken from a previous two-week reserve computation period. This reserve requirement can be satisfied either by holding balances at the Federal Reserve during the reserve maintenance period, or with cash held on a bank's premises during the computation period (called "applied vault cash"). Around two-thirds of total reserve requirements are met with vault cash. To meet the portion of reserve requirements not satisfied with vault cash, a bank my accumulate reserves over a maintenance period in any daily pattern, based on its end-of-day holdings.

Clearing balance requirements represent obligations to hold reserves that are set at the discretion of a bank before each reserve maintenance period. Only balances held at the Federal Reserve during the two-week reserve maintenance period are eligible to satisfy clearing balance requirements. Both reserve requirements (including the portion that cannot be met with vault cash) and clearing balance requirements are known with certainty before the beginning of a given maintenance period.

A bank is penalized for ending any day overdrawn on its account at the Fed, as well as for failing to meet its requirements by the end of the maintenance period. To obtain the necessary reserves to avoid these fees if unable to borrow the necessary amount of reserves from another bank, a qualifying bank may borrow reserves directly from the Federal Reserve at its discount window facility under the primary credit program, at a rate typically set 100 basis points above the target federal funds rate. This spread between the primary credit rate and the funds rate target is generally viewed as

representing a de facto penalty associated with being deficient.[5] The Federal Reserve does not pay interest on reserves held in excess of requirements.[6] Thus, the opportunity cost of holding excess reserves is a bank's marginal funding cost, which is represented in most studies by the federal funds rate.

To provide banks with some flexibility in meeting their requirements for avoiding these penalties and costs, the Fed allows banks to apply excess reserve balances held in one maintenance period to meet reserve requirements in the following period, in an amount up to 4 percent of reserve requirements in the second period. Similarly, a bank may end a period up to 4 percent short of its reserve requirements and pay no penalty, so long as it holds sufficient excess reserves in the following period to offset this deficiency.[7]

Link between the Supply of Reserves and the Federal Funds Rate

Participation in the brokered segment of the federal funds market, from which the rate data used in this study is taken, is dominated by larger banking institutions. The rate in this segment of the market will be influenced by the relative probabilities and costs these banks associate either with ending any day overdrawn or maintenance period deficient of their requirements, or with accumulating excess reserves. The probability of each of

[5] Technically, borrowing from the discount window addresses the reserve deficiency, as the Fed will credit the reserve balance of the borrowing bank when it extends the loan, thereby increasing reserve supply.
[6] Banks also do not earn interest on reserves used to meet reserve requirements. Banks earn income credits, at a rate based on market rates, on the balances held to meet clearing balance requirements. Credits earned can be used only to pay for priced-services offered by the Federal Reserve, such as check clearing fees and Fedwire transfer charges. These remuneration policies on requirements have no direct influence on the determinants or behavior of the federal funds rate. In 2006, the Federal Reserve Act was amended, granting the Federal Reserve authority to pay interest on balances held by depository institutions, including balances used to meet reserve requirements, effective October 1, 2011.
[7] Instead of having carryover flexibility, clearing balance requirements are considered to have been satisfied so long as banks accumulate an amount of reserves anywhere within a narrow band around a specified level.

these outcomes is importantly influenced by the aggregate supply of reserves the Desk intends to provide on any day and for a maintenance period as a whole.

The aggregate supply of reserves needed to maintain the federal funds rate around its target is closely linked to the level that allows banks to meet all their requirements, but without accumulating excess reserves. [8,9] When the supply of reserves becomes so low that some banks have no alternative but to borrow at the Fed's discount window to avoid ending a maintenance period short of their requirements or ending any day overdrawn, upward pressure on the funds rate will build, until market rates reach a level at which a bank would prefer to pay the primary credit rate for borrowing directly from the Fed. And when reserve supplies reach a level that presents some banks with the prospect of accumulating unwanted excess reserves for the period, rates will fall off, conceivably all the way to zero. In effect, at least for larger banks that are active in the federal funds market, requirements are binding and are the principal determinant of reserve demand.

[8] Smaller-sized banks that don't have access to funding markets which would allow for a quick adjustment in their reserve balance typically demand some level of excess reserves as a source of liquidity, to guard against reserve draining shocks. As a group, these smaller banks historically have held about $1.5 billion of reserves in excess of their requirements, measured both on average over each day in a period. Reflecting their inability to access broad funding markets, this "frictional" demand amongst smaller banks has proven to be largely insensitive to both current trading conditions in the funds market and to the level of the funds target. In describing the link between the supply of reserves and the federal funds rate, the excess reserve demands of these banks is ignored with no loss of generality. In effect, their holdings of excess reserves are akin to an autonomous factor that reduces reserve supply, which the Desk must offset in its reserve provision to ensure that the larger banks can accumulate sufficient reserves to meet their requirements. Demands for excess reserves by small and large banking institutions are discussed in Federal Reserve Bank of New York (2006), and have been described in earlier annual reports in this series.

