

On the Pervasive Effects of Federal Reserve Settlement Regulations

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The purpose of this paper is to determine whether Federal Reserve settlement effects have also appeared in the overnight London interbank offer rate (LIBOR) since the Federal Reserve removed the reserve requirements on Eurocurrency liabilities.¹ We begin by explaining why this is an important issue and by describing the characteristics of these settlement effects.

The primary reason to examine this change in reserve requirements is to determine the reach of U.S. Federal Reserve regulatory changes. Markets are becoming increasingly global and, accordingly, large bank operations are becoming increasingly global. Finding a settlement effect in LIBOR would suggest that banks receiving U.S. deposits actively use the London interbank loan market to manage their domestic reserve accounts. A regular pattern or effect in LIBOR created by a Federal Reserve rule change would show that the impact of Fed regulations is not limited to the national boundaries of the United States. Finding a settlement effect in LIBOR also would show that the mechanics of one market can spill over into other markets thought to be independent.

Since implementation of the Monetary Control Act in 1980, most depository institutions in the United States have been subject to the Federal Reserve's statutory reserve requirements. These requirements establish the percentage of each liability category for which a bank must maintain reserves, either as vault cash or as deposits in the bank's Federal Reserve account.² (See the boxed insert: "The Federal Reserve's Statutory Reserve Requirements.") A settlement effect, referred to above, is a regular pattern of interest rate changes associated with the days that banks must settle their reserve accounts with the Fed. Under rules in place since February 1984, the primary reserve management process calls for a biweekly settlement of reserve accounts.³ This two-week cycle is known as the reserve maintenance period, which begins on a Thursday and ends two weeks later on Wednesday. The last day of each reserve maintenance period, called settlement Wednesday, is when banks must settle their reserve account with the Fed. The settlement rules require that, on settlement Wednesday, a bank's total actual reserves over the two-week period equal or exceed its total *required* reserves for that two-week period. Successfully so doing is referred to as *settling* with the Fed. Banks manage their actual reserves by trading deposits at Federal

¹ The British Bankers Association (BBA) publishes daily reference rates at various short maturities based on a survey of the major London banks. These survey rates are referred to as LIBOR. The BBA survey rates serve as commonly accepted benchmark rates and were crucial to the development of the LIBOR and Eurodollar futures markets. In fact, the BBA is described as "fixing" the benchmark rate when it provides its daily LIBOR data. The BBA has been fixing LIBOR reference rates at various short maturities since the late 1980s but did not begin providing an overnight LIBOR reference rate until 2001. Our data are not BBA reference rates. Our data are the closing overnight dollar-based cash market rates in the London interbank market, and our data source appropriately refers to this rate series as overnight LIBOR, which is how we refer to it in this paper. However, we remind the reader that our data are not the rates fixed by the BBA for reference rates.

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² Regulation D states that the reserves that depository institutions are required to maintain are to facilitate the implementation of monetary policy by the Federal Reserve System. However, Goodfriend and Hargraves (1983) discuss that banks have been required to hold reserves since 1863 and the rationale for the reserves has changed over time. Reserves initially were required for liquidity, and this rationale was maintained until 1931. In 1931, the liquidity rationale was replaced by the idea that required reserves play a role in the execution of the Fed's credit policies. In the 1950s, Fed policy statements began shifting toward money stock issues; in the late 1970s, M1 became the primary intermediate policy target. The Monetary Control Act of 1980 imposed universal reserve requirements based on the argument by the Fed that its ability to control monetary aggregates was being weakened by deposits moving outside the Fed's jurisdiction; this process officially brought us to the current rationale that required reserves are for implementing monetary policy.

³ Many small banks settle their reserve position each week based on a reserve requirement amount that is set once each quarter. However, the vast majority of reservable deposits are held in banks that are subject to biweekly settlement. Accordingly, studies of market pressures created by reserve account management, like this study, focus on the biweekly settlement process.

Table 1

Spreads Over 3-Month T-bills

Time period	Federal funds (basis points) spread relative to 3-month T-bills	Overnight government repo (basis points) spread relative to 3-month T-bills	LIBOR spread (basis points) relative to 3-month T-bills
8/4/86 through 1/31/95	45 (43)	47 (43)	55 (51)
2/7/91 through 1/31/95	6 (4)	16 (14)	15 (14)

NOTE: Numbers provided here are mean spreads; numbers in parentheses are median spreads.

Reserve Banks among themselves in the federal funds market. This trading over the two-week period may create pressure in the federal funds market and cause spikes in interest rate changes and volatility on settlement Wednesdays, which are the settlement effects.

At first glance, it seems unlikely that a change in reserve requirements on Eurocurrency liabilities would create settlement effects in LIBOR; after all, settlement effects are the result of banks reconciling their reserves requirements for their domestic bank deposits. Banks generate funds, generally in the form of deposits, and the reserve requirements mandate that a percentage of these funds be held in reserve. However, not all of a bank's funding sources are in the form of traditional deposits and the regulations exempt certain sources of funds from reserve requirements. The most common source of exempt funds for managing reserve accounts are funds purchased through the federal funds market. Banks are allowed to bring in funds through the federal funds market to increase their actual reserves, and the exemption from reserve requirements on federal funds allows this to be done without an accompanying increase in their required reserves. That is, the reserve requirement on the liability created by the purchase of federal funds is 0 percent. In contrast, from 1980 until the end of 1990, Eurocurrency liabilities had a reserve requirement of 3 percent⁴; by 1991, that requirement had become 0 percent. This eventual exemption from reserve requirements for Eurocurrency liabilities is what has raised the possi-

bility of a settlement effect in LIBOR: Without the 3 percent reserve requirement, reserve deposits that are borrowed in the Eurocurrency markets for settlement purposes are now essentially equivalent to deposits borrowed in the federal funds market. Accordingly, then, the law of one price should apply and drive the rates in these markets together.⁵ (We show this in Table 1.) However, for settlement effects to appear in LIBOR, banks subject to U.S. Federal Reserve settlement regulations must be using Eurocurrency liabilities to manage their reserve accounts actively enough to affect LIBOR on settlement Wednesdays. The federal funds trading desk manager of a major U.S. bank confirms that banks began managing their reserve accounts with Eurocurrency liabilities after the reduction in their reserve requirement. So, if banks are now using these liabilities to manage their reserve accounts, our question is: Are settlement pressures pervasive enough to reach overseas to create settlement effects in LIBOR?

We use closing overnight dollar-based LIBOR to test for a settlement Wednesday effect in the Euro-dollar market because LIBOR is the rate that major London banks offer for Eurocurrency liabilities to other banks. For the pre-1991 period, when Eurocurrency liabilities were subject to a 3 percent reserve requirement, we do not find any settlement effects in overnight LIBOR. We do find settlement effects concurrent with the change to the 0 percent

⁴ An amendment to Regulation D changed the reserve requirement on Eurocurrency liabilities: From August 1980 through the reserve maintenance period ending December 12, 1990, the requirement was 3 percent; for the one reserve maintenance period from December 13 through December 26, 1990, the requirement was 1.5 percent; as of December 27, 1990, the requirement was changed to its current 0 percent.

⁵ We expect minor risk differences between the Eurocurrency markets and the federal funds market, so the law of one price will not hold exactly. For example, even with a 0 percent reserve requirement, Eurocurrency liabilities are a reservable liability of the bank and hence may affect the marginal reserve requirement on other liabilities as well as the required frequency of deposit reporting and reserve settlement. However, without a reserve requirement on Euro-market U.S. dollars, the rates in the two markets should be close enough to allow Euro-market U.S. dollars to be a viable source of funds for bank settlement.

reserve requirement. In related work, Griffiths and Winters (1997) found settlement effects in closing federal funds rates and closing overnight government repurchase agreements (repo) rates. Thus, we test closing federal funds rates and closing overnight government repo rates for settlement effects during both periods—when Eurocurrency liabilities carried a 3 percent reserve requirement and after the reserve requirement was reduced to zero. We find settlement effects in federal funds rates during both periods, which suggests that a settlement effect in LIBOR only when the reserve requirement is 0 percent is a direct result of the reduction in that reserve requirement. Our results suggest the following: (i) Federal Reserve policies are sufficiently pervasive to have global effects and (ii) the effects of the federal funds market microstructure for U.S. depository institutions spill over into other markets.

In the next section, we discuss the existing theoretical and empirical literature on the rate change and variance patterns unique to reserve account settlement with the U.S. Federal Reserve, as well as the relevant institutional details for U.S. reserve account management related to federal funds trading and the relationship between LIBOR and British bank settlement. We then present the data and methods and finally our test results.

INSTITUTIONAL DETAILS

In this section, we provide various institutional details as background on the different markets. We begin with a brief history of the Eurodollar market and discuss the bank settlement procedures in the United States and the United Kingdom. We also discuss the existing theoretical and empirical literature on the rate change and variance patterns unique to the reserve account settlement process with the Federal Reserve.

