NBER WORKING PAPER SERIES

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Working Paper No. 1812

NATIONAL BUREAU OF ECONOMIC RESEARCH
1050 Massachusetts Avenue
Cambridge, MA 02138
January 1986

Associate professor of finance, University of Washington, and research associate, National Bureau of Economic Research. I am grateful to Michael R. Darby, Robert H. Rasche, Gordon H. Sellon, and Carl E. Walsh for helpful comments and to the National Science Foundation (Grant No. SES-8408603) for research support. The research reported here is part of the NBER's research program in Financial Markets and Monetary Economics. Any opinions expressed are those of the author and not those of the National Bureau of Economic Research.

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ABSTRACT

The response of interest rates to money announcement surprises is examined both theoretically and empirically in this paper. In the theoretical models developed, not only changes in operating procedures, but also reserve requirement systems, are found to potentially affect the response. Moreover, under the current two-week contemporaneous reserve requirements (CRR) adopted in February 1984, the responses in the first and second weeks of the two-week reserve maintenance period may differ. The empirical results generally conform to the predictions of the theoretical models. The response of the Treasury bill yield to money announcement surprises changed significantly following changes in either operating procedures or reserve requirement systems in October 1979, October 1982, and February 1984.

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The larger responses of interest rates to weekly money announcements following the Federal Reserve's change in operating procedures on October 6, 1979, are well documented. Both Roley (1982, 1983) and Cornell (1983a) estimate increased responses of Treasury bill yields following October 1979, and Cornell (1983a) provides initial estimates of similar increases for long-term yields. Loeys (1985) presents evidence that the response once again declined, perhaps coinciding with the Federal Reserve's announced change in operating procedures in October 1982. A further change potentially affecting the response of interest rates to money announcements was made in February 1984, when contemporaneous reserve requirements (CRR) replaced lagged reserve requirements (LRR). In the eight months following the adoption of CRR, Gavin and Karamouzis (1984) estimate responses smaller than those in the preceding period.

While most explanations of the estimated responses of interest rates to money announcement surprises rely on informal models, several theoretical frameworks have been advanced. Urich (1982) presents a model of the policy anticipations effect emphasizing the role of the Federal Reserve's monetary target rule or reaction function. The model also assumes the federal funds rate (or money market conditions) operating procedure along with fixed commodity prices. As a result, real interest rates change in response to money announcement surprises. Nichols, Small, and Webster (1983) also emphasize the effects of persistent money demand shocks and the Federal Reserve's desire to offset such shocks. In this model, however, the money stock is assumed to be controlled directly. In contrast to these approaches, Siegel (1985) specifies a model in which money announcement surprises provide information about economic activity.[1/] Finally, Roley and Walsh (1985) introduce factors such as reserve requirements and different operating procedures in explaining both pre- and post-October 1979 responses. Moreover, despite the skepticism of Cornell (1983b), Shiller, Campbell, and Schoenholtz (1983), and Hardouvelis (1984), the significant estimated responses of long-term interest rates are found to be consistent with the policy anticipations hypothesis. Roley and Walsh (1985) also show, however, that the expected inflation hypothesis is consistent with the estimated response of the term structure. In this case, commodity prices adjust instantaneously to news about the money stock.

The purpose of this paper is to develop theoretical models of the response of interest rates to money announcement surprises under alternative operating procedures and reserve requirement systems, and then to examine their empirical implications. In addition to the federal funds rate and nonborrowed reserves operating procedures investigated by Roley and Walsh (1985), the so-called borrowed reserves procedure -- presumably in affect since October 1982 -- also is examined. Moreover, the effect of the switch from CRR to LRR is considered. Nichols and Small (1985) suggest that this change could increase the observed responses.

In the first section, a model of the response of interest rates to money announcement surprises under LRR is presented. The model is then used to examine the implications of the federal funds rate, nonborrowed reserves, and borrowed reserves operating procedures. In the second section, models are specified under a hypothetical one-week CRR system as well as the current two-week CRR system. The effects of alternative operating procedures again are compared in these models.

Empirical results of the response of interest rates to money announcement surprises for various subperiods from September 1977 through May 1985 are presented in the third section. In the fourth section, the main conclusions are summarized.

I. RESPONSE UNDER LAGGED RESERVE REQUIREMENTS

In this section, the basic model used in investigating the responses of interest rates to money announcement surprises is first presented. While this model is specified assuming lagged reserve requirements, it is adapted easily in the subsequent section where CRR is considered. Following the presentation of the basic model, the responses of interest rates under alternative operating procedures in the presence of LRR are derived and compared. Many of the intermediate steps also are relevant to subsequent models which assume CRR.

A. The Model

The theoretical framework used here is based on that presented by Roley and Walsh (1985). Areas in which major differences occur are noted below. At the outset, however, it is useful to note that the model is specified as linear in levels, while Roley and Walsh (1985) specify a log-linear model. The linear-in-levels model is particularly useful when the current 2-week CRR system is examined.

Each version of the model is comprised of the Federal Reserve's policy rule, the demand for money, a term-structure relationship, and the demand for and supply of reserves. The Federal Reserve's policy rule is represented as[2/]

$$M^T_{t+j} = (1+g)^{n+j} M^B_{t-n} + (1-\lambda)^{1+j} [E(M_{t-1}|\Omega_t)-(1+g)^{n-1} M^B_{t-n}], \quad j=0,1,2,... \tag{1}$$

Equation (1) represents the Federal Reserve's short-run target path for the level of nominal money, M^T_{t+j} (j=0,1,2,...). It depends on the base level of the nominal money stock set n-weeks previously, M^B_{t-n}, and the long-run growth rate target, g. The second term on the right-hand side of (1) represents the expected deviation of the previous week's money stock from its long-run target value, subject to the Federal Reserve's information set, Ω_t. Policymakers offset deviations from the long-run target according to the short-run adjustment parameter, λ. If $\lambda=1$, the short-run target always corresponds to the long-run target. If $\lambda=0$, the previous week's expected deviation from target is fully accommodated. If $0 < \lambda < 1$, the short-run path will eventually become arbitrarily close to the long-run path. In the long run, then, expected inflation is constant since long-run money growth is unchanged. As a result, there is no inconsistency in assuming that expected inflation is constant in the long run. If commodity prices are perfectly flexible, however, expected inflation over shorter periods would change depending on the short-run money target paths. Such perfect short-run price flexibility is not assumed in the model. Thus, the response of interest rates to money announcement surprises is modeled with the policy anticipations effect.