[9] In principle, given the asymmetry between the cost of borrowing from the discount window and the opportunity cost of holding excess reserves, the level of aggregate reserves needed to maintain the funds rate around the target may allow for some non-zero level of demand for excess reserves amongst banks active in the funds market. However, empirically this level of excess is very slight and insensitive to the at least modest changes in the target rate, and so is ignored in this discussion.

The structure of requirements in a multi-day reserve maintenance period allows banks to freely substitute reserve holdings between days within a maintenance period, limited only by the penalties associated with end-of-day overdrafts. Nonetheless, within a maintenance period the funds rate could be influenced by the pace at which reserves are provided, even if ultimately the level of reserves provided for the period as a whole is consistent with banks just meeting their requirements, and certainly when it is not.

The nature of this relationship is illustrated in Figure 1. Relatively high levels of reserves accumulated early on in a period, consistent with the "Soft rates" path in this figure, could put downward pressure on rates for much of the period by fostering a perception among banks that they face a heightened risk of ending the maintenance period having accumulated excess reserves. Conversely, a low pace of reserve provision in the early part of a maintenance period, as in the "Firm rates" path in this figure, could place upward pressure on rates early in a period by raising fears among banks that they either might end any day in overdraft or might have difficulty meeting all their requirements before the end of the period. Our empirical analysis should allow us to approximate the path of reserve accumulation over a maintenance historically associated with maintaining the federal funds rate around its target, and provide an indication of how sensitive the funds rate is to deviations from this path at different points in the period.[10]

Desk's Daily Operating Procedure

[10] The actual path of reserve provision that keeps the funds rate around its target throughout the entire period need not correspond to the even daily pace drawn in Figure 1.

Each morning, the Desk compiles forecasts of all the autonomous factors for that day (and for upcoming days), which when combined with the known value of the domestic portfolio are used to derive an estimate of the supply of reserves prior to any new open market operations.[11] An estimate is also made of the level of reserves consistent with trading in the funds market at rates around the target at any point in the maintenance period. The Desk will then arrange OMOs to align the supply of reserves with this desired level. All these estimates are subject to error, although only errors to the projections of reserve supply can be measured *ex post*.

Intra-day Federal Funds Rate Behavior

The intra-day behavior of the federal funds rate displays some distinct characteristics which influenced our empirical specification. A representative daily timeline of daily fed funds trading activity and rate behavior is provided in Figure 2.

The funds rate tends to exhibit very low volatility throughout the morning and until late-afternoon trading. Desk decisions about the level of reserves to supply on the day are made at a point relatively early in the trading session. To the extent that intra-day volatility in rates is observed, it is largely confined to trading late in the session, and especially in the last 30 minutes, when banks are attempting to make final adjustments to their reserve holdings to reach desired end-of-day positions, at which point very abrupt and erratic rate movements may be observed. Even on days when reserve supply has proven to be extremely low or high relative to requirements, the impact on rate

[11] Borrowing from the discount window may be assumed to be near-zero, on the assumption that the Desk's operations will preclude the need for such borrowing.

movements as banks strove to avoid accumulating unwanted excess reserves or borrowing from the Fed typically has been confined to trading very late in the session.[12]

An explanation for this intra-day pattern is that rates in the morning and through mid-afternoon are largely driven by banks' expectations of whether they might face a reserve deficiency or accumulate unwanted excess reserves. And reserve supply on a given day does not appear to shape the formation of these rate expectations.[13] Only relatively late in the session, when the amount of trading needed for banks to achieve their desired end-of-day positions has diminished significantly, does the level of aggregate reserve balances available that day, or the level of reserves cumulated through that day, begin to show through to rates. At that point, with limited time remaining before the end of the trading session at the close of Fedwire, rates may move abruptly if there is a sizable aggregate reserve shortage or surplus.

Consistent with this general observation of rate behavior, we examine separately the determinants of a representative morning rate, and the determinants of late-afternoon rate movements. One hypothesis we examine is whether the morning rate—which, because rates remain stable through most of the trading session, is also representative of rates throughout much of the trading session—is influenced by the levels of reserves banks have accumulated through the previous day in a period.

[12] See Bartolini et al (2005) and Burke and Carpenter (2007) for a further discussion of this observed pattern. Bartolini et al also provides insight into the distribution of trading volumes between late-day trading and the rest of the trading session.

[13] Although the Desk publishes the sizes of any open market operations it arranges, it does not publish its estimates of autonomous factors or aggregate reserve supply for the day.

Because of data limitations, we approximate late-day volatility or movement in rates by taking the difference between the average rate for the entire day and the representative morning rate. The trading activity that determines this difference is heavily concentrated late in the day. We examine how these late-day rate movements are influenced by both the level of reserves on the day and the quantity cumulated through the previous day.