A Brief History of the Eurodollar Market

We begin this section with a brief history of the Eurodollar market, which may be unfamiliar to some readers. We draw our discussion from Stigum (1990, Chap. 7, pp. 207-11).

Prior to World War II, it was not uncommon for banks outside the United States to take dollar deposits, but there was little volume in this market and the market had little economic significance. During the 1950s, things began to change as the cold war between the United States and communist countries intensified. Specifically, Soviet businesses

needed U.S. dollars for trade but were concerned about holding their dollar deposits in U.S. banks; so, they moved their dollar deposits to banks outside of the United States. This scenario contributed to the birth of the modern Eurodollar market.

Historically, the British pound sterling was the leading currency for international trade. However, following World War II the British ran large balance of payments deficits, so a constant threat of devaluation of the pound sterling existed. In addition, the British restricted the use of the pound sterling in financing international trade, so international trade moved toward the U.S. dollar.

As the Eurodollar market began to grow, U.S. banks were reluctant participants. In fact, Stigum describes their entry into the market as “defensive.” However, the interest rate restrictions under Regulation Q forced U.S. banks to play in the Eurodollar market when depositors could get better rates outside the United States. Also, during the 1960s the United States tried to improve its balance of payments deficits by imposing capital constraints that limited the flow of dollars from U.S. banks to foreign borrowers, which created demand for Eurodollar loans.

Stigum notes that the above factors were significant contributors to the growth of the Eurodollar market, but that dollar depositors both in and out of the United States have the ability to place their deposits both in and out of the United States; so, where the dollar deposits go depends on the relative attractiveness of the deposit. Currently, the relative attractiveness of Eurodollar deposits is that they are, in particular, free of Federal Reserve statutory reserve requirements.

Federal Reserve Bank Settlement and the Federal Funds Market Literature

Since 1980, most depository institutions in the United States have been subject to the Federal Reserve’s statutory reserve requirements. To enforce these requirements, since February 1984, the Fed has compared each bank’s actual and required reserves during a 14-day reserve maintenance period. (For details, see the boxed insert.) Reserve maintenance periods begin every other Thursday and end on Wednesday 14 days later (“settlement Wednesday”). A maintenance period typically has 10 trading days.

A bank satisfies its statutory reserve requirement by holding an adequate amount of eligible vault cash and/or deposits at Federal Reserve Banks; no

THE FEDERAL RESERVE'S STATUTORY RESERVE REQUIREMENTS

Statutory Reserve Requirements Since 1980

The Monetary Control Act of 1980 governs statutory reserve requirements in the United States. The act, implemented in November 1980 through the Federal Reserve's Regulation D (12 CFR 204), imposes federal statutory reserve requirements on all U.S. chartered federally insured depositories (including their Edge and agreement corporation subsidiaries) and on branches and agencies of foreign banks if the parent firm's consolidated worldwide assets exceed \$1 billion or if the branch or agency is eligible to apply for federal deposit insurance.¹ Within broad limits, the act delegates the setting of specific reserve-requirement ratios to the Board of Governors of the Federal Reserve System.²

The act imposes statutory reserve requirements on three classes of depository institutions' liabilities: net transaction deposits, nonpersonal time (including savings) deposits, and net Eurocurrency liabilities. If any of the net amounts are negative, the amount for reserve-requirement purposes is zero.

- **Net transaction deposits:** A transaction account is defined as "a deposit or account on which a depositor or account holder is permitted to make withdrawals by negotiable or transferable instrument, payment orders of withdrawal, telephone transfers, or similar devices for the purpose of making payments or transfers to third persons or others." A depository's net transaction deposits were defined, if positive, to be total transaction deposits minus the sum of cash items in process of collection and balances held at other depository institutions that could be immediately withdrawn.

¹ This text is a general summary. Various provisions and applications of Regulation D have changed through time. At the time of this writing, the current version of Regulation D was available at < http://www.federalreserve.gov/regulations/title12/sec204/12cfr204_01.htm > . Specific legal definitions are contained in Regulation D and its staff interpretations. The citation 12 CFR 204 refers to section 204 of Chap. 12 of the Code of Federal Regulations.

² Limits in the legislation include a reserve requirement range of 0 to 9 percent on time deposits (including savings deposits) and 8 to 14 percent on net transaction deposits.

- **Nonpersonal time deposits:** Time deposits (including savings deposits, which are regarded as time deposits without a specific maturity date) are defined, generally speaking, to be all deposits that are not transaction deposits. A nonpersonal deposit is a deposit in which the beneficial interest is held by other than a natural person; a natural person is an individual or sole proprietorship.
- **Eurocurrency liabilities:** Eurocurrency liabilities are the sum of net borrowing by domestic banking offices from foreign offices plus certain assets sold by domestic banking offices to foreign offices. (For reserve requirement purposes, the sale of the asset to a foreign office is treated as a dollar-for-dollar reduction in the reservable deposits of the domestic office.) Specifically, Regulation D specifies that Eurocurrency liabilities include the following:
 - a. For a depository institution or an Edge or agreement corporation organized under the laws of the United States, the sum of the following transactions of U.S. offices with related offices outside the United States³:
 - Net balances due to a depository's non-U.S. offices and its international banking facilities (IBF) from its U.S. offices;
 - Assets (including participations) acquired from its U.S. offices and held by its non-U.S. offices, by its IBF, or by non-U.S. offices of an affiliated Edge or agreement corporation; and, for Edge and agreement corporations, assets acquired from its U.S. offices and held by non-U.S. offices of its U.S. or foreign parent institution, its IBF, or by non-U.S. offices of an affiliated Edge or agreement corporation; and
 - Credit outstanding from a depository institution's non-U.S. offices to U.S. residents (other than assets acquired and net balances due from its U.S. offices), except credit extended (i) from

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³ For definitions and discussion of Edge corporations, agreement corporations, and international banking facilities, see Marcia Stigum's *The Money Market* (1990, 3rd ed., Chaps. 6 and 7).

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its non-U.S. offices in the aggregate amount of \$100,000 or less to any U.S. resident; (ii) by a non-U.S. office that at no time during the computation period had credit outstanding to U.S. residents exceeding \$1 million; (iii) to an international banking facility; or (iv) to an institution that will be maintaining reserves on such credit pursuant. Credit extended from non-U.S. offices or from an IBF to a foreign branch, office, subsidiary, affiliate of other foreign establishment (*foreign affiliate*) controlled by one or more domestic corporations is not regarded as credit extended to a U.S. resident if the proceeds will be used to finance the operations outside the United States of the borrower or of other foreign affiliates of the controlling domestic corporation(s).

- b. For a U.S. branch or agency of a foreign bank, the sum of the following:
 - Net balances due to its foreign bank and its IBF after deducting an amount equal to 8 percent of the following: the U.S. branch or agency's total assets less the sum of (i) cash items in process of collection; (ii) unposted debits; (iii) demand balances due from depository institutions organized under the laws of the United States and from other foreign banks; (iv) balances due from foreign central banks; and (v) positive net balances due from its IBF, its foreign bank, and the foreign bank's U. S. and non-U. S. offices; and,
 - Assets (including participations) acquired from the U.S. branch or agency (other than assets required to be sold by federal or state supervisory authorities) and held by its foreign bank (including offices thereof located outside the United States), by its parent holding company, by non-U.S. offices or an IBF of an affiliated Edge or agreement corporation, or by its IBFs.

Reserve Settlement with the Federal Reserve

The accounting rules that govern a depository institution's reserve settlement with the Federal Reserve depend on the specific circumstances of the bank.⁴ Generally, settlement rules differ across banks with respect to (i) whether during the previous reserve maintenance period the bank had a deficiency (actual reserves less than required) or surplus (actual reserves more than required) and (ii) whether the bank had a clearing balance contract with the Federal Reserve.⁵

Prior to 1990, relatively few banks had clearing balance contracts with the Federal Reserve and, hence, the settlement rules applicable to most banks were those for depository institutions without clearing balance contracts. Within those rules, one of the more important is that a bank may carry a deficiency or surplus forward only once, to the next maintenance period. If a deficiency is not fully offset by holding additional reserves during the next period, the bank may be subject to a monetary penalty (charged at the discount rate in effect as of the beginning of that month plus 2

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⁴ The Federal Reserve's settlement rules use the concepts of a "reserve maintenance period" and a "reserve computation period." The reserve maintenance period is the interval (14 days in duration as of February 1984 and 7 days in duration prior to February 1984) during which the institution must hold enough deposits at the Federal Reserve to satisfy its reserve requirement after subtracting from its requirement the amount of its vault cash that is eligible to satisfy the requirement. The amount of a depository institution's reserve requirement is calculated from its liabilities during the reserve computation period. For more specific definitions and examples, see the Federal Reserve's *Reserve Maintenance Manual* at < <http://www.frbstl.org/Accounting/CustomerReferenceGuide.cfm> > .

