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THE RESPONSE OF SHORT-TERM INTEREST RATES TO WEEKLY MONEY ANNOUNCEMENTS

V. Vance Roley

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ABSTRACT

The response of short-term interest rates to weekly money announcements since the Federal Reserve's change in operating procedures on October 6, 1979, is examined in this paper. The results indicate that the response increased significantly since October 1979, and that it varies nonlinearly according to the relation of money growth to the Federal Reserve's long-run targets. The results also suggest that the increase in the response and the rise in the volatility of unanticipated money have contributed about equally to the large rise in interest rate volatility during this period.

V. Vance Roley
Federal Reserve Bank of Kansas City
925 Grand Avenue
Kansas City, Missouri 64198
(816) 881-2959

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THE RESPONSE OF SHORT-TERM INTEREST RATES TO WEEKLY MONEY ANNOUNCEMENTS

V. Vance Roley*

Each Friday at 4:10 p.m., e.s.t., the Federal Reserve announces its estimate of the narrowly defined money stock for the statement week ending nine days previously. These money announcements have become one of the main events in financial markets if for no other reason than the fact that significant movements in interest rates have been associated with large unanticipated changes in the money stock. Moreover, since the late 1970s interest rate fluctuations in response to money stock announcements have dramatically increased. Over the 1 1/2 hour intervals spanning the weekly announcements, for example, the variance of the change in the 3-month Treasury bill yield in the two years since October 1979 is more than 30 times larger than that of the previous two-year period.[1/]

Two factors may account for a large portion of the increased volatility of short-term interest rates. First, on October 6, 1979, the Federal Reserve adopted a reserve-aggregate approach to monetary control replacing a procedure which emphasized stability of short-term yields. Second, despite the greater emphasis placed on monetary control, the variance of weekly announced changes in the money stock has risen by about 65 percent since late 1979. In turn, if greater volatility of announced changes makes future changes more difficult to predict, the volatility of unanticipated weekly changes in money would have also increased.[2/] Thus, if financial markets are efficient and if weekly money announcements contain relevant information, larger unanticipated changes in money may have caused larger fluctuations in interest rates.

The purpose of this paper is twofold. First, the basic linear model advanced by Berkman [1], Mishkin [11], Grossman [8], and Urich and Wachtel [20] to investigate the impact of unanticipated changes in money on interest rates is extended. The generalized model allows the most recent week's unanticipated change in money as well as revisions to the previous week's announced level to affect interest rates. The model also relaxes the linearity assumption, and, following Urich and Wachtel [19], distinguishes among unanticipated money changes according to the relationship of the money stock to the Federal Reserve's targets. Second, the generalized model is used to estimate the relative contributions of the change in the market's responsiveness to unanticipated changes in money and the increase in the volatility of unanticipated changes in explaining the rise in interest rate volatility since October 6, 1979. To anticipate these results, the increase in market responsiveness is found to account for about 30 percent of the increased volatility of the 3-month Treasury bill yield, and the rise in the volatility of unanticipated changes in money is estimated to account for another 25 percent. In previous studies using simple linear models, the percentage increases associated with these two sources have ranged from about 28 to 35 percent and 2 to 7 percent, respectively. (See Evans [4] and Roley [16].)

In the first section of this paper, the specification, data, and estimation results of the basic linear model are presented and compared to previous studies. The estimation and test results of the generalized model are discussed in the second section. In the third section, the implications of the Federal Reserve's change in its monetary control procedures are investigated. The main conclusions of this paper are summarized in the final section.

I. The Basic Model

In this section, the efficient markets hypothesis is used to motivate a simple linear model of the response of short-term interest rates to unanticipated weekly changes in money. Following the discussion of the important features of this specification, the data and estimation results are presented. The estimated equations are then contrasted to those reported in previous studies, and the estimated responses in the pre- and post-October 1979 periods are compared.

Specification

The notion that financial markets are efficient has been frequently employed to model the behavior of interest rates.[3/] In the specific case involving the response of short-term interest rates to unanticipated weekly changes in money, the efficient markets hypothesis has two main implications. First, immediately prior to a money announcement, the market uses all information which is costlessly available in setting interest rates, including the expected money stock announcement. Thus, any change in money market yields immediately following a money announcement should not be correlated with information which was previously available. Second, if the announced weekly change in money differs from the market's expectation, and if the new information is relevant, money market yields will move to new equilibrium levels shortly after the announcement.

Assuming interest rate responses are linear, these consequences of the efficient markets hypothesis imply [4/]

$$\Delta R_t = b \cdot (\Delta M_t - \Delta M_t^e) + e_t \qquad (1)$$

where ΔR_t = change in the short-term yield over a time interval including the money stock announcement in week t

ΔM_t = announced weekly change in the narrowly defined money stock in week t

ΔM_t^e = market's rational expectation of the announced weekly change in the narrowly defined money stock in week t b = estimated coefficient

e_t = random error term uncorrelated with any information available to the public prior to the money announcement in week t.

The coefficient in this equation reflects the movement in short-term yields associated with an unanticipated weekly change in money. Under the pre-October 1979 monetary-control procedures used by the Federal Reserve, previous studies have found that this estimated response was positive. (See Berkman [1], Grossman [8], and Urich and Wachtel [20].) If an announcement was higher than expected during this regime, for example, the observed rise in short-term yields most likely resulted from the market's assessment that the Federal Reserve would try to offset at least part of the unanticipated rise. Under the new monetary control procedures, the estimated response would also be expected to be positive, and two factors may cause it to be somewhat larger than before. First, under the reserve-aggregate approach, excess demand for reserves at a given level of money market yields is not accommodated by increasing nonborrowed reserves. In turn, with lagged reserve accounting, the new information provided by a larger-than-anticipated weekly increase in money may cause investors to revise upwards their expectation of the aggregate demand for reserves through Wednesday of the current statement week. Thus, with a fixed supply of non-borrowed reserves, investors might expect short-term yields to rise in this case to equilibrate the market for reserves. Second, in conjunction with the adoption of the reserve-aggregate approach, the market may have detected a greater commitment on the part of the Federal Reserve to offset unanticipated fluctuations in money growth. Thus, for both of these reasons, the change in policy regimes makes the Lucas [10] critique relevant.