The demand for money in week t also is specified in terms of nominal levels, and it is represented as

$$M_t = a_0 - a \cdot i_t + u_t, \tag{2}$$

The opportunity cost of holding money is represented by the federal funds rate, i_t, for simplicity.[3/] The parameter representing the interest rate responsiveness of money demand, a, is assumed to be positive, and the constant term, a_0, is assumed to embody effects from the price level and

GNP. These latter variables are not explicitly considered here.

Because equation (2) represents weekly money demand, the random disturbance u_t is likely to exhibit a high degree of serial correlation.[4/] To model this in a simple way, assume

$$u_t = \rho \cdot u_{t-1} + \varepsilon_t, \qquad |\rho| < 0 \tag{3}$$

where ε_t is a white noise process.

To represent long-term yields, an expectations model of the term structure is employed. It is assumed that the h-week rate, $r_{h,t}$, depends on the average of the current week's federal funds rate, i_t, and expected future levels of the federal funds rate. Formally, the term structure relationship is represented as

$$r_{h,t} = (1/h) \cdot i_t + (1/h) \cdot \sum_{j=1}^{h-1} E(i_{t+j} | \Omega_t). \tag{4}$$

The remaining relationships to be specified involve the market for reserves. The demand for total reserves under LRR is

$$TR_t^D = RR_t + ER_t = k \cdot M_{t-2} + w_t, \tag{5}$$

which equals the sum of required and excess reserves. In turn, this sum is represented by the reserve requirement ratio k, multiplied by the level of the money stock occurring two weeks ago under LRR, plus a random error term, w_t. This random error term is further assumed to exhibit first-order autocorrelation

$$w_t = \theta \cdot w_{t-1} + e_t, \qquad |\theta| < 1 \tag{6}$$

and it may be viewed as a disturbance related to money multiplier errors. While this error term does not play a major role in analyzing the impact of money announcements under LRR, it is important when CRR is examined.[5/]

Finally, the supply of total reserves is represented as

$$TR_t^S = NBR_t + b_0 + b\cdot(i_t - d_t) + v_t, \quad (7)$$

where $$BR_t = b_0 + b\cdot(i_t - d_t) + v_t. \quad (8)$$

The supply of total reserves equals the sum of nonborrowed (NBR_t) plus borrowed (BR_t) reserves. In turn, borrowed reserves are a function of frictional borrowing, b_0, and the positive spread between the federal funds rate and the discount rate, d_t. The remaining variable, v_t, represents a mean-zero random error term, assumed to be serially uncorrelated for simplicity. In addition, the errors ε_t, e_t, and v_t are assumed to exhibit zero contemporaneous correlation.

Combining the demand for and supply of reserves, (5) and (7), equilibrium in the reserves market can be represented as

$$k\cdot M_{t-2} + w_t = NBR_t + b_0 + b\cdot(i_t - d_t) + v_t. \quad (9)$$

Note that in the reserves market, there is not a direct link between the current federal funds rate, i_t, and the current week's money stock, M_t. Instead, the current federal funds rate depends on the level of the money stock two weeks ago. As a consequence, all of the operating procedures discussed below in this section essentially operate through the demand for money.6/

Regardless of the type of operating procedure, the Federal Reserve sets the short-run target path for money (1) by first predicting the level of the money stock in the previous statement week. Policymakers are assumed to know the level of the money stock in the statement week before last, M_{t-2}, when the short-run path is set. This value also corresponds to the level of the money stock announced in the current week. From the demand for money (2), policymakers then solve for the implied path of the federal funds rate. The next step depends on the particular operating procedure.

In assessing monetary policy at the beginning of a statement week, it is assumed that the public's information set only differs from the Federal Reserve's by the information contained in the weekly money announcement. The public's information set before the money announcement is denoted as Ω_t^b, and after the announcement as Ω_t^a, which includes M_{t-2}. The Federal Reserve bases policy at the beginning of the week on Ω_t^a.

Given these assumptions, the unanticipated component of the money announcement can be calculated. From (2) and (3), the public's expectation of the announced value of money stock is

$$E(M_{t-2}|\Omega_t^b) = a_0 - a\cdot i_{t-2} + \rho\cdot u_{t-3} + \varepsilon_{t-2}. \tag{10}$$

The public observed i_{t-2} two weeks ago, and discovered u_{t-3} during the previous week's money announcement. Thus, from (10), the money announcement surprise equals

$$M_{t-2} - E(M_{t-2}|\Omega_t^b) = M_{t-2}^u = \varepsilon_{t-2}, \tag{11}$$

where M_{t-2}^u denotes unanticipated money. Non-zero values of ε_{t-2} cause the public to reassess the short-run money path (1), and possibly the current week's federal funds rate depending on the operating procedure.

1. Federal Funds Rate Response

The response of the federal funds rate to a money announcement surprise depends on the particular operating procedure in affect. Under the federal funds rate (FFR) procedure, the Federal Reserve is assumed to set the federal funds rate according to

$$i_t = i_t^T + \eta_t, \tag{12}$$

where i_t^T is the level of the federal funds rate consistent with the short-run money target path (1), and η_t represents any discretionary changes relevant to statement week t. It also is assumed that $E(\eta_t|\Omega_t^b) = 0$. That is, the public observes i_t, but it cannot observe or infer i_t^T until after the money announcement.[7/] Because the Federal Reserve sets i_t at the beginning of the week and maintains this level throughout the week, the money announcement surprise (11) has no affect:

$$i_t^a - i_t^b = 0, \tag{13}$$

where i_t^b and i_t^a represent the federal funds rate before and after the money announcement, respectively. To keep the federal funds rate constant in response to the money announcement surprise, nonborrowed reserves are changed by $(k/b)\cdot\varepsilon_{t-2}$ as may be seen by combining (9), (11), and (13).[8/]

Under the nonborrowed reserves (NBR) procedure, policymakers use i_t^T to solve for the target level of NBR_t from (9). Again, this recurssive structure follows from LRR. As before, a discretionary component is allowed, so that actual nonborrowed reserves during the week can be represented as

$$NBR_t = NBR_t^T + \psi_t, \tag{14}$$

where $E(\psi_t|\Omega_t^b) = 0$. Also, following Roley and Walsh (1985), the public is assumed to observe NBR_t. An alternative assumption is adopted below following Nichols and Small (1985), who suggest that money announcements provide information about the supply of reserves.