⁵ Clearing balance contracts are discussed in chapters 8 and 11 of the *Reserve Maintenance Manual*. See also E.J. Stevens, "Required Clearing Balances," Federal Reserve Bank of Cleveland *Economic Review*, December 1993, p. 2-14, and J.N. Feinman, "Reserve Requirements: History, Current Practice, and Potential Reform," *Federal Reserve Bulletin*, June 1993, pp. 569-89. Note that the older term "required clearing balance" has been replaced by the term "clearing balance requirement" in more recent Federal Reserve publications. This seems fully appropriate because, unless a bank has a history of excessive overnight and/or daylight overdrafts at the Federal Reserve, clearing balance requirements are a voluntary commitment by a bank to maintain deposits at the Fed above and beyond those required to satisfy mandatory statutory reserve requirements. In exchange for maintaining the additional deposits, the bank receives earnings credits that can be used to defray the cost of financial services (such as check clearing) purchased from the Fed. Prior to December 1990, few larger banks had clearing balance contracts; this changed sharply after the December 1990 reduction in reserve requirements. (See, for example, Feinman, Figure 9, p. 583.)

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percentage points, at an annual rate). Conversely, if a surplus is not fully utilized to satisfy requirements during that next period, it is lost. This rule does not prohibit a bank from carrying forward a deficiency or surplus from one maintenance period to the next—but it does prohibit carrying forward the *same* deficiency or excess.⁶ The rules limit the maximum amount (deficiency or surplus) that can be carried forward from a reserve maintenance period into the next to the greater of 4 percent of the bank's required reserves or \$50,000.⁷ Banks whose actual reserves repeatedly fall short of required reserves may receive, in addition to monetary penalties, admonitions or "counseling" from the Fed.

Beginning in 1991, the somewhat different settlement rules that apply to depository institutions with clearing balance contracts are important. Following the December 1990 and April 1992 reductions in reserve requirements, many larger banks entered, for the first time, into clearing balance contracts with the Fed.⁸ Between December 1990 and December 1992, for example, the aggregate amount of clearing balance contracts increased from \$2 billion to \$6 billion. Settlement rules for such banks are more complex than those for banks without clearing balance contracts because a depository institution might incur a deficiency or surplus with respect to its clearing balance requirement, its statutory reserve requirement, or both. Settlement is somewhat less onerous, however,

because the clearing balance requirement provides a cushion for the bank with respect to satisfying its statutory reserve requirement.⁹ Under the Federal Reserve's accounting rules, settlement begins, first, by subtracting eligible vault cash from the depository's statutory reserve requirement.¹⁰ Next, the remaining portion of the statutory requirement is subtracted from the amount of deposits held at the Fed. Finally, the remaining amount of deposits held at the Fed is compared with the clearing balance requirement. Because of the sequencing of these operations, banks with clearing balance requirements are highly unlikely to be deficient with respect to their statutory reserve requirement. Further, the clearing balance requirement is said to be satisfied if the bank is within \$25,000 or 2 percent (above or below) of the required amount.

As noted before, a deficiency or surplus can be carried forward into the next maintenance period but the same deficiency or surplus cannot be carried forward to a subsequent period. The maximum deficiency or surplus that may be carried forward is equal to the greater of 4 percent of the sum of the bank's statutory reserve requirement plus its clearing balance requirement or \$50,000, minus the clearing balance allowance (the greater of \$25,000 or 2 percent of the clearing balance requirement).¹¹

—Richard G. Anderson

⁶ For specific examples on deficiencies, see *Reserve Maintenance Manual*, Table 2, examples "D" and "F," p. XI-5; on surpluses, see *Reserve Maintenance Manual*, Table 1, examples "D" and "E," p. XI-2.

⁷ Prior to September 1992, the carryover was the greater of (i) 2 percent of required reserves plus the clearing balance requirement or (ii) \$25,000.

⁸ In December 1990, the reserve requirement ratios on nonpersonal time deposits and Eurocurrency liabilities were reduced to zero. In April 1992, the marginal reserve requirement ratio on net transaction deposits was reduced to 10 percent from 12 percent. For a detailed discussion and examples of the reserve settlement rules applicable to banks with clearing balance requirements, see *Reserve Maintenance Manual*, chapter XII.

⁹ These aspects are compared by Feinman (1993).

¹⁰ The eligibility of vault cash has changed through time. Prior to 1917, all vault cash held during the reserve maintenance period was eligible. From 1917 to 1959, no vault cash was eligible. Between December 1959 and December 1960, vault cash eligibility was phased in on a pro rata monthly scale. Beginning in September 1968, eligible vault cash was the amount held during the 7-day period that ended 14 days prior to the end of a 7-day reserve maintenance period. Beginning February 1984, eligible vault cash was the amount held during the 14-day period ending 31 days prior to the end of a 14-day maintenance period. Beginning November 1992, eligible vault cash was the amount held during the 14-day period ending 17 days prior to the end of a 14-day reserve maintenance period. Since July 1998, eligible vault cash has been the amount held during the 14-day period ending 45 days before the end of the reserve maintenance period.

¹¹ For details, see chapter IX of the *Reserve Maintenance Manual*.

other assets may be used. The eligibility of vault cash has varied through time. During the first part of our sample period (prior to September 1992), eligible vault cash was the average amount held by the bank during a 14-day period ending 31 days before the end of the maintenance period. During the latter part of our sample (beginning September 1992), it was the average amount held during a 14-day period ending 17 days before the end of the maintenance period. At the close of the maintenance period, eligible vault cash is subtracted from the bank's required reserves. The remainder is subtracted from the average daily amount of deposits held by the bank at the Federal Reserve. If the result is negative, the bank is deficient. If positive, the bank has a surplus. Prior to September 1992, a bank could carry over into the next maintenance period, without penalty, a deficiency or surplus equal to the greater of (i) 2 percent of the sum of its required reserves plus its clearing balance requirement or (ii) \$25,000. (Again, see the boxed insert for details.) In September 1992, this was increased to the greater of 4 percent or \$50,000.⁶ Federal Reserve rules require that a penalty be assessed if a deficiency is not offset by reserve holdings during the subsequent maintenance period. Although the rules prohibit carrying forward the *same* deficiency into a subsequent (third) period, a bank may carry forward a new deficiency. That is, a bank's reserves during the current maintenance period may be sufficient to fully satisfy a previous period's deficiency that has been carried forward but, at the same time, inadequate to avoid carrying forward a new deficiency based on its required reserves for the current maintenance period. A surplus carried forward, but not used to satisfy required reserves, expires unused.

Theoretical and empirical studies have described the unique rate change and variance patterns created by the settlement rules. Table 2 provides a cross-reference between the theoretical predictions and the empirical results from the settlement rules.

Griffiths and Winters (1995) provide a model of federal funds rate pressures based on the Federal Reserve settlement rules. Their model provides daily

rate pressure predictions across the two-week reserve maintenance period. The daily predictions (Table 2, column 1 of panel A) are as follows:

- rates are expected to decline on Fridays in advance of the weekend,
- rates are expected to decline on the second Tuesday (the day before settlement), and
- rates are expected to rise on the second (settlement) Wednesday.

The predicted rate pressures should create additional daily empirical rate changes when the predicted daily pressures abate. We present the predicted empirical pattern in column 2 of panel A in Table 2. The additional rate changes not described in Griffiths and Winters are the rebound effects that follow from the abatement of the rate pressures predicted in their model. Specifically, one would expect to find the following rebound effects:

- rates are expected to rise on Mondays following the abatement of lending pressure on Fridays, and
- rates are expected to decline on the first Thursday (the first day of the reserve maintenance period) following the abatement of the borrowing pressure on settlement Wednesday of the previous reserve maintenance period.

The empirical literature shows strong support for the rate pressures predicted by Griffiths and Winters (1995). Specifically, declining rates on Fridays and rising rates on settlement Wednesday appear in all five papers presented in panel A. Also, three of the five papers show declining rates on the second Tuesday. In addition, all five papers show the expected rebound effect on the first Monday and four of five papers show the expected rebound on the second Monday. There is not a consistent rebound effect on the first Thursday.

Griffiths and Winters (1995) do not predict specific rate pressures on the first Tuesday, the first Wednesday, or the second Thursday. However, they do identify a general preference for selling over purchasing federal funds across a reserve maintenance period, which suggests declining rates in the absence of any specific rate pressures. The five papers cited show a tendency for rates to decline on the first Tuesday and the first Wednesday and for no rate change on the second Thursday.

⁶ The purpose of the increase in carryover to 4 percent from 2 percent was to make successful settlement easier for banks. Griffiths and Winters (2000) examine the size of the settlement effects in closing federal funds and overnight government repo rates around this regulation change. They find no reduction in the identified settlement effects after the increase in the allowable range.