Another feature of the model (1) also deserves comment. In particular, to estimate the effects of unanticipated changes in money, the time interval used to measure changes in interest rates either should be short, or innovations in other relevant economic variables should be included in the specification. The former approach is employed by Berkman [1], Grossman [8], and Urich and Wachtel [20], while the latter is adopted by Mishkin [11].5/ In the studies by Berkman [1] and Urich and Wachtel [20], however, changes in interest rates from 3:30 p.m. on Thursday to either 10:30 a.m. or 3:30 p.m. on Friday are used to estimate the impact of Thursday money announcements. In this case it can be easily shown that if the money surprise causes investors to revise their expectations about other relevant economic data typically announced on Friday at 9:00 a.m.—such as the unemployment rate and the consumer price index—then the estimated response will be biased. Biases could also be present in Mishkin's [11] estimates because of the failure to include surprises in all relevant data. However, Mishkin's use of quarterly data makes this a virtually impossible task. Because of the importance of collecting adequate data, the data used here are discussed in some detail below.

Data

All of the data described below are weekly and span the period beginning on September 29, 1977, and ending on November 20, 1981. For the subsample beginning on September 29, 1977, and ending on October 11, 1979, three of the 106 observations are excluded due to discount rate changes on the day of a money announcement. In the post-October 6, 1979, subsample, six of the 111 observations are omitted due to four discount rate changes and two dates with missing values for one of the series.

Changes in the Money Stock. 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. Both a revised estimate of the previous week's announced level and the change in money for the statement week ending on Wednesday of the previous calendar week are reported. The data from September 29, 1977, through January 31, 1980, correspond to "old M1," and weekly changes were announced on Thursday. From February 8, 1980, through November 20, 1981, weekly money announcements were made on Friday, and they were in terms of M1-A and M1-B. Announced changes in M1-B are analyzed here because of the emphasis placed on M1-B by Federal Reserve policymakers and market participants. Also, it should be noted that the M1-B data for 1981 are those for nonshift-adjusted money balances.[6/]

Because of the changes in both policy regimes and money definitions, the data are divided into three subsamples. The first corresponds to pre-October 6, 1979, weekly announced changes in M1. Weekly changes in M1 in the post-October 6, 1979, period comprise the second subsample. The third subsample corresponds to announced weekly changes in M1-B.

Expected Changes in the Money Stock. Because the efficient markets hypothesis implies that only unanticipated changes in money cause movements in interest rates at the time of an announcement, some measure of the market's expectation must be obtained. A convenient source of this expectation is the data constructed by Money Market Services, Inc., which surveys about 60 money market participants each week.[7/] Prior to February 8, 1980, surveys were conducted twice each week, on Tuesday and Thursday. Since this time the survey has been conducted only once each week, on Tuesday. For the period ending on February 8, 1980, the median of the Thursday survey is used to represent the market's anticipated money announcement on each Thursday. For the remainder of the sample, both the median of the Tuesday survey and a revised expectation reflecting the availability of new information from Tuesday to Friday are used for each Friday's money announcement.

The estimated equation used to form the revised expectation is reported in the first row of Table 1. The revised expectation is defined to equal the fitted values of the regression of the announced change in money at 4:10 p.m. on Friday on the survey measure and the change in the 3-month Treasury bill yield from Tuesday at 3:30 p.m. to Friday at 3:30 p.m. The change in the 3-month bill yield is taken as a proxy representing the receipt of all new information during this period. The test results reported in the last column indicate that the change in the bill yield adds significant information to the survey measure.

Both the survey measure and the revised expectation are subjected to three tests in the remaining rows of Table 1.[8/] First, the unbiasedness of the survey data is examined. If the survey data are rational, no systematic bias should be evident. The test results indicate that unbiasedness cannot be rejected at the 5 percent level of significance, although it can be rejected at the 10 percent level. A similar test is not reported for the revised expectation measure since it is unbiased by construction.

Second, the efficiency of both the survey and revised expectations measure is tested. Following Modigliani and Shiller [12], the basic notion behind this concept is that if weekly changes in money are generated by an autoregressive process, the market's expectation should be generated by the same process. Thus, coefficients on lagged values of weekly changes in money in a regression with $\Delta M_t - \Delta M_t^e$ as the dependent variable should be insignificantly different from zero.[9/] As indicated in equations (1.3) and (1.4) in the table, the null hypothesis cannot be rejected at reasonable significance levels for either of the expectations measures.