Under these assumptions, the response of the federal funds rate to money announcement surprises can be determined from (9), (11), and (14):

$$i_t^a - i_t^b = (k/b)\cdot\varepsilon_{t-2} = (k/b)\cdot M_{t-2}^u. \tag{15}$$

In this case, a positive money announcement surprise causes the expected aggregate demand for total reserves (5) to be revised upwards. Given that nonborrowed reserves are constant, the reserves market must clear through an increase in borrowing, which exerts upward pressure on the federal funds rate.

Nichols and Small (1985) characterize the response of the federal funds rate under the NBR procedure somewhat differently. They suggest that the federal funds rate responds to money surprises because of the new information provided about the supply of reserves. Again using (9) and (11), the response of the federal funds rate in this case is

$$i_t^a - i_t^b = (k/b)\cdot\varepsilon_{t-2} - (1/b)\cdot[E(NBR_t|\Omega_t^a) - E(NBR_t|\Omega_t^b)], \qquad (16)$$

which includes both reserves demand and supply effects.[9/] Implicit in (16) is the notion that the public does not observe NBR_t in week t. For convenience, assume $\psi_t = 0$, which implies

$$E(NBR_t|\Omega_t^a) - E(NBR_t|\Omega_t^b) = E(NBR_t^T|\Omega_t^a) - E(NBR_t^T|\Omega_t^b). \qquad (17)$$

That is, changes in the expected level of nonborrowed reserves reflect reassessments about the nonborrowed reserves target path. Using the policy rule (1), the expected demand for money in week t from (2), and reserve market equilibrium (9), the change in the expected target value of NBR_t is

$$E(NBR_t^T|\Omega_t^a) - E(NBR_t^T|\Omega_t^b) = k\cdot\varepsilon_{t-2} - (b/a)[\rho^2 - (1-\lambda)\rho]\varepsilon_{t-2}. \qquad (18)$$

Finally, (17) and (18) can be substituted into (16) to obtain

$$i_t^a - i_t^b = (1/a)\cdot[\rho^2 - (1-\lambda)\rho]M_{t-2}^u. \qquad (19)$$

The response of the federal funds rate is not unambiguously positive in this case. However, the greater the persistence of money demand shocks (ρ), and the more the Federal Reserve offsets deviations from its money target (λ), the larger the response. In any event, the model can easily handle this case. In what follows, the informational assumptions about reserves adopted by Roley and Walsh (1985) will be maintained.

The borrowed reserves (BR) procedure is the final operating procedure to be considered. Under the BR procedure, it is assumed that the Federal Reserve sets

$$BR_t = BR_t^T - \psi_t, \tag{20}$$

where ψ_t is again a discretionary weekly component, entered with a minus sign to make it consistent with that introduced for the NBR procedure. To implement the BR procedure under LRR, the Federal Reserve again determines the target level of the federal funds rate as before. From this value, the target level of borrowed reserves is determined from (8). The Federal Reserve then offsets all movements in the federal funds rate during the week except those from errors in the borrowings function, v_t, by changing nonborrowed reserves. Thus, actual nonborrowed reserves during week t equal

$$NBR_t = E(NBR_t|\Omega_t^b) + \psi_t + k\cdot\varepsilon_{t-2} + w_t. \tag{21}$$

To the extent that the money announcement surprise is not fully offset as in (21), the federal funds rate could respond. In the absence of this behavior, however, movements of the federal funds rate during the week correspond to $-b\cdot v_t$, which is independent of the money surprise. As a result, the federal funds rate response under a pure BR procedure should coincide with that of the FFR procedure (13).

2. Term Structure Response

The response of expected future levels of the federal funds rate is independent of the particular operating procedure used by the Federal Reserve. This is because policy is initially based under all operating procedures on the federal funds rate and its affect on money demand. Even in the current week under the NBR procedure, the observed federal funds rate is expected to be the target level until shocks become apparent.

Consider the response of the expected federal funds rate in some future week, t + j (j=1,2,3,...). From (2), the demand for money in week t+j is

$$M_{t+j} = a_0 - a \cdot i_{t+j} + u_{t+j}. \tag{22}$$

From this expression, the response of the expected federal funds rate may initially be represented as

$$E(i_{t+j}|\Omega_t^a) - E(i_{t+j}|\Omega_t^b) = -(1/a)[E(M_{t+j}|\Omega_t^a) - E(M_{t+j}|\Omega_t^b)]$$

$$+(1/a)[E(u_{t+j}|\Omega_t^a) - E(u_{t+j}|\Omega_t^b)]. \tag{23}$$

Using (3), the second term on the right-hand side of (23) equals $\rho^{j+2}\ \varepsilon_{t-2}$, which represents the persistence of the money demand shock in week t-2. The first term on the right-hand side depends on the assessed change in the short-run money path due to the new information about the money stock in week t-2. In particular, from the policy rule (1),

$$E(M_{t+j}|\Omega_t^a) - E(M_{t+j}|\Omega_t^b) = (1-\lambda)^{1+j}[E(M_{t-1}|\Omega_t^a) - E(M_{t-1}|\Omega_t^b)]. \tag{24}$$

In turn, the revision in the assessment of the previous week's money stock following the M_{t-2} announcement is

$$E(M_{t-1}|\Omega_t^a) - E(M_{t-1}|\Omega_t^b) = \rho \cdot \varepsilon_{t-2} = \rho \cdot M_{t-2}^u. \qquad (25)$$

Combining (23), (24), and (25), the response of the expected future federal funds rate is

$$E(i_{t+j}|\Omega_t^a) - E(i_{t+j}|\Omega_t^b) = (1/a) \cdot [\rho^{j+2} - (1-\lambda)^{1+j} \rho] \cdot M_{t-2}^u \qquad (26)$$

which has an interpretation analogous to that of (19). Finally, using (26) along with (4), the response of the term structure is

$$r_{h,t}^a - r_{h,t}^b = (1/h)(i_t^a - i_t^b) + (1/h) \sum_{j=1}^{h-1} (1/a)[\rho^{j+2} - (1-\lambda)^{1+j} \rho] \cdot M_{t-2}^u. \qquad (27)$$

Given unchanged model parameters, the term structure response across regimes only differs by the first term. For long-term rates, the responses are approximately the same. However, Roley and Walsh (1985) found that parameters changed across the FFR and NBR procedures, and such changes were evident under both the policy anticipations and expected inflation hypotheses.[10/]

II. RESPONSE UNDER CONTEMPORANEOUS RESERVE REQUIREMENTS

The response of interest rates to money announcement surprises under CRR is examined in this section. The response is first analyzed under a one-week CRR system, which includes many of the factors relevant to the two-week CRR case. Then, the two-week CRR system is examined. In both versions of CRR, the reserve computation and maintenance periods are assumed to coincide. Allowing differences of one or two days in these periods should not matter in terms of the effects of money announcements, while these short lags may be important in other applications involving the end of the reserve maintenance period.