With strong empirical support for the rate change pattern predicted by Griffiths and Winters (1995) the question becomes: What pattern of rate changes is necessary to identify a settlement effect in a substitute funding source for reserve account management? Griffiths and Winters (1997) suggest that the rate change that is unique to the U.S. settlement process is the rate increase on settlement Wednesdays. They argue that any entity with non-earning cash on Fridays (not just banks with deposits at the Federal Reserve) will have an incentive to lend (invest) on Fridays to avoid leaving the funds idle over the weekend. Thus, rates across money market instruments (domestic and foreign) should decline as non-earning cash is moved into investment vehicles for the weekend.⁷ Then, following the weekend, rates should rebound on Monday. Gibbons and Hess (1981) find negative returns on T-bills on Mondays and positive returns on T-bills on Wednesdays, reflecting a T-bill yield increase on Mondays and decrease on Wednesdays. Thus, the rate increases that occur on Mondays, cited in Table 2, panel A, are not unique to the U.S. settlement process. In addition, the general tendency for rates to decline on the first Wednesday of the reserve maintenance period is not unique to the U.S. settlement process. Accordingly, the only consistent daily rate change shown in the cited papers that is unique to the U.S. settlement process is the rate increase on settlement Wednesday.

Up to this point, we have described the daily rate changes created by reserve account management for successful settlement. However, rate changes are only part of the picture because the settlement rules also create a predictable pattern in daily and intraday variances. Panel B of Table 2 summarizes the predicted daily variance pattern and some of the empirical work on variances related to the settlement process.

Spindt and Hoffmeister (1988) provide a model for daily and intraday federal funds rate variance based on the U.S. settlement rules. The predictions from their model (Table 2, column 1 of panel B) are as follows:

- daily variances are expected to increase on Fridays because positions must be taken on Friday to cover reserve requirements for Saturday and Sunday;
- daily variances are expected to increase as settlement approaches, with the largest daily variance on settlement Wednesday; and
- intraday variances are expected to increase as the close of the business day approaches.

Spindt and Hoffmeister focus on variances during a reserve maintenance period. Thus, their variance predictions do not include the effect of the transition from one reserve maintenance period to the next. We expect to see an empirically large variance on the first Thursday of the reserve maintenance period following the abatement of the settlement pressures from the preceding day.

The last five columns of Table 2, panel B, reproduce some empirical results on variances across a reserve maintenance period to highlight the importance of both the pattern and the magnitude of the variances. Columns 3 through 5 are reproduced from Table 4 in Griffiths and Winters (1995). Column 3 shows that daily variances increase on Fridays and as settlement approaches, with the variance on settlement Wednesday being by far the largest. Columns 4 and 5 provide variance estimates for the morning and afternoon on each day of the reserve maintenance period. The day-to-day patterns in the morning and afternoon are generally consistent with the daily pattern. In addition, the afternoon variance is larger than the morning variance for each day of the reserve maintenance period, as predicted by Spindt and Hoffmeister. Columns 6 and 7 of panel B in Table 2 are reproduced from Griffiths and Winters (1997). These daily variances are calculated using closing federal funds and overnight general collateral government repo rates. These variance results show that daily variances increase as settlement approaches, with the addition of a large variance in the first Thursday. In the federal funds market, the variance on settlement Wednesday is the largest daily variance; in repos, settlement Wednesday is large relative to the daily variances from the middle of the reserve maintenance period but is the second-largest daily variance. Accordingly, the empirical results on variances provide support for the predicted variance patterns across the reserve maintenance period and suggest that the general pattern in daily variances created by the

⁷ Griffiths and Winters (1997) find that rates decline on Fridays in both government repos and Government National Mortgage Association (GMNA) repos. A review of the literature finds no day-of-the-week studies in commercial paper, negotiable CDs, bankers' acceptances, or Eurodollar deposits, so we are unable to provide additional support for declining rates on Fridays being a common occurrence across private-issue money market instruments. Because the issue of declining rates across private-issue money market instruments is outside the focus of this paper, we leave this issue for further research.

Table 2

Patterns in Rate Changes and Variances Related to Federal Reserve Settlement Rules

A: Daily Rate Changes

Day of reserve maintenance period	Prediction ^a	Expected empirical pattern	Daily high/low rate ^a	Daily average rate ^b	Closing federal funds rate ^c	Closing repo rate ^c	Intraday federal funds rate ^d
1st Thursday	None	–	–	+	NS	NS	NS
1st Friday	–	–	–	–	–	–	–
1st Monday	None	+	+	+	+	+	+
1st Tuesday	None	None	–	–	–	NS	–
1st Wednesday	None	None	–	–	NS	–	–
2nd Thursday	None	None	NS	NS	+	NS	NS
2nd Friday	–	–	–	–	–	–	–
2nd Monday	None	+	NS	+	+	+	+
2nd Tuesday	–	–	NS	–	–	NS	–
2nd Wednesday	+	+	+	+	+	+	+

B: Daily and Intraday Variances

Day of reserve maintenance period	Prediction ^e	Expected empirical pattern	Daily high/low rate ^f	Morning high/low rate ^f	Afternoon high/low rate ^f	Closing federal funds rate ^g	Closing repo rate ^g
1st Thursday	None	+	124	31	94	3.003	2.286
1st Friday	+	+	238	88	136	1.387	1.004
1st Monday	None	None	112	42	57	2.398	1.004
1st Tuesday	None	None	143	15	98	2.422	1.451
1st Wednesday	None	None	164	21	86	1.483	1.059
2nd Thursday	None	None	194	70	75	1.831	1.058
2nd Friday	+	+	310	73	164	1.842	1.225
2nd Monday	+	+	245	71	114	3.992	2.679
2nd Tuesday	+	+	1795	43	1587	3.171	1.792
2nd Wednesday	+	+	4029	249	3031	5.717	2.543

NOTE: This table provides theoretical and empirical evidence for the daily rate change pattern in the overnight federal funds rates and overnight general collateral repo rates. NS is an insignificant parameter estimate; None is either no prediction or no expectation.

^aGriffiths and Winters (1995) provide a model that predicts specific daily rate changes in the federal funds market and provides empirical support for the prediction using daily high and low federal funds rates.

^bHamilton (1996) examines daily rate changes and variance in a GARCH model using the daily average (effective) federal funds rate.

^cGriffiths and Winters (1997) examine daily rate changes in the primary funding source (federal funds) and a substitute funding source (overnight general collateral repos) using daily closing rates.

^dCyree and Winters (2001) examine daily rate changes in a GARCH model using hourly federal funds rates.

^eSpindt and Hoffmeister (1988) model the federal funds market. The model provides predictions for daily and intraday patterns in federal funds rate variances. We provide the daily pattern in this table and note that the intraday prediction is for variance to increase in the afternoon.

^fGriffiths and Winters (1995) use high and low rates to estimate daily and intraday variances, and their estimates (reproduced here) support the predictions from Spindt and Hoffmeister (1988). We provide the Griffiths and Winters point estimates because the magnitude of the variance estimates is important.

^gGriffiths and Winters (1997) use closing federal funds rates and closing overnight general collateral government repo rates to estimate the daily variance pattern in the primary (federal funds) and a secondary (government repos) funding source for management of Federal Reserve accounts for settlement.

settlement rules spills over into the variances of substitute funding sources.⁸

We note that Spindt and Hoffmeister (1988) and Griffiths and Winters (1995) model bank reserve account management in the absence of Federal Reserve open market activity to manage interest rates. Bartolini, Bertola, and Prati (2000 and 2001) extend the previous models by incorporating Fed market intervention into a model of bank behavior during reserve maintenance periods. The Bartolini, Bertola, and Prati (2001) model suggests that patterns in interest rate volatility should reflect the market's confidence in the Fed's commitment to rate targeting. They suggest that the Fed's move in 1994 toward more transparency in rate targeting and a tendency to change target rates only at FOMC meetings should give the market more confidence in the Fed's commitment to rate targeting. They suggest that, since 1994, less federal funds rate volatility across maintenance periods and as settlement approaches provides support for their model. We note that the patterns found by Bartolini, Bertola, and Prati (2001) are consistent with the literature cited above. However, it has been widely understood that the Fed has been targeting interest rates since the mid-1980s (see Thornton 1988 and 2002), so the patterns identified in the literature cited in Table 2 occurred during a period when the market understood that the Fed was managing interest rates and occurred despite the Fed's active efforts to manage interest rates.

In summary, the daily rate changes and variances that are unique to the U.S. settlement process are the biweekly rate increase and the variance increase on settlement Wednesdays. Accordingly, we focus on settlement Wednesdays to determine whether the effect of U.S. settlement rules reach overseas when Eurocurrency liabilities become a substitute funding source for reserve account management. However, before we can test for a biweekly settlement Wednesday effect, we must determine whether British banking regulations create any daily rate change or variance patterns that would appear biweekly on U.S. settlement Wednesdays.