Finally, the forecast performances of the two expectations measures are compared to that of an autoregressive model. Because the autoregressive model is

Table 1
RATIONALITY OF THE SURVEY DATA
(February 1980-November 1981)

Revised Expectation $\Delta M_t = b_0 + b_1 \cdot \Delta M^e_t + b_2 \cdot (R_{F,t} - R_{Tu,t}) + e_t$

	Coefficient Estimates*			Summary Statistics			Test/Forecast (H_0: $b_0=b_2=0, b_1=1$)	
	b_0	b_1	b_2	$\bar{R}^2$	SE	DW(2)	F(3,89)	MS
(1.1)	0.0099 (0.2469)	1.5127 (0.2162)	1.0719 (0.4171)	.36	2.23	1.81	3.9384	.0110

Unbiasedness $\Delta M_t = b_0 + b_1 \cdot \Delta M^e_t + e_t$

	b_0	b_1	$\bar{R}^2$	SE	DW(0)	F(2,92) (H_0: $b_0=0, b_1=1$)	MS
(1.2) Survey	-0.0942 (0.3806)	1.5152 (0.2174)	.34	2.28	1.83	2.8812	.0596

Efficiency $\Delta M_t - \Delta M^e_t = b_0 + b_1 \cdot \Delta M_{t-1} + b_2 \cdot \Delta M_{t-2} + b_3 \cdot \Delta M_{t-3} + e_t$

	b_0	b_1	b_2	b_3	$\bar{R}^2$	SE	h	F(4,87) (H_0: $b_0=b_1=b_2=b_3=0$)	MS
(1.3) Survey	0.1593 (0.2620)	-0.1244 (0.0945)	-0.0019 (0.0984)	-0.0736 (0.0943)	-.01	2.37	1.10	0.5296	.7172
(1.4) Revised	-0.0060 (0.2546)	0.0012 (0.0911)	0.0094 (0.0945)	-0.0438 (0.0915)	-.03	2.27	1.75	0.0790	.9854

Forecasts
Autoregressive $\Delta M_t = b_0 + b_1 \cdot \Delta M_{t-1} + b_2 \cdot \Delta M_{t-2} + b_3 \cdot \Delta M_{t-3} + e_t$

	b_0	b_1	b_2	b_3	$\bar{R}^2$	SE	h	Forecast RMSE
(1.5) Auto-regressive	0.7209 (Q.2935)	-0.3912 (0.1059)	-0.2299 (0.1103)	-0.1723 (0.1057)	.12	2.65	0.43	2.59
(1.6) Survey								2.25
(1.7) Revised								2.19

*Standard errors of estimated coefficients in parentheses.

ΔM_t = announced weekly change in narrowly defined money in week t, in billions of dollars (Source: Board of Governors of the Federal Reserve System, H.6.)

ΔM^e_t = expectation of announced weekly change in narrowly defined money in week t, in billions of dollars (Source: Money Market Services, Inc.)

$R_{F,t}$ = average of the bid and ask quotations on the 3-month Treasury bill yield at 3:30 p.m. on Friday in week t, in percent (Source: Federal Reserve Bank of New York, "Quote Sheet of Closing Rates.")

$R_{Tu,t}$ = average of the bid and ask quotations on the 3-month Treasury bill yield at 3:30 p.m. on Tuesday in week t, in percent (Source: Federal Reserve Bank of New York, "Quote Sheet of Closing Rates.")

e_t = random error term

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

SE = standard error

DW(i) = Durbin-Watson statistic adjusted for i gaps

h = Durbin's h statistic

h′ = t statistic on autocorrelation coefficient in the regression suggested by Durbin [3] when $1-V(b_1)\cdot N_3<0$, where N_3 = number of observations in the third subsample

MS = marginal significance level, which is the probability of obtaining that value of the F statistic or higher under the null hypothesis (H_0)

RMSE = root-mean-square error

estimated over the entire forecast period, its root-mean-square error (RMSE) is actually understated. Nevertheless, in contrast to other survey data, the survey data used here exhibit a lower root-mean-square error than the simple autoregressive model.[10/] Again by construction, the revised expectation measure registers a better performance than the survey measure.

Interest Rates. Following Grossman [8], the change in short-term interest rates in response to an unanticipated weekly change in money is represented by the difference in 3-month Treasury bill yield from 3:30 p.m. to 5:00 p.m. on the day of a money announcement. The yield data for 3:30 p.m. are taken from a daily release prepared by the Federal Reserve Bank of New York, "Quote Sheet of Closing Rates." The 5:00 p.m. data are taken from the Telerate data base. Both series are converted to coupon-equivalent yields, in percent, and the average of the bid and ask quotes is used.

Because the two yield series are taken from different sources, the consistency of the two series is examined. To investigate their consistency, an implication of the efficient markets hypothesis is used to form a test—i.e., that the 3-month yield follows a random walk over the 1 1/2 hour period. In a specification analogous to that used for the unbiasedness test in Table 1, the hypothesis that the bill yield follows a random walk cannot be rejected at the 5 percent level of significance. Moreover, in the two post-October 1979 subsamples, the marginal significance levels are both over 30 percent, while in the first subsample it equals about 10 percent.[11/] Thus, on the basis of these tests, it appears that the data from these two sources are consistent.

Empirical Results

Estimation results of the basic linear model are presented on the top half of Table 2. In addition to a variable representing unanticipated money, the equations include both a constant term and a measure of anticipated money

Table 2
EMPIRICAL RESULTS OF THE BASIC MODEL*

$$\Delta R_t = b_0 + b_1 \cdot (\Delta M_t - \Delta M_t^e) + b_2 \cdot \Delta M_t^e + e_t$$