III. Literature Review

Much of the earlier literature up through the mid-1990s examining liquidity effects focused on the relationship between the monetary aggregates (e.g., M1 and M2) and interest rates, and used low frequency data (monthly or quarterly). The interest rate examined was either the federal funds rate or a short-term interest rate such as the rate on 3-month Treasury bills (see Table 2 in Pagan and Robertson (1995) for a summary of selected studies). Studies employing a single equation, typically regressing the interest rate on the money supply and other economic variables, tended to find no liquidity effect. Later studies employed simultaneous equation estimation techniques and were more likely to find evidence of a liquidity effect.

The work of Hamilton (1997) was among the first that focused on the federal funds market at the daily frequency. Hamilton examined the change in the federal funds rate from day to day and its relationship with a supply shock to reserves, namely the forecast miss for Treasury's account held at the Federal Reserve. His results suggest the presence of a liquidity effect only on certain days of a maintenance period.

Thornton (2001) reexamines Hamilton's study and finds that Hamilton's results are driven by a few outliers. In addition, Hamilton's results do not appear to hold for other sample periods. Thornton then examines the relationship between non-borrowed reserves (total reserves less borrowing from the discount window) and changes in the federal funds rate target. Thornton does not find a statistically significant relationship and concludes that a liquidity effect does not exist at the daily frequency.

Carpenter and Demiralp (C&D, 2006) examine the relationship between the effective federal funds rate minus the target rate and forecast misses for all the autonomous factors, not just the Treasury balance as in Hamilton's work. This approach provides a more direct measure of a shock to the supply of bank reserves. They find that the liquidity effect exists at the daily frequency, and also that the liquidity effect is non-linear in that only large forecast misses ($1 billion or more in absolute value) have a significant effect in the federal funds market.

More recently, Thornton (2006) has extended C&D's analysis in a number of dimensions. For example, Thornton examines the change in the effective federal funds rate, examines a longer sample period, and deletes outlier observations. Thornton's results confirm C&D's findings of a liquidity effect, but the magnitude of the relationship is smaller.

IV. Data

The daily data used in our study cover the first full maintenance period in 2002 through the last full maintenance period in 2005. Data on the effective federal funds rate (Eff) and the target federal funds rate (Tar) is available from the FRBNY public website (www.newyorkfed.org). The effective federal funds rate is a trade-weighted average of federal funds transactions provided to the Desk by a group of the major brokers in this market. The morning (AM) federal funds rate is a representative rate taken from an informal "reading" of the market conducted by the Desk, which is made by calling the major brokers, typically close to 9 a.m. The dispersion in rate quotes provided by the individual brokers is almost always extremely small if not nonexistent.[14] Data on the supply of bank reserves was obtained from FRBNY's proprietary database.

The focus of this study is the determinants of the morning rate minus the target rate (AM-Tar), and the effective rate minus the morning rate (Eff-AM).[15] This latter spread reasonably reflects by how much the federal funds rate moves during the day.[16] A positive spread would suggest that the federal fund rate increased over the course of the day, and a negative spread would suggest that the federal funds rate decreased over the course of the day.

Explanatory variables include measures of reserves on each day *t* in a maintenance period (R_t), and cumulated reserves through the previous day *t-1* (CR_{t-1}). Both variables are measured relative to total maintenance period requirements (TMPR)—the quantity of

[14] These individual quotes provided by the brokers have not been saved.
[15] The sum of these two spreads is the effective minus target spread, which has been the focus of most previous studies.
[16] But because the effective rate includes rates from the morning, actual rate movements will exceed the difference between the average rate and the morning rate.

reserves banks must accumulate over the course of an entire period to meet all requirements—in order to compare periods with low requirement to periods with high requirements.[17,18] We expect that higher levels of cumulated reserves will generally be associated with lower spreads for both (AM-Tar) and (Eff-AM), but as discussed previously, daily reserve levels are only important for (Eff-AM). These reserves measures will be interacted with dummy variables for different days of the maintenance period, to capture how the association between reserve levels and the funds rate evolves over the course of a maintenance period.

To control for market expectations for policy changes in the federal funds rate target, we allow for anticipation effects up to 5 days ahead of each meeting date, but only for days that fell within the same maintenance period as the meeting itself.[19] We control for a variety of calendar events that influence the behavior of the funds rate, including a separate dummy variable for each day in a maintenance period (R1 representing the first Thursday of a maintenance period, through W2 representing the second Wednesday of a maintenance period). Also included are dummy variables for "high payment flow dates" such as month start and month end dates, and mid-month tax dates. Quarter start, quarter end, and year-end dates have separate dummy variables. Dummy variables are also

[17] Daily reserve measures exclude reserves created by banks' borrowing at the discount window under the primary credit program. Measures of cumulated reserves through the previous day include such borrowing.
[18] Note that TMPR has the same value on all days in a maintenance period, but may change from period to period. The calculation of TMPR was adjusted upwards to include the Desk's estimate of frictional excess reserve demand of smaller banks. It also is intended to capture carryover positions larger banks brought into a maintenance period that could have generated some positive or negative excess demand. As historical values for these types of estimates were not kept, they had to be inferred by the total level of reserve balances that the Desk actually intended to provide each period; and of course, the original estimates themselves could have been wrong. TMPR was constructed by taking actual total reserves provided during an entire maintenance period, less the size of any reserve supply projection miss made on the last day of the period and less primary credit discount borrowing on the final day.
[19] During our sample period, almost all FOMC policy decisions appeared to have been fully anticipated.

included for the first trading day after each Monday holiday and for the day after each non-Monday holiday. We also include a dummy variable for the day of and day after the blackout in New York City on August 14, 2003, which had a pronounced impact on trading and rates. Table 1 presents summary statistics for the main variables of interest in this study.