⁸ The only assets that are acceptable as reserves are vault cash and deposits at the Fed. Many possible sources can provide cash or Fed deposits, and (historically) most of these sources of funds alter a bank's required reserves. Accordingly, a substitute for federal funds is a funding source that does not alter required reserves or, in other words, has a 0 percent reserve requirement.

British Bank Settlement and LIBOR

LIBOR is the rate that major London banks offer to other banks on short-term funds. Thus, in the overnight market, LIBOR-based trades are similar to federal funds trades as banks make one-day trades of funds. Given the similarities in the trades in the overnight federal funds and overnight LIBOR-based markets, when the Fed reduced the reserve requirement on Eurocurrency liabilities to 0 percent, the overnight Eurodollar market became a viable substitute for the federal funds market as a source of deposits at the Fed for bank settlement. If the LIBOR-based market acts as a substitute, we would expect to see the settlement Wednesday effect spillover into LIBOR. However, before we can test LIBOR for U.S. Federal Reserve settlement effects, we must understand the settlement rules under which the London banks operate.

Settlement or clearing banks are required to keep small amounts of cash on deposit with the Bank of England. The deposits are not for monetary policy objectives or for clearing, but, instead, are intended to cover central bank operating costs. Each bank must cover its required reserves on a daily basis. With this daily settlement, the central bank intervenes in the market several times each day to ensure adequate liquidity.⁹ Given daily settlement, the U.K. settlement process will not cause day-of-the-week regularities in rate changes and variances. Accordingly, we are able to test overnight LIBOR rates for U.S. settlement effects.

Swanson (1988), Fung and Isberg (1992), and Mougoue and Wagster (1997) examine the causality between three-month domestic CD rates and three-month Eurodollar rates and achieve mixed results on the direction of the causality. In this paper, we have a specific expectation on causality: In the absence of confounding effects in the British banking regulations, we expect that U.S. overnight market behavior resulting from Federal Reserve settlement rules will create the appearance of settlement effects in overnight LIBOR after the change to a 0 percent reserve requirement on Eurocurrency liabilities.

⁹ The Bank of England conducts its daily trading at noon and 2:30 p.m. The Bank may also trade at 9:45 a.m. if it forecasts a large shortage for the day. The Bank stands ready to intervene for settlement banks only at 3:50 p.m. to provide the necessary end-of-the-day liquidity. The multiple daily interventions by the Bank of England create interesting intraday research opportunities. However, we have access only to daily closing overnight LIBOR rates and thus leave the intraday questions for further research.

DATA AND METHODS

Data

For this paper, we use daily closing data for (i) federal funds rates, (ii) overnight general-collateral government repo rates, and (iii) overnight LIBOR. LIBOR coincides with the London close while the other rates reflect the New York close. Since London time is typically five hours ahead of New York time, the London close occurs late morning New York time. Accordingly, overnight LIBOR established at the close in London is established during the late morning in New York. We also use three-month T-bill yields as a proxy for the general level of short-term interest rates. To control properly for contemporaneous changes in short-term interest rates and thus isolate the daily settlement effects, we must account for the time difference between London and New York in our application of T-bill annualized yields. Accordingly, we use the U.S. closing T-bill yields in our tests on federal funds rates and on overnight general-collateral government repo rates, and we use 11:00 a.m. (Eastern time) T-bill yields in our tests on overnight LIBOR.

The sample period covers August 4, 1986, through January 31, 1995. The beginning of the sample period coincides with the first available date for the overnight LIBOR rates. Ending the sample on January 31, 1995, stops the sample period before the majority of U.S. banks began actively using retail-deposit sweep programs. Active use of such sweep programs altered the reserve positions of U.S. banks to a point where Anderson and Rasche (2001) describe the reserve requirements for most banks as “voluntary constraints.” Thus, the active use of sweep programs likely altered the reserve account management behavior of most banks. We end our sample at January 31, 1995, to avoid any possible change in reserve account management from the active use of retail-deposit sweep programs. Also, ending the sample period at this time provides approximately four years of data before and after the reserve reduction on Eurocurrency liabilities. The entire sample period coincides with the two-week reserve maintenance period used by the Federal Reserve.¹⁰ The data on federal funds, over-

night repos, and three-month T-bills were collected from the daily logs of the International Monetary Market (IMM) division of the Chicago Mercantile Exchange. The IMM acquires the data from Telerate, and our overnight LIBOR data were purchased from Knight-Ridder, Inc.

Methods

Griffiths and Winters (1997) test for settlement rate-change effects in overnight government repos in a three-equation SUR model (seemingly unrelated regression) with dependent variables for government repos, federal funds, and GNMA repos. The basic equation in their SUR model was

$$(1) \quad Spd_t = a_1D_{14} + a_2D_{15} + a_3D_{11} + a_4D_{12} + a_5D_{13} + a_6D_{24} + a_7D_{25} + a_8D_{21} + a_9D_{22} + a_{10}D_{23} + a_{11}TB_t + \varepsilon_t,$$

where Spd_t is the change in the spread of an overnight rate (government repos, federal funds, GNMA repos) for day t ($Spd_t - Spd_{t-1}$) relative to three-month T-bill yields¹¹; D_{ik} is a 0/1 dummy variable with i representing the first or second week of the reserve maintenance period and k representing the specific day of the week; and TB_t is the change in the three-month T-bill yield for day t ($yield_t - yield_{t-1}$). The change in T-bill yields is included in the model to control for changes in the general level of short-term interest rates.

The benefit of the SUR model is that it allows us to test for differences in parameter estimates across equations. The limitation of the SUR model in testing for settlement effects is that it does not allow us to incorporate the known daily heteroskedasticity in the federal funds market. Accordingly, Griffiths and Winters separately test daily variances with the following equation:

$$(2) \quad Var_t = a_1D_{14} + a_2D_{15} + a_3D_{11} + a_4D_{12} + a_5D_{13} + a_6D_{24} + a_7D_{25} + a_8D_{21} + a_9D_{22} + a_{10}D_{23} + \varepsilon_t,$$

where Var_t is the square of the daily spread change.

¹¹ Griffiths and Winters (1997) note that standard conventions suggest that the change in spread be specified as the log relative [$\ln(Spd_t / Spd_{t-1})$] or as the percent change [$(Spd_t - Spd_{t-1}) / Spd_{t-1}$]. However, the spread between overnight instruments and three-month T-bills is negative at several points during their sample period. A negative spread precludes using the standard conventions, and thus they use the first difference in daily spreads to calculate spread changes. We also have negative spreads at various times, and, therefore, we also use the first difference in daily spreads.

¹⁰ The Federal Reserve switched from a one-week reserve maintenance period to a two-week reserve maintenance period for the maintenance period beginning on February 2, 1984. From that date to the present, the Fed has used a two-week maintenance period.

The presence of heteroskedastic daily variances suggests the need for a G/ARCH (general/autoregressive conditionally heteroskedastic) model that allows for the estimation of returns and conditional variance simultaneously.¹² Such a model allows for the explicit inclusion of heteroskedasticity in the estimation process, which improves the model's standard errors and thus the *t* statistics. However, a GARCH estimation precludes the direct testing of differences in parameter estimates between equations that can be done in an SUR model. So, to test for settlement effects, ideally we would like a model that includes features of both SUR models and GARCH models. However, at the present time such a model does not exist, so we must choose which type of model works best in this situation. Since we are most interested in determining whether a settlement effect exists and since we have other methods for comparing the size of the effects, we choose to use a GARCH model because of its benefits for the estimation of standard errors and *t* statistics.

Specifically, we chose a GARCH-M model, where the M denotes that the conditional variance is included in the mean equation and allows the conditional variance to provide information about returns (rate changes in this setting). Then, from the set of GARCH-M models, we chose the model proposed by Glosten, Jagannathan, and Runkle (GJR) (1993) because of its definition of the asymmetric term in the conditional variance. All GARCH-M models contain an intercept and two prespecified variables in the variance equation: (i) a trend term (the ARCH effect) and (ii) a persistence term (the GARCH effect). The innovation in the GJR-M model is a third prespecified term that is based on the sign of the prediction errors (the asymmetric term). This asymmetric term allows that certain prediction errors are more important to the market than other prediction errors. The GJR-M asymmetric term is a binary dummy variable, which we believe is intuitively appealing for the federal funds/LIBOR markets. In addition, we chose to estimate the GJR-M model with robust errors to calculate properly the *t* statistics for the model parameter estimates (see Bollerslev and Wooldridge, 1992).

In the reserve maintenance process, banks typically have either excess reserves (actual reserves > required reserves) or short reserves (actual reserves <

required reserves) and the period-ending excess or short position carries forward as the starting reserve position in the next reserve maintenance period. Excess reserves are an opportunity cost for the bank because it could have invested the excess but did not. Conversely, short reserves indicate that the bank has invested federal funds using an interest-free loan from the Federal Reserve. Thus, a clear asymmetry exists, which we believe makes the dummy variable definition for the asymmetric term in the GJR-M model appropriate.