	Estimation Period	NOB	Coefficient Estimates b_0	b_1	b_2	Summary Statistics $\bar{R}^2$	SE	DW(1)	Test Statistics† H_0: $b_0=b_2=0$ F-Statistic	MS	Chow Test F-Statistic	MS	Goldfeld-Quandt F-Statistic	MS
(2.1)	9/29/77-10/04/79 (I)	103	-0.0027 (0.0045)	0.0065‡ (0.0025)	-0.0014 (0.0031)	.05	.039	1.79(3)	0.54(2,100)	.59	1.42(3,97)	.24	0.91(31,31)	.61
(2.2)	10/11/79-1/31/80 (II)	17	0.0014 (0.0205)	0.0510‡ (0.0161)	-0.0070 (0.0223)	.34	.083	1.90(0)	0.50(2,14)	.95	0.47(3,11)	.71	2.49(3,3)	.24
	2/08/80-11/20/81(III)													
(2.3)	Survey	88	0.0160 (0.0230)	0.0657‡ (0.0096)	-0.0531† (0.0210)	.34	.207	2.01(6)	3.22(2,85)	.04	1.49(3,82)	.22	1.99(26,26)	.04
(2.4)	Revised	88	0.0078 (0.0224)	0.0692‡ (0.0099)	-0.0106 (0.0128)	.35	.205	1.91(6)	0.36(2,85)	.70	1.10(3,82)	.36	1.63(26,26)	.11

$$\Delta R_t = b_1 \cdot (\Delta M_t - \Delta M_t^e) + e_t$$

Test: b_1 equal across periods†

Test for Periods	F-Statistic	MS
I, II, and III (Survey)	18.0586(2,205)	(§)
I, II, and III (Revised)	22.5002(2,205)	(§)
I and II	8.5661(1,205)	.0039
II and III (Survey)	0.2452(1,205)	.6268
II and III (Revised)	1.0208(1,205)	.3147
I and III (Survey)	28.6978(1,205)	(§)
I and III (Revised)	37.7133(1,205)	(§)

*See the notes in Table 1.
†Numbers of parentheses are degrees of freedom in the F test.
‡Estimated coefficient is more than twice its standard error.
§Less than 0.0001.
ΔR_t = change in the average of the bid and ask quotations on the 3-month Treasury bill yield from 3:30 p.m. to 5:00 p.m. on the day of the money announcement, in percentage points (Sources: Federal Reserve Bank of New York, "Quote Sheet of Closing Rates," and Telerate data base.)
NOB = Number of observations in the estimation period

in order to evaluate the efficient markets hypothesis. This basic form of the model is estimated over the three subsamples described above. Again, the first subsample comprises all of the available survey data prior to October 6, 1979, and the post-October 6, 1979, period is divided into two subsamples corresponding to Thursday M1 announcements and Friday M1-B announcements.[12/] In the latter of these subsamples, two equations are estimated—one using the Tuesday survey measure and the other using the revised expectation measure which includes new information from Tuesday to Friday.

The estimation results indicate that the relationship between unanticipated changes in money and changes in the 3-month Treasury bill yield is statistically significant in each of the subsamples. Also, with one exception, the hypothesis that only unanticipated money affects the movement in the bill yield cannot be rejected at high levels of significance. Moreover, specification tests of equations (2.1), (2.2), and (2.4) reported in the last two columns of the table do not reveal any significant structural shifts or heteroscedasticity problems.

In contrast to these results, equation (2.3)—which is estimated using the unadjusted survey measure—has several undesirable characteristics. In particular, the effect of anticipated money is statistically significant at the 5 percent level. As a result, the hypothesis that only unanticipated money matters can be rejected at low significance levels. Furthermore, the results of the Goldfeld-Quandt test indicate that the null hypothesis of homoscedasticity can also be rejected. At least in part, these results motivate the use of the revised expectation.

The individual coefficient estimates in Table 2 support the view that the 3-month Treasury bill yield has become more responsive to unanticipated announced changes in money since October 6, 1979. In particular, a $1 billion money surprise in the first period is associated with a 0.7 basis point rise in the bill yield, while in the third period the response rises substantially to about 7 basis points. The hypothesis that the response coefficients are the same across periods is formally tested on the bottom half of Table 2. The estimated equations used for the tests are based on the specification in which only unanticipated money matters.[13/] The test results indicate that the null hypothesis can be uniformly rejected when comparing the estimated response in the first period to that of either the second or third periods, or both. Thus, the empirical results of the basic linear model suggest that the Federal Reserve's change in its monetary-control procedure may have significantly affected the responsiveness of short-term rates to unanticipated announced changes in money.

Comparison to Previous Studies

As mentioned above, several studies have previously examined the responsiveness of short-term interest rates to unanticipated weekly changes in money in the pre-October 1979 period. Of these studies, the methodologies employed by Grossman [8] and Urich and Wachtel [20] correspond most closely to that used here. Thus, as a check on the robustness of the estimates to slight variations in data and sample size, a comparison to their estimates is presented.

Apart from an apparent difference in sample size and the possible use of quoted bids on Treasury bills, Grossman's estimation results should correspond exactly to those presented here for the pre-October 1979 period.[14/] Urich and Wachtel's results, however, may differ because of their use of yield data collected on Fridays at 10:30 a.m. instead of Thursdays at 5:00 p.m. The estimates reported in these studies, and their attempted replications, are presented in Table 3. On the top half of the table, estimates of the basic linear model are compared. In terms of Grossman's results (3.1), the replication (3.2) yields qualitatively similar estimates, but the degree of disparity is nevertheless puzzling.[15/] The disaggregation of money surprises into positive and negative components sheds some light on the source of this difference, as it appears that the disparity may result from the estimated effects of negative surprises.

The difference in estimation results in comparison to Urich and Wachtel's study is even more striking. In particular, they find that anticipated money is a statistically significant determinant of the change in the bill yield from Thursday at 3:30 p.m. to Friday at 10:30 p.m. Moreover, both positive and negative surprises are statistically significant, as is apparent in the bottom of the table.

II. Extensions to the Basic Model

In this section, the basic linear model is generalized in several directions. First, an additional term is included in the specification to test the possibility that revisions to the previous week's announced level of the money stock affect short-term interest rates. Second, the possibility that interest rates respond nonlinearly to unanticipated changes in money is examined. Finally, the degree of interest rate responsiveness is allowed to vary depending on the relation of the observed money stock to the Federal Reserve's monetary aggregate targets.