A. <u>One-Week CRR</u>

Under one-week CRR, the demand for reserves depends on the current week's money stock, M_t. To reflect this change, equation (5) is respecified as

$$TR_t^D = k \cdot M_t + w_t. \tag{28}$$

Even at this stage, some important differences between the LRR and one-week CRR specifications are apparent. Of primary importance is the fact that the model loses its recursive structure. In particular, equilibrium in the reserves market implies a positive relationship between the current money stock and the current federal funds rate:

$$k \cdot M_t + w_t = NBR_t + b_0 + b \cdot i_t - b \cdot d_t + v_t, \tag{29}$$

which is obtained from (28) and (7).

In setting policy, the Federal Reserve again starts by using the policy rule (1) to find target values for the money stock. Then, given these target values, the monetary authority sets one of its instruments -- either i_t, NBR_t, or BR_t -- from equilibrium values in the money market obtained by combining money demand (2) and supply (29) for the current and future weeks.

In forming assessments about expected money under CRR, the public uses the equilibrium expression for the money stock, found by combining (2) and (29). In this case, the money announcement surprise is:

$$M_{t-2} - E(M_{t-2}|\Omega_t^b) = (\frac{b}{ak+b}) \cdot [\varepsilon_{t-2} - E(\varepsilon_{t-2}|\Omega_t^b)]$$

$$-(\frac{a}{ak+b}) \cdot [e_{t-2} - E(e_{t-2}|\Omega_t^b)], \tag{30}$$

which combines money demand and supply errors.

As indicated in (30), a portion of these errors is predictable under CRR. In particular, the equilibrium expression for the federal funds rate in week t-2 also depends on these errors. Since the value of the federal funds rate in week t-2 was observed, a linear combination of the errors is known:[11/]

$$\varepsilon^*_{t-2} = \left(\frac{k}{ak+b}\right)\varepsilon_{t-2} + \left(\frac{1}{ak+b}\right)e_{t-2}. \tag{31}$$

Using (31), the linear least squares estimates of ε_{t-2} and e_{t-2} are

$$E(\varepsilon_{t-2}|\Omega^b_t) = \frac{(ak+b)\ k\sigma_\varepsilon^2}{(\sigma_e^2+k^2\sigma_\varepsilon^2)}\cdot\varepsilon^*_{t-2}, \tag{32}$$

$$E(e_{t-2}|\Omega^b_t) = \frac{(ak+b)\sigma_e^2}{(\sigma_e^2+k^2\sigma_\varepsilon^2)}\cdot\varepsilon^*_{t-2}, \tag{33}$$

where σ_ε^2 and σ_e^2 denote the unconditional variances of ε_{t-2} and e_{t-2}, respectively. From (31), (32), and (33), the money announcement surprise (30) reduces to

$$M_{t-2} - E(M_{t-2}|\Omega^b_t) = M^u_{t-2} = \varepsilon_{t-2} - E(\varepsilon_{t-2}|\Omega^b_t). \tag{34}$$

The observed linear combination of the errors (31) serves to eliminate their independence. That is, given ε^*_{t-2}, high values of ε_{t-2} imply low values of e_{t-2}, and vice versa.[12/]

1. Federal Funds Rate Response

Under the FFR procedure, the monetary authority finds i^T_t using the method outlined above. As before, this level of the federal funds rate, perhaps including a discretionary component, is maintained throughout the week. Thus, the federal funds rate does not respond to money announcment surprises, as in (13).

Under the NBR procedure, the Federal Reserve uses the expression for the equilibrium value of money to solve for the level of nonborrowed reserves consistent with the target level of the money stock from (1). From the equilibrium expression for the federal funds rate, which can be solved by combining (2) and (29), and using the information about money demand and supply errors (31), the response of the federal funds rate to money announcements is

$$i_t^a - i_t^b = (\frac{k}{ak+b})(\rho^2-\theta^2)\cdot M_{t-2}^u, \qquad (35)$$

where M_{t-2}^u is defined as in (34). In comparison to the LRR case (15), the response of the federal funds rate under the NBR procedure with one-week CRR is unambiguously smaller. Because of CRR, the response depends on the autocorrelations (ρ and θ) of money demand and supply errors. The response also is smaller under CRR due to the offsetting affects of money demand and supply errors.

Under the BR procedure, the Federal Reserve finds the target level of the money stock as before, along with the implied nonborrowed reserves target from the equilibrium expression for money implied by money demand (2) and supply (29). From the equilibrium expression for i_t, also found using (2) and (29), the implied target level of the federal funds rate, i_t^T, is determined. Then, the target level for borrowed reserves is obtained from the borrowings function (8). As before, it is assumed that the federal funds - discount rate spread is used to hit the borrowings target. Under CRR, the federal funds rate again only fluctuates in response to borrowings function errors, v_t, but at a reduced amount equal to $-(1/ak+b)\cdot v_t$.

Thus, under one-week CRR, the BR procedure should yield less volatility in the federal funds rate than under LRR. Moreover, the federal funds rate again does not respond to money announcement surprises in this case as long as all errors except v_t are accommodated.

2. Term Structure Response

To consider the response of the term structure to money announcement surprises under one-week CRR, the same policy rule as before is assumed. In particular, the changed assessment about the short-run money path is given by (24). Based on the new information about M_{t-2}, the public revises its expectation of M_{t-1} according to

$$E(M_{t-1}|\Omega_t^a) - E(M_{t-1}|\Omega_t^b) = (\frac{1}{ak+b})(b\rho + ak\theta)\cdot M_{t-2}^u \tag{35}$$

which is obtained from the equilibrium solution for M_{t-1} and the information about money demand and supply errors (31). From equilibrium in the money and reserves markets, changes in the expected nonborrowed reserves and federal funds rate paths also can be derived. For nonborrowed reserves, the change can be represented as

$$\begin{aligned} E(NBR_{t+j}|\Omega_t^a) - E(NBR_{t+j}|\Omega_t^b) &= (\frac{ak+b}{a})[E(M_{t+j}|\Omega_t^a) - E(M_{t+j}|\Omega_t^b)] \\ &\quad - (\frac{b}{a})[E(u_{t+j}|\Omega_t^a) - E(u_{t+j}|\Omega_t^b)] \\ &\quad + [E(w_{t+j}|\Omega_t^a) - E(w_{t+j}|\Omega_t^b)]. \end{aligned} \tag{36}$$