V. Regression Framework and Results

Morning rates relative to the target

In examining the intra-day behavior of the federal funds rate, we first examine the AM rate minus the FOMC target federal funds rate (AM-Tar). For this variable of interest, we will focus on the effect of cumulated reserves, i.e., the quantity of reserves banks have cumulated through the previous day towards meeting their requirements for the maintenance period plus any frictional excess holdings. Reserves on the given day are not included since the level of reserves is not yet known or, at the time of the actual reading for the dependent variable, even determined.[20] A Lagrange Multiplier test for no ARCH effects is rejected at the 95% confidence level, so we will present results from the Threshold GARCH (TARCH) model based on Glosten, Jagannathan, and Runkle (GJR, 1993). The model is as follows:

$$(AM - Tar)_t = \alpha + \beta' X_t + \varepsilon_t$$

[20] As discussed previously, this dependent variable (AM-Tar) is representative of rates for most of the session until late-day trading, even after the daily level of reserves has been determined.

$$Var(\varepsilon_t) = \sigma^2_t = \gamma_0 + \gamma_1 \varepsilon^2_{t-1} + \gamma_2 \varepsilon^2_{t-1}(1(\varepsilon_{t-1}<0)) + \gamma_3 \sigma^2_{t-1}$$

The γ_1 coefficient will capture ARCH effects, and the γ_3 coefficient will capture GARCH effects. The γ_2 coefficient will capture whether or not negative shocks ($\varepsilon_{t-1}<0$) have an asymmetric effect on the conditional variance

The results in Table 2 show that most (all but one) of the cumulated excess coefficients are negative, as expected, indicating that there is a negative relationship between cumulated excess reserves (CR_{t-1}/TMPR)and the (AM-Tar) spread for day *t*. Furthermore, the magnitude of the coefficients increases as the maintenance period progresses. From the first Tuesday (T1) to the second Wednesday (W2), the coefficients on the cumulated reserve variable increase in magnitude from -.013 to -.585. This finding suggests that the sensitivity of the morning funds rate (relative to its target) to variations in the level of reserves cumulated through the previous day from their average tends to rise as a maintenance period progresses, a result in keeping with bank's diminishing capacity to "average" reserve holdings as a maintenance period unfolds.[21] The significance of the estimated coefficients on the cumulated reserves variable also tends to rise as the period progresses, a finding also in keeping with bank's having less scope for averaging as the end of a maintenance period nears.

[21] The estimated values of the coefficients on the reserve variables and the day-in-period dummy variables are difficult to interpret directly. However, the deviation of the morning rate from the target associated with the average level of reserves cumulated through the previous day for each day of the maintenance period can be calculated by summing the day-in-period dummy terms to the product of the cumulated reserves coefficient and the average cumulated level of reserves for each day in the period. These calculations are in keeping with actual experience.

In general, estimated values and the statistical significance of the various dummy variables for high payment flow and other days are plausible (Figure 3).

Effective rate less the morning rate

Table 3a presents OLS results with the dependent variable set as the effective federal funds rate minus the AM rate (Eff–AM) for day *t*. Since we are investigating the effective federal funds rate, we include excess reserve levels for a given day along with our measure of cumulated excess reserves. Independent variables include the two reserve measures (R_t/TMPR) and (CR_{t-1}/TMPR), with different coefficients for each day in a maintenance period, and a set of dummy variables capturing various calendar effects. A Lagrange multiplier test for no ARCH effects could not be rejected at the 95% confidence level.

The results in Table 3a show that most of the coefficients on daily reserves (R_t/TMPR) and cumulated reserves (CR_{t-1}/TMPR) are negative. This suggests that higher reserve levels result in a federal funds rate that trades lower over the course of the day. But in general, the relationship between these reserve measures and movements in rates over the course of the day is not as strong as what was found between reserves and the morning rate level relative to target, reported in Table 2. Somewhat counter-intuitively, both sets of coefficients peak in magnitude on the second to last day of a maintenance period (T2), instead of the last day of a maintenance period (W2). In fact the coefficients for both reserve measures for W2 are insignificant. For the most part the various dummy variables capturing calendar effects were not found to be as statistically significant as

they were in the morning rate equation, including the day-in-period variables, but these were retained in our reported results.