We also tested two other specifications of GARCH-M to ensure that our results were not an artifact of our model choice. The other models are the EGARCH-M specification suggested by Nelson (1991), with two different specifications of the error term in the mean equation: (i) a normal distribution of errors and (ii) a generalized error distribution. The results from these specifications are qualitatively similar to the results reported below.¹³ They are omitted here for brevity, but are available upon request.

Cyree and Winters (2001) examine closing federal funds rates in a GARCH-M model and find significant ARCH/GARCH effects. They suggest that these ARCH/GARCH effects are consistent with the Spindt and Hoffmeister (1988) model of daily federal funds rate variances. Cyree and Winters do not find a significant mean effect for the conditional variance in federal funds rate changes. However, we include the conditional variance in the mean equation for the spread changes we examine to allow for the possibility that the conditional variance provides information about daily spread changes, thus ensuring that we have properly isolated the daily settlement effects in the spreads.

We start our model by putting equations (1) and (2) in the GARCH-M model developed by GJR

¹³ We tested the specification of our GJR-M model against the EGARCH-M models using likelihood ratio tests and found no significant difference between the models. Accordingly, we chose to report the GJR-M model results because of the intuitive appeal of the model relative to the incentives created by the Federal Reserve settlement rules. In addition, we performed the Box-Ljung Q-test on the residuals and squared residuals. In all cases, the residuals are negatively serially correlated, as expected, and the inclusion of lagged rate changes in the model does not remove the serial correlation. Also, including lagged rate changes in the model does not alter the interpretation (i.e., the qualitative values or significance) of the daily dummy variables. We note that Hamilton (1996) concludes that banks do not view reserves from different days as perfect substitutes, so we chose to use a model specification without lagged rate changes because we believe this best fits the economic realities of the federal funds market and its substitute markets for overnight money.

¹² See Bollerslev, Chou, and Kroner (1992) for a review of the finance literature using GARCH models.

(1993).¹⁴ We extend equations (1) and (2) to include controls for quarter-ends (see Hamilton, 1996), and we remove the change in T-bill yields from the mean equation.¹⁵ We estimate our GARCH-M model with all the daily dummy variables in equations (1) and (2) and find results that are generally consistent with previous empirical results and with our expectations for LIBOR. However, we note that the model becomes difficult to converge and the results are very sensitive to starting point inputs. We believe the difficulties lie in the large number of dummy variable parameter estimates required when we use all the dummy variables. Furthermore, we have argued that settlement Wednesday is the one day that is unique to the U.S. bank settlement process, so we modify our model to reduce the number of dummy variables in the model. The new model converges easily and is not as sensitive to starting point inputs, yet the results remain consistent with the full-model empirical results, with previous empirical results in the literature, and with expectations. The model used to generate the results reported in the tables is as follows:

The GJR-M mean equation is:

$$(3) \quad \Delta Spd_t = a_0 + a_1 1stFriday + a_2 2ndFriday + a_3 SetWednesday + a_4 QTR + \lambda \sigma_t^2 + \varepsilon_t,$$

where ΔSpd_t is the first difference in the daily spread on day t and the spread is defined as the rate on the overnight instrument minus the yield on three-month T-bills¹⁶; *1stFriday* is a 0/1 dummy variable

that equals 1 on the first Friday of each reserve maintenance period and 0 otherwise; *2ndFriday* is a 0/1 dummy variable that equals 1 on the second Friday of each reserve maintenance period and 0 otherwise; *SetWednesday* is a 0/1 dummy variable that equals 1 on settlement Wednesday and 0 otherwise; *QTR* is a 0/1 dummy variable that equals 1 on the last trading day of each quarter and 0 otherwise; σ_t^2 is the conditional variance (volatility-in-mean term).

Note that in dummy variable regression models with omitted dummy variables, the parameter estimates of the remaining dummy variables are relative to the average of the omitted dummy variables. Fridays have falling rates, so we chose to keep the two Friday dummy variables in the model so that any model bias from omitting some dummy variables would be against finding a settlement Wednesday effect in the mean equation. The conditional variance equation for the GJR-M model is

$$(4) \quad \sigma_t^2 = b_0 + b_1 \varepsilon_{t-1}^2 + b_2 \sigma_{t-1}^2 + b_3 \varepsilon_{t-1} I_t + c_1 1stFriday + c_2 2ndFriday + c_3 SetWednesday + c_4 QTR,$$

where I_t is a 0/1 dummy variable that equals 1 if the lagged error is negative and 0 otherwise. The indicator variable accounts for asymmetry in the conditional variance equation as the addition to the variance based on the sign of last period's error.

Note that in equation (4) the daily dummy variables and quarter-end dummy variable are contemporaneous with the conditional variance (which is not common in a GARCH model). This is important (and appropriate) in the daily dummy variables because the daily variances created by the settlement rules are conditioned by the day of the reserve maintenance period. Similarly, the quarter-end dummy variable is contemporaneous because, as Hamilton (1996) shows, there are significant quarter-end conditioning effects on the daily variance.

Summary Statistics on Daily Spreads

Table 1 shows the mean (median) spreads for the overnight rates relative to three-month T-bill yields for both the entire sample period and the subsample period after the reserve requirement reduction. Note that only after the reserve requirement change are Eurocurrency liabilities a substitute funding source for federal funds in the settlement process. In addition to these summary statistics, we conducted various mean difference tests. We find that each average spread is significantly lower (at the 1 percent level) after the reserve reduction. In

¹⁴ GJR uses non-standard GARCH-M notation. We chose to present our model using standard GARCH(1,1)-M notation as in Chou, Engle, and Kane (1992), with the addition of the GJR binary asymmetric term in the conditional variance.

¹⁵ Griffiths and Winters (1997) include the change in T-bill yields as a proxy for the change in the general level of short-term interest rates. We attempted to include the change in T-bill yields as an explanatory variable in the mean equation, but very inconsistent parameter estimates on T-bill yields across federal funds, repos, and LIBOR lead us to remove T-bill yields from the explanatory variables in the mean equation. Note, T-bills still appear as the base rate in the spreads used as the dependent variable. Also note that equation (4) cannot include a T-bill variable as an explanatory variable because T-bill yields are part of the dependent variable in equation (3); thus, including T-bill yields in equation (4) would create a contemporaneous endogenous variable, which is not allowed in the conditional variance of a GARCH model.

¹⁶ While we are directly interested in the rate change behavior of our test rates, we define the dependent variable in terms of a spread to prevent any general trends in the levels of rates from affecting our results. An alternative to using T-bill yields as the base rate would be to use the daily average rate for federal funds, repos, and LIBOR as the base rate. This could be done for federal funds by using the effective federal funds rate. However, we know of no source for daily average repo rates or for daily average LIBOR, so we chose to stay with T-bill yields as our base rate.

the period after the reserve reduction, we find that the average repo and LIBOR spreads are not different from each other, but that both are significantly higher (at the 1 percent level) than the average federal funds spread. Thus, after the implicit reserve tax was removed, the spread on LIBOR is similar to the spread on government repos—making the LIBOR-based liabilities a viable alternative to repos as a substitute for federal funds, as would be expected from the law of one price. Based on the average spreads, the substitute funding sources are not an attractive alternative to federal funds. However, the rate comparison may be very different on settlement Wednesdays.

RESULTS

This section presents our empirical results. The focus of our tests is to investigate overnight LIBOR spreads for U.S. settlement effects. However, before we can investigate LIBOR spreads we must first test for the presence of a settlement effect in federal funds spreads (the primary funding source) and overnight government repo spreads (the domestic substitute funding source) across our sample period. Accordingly, we begin our settlement effect tests on federal funds spreads. We follow federal funds with tests on overnight repos, and we conclude with tests on overnight LIBOR.

Federal Funds

We begin our analysis by estimating our GARCH-M model on the daily change in federal funds spreads. We divide our sample into two subsamples: before and after the lifting of the reserve requirement on Eurocurrency liabilities. The 3 percent reserve regime ended with the maintenance period that closed December 12, 1990, and the 0 percent regime began with the maintenance period that opened December 27, 1990. The purpose of this analysis of federal funds rates is to determine whether the previously identified settlement effects in rate changes and variance appear in federal funds rates during both subperiods of our sample. The results on federal funds are reported in Table 3.

The first column of Table 3 reports results for the period from August 4, 1986, through December 12, 1990. The mean (spread-change) equation has, in general, the predicted pattern. That is, spreads fall on Fridays and rise on settlement Wednesday relative to average spread. The increase on settlement Wednesday supports a settlement effect in rate changes.