In turn, the response of the expected future federal funds rate is

$$\begin{aligned} E(i_{t+j}|\Omega_t^a) - E(i_{t+j}|\Omega_t^b) &= -(\frac{1}{ak+b})[E(NBR_{t+j}|\Omega_t^a) - E(NBR_{t+j}|\Omega_t^b)] \\ &\quad + (\frac{k}{ak+b})[E(u_{t+j}|\Omega_t^a) - E(u_{t+j}|\Omega_t^b)] \\ &\quad + (\frac{1}{ak+b})[E(w_{t+j}|\Omega_t^a) - E(w_{t+j}|\Omega_t^b)]. \end{aligned} \tag{37}$$

Combining (24), (35), (36), and (37), the response of the expected federal funds rate in week t+j is

$$E(i_{t+j}|\Omega_t^a) - E(i_{t+j}|\Omega_t^b) = [\frac{\rho}{a}^{j+2} - \frac{(1-\lambda)^{1+j}}{a(ak+b)} (b\rho + ak\theta)] \cdot M_{t-2}^u. \qquad (38)$$

The first term in the brackets on the right-hand side is identical to that of (26), and it reflects the effects of persistent money demand shocks. The second term is the Keynesian liquidity effect. If the short-run money path is raised through positive money shocks, future interest rates will be lower than before. The effect on the term structure can be solved using (4), and the net response depends on the difference of the above two effects along with the response of the current week's federal funds rate. Comparing (38) to (26), the response to money announcement surprises is larger under CRR if $\rho-\theta>0$, and vice versa.

B. Two-Week CRR

The linear form of the model presented thus far is particularly advantageous when investigating a two-week CRR system such as that adopted in February 1984. In this case, the only change involves the demand for total reserves, which is represented as

$$\begin{aligned}(1/2)\cdot(TR_{t+2i} + TR_{t+2i-1})^D &= (1/2)\cdot[(RR_{t+2i} + RR_{t+2i-1}) + (ER_{t+2i} + ER_{t+wi-1})] \\ &= k\cdot(1/2)\cdot(M_{t+2i} + M_{t+2i-1}) \\ &+ (1/2)\cdot(w_{t+2i} + w_{t+2i-1}),\ i=0,1,2,\ldots \qquad (39)\end{aligned}$$

which is specified for nonoverlapping two-week periods.

The Federal Reserve is assumed to implement policy in the same basic way as under one-week CRR. To investigate this case, it is assumed that the public expects CRR to be satisfied subject the random error, w_{t+j}, in both weeks of the reserve maintenance period. In the second week, however, errors from the first week have an affect not only through their use in predicting the current week's money stock, but also through the two-week averages of the demand for and supply of reserves.

1. Federal Funds Rate Response

Under both the FFR and BR procedures, the implementation of monetary policy closely follows the steps outlined in the presence of one-week CRR. Again, the federal funds rate does not respond to money announcement surprises under either procedure. For the BR procedure, however, the lack of response depends on the Federal Reserve accommodating all shocks through changes in nonborrowed reserves, except borrowings function errors, v_t. To the extent that some shocks are not fully accommodated, the response of the federal funds rate may resemble that presented below for the NBR procedure. In any event, the implications of two-week CRR are developed more fully when the NBR procedure is analyzed.

Under the nonborrowed reserves procedure, the federal funds rate response differs across weeks depending on the week of the reserve maintenance period. To start, assume that announced money, M_{t-2}, is for the second week of a reserve maintenance period. Combining reserve demand (39) with reserve supply (7) averaged over the reserve maintenance period implies

$$k\cdot(1/2)\cdot(M_{t-2} + M_{t-3}) + (1/2)\cdot(w_{t-2} + w_{t-3})$$
$$= (1/2)\cdot(NBR_{t-2} + NBR_{t-3})$$
$$+ b_0 + (1/2)\cdot b\cdot i_{t-2} + (1/2)\cdot b\cdot i_{t-3}$$
$$- b\cdot d_t + (1/2)\cdot v_{t-2} + (1/2)\cdot v_{t-3}. \quad (40)$$

Solving (40) for i_{t-2} and substituting into (2) specified for M_{t-2} yields equilibrium money in week t-2. Using this relationship along with (31), the money announcement surprise can be shown to be the same as that derived under one-week CRR, equation (34). This follows because the public knows the values of all variables in (40) except M_{t-2} and w_{t-2}, as was the case with one-week CRR.

The response of the current week's federal funds rate can be found by first solving for the equilibrium level of the funds rate from (2), (39), and total reserve supply for week t (7), where week t also corresponds to the second week of a reserve maintenance period. From the expression for the equilibrium federal funds rate, the response to the money announcement surprise can initially be represented as

$$i^a_{t,2} - i^b_{t,2} = (\frac{k}{ak+b})\cdot[E(u_t|\Omega^a_t) - E(u_t|\Omega^b_t)] + (\frac{k}{ak+b})\cdot[E(M_{t-1}|\Omega^a_t)$$
$$- E(M_{t-1}|\Omega^b_t)] + (\frac{1}{ak+b})\cdot[E(w_t|\Omega^a_t) - E(w_t|\Omega^b_t)]$$
$$+ (\frac{1}{ak+b})\cdot[E(w_{t-1}|\Omega^a_t) - E(w_{t-1}|\Omega^b_t), \quad (41)$$

where $i_{t,2}$ indicates that week t is the second week of a reserve maintenance period. From (41), the money announcement not only affects the federal funds rate through revisions in the current week's money demand and supply errors, u_t and w_t, but also through revisions in the assessments about the previous statement week's money stock level and money supply error. If either of these latter two magnitudes are revised upward, the federal funds rate rises since reserve demand during the two-week period is higher than previously expected, and reserve requirements must be satified by the end of the second week. Given that the market observes i_{t-2}, however, the effects of these errors are not independent. In particular, analogous to the one-week CRR case, the interdependence is described by (31).

Using (3), (6), and (31), the reassessments about the money demand and supply errors in (41) can be evaluated as before. Since week t-1 is the first week of a reserve maintenance period and the public expects CRR to be satisfied during both weeks, the revision in the expected money stock in the previous week is given by (35). As a consequence, the response of the federal funds rate is

$$i^a_{t,2} - i^b_{t,2} = (\frac{k}{ak+b})[(\rho^2 - \theta^2) + (\frac{b}{ak+b})(\rho-\theta)]\cdot M^u_{t-2}. \qquad (42)$$

In comparison to the one-week CRR case (35), the response to money announcement surprises is larger during the second week of a reserve maintenance period if $\rho-\theta>0$, and vice versa.