The two different reserve measures used—cumulated reserves through the previous day and daily reserve levels (before discount window borrowing) are possibly collinear, because the level of reserves the Desk intends to leave on any day is often a function of the level of reserves cumulated through the previous day in the period.[22, 23] Both as a way to address this potential problem, and to test whether the coefficients on these two measures of reserves are the same for a given day, we re-estimated this equation replacing cumulated reserves through the previous day and daily reserves with their sum, i.e., cumulated reserves through the current day (less discount window borrowing on the current day). The null hypothesis that the coefficients on reserves on the day and reserves cumulated through the previous day are the same for each respective day in the maintenance period could not be rejected.[24] These results are reported in Table 3b. Observations about the sign and significance of the single reserve measure are similar to those discussed for the two reserve measures in Table 3a.[25]

VI. Discussion and Conclusion

[22] Projection misses to autonomous factors can cause actual reserve levels to differ from the Desk's intended level.

[23] However, the correlation coefficient (conditional on the day of the maintenance period) between R_t and CR_{t-1} never exceeds .7 in absolute value.

[24] The trade-off between reserves held on any day and reserves cumulated through the previous day is necessarily limited by restrictions against end-of-day overdrafts. The acceptance of the null hypothesis, then, suggests that in our data sample there were few instances when aggregate daily reserves were not sufficient to let banks readily avoid ending the day overdrawn.

[25] We also explicitly tested for equality between the R_t and CR_{t-1} coefficients for each respective day of the maintenance period. The null hypothesis of equality could be rejected at the 95% confidence level only for R2, the second Thursday of a maintenance period.

The estimated results show the expected negative relationship between measures of reserve levels and the behavior of the federal funds rate. For the morning level of this rate relative to its target, only reserve levels cumulated through previous day matter, whereas both reserves cumulated through the previous day and reserves available on the day influence how the rate moves during the day. The findings suggest that there may be a one-for-one trade-off between previously cumulated and daily reserve levels (so long as banks have sufficient reserves on the day to avoid end-of-day overdrafts). However, the relationship between reserves and rate behavior clearer for the morning rate equation. This finding may reflect the fact that our measure of intra-day rate movement (Eff-AM) is acting as a proxy for the actual variable of interest--a measure of the late-day funds rate, which is not available, relative to the morning rate.

A possible extension of this study is to account for a possible non-linear relationship between reserve levels and the funds rate. Carpenter and Demiralp (2006) present some empirical evidence to support this view. We will employ similar techniques to capture non-linear relationships.

REFERENCES

Bartolini, Leonardo, Spence Hilton, and Alessandro Prati. (2005) "Money Market Integration," Federal Reserve Bank of New York, Working Paper.

Bartolini, Leonardo, Gudell Svenja, Spence Hilton, Krista Schwarz. (2005) "Intraday Trading in the Overnight Federal Funds Market," *Current Issues in Economics and Finance*, Vol. 11, No. 11 (November).

Board of Governors of the Federal Reserve System. (2005) The Federal Reserve System, Purposes and Functions. Washington, DC.

Burke, Christopher and Seth Carpenter. (2007) "Open Market Operations and the Intraday Behavior of the Federal Funds Rate" mimeo, Board of Governors of the Federal Reserve System.

Carpenter, Seth and Selva Demiralp. (2006) "The Liquidity Effect in the Federal Funds Market: Evidence from Daily Open Market Operations," *Journal of Money, Credit, and Banking*, Vol. 38, No.4 (June): 901-920.

Engle, Robert. (1982) "Autoregressive conditional heteroskedasticity with estimates of the variance of United Kingdom inflation," *Econometrica*, 50: 987-1007.

Federal Reserve Bank of New York. (2006) "Domestic Open Market Operations during 2005" (January).

Glosten, L. R., R. Jagannathan, and D. Runkle. (1993) "On the relation between the expected value and the volatility of the nominal excess return on stocks," Journal of Finance, vol. 48: 1779-1801.

Hilton, Spence (2005) "Trends in Federal Funds Rate Volatility," *Current Issues in Economics and Finance*, Vol. 11, No. 7 (July).

Hamilton, James. (1997) "Measuring the Liquidity Effect," Am*erican Economic Review*, vol. 87, no. 1 (March): 80-97.

Pagan, Adrian R. and John C. Robertson. (1995) "Resolving the Liquidity Effect," Federal Reserve Bank of St. Louis *Review*, May/June: 33-54.

Thornton, Daniel L. (2001) "Identifying the Liquidity Effect at the Daily Frequency," Federal Reserve Bank of St. Louis *Review*, July/August: 59-78.

----------. (2006) "The Daily Liquidity Effect," Federal Reserve Bank of St. Louis Working Paper Series #20A (April).