The variance equation shows significant ARCH/GARCH effects, which suggests that daily variances

are conditional. The significant and positive ARCH effect (ε_{t-1}^2) suggests trends in the daily variances, while the significant and positive GARCH effect (σ_{t-1}^2) suggests that shocks persist in the daily variances. Both effects are consistent with the model of daily federal funds variances by Spindt and Hoffmeister (1988). The settlement Wednesday parameter estimate is positive and significant at the 1 percent level, and it is much larger in magnitude than either of the Friday parameter estimates. This finding is consistent with a settlement effect in the conditional variance.

These results suggest that the predicted rate change and variance regularities are present in federal funds during the subperiod when Eurocurrency liabilities carried a 3 percent reserve requirement. With these results, it is reasonable to expect a settlement Wednesday effect in rates on substitute funding sources. A substitute funding source for federal funds is a U.S. dollar source of deposits at the Fed that carries a 0 percent reserve requirement and, thus, through the law of one price should cost a bank approximately the same interest rate as federal funds. During the period with the 3 percent reserve requirement on Eurocurrency liabilities, government repos were a substitute for federal funds but Eurocurrency liabilities were not. So, during this time period we would expect to find a settlement Wednesday effect in overnight government repo rates, but not in LIBOR.

The third column of Table 3 presents the parameter estimates from our GARCH-M model for federal funds during the subperiod from February 7, 1991, through January 31, 1995. Beginning this subperiod on February 7, 1991, removes the first three reserve maintenance periods under the new rules from our analysis. This allows the market a little time to adjust to the new rules. Feinman (1993) notes, in fact, that substantial volatility occurred with the change to the new rules. Also, the manager of the federal funds trading desk of a large regional bank has said that it took banks several weeks to adjust to the new rules. Accordingly, we believe that removing the first three reserve maintenance periods, while clearly arbitrary, is reasonable.¹⁷

¹⁷ Including these periods prevents our GARCH-M model from converging for federal funds due to the unusual volatility during this six-week period. Using other methods that allow us to include the six-week period, we find qualitatively similar results to our GARCH results excluding the six weeks. These results are omitted for brevity, but are available upon request. Because we anticipate daily heteroskedasticity, we believe a GARCH model is the best method for our tests.

Table 3

Federal Funds GARCH Model Results

Variable	8/4/86–12/12/90		2/7/91–1/31/95	
	Estimate	t statistic	Estimate	t statistic
Mean equation				
Intercept	-0.0015	-0.31	0.0219***	3.74
1stFriday	-0.0382**	-2.45	-0.1263***	-9.34
2ndFriday	-0.0689***	-4.59	-0.0803***	-8.17
SetWednesday	0.1315***	5.34	0.0840**	2.24
QTR	0.0957	1.30	0.1281**	2.05
σ_t^2	0.0600**	2.13	-0.1058***	-3.26
Variance equation				
Intercept	0.0284***	43.16	0.2088***	4.98
ε_{t-1}^2	0.0194**	2.22	0.4357***	6.28
σ_{t-1}^2	0.8980***	35.03	0.6459***	11.51
$\varepsilon_{t-1}^2 I_t$	-0.7211***	-26.89	0.1877	1.41
1stFriday	-0.0187***	-10.47	-0.0356***	-2.68
2ndFriday	-0.0031	-1.26	-0.0170**	-1.95
SetWednesday	0.3609***	6.74	0.3686***	3.70
QTR	0.1145**	2.23	0.7416*	1.85

NOTE: This table reports the results for estimating the GARCH-M model on the spread of the overnight federal funds rate relative to the closing three-month T-bill rates. The model is estimated twice. The first estimation is for the period from 8/4/86 through 12/12/90 when the reserve requirement for Eurocurrency liabilities is 3 percent. The second estimation is for the period from 2/7/91 through 1/31/95 when the reserve requirement for Eurocurrency liabilities is 0 percent. The mean equation for the GARCH-M model is $\Delta Spd_t = a_0 + a_1 1stFriday + a_2 2ndFriday + a_3 SetWednesday + a_4 QTR + \lambda \sigma_t^2 + \varepsilon_t$.

The conditional variance equation is $\sigma_t^2 = b_0 + b_1 \varepsilon_{t-1}^2 + b_2 \sigma_{t-1}^2 + b_3 \varepsilon_{t-1}^2 I_t + c_1 1stFriday + c_2 2ndFriday + c_3 SetWednesday + c_4 QTR$.

*/**/*** denote significance at the 10/5/1 percent levels.

The spread change results on Fridays and settlement Wednesday are consistent with the predicted pattern and consistent with the results from the earlier subperiod. The variance equation shows significant ARCH/GARCH effects.¹⁸ The variance equation also shows a settlement Wednesday parameter estimate that is positive and significant at the 1 percent level and substantially larger than the Friday parameter estimates. This finding is consistent with expectations and the results from the previous subperiod and is consistent with Feinman's

(1993) observation of increased variance after the reserve reduction.

These results suggest that the predicted pattern is present in the later subperiod. Again, this means we would expect to find a settlement Wednesday effect in rates of substitute funding sources.

Overnight Government Repos

Table 4 presents the results from estimating our GARCH-M model on overnight government repos. Government repos are a substitute funding source for federal funds in the settlement process across our entire sample period. Accordingly, we expect to find settlement effects in overnight government repo rate changes and variances across our entire sample period. It is important to identify a settlement effect in a substitute funding source

¹⁸ Note that the sum of the ARCH and GARCH parameter estimates is greater than 1, which is usually considered a sign of an estimation error because it suggests that the conditional variance grows rapidly. However, during this time period, federal funds rates are much more volatile than during the earlier sample, with settlement Wednesday volatility being extremely high. Accordingly, we believe these estimates are reasonable.

Table 4

Overnight Government Repo GARCH Model Results

Variable	8/4/86–12/12/90		2/7/91–1/31/95	
	Estimate	t statistic	Estimate	t statistic
Mean equation				
Intercept	-0.0082*	-1.75	-0.0011	-0.19
1stFriday	-0.0368***	-3.01	-0.0876***	-5.89
2ndFriday	-0.0224	-1.28	-0.0622***	-5.53
SetWednesday	0.0540**	2.00	0.0603***	2.73
QTR	0.0385	0.58	0.1589	1.64
σ_t^2	0.4502***	5.25	0.0094	0.11
Variance equation				
Intercept	0.0102***	25.62	0.0264***	32.26
ε_{t-1}^2	0.2835***	1.51	0.0433***	2.68
σ_{t-1}^2	0.3471***	15.28	0.4732***	18.62
$\varepsilon_{t-1}^2 I_t$	-0.2591***	-10.46	-0.3917***	-14.14
1stFriday	-0.0100***	-7.05	-0.0143***	-6.88
2ndFriday	0.0128***	3.47	-0.0159***	-8.51
SetWednesday	0.0627***	13.53	0.0453***	7.27
QTR	0.0698***	3.73	0.1805**	2.52

NOTE: This table reports the results for estimating the GARCH-M model on the spread of the overnight government repo rate relative to the closing three-month T-bill rates. The model is estimated twice. The first estimation is for the period from 8/4/86 through 12/12/90 when the reserve requirement for Eurocurrency liabilities is 3 percent. The second estimation is for the period from 2/7/91 through 1/31/95 when the reserve requirement for Eurocurrency liabilities is 0 percent. The mean equation for the GARCH-M model is $\Delta Spd_t = a_0 + a_1 1stFriday + a_2 2ndFriday + a_3 SetWednesday + a_4 QTR + \lambda \sigma_t^2 + \varepsilon_t$. The conditional variance equation is $\sigma_t^2 = b_0 + b_1 \varepsilon_{t-1}^2 + b_2 \sigma_{t-1}^2 + b_3 \varepsilon_{t-1}^2 I_t + c_1 1stFriday + c_2 2ndFriday + c_3 SetWednesday + c_4 QTR$. */**/** denote significance at the 10/5/1 percent levels.

across the entire period for comparison with Eurocurrency liabilities, which only became a substitute in the latter part of the sample period. The first column of Table 4 reports the results from the subperiod when Eurocurrency liabilities carried a 3 percent reserve requirement, and the third column of Table 4 reports the results from the subperiod with no reserve requirement.

The first set of results shows a negative and significant estimate at the 1 percent level for the first Friday and a positive and significant estimate at the 5 percent level for settlement Wednesday. The variance results indicate significant and positive ARCH/GARCH effects, which are consistent with the results for federal funds. Both Fridays and settlement Wednesday contribute significantly to the conditional variance. The settlement Wednesday param-

eter estimate is positive and about five times larger than the Friday parameters. These results are consistent with the existence of settlement effects in a substitute funding source during the subperiod with the 3 percent reserve requirement.