Now consider the response of the federal funds rate when the money announcement is in the first week of a reserve maintenance period. In this case, the money announcement surprise again corresponds to (34), the surprise under one-week CRR. As before, this follows since the public expects reserve requirements to be satisfied during each week of the reserve maintenance period. Similarly, the federal funds rate response is given by (35), the response under one-week CRR. That is, during the first week of a reserve maintenance period, the previous week's errors do not play a direct role in satisfying the current period's reserve requirements, in contrast to the previous case. Therefore, under the NBR procedure, two-week CRR implies that the response of the federal funds rate to money announcement surprises is larger in the second week of a reserve maintenance period if $\rho-\theta>0$. Moreover, the response in the first week of the reserve maintenance period is smaller than that under LRR (15).[13/] These same results hold for the BR procedure if nonborrowed reserves are not changed to accomodate money announcement surprises.

2. Term Structure Response

Under two-week CRR, the response of expected future spot rates again does not depend on the particular operating procedure used. The response also does not depend on the week of the reserve maintenance period. To examine this case, first consider changes in the assessments about the previous week's money stock, M_{t-1}, which play a key role in determining the term structure response through the monetary policy rule (1).

When weeks t-2 and t are the second weeks of reserve maintenance periods, M_{t-1} is the money stock for the first week of a reserve maintenance period. Thus, the revision in the assessment of M_{t-1} is given by (35), and the response of expected future levels of the federal funds rate is given by (38), the same as one-week CRR.

When weeks t-2 and t are the first weeks of reserve maintenance periods, M_{t-1} is the money stock for the second week. In this case, it may seem that information about M_{t-2} should have a different impact on assessments of M_{t-1} than before because reserve requirements must be satisfied by the end of the second week. This differential impact is, however, negated due to the information about money demand and supply errors contained in the federal funds rate in week t-2 (31). As a consequence, it can be shown that the revision in the assessment of M_{t-1} is again given by (35), and the response of expected future levels of the federal funds rate is represented by (38) as before.

Combining the response of expected future spot rates with that of the current federal funds rate using (4), the response of h-week interest rates under the FFR procedure is larger for two-week CRR than LRR if $\rho-\theta>0$, and vice versa. Moreover, the response under two-week CRR is the same across reserve maintenance weeks. Under the NBR procedure, the term structure response is larger during the second week of a reserve maintenance period than the first week if $\rho-\theta>0$ due to the larger response of the current federal funds rate. In this case, the h-week yield's response in the second week is larger by $(\frac{bk}{h})(\frac{1}{ak+b})^2(\rho-\theta)$. Under the BR procedure, the response again depends on whether the federal funds rate-discount rate spread is strictly used to hit the borrowings target. If the spread is used, the term structure response coincides with that of the FFR procedure. Alternatively, if nonborrowed reserves are not changed to offset the effects of money announcement surprises, the response under the BR procedure coincides with that of the NBR procedure.

III. EMPIRICAL RESULTS

The models developed in preceding sections yield several testable hypotheses about the response of interest rates to money announcement surprises. First, under the FFR procedure in effect prior to October 1979, the federal funds rate should not respond to money announcement surprises. Second, following the implementation of the NBR procedure in October 1979, the federal funds rate should exhibit a positive response, and in this case the response of the term structure should be larger than before. Third, from October 1982 to February 1984, when the BR procedure was used under LRR, the response of the federal funds rate depends on whether nonborrowed reserves were changed to accommodate money announcement surprises. If the federal funds - discount rate spread was exclusively used to hit the borrowed reserves target, the federal funds rate again should not respond. In this instance, the term structure response also would be less than in the October 1979 - October 1982 period. Finally, since February 1984, when the BR procedure was used under CRR, the response of interest rates again should change, with the direction depending on the relative size of the autocorrelations of money demand and supply errors. Moreover, the response also could depend on the particular week of the two-week reserve maintenance period. These hypotheses are examined below, following brief discussions of the empirical specification and data.

A. Specification and Data

Following Grossman (1981) and Urich and Wachtel (1981), the usual efficient markets model is initially used to estimate the response of interest rates to weekly money announcements. This model -- which is exhibited in Table 1 -- is estimated for both the federal funds rate and the 3-month Treasury bill yield. Under the null hypothesis of market efficiency, both the coefficient on the expected announced change in money (β_2) and the constant should equal zero.

The data used in estimating the response of interest rates to money announcement surprises span the periods indicated in the left-hand column of Table 1. The dates correspond to money announcement days. The first observation is for the money announcement on September 29, 1977, and the last observation occurs on May 30, 1985.

The money stock data consist of announced weekly changes in the narrowly defined money stock, in billions of dollars, as reported in the Federal Reserve's H.6 release. Data for the expected announced change in the money stock are based on the survey data compiled by Money Market Services, Inc. These survey data, however, exhibit two potential problems. First, in the pre-October 1979 period, Grossman (1981) estimates a significant additive bias for the survey data. Second, at times the survey data were collected several days before the weekly money announcement. To form an unbiased on informationally efficient measure of the expected change in money, fitted values are taken from estimated equations of the form

$$\Delta M_t = c_0 + c_1 \cdot \Delta M_t^e + c_2 \cdot \Delta RTB_t' + u_t, \qquad (43)$$

where ΔM_t = announced change in the money stock

ΔM_t^e = survey measure of the expected announced change

$\Delta RTB_t'$ = change in the 3-month Treasury bill yield from the first daily observation following the previous money announcement to the daily observation just before the current week's money announcement

u_t = random error term

c_0, c_1, c_2 = estimated coefficients.

The estimation results of equation (45) indicate several biases, including a statistically significant intercept in the pre-October 1979 period and an estimate of c_1 significantly greater than unity in the post-February 1984 period. In addition, the change in the Treasury bill yield prior to the money announcement provided statistically significant information in the October 1979 - October 1982 and October 1982 - February 1984 periods. While the revised measure does not significantly change the estimated responses of interest rates to money announcement surprises, it reduces the statistical significance of expected money in several of the estimated equations.[14/]

The yield data are taken from the H.15 release, published by the Federal Reserve. The change in the 3-month Treasury bill yield is measured from 3:30 P.M. on the day of a money announcement to 3:30 P.M. on the following business day. The change in the federal funds rate is defined similarly, except that it is a daily-averaged figure. Nevertheless, it predominately reflects federal funds trading prior to 3:30 P.M. Thus, any effects of money announcements -- which are made at 4:10 P.M. -- should be reflected in the measured yields.