Figure 1

Alternative Paths for Reaching Total Maintenance Period Requirements

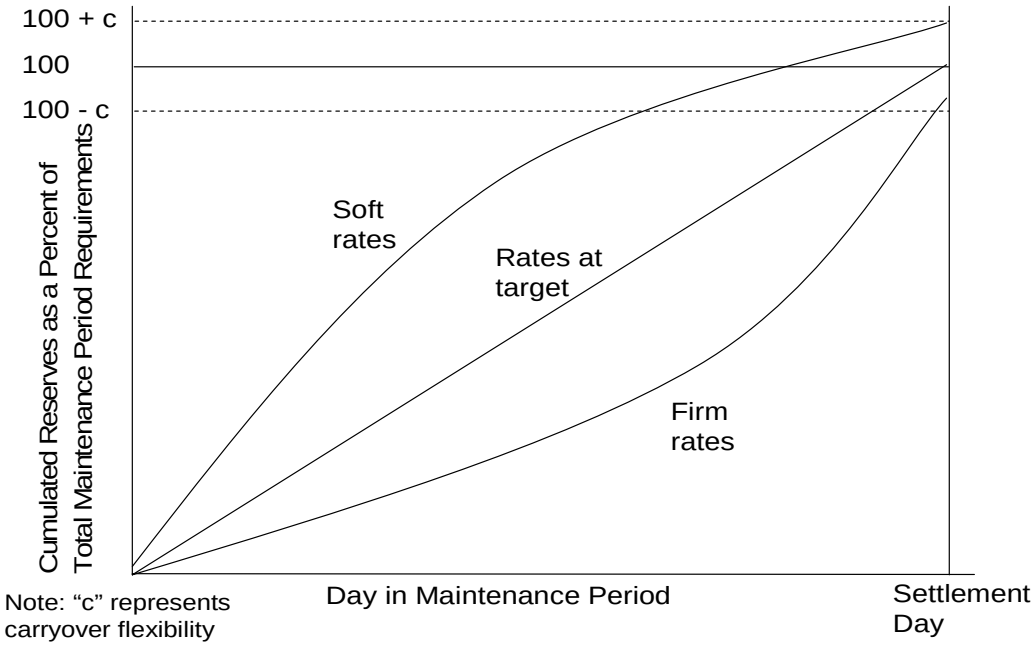
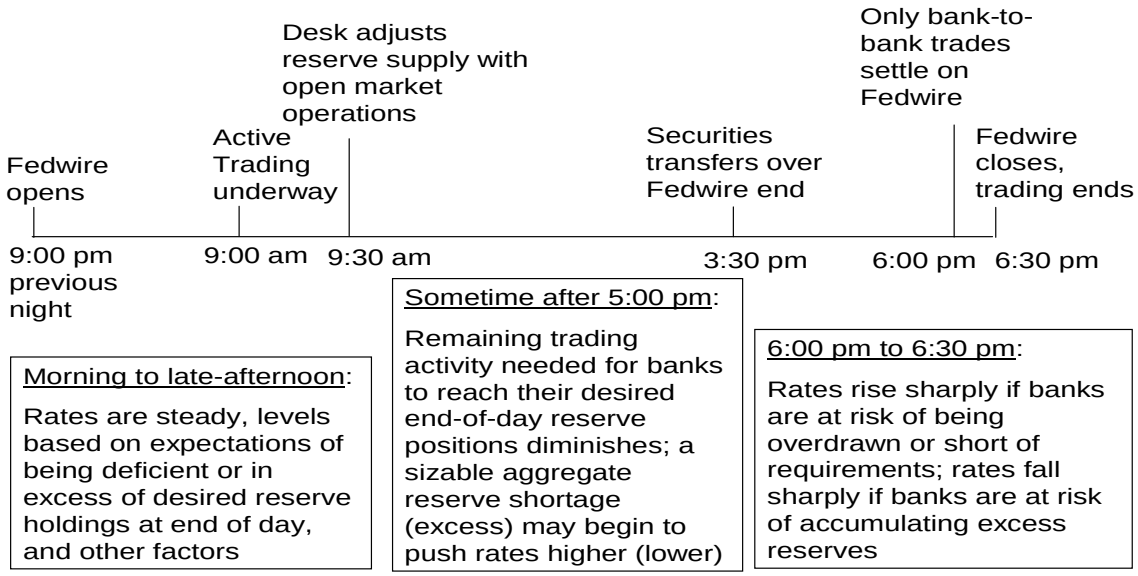