Money Stock Revisions

In conjunction with each week's announced change in money, the Federal Reserve announces a revised estimate of the previous week's level of the

Table 3
COMPARISON TO PREVIOUS STUDIES FOR THE 9/29/77-10/04/79 PERIOD*

Basic Model $\Delta R_t = b_0 + b_1 \cdot (\Delta M_t - \Delta M_t^e) + b_2 \cdot \Delta M_t^e + e_t$

	NOB	Coefficient Estimates‡ b_0	b_1	b_2	Summary Statistics R^2	$\bar{R}^2$	SE	DW(i)
(3.1) Grossman [8]†		0.0048 (1.37)	0.0083 (4.32)	-0.0018 (-0.73)		.16	.029	1.86
(3.2) Replication	99	0.0052 (1.23)	0.0066 (2.84)	-0.0014 (-0.47)	.08	.06	.036	1.80(7)
(3.3) Urich and Wachtel [20]		0.0181 (3.4)	0.0119 (4.2)	-0.0100 (-2.8)	.20		.045	1.77
(3.4) Replication	104	-0.0033 (-0.69)	0.0074 (2.87)	-0.0010 (-0.3)	.08	.06	.040	1.87(2)

Positive and Negative Surprises $\Delta R_t = b_0^+ + b_0^- + b_1 \cdot (\Delta M_t - \Delta M_t^e)^+ + b_2 \cdot (\Delta M_t - \Delta M_t^e)^- + e_t$

	NOB	b_0^+	b_0^-	b_1	b_2	$\bar{R}^2$	SE	DW(i)
(3.5a) Grossman [8]†	39	-0.014 (-1.10)		0.021 (2.50)		.12		
(3.5b) Grossman [8]†	58		-0.003 (-0.53)		0.002 (0.69)	.01		
(3.6) Replication	97	-0.013 (-1.63)	-0.009 (-1.34)	0.021 (3.86)	-0.002 (-0.60)	.16	.032	1.69(8)

$\Delta R_t = b_0 + b_1 \cdot (\Delta M_t - \Delta M_t^e)^+ + b_2 \cdot (\Delta M_t - \Delta M_t^e)^- + e_t$

	NOB	b_0	b_1	b_2	$\bar{R}^2$	SE	DW(i)
(3.7) Urich and Wachtel [19]		--	0.014 (>2)	0.010 (>2)		.046	
(3.8) Replication	104	-0.007 (-1.27)	0.019 (3.89)	-0.001 (-0.24)	.13	.035	1.85(2)

*See the notes in Tables 1 and 2.
†The replications of Grossman's [8] results use yields represented as bids on a bank discount basis.
‡Numbers in parentheses are t statistics.

$(\Delta M_t - \Delta M_t^e)^+ = (\Delta M_t - \Delta M_t^e)$ if the surprise is positive, zero otherwise

$(\Delta M_t - \Delta M_t^e)^- = (\Delta M_t - \Delta M_t^e)$ if the surprise is negative, zero otherwise

b_0^+ = coefficient multiplied by a dummy variable with value of unity if $(\Delta M_t - \Delta M_t^e) > 0$, zero otherwise

b_0^- = coefficient multiplied by a dummy variable with value of unity if $(\Delta M_t - \Delta M_t^e) < 0$, zero otherwise money stock. Because this revised estimate represents new information which may be relevant to investor's expectations about future Federal Reserve policy actions as well as inflation, it might be expected that interest rates respond to these revisions.

The hypothesis that the 3-month bill yield responds to revisions in past money stock data may be tested in the equation

$$\Delta R_t = b_1 \cdot (\Delta M_t - \Delta M_t^e) + b_2 \cdot (M_t - M_t^e) + e_t \qquad (2)$$

where M_t = announced level of the narrowly defined money stock in week t

M_t^e = market's expectation of the announced level of the narrowly defined money stock in week t

b_1, b_2 = estimated coefficients.

In this equation, the hypothesis that revisions do not affect interest rates is equivalent to the hypothesis that rates do not respond to surprises in the level of the money stock. This equivalence may be seen by first noting that

$$\Delta M_t = M_t - M_{t-1}^r \qquad (3)$$

where M_{t-1}^r = announced revision in week t of the previous week's announced level of the narrowly defined money stock.

In turn, if investors expect no revision in the previous week's announced level of the money stock, then

$$\Delta M_t^e = M_t^e - M_{t-1} \qquad (4)$$

where M_{t-1} = level of the narrowly defined money stock announced in week t-1.

Equations (3) and (4) together imply that equation (2) may be rewritten as

$$\Delta R_t = (b_1 + b_2) \cdot (\Delta M_t - \Delta M_t^e) + b_2 \cdot (M_{t-1}^r - M_{t-1}) + e_t . \qquad (2')$$

Thus, the testing $b_2 = 0$ in (2) is equivalent to testing the hypothesis that the bill yield does not respond to money stock revisions. Moreover, the hypothesis that interest rates respond equally to announced weekly changes in money and to revisions in the previous week's announced level is equivalent to testing $b_1=0$ in equation (2).

The estimation results of equation (2) for the first and third periods are presented on the top half of Table 4. For the first period, neither of the estimated coefficients is statistically significant at the 5 percent level. In the third period, however, the estimated coefficient on the surprise associated with the announced change, b_1, is statistically significant when the revised expectation measure is used. The estimated coefficient on the unanticipated component of the announced money stock level is again insignificant in this case. As a whole, the results suggest that the 3-month bill yield does not respond to announced revisions in the level of the money stock.