The second set of results on overnight government repos shows strong evidence of the predicted spread change effects with significant (1 percent level) and negative spread changes on Fridays and a significant (1 percent level) and positive spread change on settlement Wednesday. The variance equation shows significant and positive ARCH/GARCH effects. As with the results on repos for the earlier subperiod, settlement Wednesday provides a significant (1 percent level) and positive contribution to the conditional variance and its parameter estimate is substantially larger (about three times)

Table 5

LIBOR GARCH Model Results

Variable	8/4/86–12/12/90		2/7/91–1/31/95	
	Estimate	t statistic	Estimate	t statistic
Mean equation				
Intercept	-0.0001	-0.03	0.0177***	4.96
1stFriday	0.0028	0.25	-0.0791***	-8.01
2ndFriday	0.0148	1.03	-0.0217***	-2.61
SetWednesday	-0.0163	-1.50	0.0368**	2.54
QTR	0.0303	0.56	0.0876	1.24
σ_t^2	0.0693	0.98	-0.5458***	-5.61
Variance equation				
Intercept	0.0030***	22.27	0.0132***	54.60
ε_{t-1}^2	0.5360***	96.37	0.0821***	8.26
σ_{t-1}^2	0.4442***	27.51	0.4504***	17.39
$\varepsilon_{t-1}^2 I_t$	-0.0514**	-2.18	-0.2533***	-6.20
1stFriday	0.0004	0.27	-0.0025***	-2.67
2ndFriday	0.0235***	12.79	-0.0087***	-12.18
SetWednesday	0.0045***	2.79	0.0251***	9.30
QTR	0.0465***	3.04	0.0954**	2.16

NOTE: This table reports the results for estimating the GARCH-M model on the spread of the overnight LIBOR rate relative to the closing three-month T-bill rates. The model is estimated twice. The first estimation is for the period from 8/4/86 through 12/12/90 when the reserve requirement for Eurocurrency liabilities is 3 percent. The second estimation is for the period from 2/7/91 through 1/31/95 when the reserve requirement for Eurocurrency liabilities is 0 percent. The mean equation for the GARCH-M model is $\Delta Spd_t = a_0 + a_1 1stFriday + a_2 2ndFriday + a_3 SetWednesday + a_4 QTR + \lambda \sigma_t^2 + \varepsilon_t$.

The conditional variance equation is $\sigma_t^2 = b_0 + b_1 \varepsilon_{t-1}^2 + b_2 \sigma_{t-1}^2 + b_3 \varepsilon_{t-1}^2 I_t + c_1 1stFriday + c_2 2ndFriday + c_3 SetWednesday + c_4 QTR$.

/ denote significance at the 10/5/1 percent levels.

than the parameter estimates on Fridays. These results show settlement effects in a substitute funding source during the subperiod with the 0 percent reserve requirement.

LIBOR

To this point, we have shown that the Fed's settlement regulations influence spread changes and variance in the primary funding source (federal funds) and in the domestic substitute funding source (government repos). In this subsection, we explore the hypothesis that LIBOR spreads become influenced by Fed settlement regulations when Eurocurrency liabilities become a substitute funding source for federal funds through the reduction in the reserve requirement to 0 percent. Again, we remind the reader that only vault cash and deposits

at the Fed can be used for settlement; therefore, a comparable substitute for federal funds would need to be a source of overnight U.S. dollar deposits at the Fed with a 0 percent reserve requirement, which, through the law of one price, should carry approximately the same interest rate as federal funds.

Table 5 presents the results from estimating our GARCH-M model on overnight LIBOR spreads. The first column reports the results from the subperiod with a 3 percent reserve requirement, and the third column reports the results from the subperiod with the 0 percent reserve requirement on Eurocurrency liabilities. In this formulation, we switch to the 11:00 a.m. quote for three-month Treasury bill rates. This allows for a time-consistent spread for (closing) overnight LIBOR rate quotes from the U.K. market relative to the relevant T-bill quote.

The first set of results shows no evidence of the settlement effects found for federal funds and overnight government repos during this subperiod when Eurocurrency liabilities were not a substitute funding source. Specifically, there is no significant spread increase on settlement Wednesday and settlement Wednesday is not the largest daily contribution to the conditional variance. These results suggest that, during the time period when Eurocurrency liabilities carried a reserve tax, banks did not use Eurocurrency liabilities in managing their reserve accounts.

The second set of results shows strong evidence of settlement effects. Specifically, the spread changes in the mean equation show a significantly positive settlement Wednesday effect. The variance equation shows significant and positive ARCH/GARCH effects. Settlement Wednesday provides a positive and significant (1 percent level) contribution to the conditional variance, with its parameter estimate being about three times larger than the parameter estimates on Fridays. These results are consistent with the results from federal funds and overnight government repos from the same subperiod, which suggests that during this period U.S. banks did become the marginal borrower in dollar-based Eurocurrency liabilities as they managed their reserve accounts on settlement Wednesdays.

The results for LIBOR in the first subperiod are clearly different from those in the second subperiod. With significant settlement effects in the latter period, the combination of LIBOR results suggests that the change in the reserve requirements on Eurocurrency liabilities had a significant impact on the overnight money markets in London.

The Size of Settlement Wednesday

At this point, we have shown that after the reserve reduction on Eurocurrency liabilities the average federal funds spread is significantly smaller than the average spreads on the substitute funding sources and that settlement Wednesday effects in spread changes exist in each asset. In this section, we discuss the size of the settlement Wednesday spread change in each instrument after the reserve reduction and the appropriate implications. Recall that the timing of the LIBOR results aligns with the late morning in the U.S. and that Griffiths and Winters (1995) show that the majority of the settlement Wednesday effect appears in the afternoon. So, since the London market closes in late morning, one would not anticipate the same magnitude of

spread changes in the London market as in the domestic markets.

To address the size of the settlement Wednesday spread change effect, we calculate the average spread change on each funding source on settlement Wednesday.¹⁹ We find the following average spread changes on settlement Wednesdays after the reserve reduction: (i) a 24-basis-point increase for federal funds, (ii) a 15-basis-point increase for overnight government repos, and (iii) an 8-basis-point increase in overnight LIBOR.

These findings are consistent with our expectations for the following reasons. First, the primary funding source should have the largest increase because it is, on average, the cheapest and most convenient source of funds (because banks are already regular and active participants in federal funds trading) and thus should be the focus of the settlement Wednesday rate pressure. Second, the rate pressure should be greater in overnight repo rates than overnight LIBOR because of the timing of the two markets: The brokered repo market is active during the afternoon in the United States, while the London LIBOR-based Eurocurrency market is closed. Thus, overnight repo rates are open to the significant rate pressures of settlement Wednesday afternoons while overnight LIBOR is not.

Control Variables

There are results from some of the control variables that deserve a brief discussion. We have delayed the discussion until this point to avoid detracting from the primary focus of the paper, which is the pervasiveness of the Federal Reserve settlement regulations.

Quarter-ends exhibit significant and positive contributions to the conditional variances across all instruments in this study and across both sample subperiods. However, only one of six quarter-end parameter estimates in the mean equations is significant. This combination of results suggests uncertainty in these markets at quarter-ends without a consistent increase or decrease in rate pressure. This finding suggests a great deal of funds movement at quarter-end without squeezes or shortages.

The asymmetric term in the conditional variance is significant and negative in five of six estimates. The one exception is for federal funds in the latter

¹⁹ We cannot directly use the parameter estimates reported from the GARCH-M model because the spread change equation includes a conditional variance effect.

period, which was unusually volatile. A significant parameter estimate suggests that some errors are more important to the market than other errors, and a negative parameter estimate suggests a reduction in the conditional variance. A negative parameter estimate from our specification of the asymmetric term suggests that, when the actual rate is less than the rate the market expected, conditional variance declines.

CONCLUSION

In this paper, we examine overnight LIBOR around the change by the Federal Reserve in the reserve requirement on Eurocurrency liabilities from 3 percent to 0 percent. The change in the reserve requirement eliminates the reserve tax on Eurocurrency liabilities and thus allows the law of one price to make Eurocurrency liabilities a viable alternative funding source for federal funds for banks in managing their reserve accounts. We find no evidence of settlement Wednesday effects in LIBOR during the period of the 3 percent reserve requirement, but we find strong evidence of settlement Wednesday effects in LIBOR during the period of the 0 percent reserve requirement. Our results suggest that, when Eurocurrency liabilities are a substitute funding source for federal funds, banks use them in managing their reserve accounts—becoming the marginal borrower on settlement Wednesdays. In contrast, when Eurocurrency liabilities carry a reserve tax, banks use other funding sources in managing their reserve accounts.

Our results suggest the following: Overnight money markets are global and the micromechanics of one market can spillover into another market and, in this case, carry the effects of Federal Reserve settlement rules into off-shore markets. That is, we demonstrate that changes in Fed policy allowing Eurocurrency liabilities to be a substitute funding source in the settlement process results in LIBOR being affected by the Fed's bank settlement procedures.

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