B. Estimation and Test Results

Estimation results of the efficient markets model for the federal funds rate and the 3-month Treasury bill yield over four subperiods are presented in Table 1. The estimated response of the federal funds rate to money announcement surprises is not statistically significant in the pre-October 1979 period, as expected under the FFR operating procedure.

In the October 1979 - October 1982 period, the results indicate that the federal funds rate increased 10 basis points in response to a positive $1 billion money announcement surprise. This estimated response is consistent with the NBR operating procedure. In the two post-October 1982 subperiods, the estimated response is once again insignificant. For the October 1982 - February 1984 period, this result suggests that the federal funds - discount rate spread was used in implementing the BR procedure. The February 1984 - May 1985 period is examined in more detail below.

Estimation results for the 3-month Treasury bill yield indicate that the response is statistically significant at the 5 percent level in three of the four periods. The estimated response increases in the October 1979 - October 1982 period, and then declines in the subsequent period. This pattern is consistent with that of the federal funds rate. In the February 1984 - May 1985 period, the response is insignificantly different from zero. Again, this period is examined in more detail below. Finally, the coefficient on expected money is statistically significant at the 5 percent level in the October 1979 - October 1982 period. This result appears to be due to the measurement of the change in the 3-month Treasury bill yield over at least a 24-hour period rather than the 1½-hour period used by Roley (1983).[15/] While this result, along with the presence of statistically significant constant terms in some regressions, is inconsistent with the efficient markets hypothesis, it has no affect on the estimated responses to money announcement surprises. In particular, the revised measure used for expected money is constructed to be orthogonal to the money announcement surprise.

Changes in the interest-rate responses across different monetary policy regimes are formally tested on the right-hand side of Table 1.[16/] For both the federal funds rate and the 3-month Treasury bill yield, the estimated responses are significantly different at the 5 percent level across the first three periods. In the post-February 1984 period, only the 3-month Treasury bill yield response is significantly different from that of the previous period. In this case, the adoption of CRR apparently affected the estimated response, which is consistent with the theoretical model presented in the previous section.

1. Further Results for the Post-February 1984 Period

As indicated in the previous section, the standard empirical specification used to investigate the response of interest rates may no longer be appropriate. Instead, the response may depend on the particular week of the two-week reserve maintenance period. This implication follows from (42) for the NBR procedure under two-week CRR. For the BR procedure, the possibility of different responses across weeks depends on whether the BR procedure is more like the NBR or FFR procedures.

The response of interest rates to money announcement surprises under CRR is estimated separately for the first and second weeks of reserve maintenance periods in Table 2.[17/] For the federal funds rate, the response to money announcement surprises in the second week is substantially larger than that in the first week. The difference, however, is not statistically significant at the 10 percent level. Combined with the results in Table 1, this lack of significance suggests that the BR procedure is essentially implemented using the federal funds rate-discount rate spread.

For the Treasury bill yield, the estimated responses to money announcement surprises again are uniformly insignificant at the 10 percent level. The point estimates, however, exhibit a pattern similar to that of the federal funds rate. The hypothesis that responses differ across the two-week reserve maintenance period can nevertheless be rejected at the 10 percent level.

IV. SUMMARY OF CONCLUSIONS

This paper analyzed the response of interest rates to money announcement surprises under alternative Federal Reserve operating procedures and reserve requirement systems. In the theoretical models developed, not only changes in operating procedures, but also reserve requirement systems, were found to potentially affect the response. Moreover, under the current two-week contemporaneous reserve requirements (CRR) system adopted in February 1984, the responses in the first and second weeks of the two-week reserve maintenance period may differ.

The empirical results generally conformed to the predictions of the theoretical models. The response of interest rates to money announcement surprises increased following the introduction of the nonborrowed reserves procedure in October 1979, and then declined following the adoption of the borrowed reserves procedure in October 1982. Furthermore, following the introduction of CRR in February 1984, the response of the Treasury bill yield again changed significantly in comparison to the response in the previous period.

Footnotes

*Associate professor of finance, University of Washington, and research associate, National Bureau of Economic Research. I am grateful to Michael R. Darby, Robert H. Rasche, Gordon H. Sellon, and Carl E. Walsh for helpful comments and to the National Science Foundation (Grant No. SES-8408603) for research support.

1. Cornell (1983b) and Roley and Troll (1983) also discuss this hypothesis. In examining the response of short-term interest rates to unanticipated announced changes in measures of real economic activity directly, however, Roley and Troll (1983) do not find any significant responses.

2. This policy rule differs from that proposed by Roley and Walsh (1985) in that all deviations are expected to be offset for $0 < \lambda < 1$. Roley and Walsh (1985) allow the possibility that some fraction of the deviation is accomodated, but in their empirical results the corresponding parameter has an estimated value of zero.

3. Roley and Walsh (1985) use the 13-week yield as the opportunity cost of holding money, mainly due to the emphasis placed on term structure effects. The same factors as before are important when the federal funds rate replaces the 13-week yield.

4. A high degree of serial correlation also is evident in quarterly money demand equations specified in level form without partial adjustment. See Roley (1985b).

5. Because of the insignificant role of w_t under LRR, Roley and Walsh (1985) assume $w_t = 0$.

6. This property also is emphasized by LeRoy (1979) and Hetzel (1982). Shock absorber effects and other effects originating on the asset side of banks' portfolios are not captured in this simplified model under LRR. See Carr and Darby (1981) and Judd and Scadding (1981). Shocks to reserves do, however, play a role in the CRR versions of the model.

7. To dampen the volatility of the federal funds rate over time, for example, policymakers may elect to set i_t at a level different from i_t^T. This adjustment in (12) is analogous to adding an additive mean-zero stochastic term to the policy rule (1). This discretionary term also is implicitly assumed to have an infinite variance so that the public cannot infer M_{t-2} from the current week's federal funds rate. The discretionary components for the nonborrowed reserves and borrowed reserves procedures are assumed to have the same property. Alternatively, the results are essentially unchanged if it is assumed that both policymakers and the public have the same information sets and that M_{t-2} is revealed to both groups at the time of the money announcement.