Figure 2

Daily Fedwire and Federal Funds Market Timeline



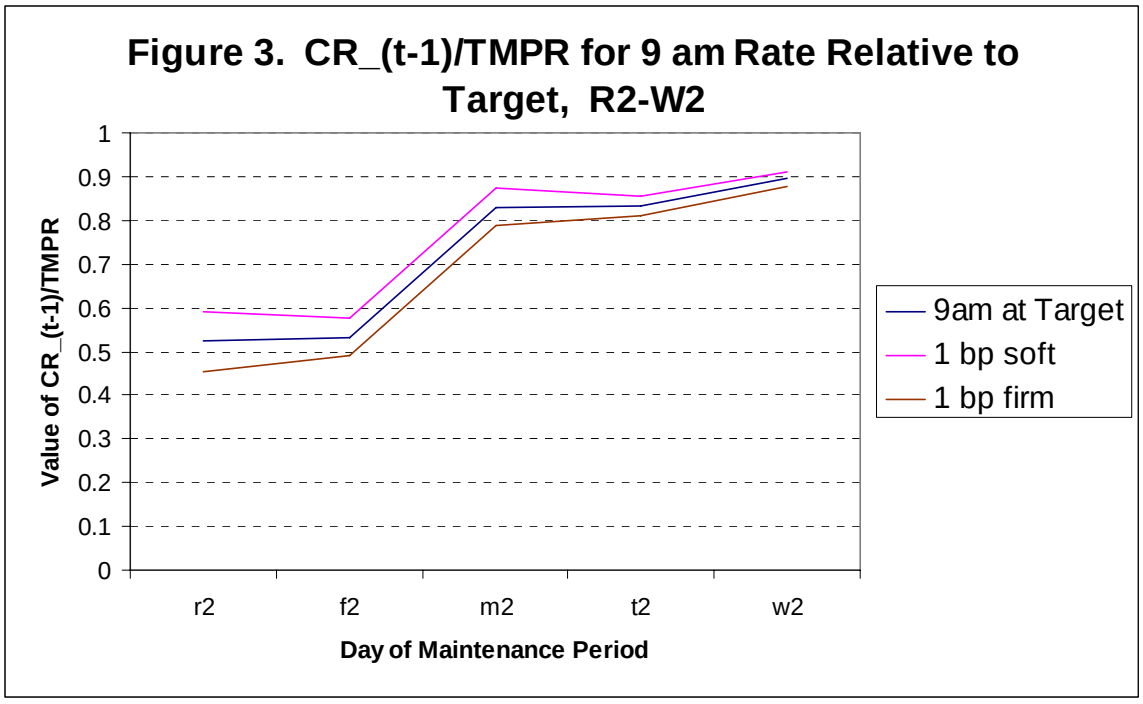


Table 1. Summary Statistics

	Mean	Std. Dev.	Min	Max
Effective minus Target	0.011	0.06	-0.39	0.45
AM minus Target	0.019	0.05	-0.13	0.31
Effective minus AM	-0.007	0.04	-0.37	0.19
Reserves/TMPR	0.103	0.06	0.05	0.32
Cumulated Reserves/TMPR	0.457	0.29	0.00	0.95
Dummy Variables				
High Payment Flow (HPF) Day	0.113	0.32		
day before quarterend	0.012	0.11		
quarterend (is zero for yearend)	0.012	0.11		
quarter start (not always equal to quarterend_t-1)	0.015	0.12		
day before yearend	0.003	0.06		
yearend	0.003	0.06		
day after Monday holiday	0.024	0.15		
day after other holiday	0.011	0.10		
obs.=988				

Table 2. TARCH results

Dependent Variable: AM minus Target	Coeff.	T-stat
f1-Cumulated Reserves$_{t-1}$/TMPR	0.648	1.78
m1-Cumulated Reserves$_{t-1}$/TMPR	-0.211	-2.28
t1-Cumulated Reserves$_{t-1}$/TMPR	-0.014	-0.18
w1-Cumulated Reserves$_{t-1}$/TMPR	-0.050	-0.66
r2-Cumulated Reserves$_{t-1}$/TMPR	-0.148	-2.11
f2-Cumulated Reserves$_{t-1}$/TMPR	-0.235	-3.00
m2-Cumulated Reserves$_{t-1}$/TMPR	-0.234	-2.04
t2-Cumulated Reserves$_{t-1}$/TMPR	-0.449	-5.36
w2-Cumulated Reserves$_{t-1}$/TMPR	-0.585	-4.54
r1	0.013	5.48
f1	-0.068	-2.57
m1	0.065	2.70
t1	-0.002	-0.06
w1	0.011	0.36
r2	0.077	2.42
f2	0.125	2.99
m2	0.194	2.25
t2	0.374	5.33
w2	0.524	4.43
am minus target_t-1	0.397	14.07
HPF	0.061	27.54
HPF day_t-1	-0.029	-7.88
day before quarter end	0.037	6.17
quarterend (is zero for yearend)	0.127	20.88
quarter start (not always equal to quarterend_t-1)	0.038	4.88
quarter start_t-1	-0.010	-0.90
day after Monday holiday	0.029	5.81
day after Monday holiday_t-1	0.009	1.32
day after other holiday	0.021	1.76
day after other holiday_t-1	0.015	2.26
fomc_5*target change	0.001	4.68
fomc_4*target change	0.001	5.68
fomc_3*target change	0.003	18.95
fomc_2*target change	0.005	19.96
fomc_1*target change	0.006	18.87
fomc day*target change	-0.004	-9.20
lag fomc day*target change	0.0002	0.47
day after Blackout	0.150	1.79
CONDITIONAL VARIANCE:		
ARCH		
arch		
L1	0.427	5.49
tarch		
L1	0.157	1.40
garch		
L1	0.214	3.09
constant	0.000	7.55
obs.=988		