Nonlinear Response to Unanticipated Changes in Money

The next extension to the basic linear model involves the addition of a nonlinear response term to the original specification (1). This term allows the magnitude of the interest rate response to vary with the absolute value of the change in unanticipated money.[16/] The model allowing a nonlinear response may be represented as

$$\Delta R_t = (b_0+b_1\cdot|\Delta M_t-\Delta M_t^e|)\cdot(\Delta M_t-\Delta M_t^e) + e_t. \quad (5)$$

In this specification, if $b_1=0$, the model reduces to equation (1).

The estimation results of the nonlinear model (5) are reported on the bottom half of Table 4. The values of the estimated coefficients indicate that the response of the 3-month bill yield per dollar of an unanticipated change in money declines with the size of the surprise. As is apparent in the table, this result holds for the first period as well as for both expectations measures in the third period. The estimated coefficients on the nonlinear terms

Table 4
EMPIRICAL RESULTS OF THE GENERALIZED MODEL*

Levels vs. Changes $\Delta R_t = b_1 \cdot (\Delta M_t - \Delta M_t^e) + b_2 \cdot (M_t - M_t^e) + e_t$

	Estimation Period	Coefficient Estimates b_1	b_2	Summary Statistics $\bar{R}^2$	SE	ρ
(4.1)	9/29/77- 10/04/79	0.0045 (0.0082)	0.0027 (0.0086)	.05	.039	0.0455 (0.0999)
(4.2)	2/08/80- 11/20/81 Survey	0.0702 (0.0380)	-0.0107 (0.0378)	.30	.213	0.0259 (0.1111)
(4.3)	Revised	0.0781 (0.0366)	-0.0093 (0.0363)	.36	.205	0.0111 (0.1115)

Nonlinear Response $\Delta R_t = [b_0 + b_1 |\Delta M_t - \Delta M_t^e|] \cdot (\Delta M_t - \Delta M_t^e) + e_t$

		b_0	b_1	$\bar{R}^2$	SE	ρ
(4.4)	9/29/77- 10/04/79	0.0163 (0.0061)	-0.0035 (0.0021)	.07	.038	0.0187 (0.1001)
(4.5)	2/08/80- 11/20/81 Survey	0.0836 (0.0193)	-0.0053 (0.0037)	.32	.211	0.0264 (0.1109)
(4.6)	Revised	0.0934 (0.0205)	-0.0061 (0.0045)	.37	.203	0.0191 (0.1112)

*See the notes in Tables 1 and 2.

ρ = estimated coefficient in the regression $\hat{e}_t = \beta + \rho \cdot \hat{e}_{t-1} + u_t$, which is substituted for the Durbin-Watson statistic due to the absence of a constant term are, however, marginally statistically significant at best. Nevertheless, in the more general model presented immediately below, nonlinear terms are found to be statistically significant.

Federal Reserve Monetary Targets

The final extension to the basic linear model (1) considered here involves the disaggregation of money surprises according to the relation of money growth to the Federal Reserve's long-run ranges.[17/] Urich and Wachtel [19] consider similar effects, although in their study short-run ranges are used. Long-run ranges are used here for two reasons. First, market participants probably made more accurate assessments of the Federal Reserve's long-run ranges. Second, the short-run ranges (and later, paths) were, in principle, set to be consistent with eventually obtaining money growth within the long-run ranges.

The model allowing both asymmetric behavior due to the long-run ranges and nonlinear responses may be written as

$$\begin{aligned}\Delta R_t = {} & (b_{10}+b_{11}\cdot UM^+_{a,t})\cdot UM^+_{a,t} + (b_{20}+b_{21}\cdot|UM^-_{a,t}|)\cdot UM^-_{a,t} \\ & + (b_{30}+b_{31}\cdot UM^+_{w,t})\cdot UM^+_{w,t} + (b_{40}+b_{41}\cdot|UM^-_{w,t}|)\cdot UM^-_{w,t} \\ & + (b_{50}+b_{51}\cdot UM^+_{b,t})\cdot UM^+_{b,t} + (b_{60}+b_{61}\cdot|UM^-_{b,t}|)\cdot UM^-_{b,t} \\ & + e_t \qquad (6)\end{aligned}$$

where the UM represent unanticipated changes in money, $\Delta M - \Delta M^e$; the subscripts a, w, and b denote money growth above, within, and below the long-run range, respectively; the superscripts "+" and "-" denote positive and negative unanticipated changes in money; and the b's are estimated coefficients. Thus, the model differs from (5) in that unanticipated changes in money are disaggregated according to whether the surprise is positive or negative, and whether observed money growth is above, within, or below the long-run range set by the Federal

Reserve.

The estimation results of this model are presented in Table 5. The results indicate that a variety of linear and nonlinear terms are statistically significant and that the estimated responses apparently vary depending on the classification of the surprise. Various hypotheses associated with this model are formally tested on the bottom of Table 5. The hypotheses that the coefficients on linear and nonlinear terms equal zero are reported on lines (5.4) and (5.5), respectively. In the first period, these hypotheses can both be rejected at very low significance levels. In the third period, the marginal significance levels are slightly higher on average, but neither hypothesis can be rejected at the 10 percent level when the revised measure of the expected announced change in money is used.