8. Some clarification concerning the timing implicit in the model may be useful. The model basically includes three intra-weekly periods: the period prior to the money announcement, the money announcement period, and the period following the money announcement when v_t is revealed. Similar timing is assumed in the subsequent CRR models. To simplify the model, the response of the federal funds rate, $i_t^a - i_t^b$, represents both the change on the announcement day and the change in the weekly average. If this distinction is instead taken into account explicitly, the response of the federal funds rate under the nonborrowed reserves procedure discussed below would differ by a scalar.

9. To consider the extreme case in which the aggregate demand for reserves is known with certainty, the first term on the right-hand side is dropped.

10. In particular, the interest reponsiveness of the demand for money is estimated to decline in the post-October 1979 period, coinciding with the rise in interest-rate volatility under the NBR procedure. The link is further analyzed by Walsh (1984).

11. I am indebted to Carl Walsh for this observation.

12. This dependence follows directly from (31), which further implies $e_{t-2} - E(e_{t-2}|\Omega_t^b) = -k\cdot[\varepsilon_{t-2} - E(\varepsilon_{t-2}|\Omega_t^b)]$.

13. The relative size of the LRR response (15) and the response in the second week of the reserve maintenance period (42) depends on a number of parameters.

14. For further details concerning the revised expected money measure, see Roley (1983). For a discussion of the relative merits of this measure, see Hein (1985) and Roley (1985a).

15. Falk and Orazem (1985) report that with the unadjusted survey measure, the statistical significance of expected money is not sensitive to the interval used to measure the change in interest rates. Using the revised measure for expected money, however, this appears not to be the case.

16. To avoid potential problems associated with heteroscedasticity, the equations in each of the periods are weighted by the reciprocals of their estimated standard errors in the tests. The equations also are specified without expected money.

17. Interest rate responses also were estimated using the difference between the logarithm of the announced money stock and the logarithm of the expected money stock. These specifications yielded results qualitatively similar to those reported in Table 2. Estimation results also were obtained for specifications including expected money. In an equation with coefficients on money surprises and expected money allowed to differ depending on the week of the reserve maintenance period, the response of the federal funds rate to money surprises was significant at the 10 percent level in the second week. The hypothesis that the responses are the same, however, could not be rejected at the 10 percent level.

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TABLE 1

Response of Interest Rates to Money Announcement Surprises

$$\Delta RFF_t = \beta_0 + \beta_1 \cdot UM_t + \beta_2 \cdot EM_t + \xi_t$$

Estimation Period	Coefficient Estimates			Summary Statistics			F-tests Across Periods	
	β_0	β_1	β_2	$\bar{R}^2$	SE	DW	F(n,m)	Periods
Sept. 29, 1977– Oct. 4, 1979(S1)	0.0045 (0.0090)	0.0037 (0.0059)	-0.0051 (0.0061)	-.01	.09	1.89	--	--
Oct. 11, 1979– Oct. 1, 1982(S2)	0.0692 (0.0531)	0.1005* (0.0242)	-0.0175 (0.0313)	.09	.64	2.50	15.22* (1,258)	S1,S2
Oct. 8, 1982– Jan. 27, 1984(S3)	0.0484** (0.0269)	0.0148 (0.0128)	0.0007 (0.1228)	-.01	.20	1.70	9.80* (1,221)	S2,S3
Feb. 3, 1984– May 30, 1985(S4)	-0.1027* (0.0308)	0.0207 (0.0187)	-0.0220** (0.0120)	.04	.24	1.50	0.08 (1,135)	S3,S4

$$\Delta RTB_t = \beta_0 + \beta_1 \cdot UM_t + \beta_2 \cdot EM_t + \xi_t$$

Estimation Period	β_0	β_1	β_2	$\bar{R}^2$	SE	DW	F(n,m)	Periods
Sept. 29, 1977– Oct. 4, 1979(S1)	0.0252* (0.0095)	0.0184* (0.0062)	-0.0080 (0.0064)	.07	.10	1.63	--	--
Oct. 11, 1979– Oct. 1, 1982(S2)	0.0749* (0.0283)	0.0851* (0.0129)	-0.0356* (0.0167)	.23	.34	1.93	21.37* (1,258)	S1,S2
Oct. 8, 1982– Jan. 27, 1984(S3)	0.0118 (0.0130)	0.0342* (0.0062)	-0.0043 (0.0059)	.30	.10	1.81	12.73* (1,221)	S2,S3
Feb. 3, 1984– May 30, 1985(S4)	0.0092 (0.0119)	-0.0007 (0.0072)	-0.0042 (0.0046)	-.02	.09	1.84	12.37* (1,135)	S3,S4

* Significant at the 5 percent level.

** Significant at the 10 percent level.

TABLE 1 (continued)

ΔRFF, ΔRTB = change in the federal funds rate and the 3-month Treasury bill yield, respectively, from 3:30 P.M. on the day of the money announcement to 3:30 P.M. on the following business day (Source: Board of Governors of the Federal Reserve System, H.15).

UM = money announcement surprise, defined as ΔM - EM, where ΔM is the announced change in the narrowly defined money stock, in billions of dollars (Source: Board of Governors of the Federal Reserve System, H.6).

EM = expected announced change in the narrowly defined money stock, based on the survey measure provided by Money Market Services, Inc.

ξ_t = random error term.

$\bar{R}^2$ = multiple correlation coefficient connected for degrees of freedom.

SE = standard error.

S1,S2,S3,S4 = sample periods 1, 2, 3, and 4.

F(n,m) = F-statistic with n and m degrees of freedom, respectively.

TABLE 2

Response of Interest Rates to Money Announcements Under CRR

$$\Delta R_t = \beta_0 + \beta_{11} \cdot UM_{t1} + \beta_{12} \cdot UM_{t2} + \xi_t$$

Dependent Variable	Coefficient Estimates β_0	β_{11}	β_{12}	Summary Statistics $\bar{R}^2$	SE	DW	$H_0: \beta_{11} = \beta_{12}$ F(n,m)
ΔRFF	-0.1267* (0.0300)	0.0026 (0.0294)	0.0351 (0.0252)	-.00	.25	1.65	0.70 (1,67)
ΔRTB	0.0052 (0.0114)	-0.0006 (0.0112)	0.0019 (0.0096)	-.03	.09	1.86	0.03 (1,67)

Notes: For further variable definitions, see the notes in Table 1. The subscripts t1 and t2 denote the first and second weeks of reserve maintenance periods, respectively. UM_{t1}, for example, takes values equal to UM_t for the first week of reserve maintenance periods, and zero otherwise.