Table 3a. OLS Results

Dependent Variable: Effective minus AM	Coeff.	T-stat
r1-Reserves$_t$/TMPR	-0.242	-0.90
f1-Reserves$_t$/TMPR	-0.382	-2.65
m1-Reserves$_t$/TMPR	0.074	0.23
t1-Reserves$_t$/TMPR	-0.288	-0.47
w1-Reserves$_t$/TMPR	0.143	0.23
r2-Reserves$_t$/TMPR	-0.779	-2.94
f2-Reserves$_t$/TMPR	-0.321	-2.98
m2-Reserves$_t$/TMPR	-0.028	-0.10
t2-Reserves$_t$/TMPR	-1.413	-5.34
w2-Reserves$_t$/TMPR	-0.072	-0.44
f1-Cumulated Reserves$_{t-1}$/TMPR	0.024	0.04
m1-Cumulated Reserves$_{t-1}$/TMPR	-0.165	-1.82
t1-Cumulated Reserves$_{t-1}$/TMPR	-0.154	-1.69
w1-Cumulated Reserves$_{t-1}$/TMPR	-0.245	-4.40
r2-Cumulated Reserves$_{t-1}$/TMPR	-0.190	-3.53
f2-Cumulated Reserves$_{t-1}$/TMPR	-0.304	-2.71
m2-Cumulated Reserves$_{t-1}$/TMPR	-0.333	-1.84
t2-Cumulated Reserves$_{t-1}$/TMPR	-0.979	-3.50
w2-Cumulated Reserves$_{t-1}$/TMPR	-0.520	-1.05
r1	0.014	0.70
f1	0.071	1.55
m1	0.042	1.55
t1	0.062	1.06
w1	0.090	1.73
r2	0.153	4.50
f2	0.228	3.16
m2	0.242	1.68
t2	0.895	3.70
w2	0.471	1.03
HPF	-0.012	-2.88
day before quarterend	-0.024	-2.66
quarterend (is zero for yearend)	-0.009	-0.32
quarter start (not always equal to quarterend_t-1)	0.009	1.04
day before yearend	-0.046	-2.03
yearend	-0.126	-1.41
day after Monday holiday	0.034	5.34
day after other holiday	-0.006	-0.55
fomc_5*target change	0.001	1.42
fomc_4*target change	0.001	3.34
fomc_3*target change	0.001	2.60
fomc_2*target change	0.0004	1.10
fomc_1*target change	0.0001	0.34
fomc day*target change	-0.0004	-0.48
lag fomc day*target change	0.001	3.75
Blackout	0.152	21.17
day after Blackout	0.154	12.65
obs.=988		

T-stats based on Newey-West standard errors.

Table 3b. OLS Results

Dependent Variable: Effective minus AM	Coeff.	T-stat
r1-(R_t)/TMPR	-0.236	-0.88
f1-(CR_{t-1}+R_t)/TMPR	-0.324	-2.45
m1-(CR_{t-1}+R_t)/TMPR	-0.121	-1.57
t1-(CR_{t-1}+R_t)/TMPR	-0.169	-1.55
w1-(CR_{t-1}+R_t)/TMPR	-0.212	-2.50
r2-(CR_{t-1}+R_t)/TMPR	-0.189	-3.67
f2-(CR_{t-1}+R_t)/TMPR	-0.310	-3.41
m2-(CR_{t-1}+R_t)/TMPR	-0.324	-1.75
t2-(CR_{t-1}+R_t)/TMPR	-0.952	-3.39
w2-(CR_{t-1}+R_t)/TMPR	-0.116	-0.68
r1	0.013	0.68
f1	0.086	2.55
m1	0.044	1.76
t1	0.059	1.39
w1	0.100	2.58
r2	0.111	3.97
f2	0.229	3.32
m2	0.260	1.68
t2	0.835	3.28
w2	0.106	0.62
HPF	-0.013	-3.28
day before quarterend	-0.024	-2.77
quarterend (is zero for yearend)	-0.009	-0.33
quarter start (not always equal to quarterend_t-1)	0.007	0.76
day before yearend	-0.047	-2.05
yearend	-0.120	-1.59
day after Monday holiday	0.030	5.47
day after other holiday	-0.006	-0.52
fomc_5*target change	0.001	1.27
fomc_4*target change	0.001	3.31
fomc_3*target change	0.001	2.60
fomc_2*target change	0.0004	1.30
fomc_1*target change	0.0001	0.49
fomc day*target change	-0.0004	-0.48
lag fomc day*target change	0.001	3.39
Blackout	0.158	23.35
day after Blackout	0.153	31.85
obs.=988		

T-stats based on Newey-West standard errors.