The next three tests in the table—reported on lines (5.6), (5.7), and (5.8)—examine the equality of coefficients across different classifications of money surprises. The hypothesis that all linear responses are equal—tested on line (5.6)—cannot be rejected at the 10 percent level in the third period. On line (5.7), the equality of nonlinear responses is investigated. The hypothesis that nonlinear responses are equal can be rejected at low significance levels in the first period, and somewhat higher levels in the third period. The most important of these tests is reported on line (5.8). In this case, the null hypothesis corresponds to the basic linear model (1). The results for both the first period and the third period with the revised expectation measure indicate that the null hypothesis can be rejected at less than the 1 percent level of significance. Thus, the generalized model appears to provide better representation of the response of the 3-month bill yield to money surprises than the simple linear model used in previous studies.

Table 5

EMPIRICAL RESULTS OF THE GENERALIZED MODEL WITH POLICY RANGES*

$$\Delta R_t = (b_{10}+b_{11}\cdot UM^+_{a,t})\cdot UM^+_{a,t} + (b_{20}+b_{21}\cdot|UM^-_{a,t}|)\cdot UM^-_{a,t} + (b_{30}+b_{31}\cdot UM^+_{w,t})\cdot UM^+_{w,t} + (b_{40}+b_{41}\cdot|UM^-_{w,t}|)\cdot UM^-_{w,t}$$

$$+ (b_{50}+b_{51}\cdot UM^+_{b,t})\cdot UM^+_{b,t} + (b_{60}+b_{61}\cdot|UM^-_{b,t}|)\cdot UM^-_{b,t} + e_t$$

	Estimation Period	Coefficient Estimates												Summary Statistics		
		b_{10}	b_{11}	b_{20}	b_{21}	b_{30}	b_{31}	b_{40}	b_{41}	b_{50}	b_{51}	b_{60}	b_{61}	$\bar{R}^2$	SE	ρ
(5.1)	9/29/77–10/04/79	-0.0054 (0.0140)	0.0049 (0.0054)	0.0406 (0.0258)	-0.0105 (0.0141)	-0.0424 (0.0241)	0.0234 (0.0078)	0.0249 (0.0088)	-0.0068 (0.0027)	-0.0046 (0.0522)	0.0027 (0.0266)	0.0265 (0.0142)	-0.0086 (0.0050)	.20	.036	-0.0299 (0.1001)
	2/08/80–11/20/81															
(5.2)	Survey	-0.0550 (0.0857)	0.0489 (0.0202)	-0.1395 (0.1880)	0.0918 (0.0844)	0.0365 (0.0646)	0.0023 (0.0100)	0.0599 (0.1140)	-0.0130 (0.0415)	0.0813 (0.0312)	-0.0081 (0.0048)	0.1086 (0.0506)	-0.0125 (0.0155)	.41	.195	-0.0114 (0.1117)
(5.3)	Revised	-0.0186 (0.0814)	0.0425 (0.0186)	0.0610 (0.1492)	-0.0118 (0.0615)	0.0478 (0.0602)	0.0016 (0.0103)	0.1622 (0.1011)	-0.0421 (0.0304)	0.0994 (0.0316)	-0.0114 (0.0057)	0.1347 (0.0505)	-0.0193 (0.0172)	.49	.182	0.0068 (0.1119)

	Within-Subsample Tests	9/29/77–10/04/79 F-Statistic	MS	2/08/80–11/20/81: Survey F-Statistic	MS	2/08/80–11/20/81: Revised F-Statistic	MS
(5.4)	H_0: $b_{i0}=0$, i=1,...,6	2.8927(6,91)	.0126	2.1629(6,76)	.0554	3.4116(6,76)	.0050
(5.5)	H_0: $b_{i1}=0$, i=1,...,6	3.3183(6,91)	.0054	1.7743(6,76)	.1149	2.0649(6,76)	.0667
(5.6)	H_0: $b_{i0}=b_{j0}$, i,j=1,...,6	2.1778(5,91)	.0628	0.8692(5,76)	.5073	0.7367(5,76)	.6004
(5.7)	H_0: $b_{i1}=b_{j1}$, i,j=1,...,6	3.4513(5,91)	.0068	1.9183(5,76)	.1002	2.0432(5,76)	.0812
(5.8)	H_0: $b_{i0}=b_{j0}$, $b_{i1}=b_{j1}$, i,j=1,...,6	2.6253(10,91)	.0075	2.4190(10,76)	.0148	3.0720(10,76)	.0026
(5.9)	H_0: $b_{i0}=b_{i1}=0$, i=1,2,5,6	1.5158(8,91)	.1620	8.3549(8,76)	(†)	10.7384(8,76)	(†)
(5.10)	H_0: $b_{i0}=b_{i1}=0$, i=3,4	6.8560(4,91)	(†)	1.4366(4,76)	.2291	2.2532(4,76)	.0703

*See the notes in Tables 1, 2, and 4.
†Less than 0.0001.

$UM^+_{a,t}$ = $(\Delta M_t-\Delta M^e_t)$ if money growth is above the upper limit of the long-run policy range and the surprise is positive, zero otherwise

$UM^-_{a,t}$ = $(\Delta M_t-\Delta M^e_t)$ if money growth is above the upper limit of the long-run policy range and the surprise is negative, zero otherwise

$UM^+_{w,t}$ = $(\Delta M_t-\Delta M^e_t)$ if money growth is within the long-run policy range and the surprise is positive, zero otherwise

$UM^-_{w,t}$ = $(\Delta M_t-\Delta M^e_t)$ if money growth is within the long-run policy range and the surprise is negative, zero otherwise

$UM^+_{b,t}$ = $(\Delta M_t-\Delta M^e_t)$ if money growth is below the lower limit of the long-run policy range, and the surprise is positive, zero otherwise

$UM^-_{b,t}$ = $(\Delta M_t-\Delta M^e_t)$ if money growth is below the lower limit of the long-run policy range and the surprise is negative, zero otherwise

The final two rows in the table further investigate the role of the policy ranges. On line (5.9), the hypothesis that the bill yield does not systematically respond to money surprises when money growth is either above or below the limits of the long-run range is tested. In the first period, this hypothesis cannot be rejected. In the third period, however, this hypothesis can be rejected at less than the 0.01 percent level of significance. Opposite to these results, the hypothesis that the bill yield does not systematically respond to money surprises when money growth is within the long-run range—tested on line (5.10)—can be rejected at extremely low significance levels in the first period, but not in the third period. Thus, these results suggest that once money growth was outside the long-run range, the market did not expect the Federal Reserve to react to further deviations during the pre-October 1979 period, but expects the Federal Reserve to react only in these situations since October 1979.

III. Implications of the October 1979 Change in Operating Procedures

The results presented above suggest that the 3-month Treasury bill yield exhibited different responses to unanticipated weekly changes in money in the pre- and post-October 1979 periods. In this section, the estimated responses across periods are further examined, and their equality is formally tested. Following these tests, the volatility of the 3-month Treasury bill yield in the post-October 1979 period is decomposed to evaluate the impact of the Federal Reserve's change in monetary-control procedures.

Market's Response to Unanticipated Changes in Money

The estimated equations reported in Table 5 are used to test whether the market's response to unanticipated weekly changes in money is significantly different in the pre- and post-October 1979 periods. The summary statistics associated with these tests are reported on the top half of Table 6. In the first row, the test considers changes in the bill yield when money growth is outside of the Federal Reserve's long-run range. In this test, the null hypothesis that the responses are equal across periods can be rejected at less than the 0.01 percent significance level when either the survey or revised measure is used to represent expected money.[18/] In contrast, the hypothesis that the responses are equal across periods when money growth is within the long-run range cannot be rejected at the 25 percent level of significance. The strong divergence in responses when money growth is outside of the long-run range is nevertheless sufficient to enable rejection of the hypothesis that all responses are equal, as reported on line (6.3).

Two conclusions may be drawn from these tests. First, the change in policy regimes has significantly affected the behavior of the 3-month bill yield in the 1 1/2 hour intervals around weekly money stock announcements. Second, this change in behavior apparently reflects the market's assessment that the Federal Reserve will respond more vigorously to deviations in money when money growth is outside of the long-run range.

Decomposition of Short-Term Interest Rate Volatility

The change in the responsiveness of the 3-month bill yield associated with the adoption of the new monetary-control procedures has direct implications for the volatility of short-term interest rates. One implication may be seen by decomposing the volatility—defined as the mean of the sum of squared 1 1/2 hour changes—of the 3-month bill yield in the third period. This decomposition is presented on the bottom of Table 6, where components consist of the volatility in the first period, the effect of changes in the volatility and type of unanticipated money, the effect of the change in the market's response,

Table 6
ESTIMATED EFFECT OF OCTOBER 1979 CHANGE IN FEDERAL RESERVE OPERATING PROCEDURES*

	Across Subsample Tests‡	Survey F-Statistic	Survey MS	Revised F-Statistic	Revised MS
(6.1)	$b_{i0}=b'_{i0}, b_{i1}=b'_{i1}$, i=1,2,5,6	6.1706(8,180)	(†)	7.6544(8,180)	(†)
(6.2)	$b_{i0}=b'_{i0}, b_{i1}=b'_{i1}$, i=3,4	0.9512(4,180)	.4370	1.2779(4,180)	.2797
(6.3)	$b_{i0}=b'_{i0}, b_{i1}=b'_{i1}$, i=1,...,6	4.4308(12,180)	(†)	5.5289(12,180)	(†)

Decomposition of Interest Rate Volatility in Period III (2/08/80-11/20/81)§

	Volatility in Period III	=	Volatility in Period I	+	Change in Volatility and Type of Unanticipated Money	+	Change in Market's Response	+	Change in Random Volatility
Survey									
Mean-Square Error	.0643		.0016		.0150		.0159		.0318
Percent of Mean-Square Error	100.0		2.5		23.3		24.7		49.5
Revised									
Mean-Square Error	.0643		.0016		.0166		.0186		.0275
Percent of Mean-Square Error	100.0		2.5		25.8		28.9		42.8

*See the notes in Tables 1, 2, and 5.
†Less than 0.0001.
‡Equations (5.1), (5.2), and (5.3) in Table 5 are used in the across subsample tests and variance decompositions.
§The mean-square error of ΔR_t in period III is decomposed according to

$$(1/N_3)\cdot\sum_{t=N_2+1}^{N_3}\Delta R_t^2 = (1/N_1)\cdot\sum_{t=1}^{N_1}\Delta R_t^2 + \Big[\sum_{i=1}^{6}\sum_{t=N_2+1}^{N_3}(b_{i0}+b_{i1}\cdot UM_{i,t})^2\cdot(1/N_3)\cdot UM_{i,t}^2 - \sum_{i=1}^{6}\sum_{t=1}^{N_1}(b_{i0}+b_{i1}\cdot UM_{i,t})^2\cdot(1/N_1)\cdot UM_{i,t}^2\Big]$$
$$+ \sum_{i=1}^{6}\sum_{t=N_2+1}^{N_3}[(b'_{i0}+b'_{i1}\cdot UM_{i,t})^2-(b_{i0}+b_{i1}\cdot UM_{i,t})^2]\cdot(1/N_3)\cdot UM_{i,t}^2 + \Big[(1/N_3)\cdot\sum_{t=N_2+1}^{N_3}e_t^2 - (1/N_1)\cdot\sum_{t=1}^{N_1}e_t^2\Big],$$

where

b_{ij}(i=1,...,6; j=0,1) = estimated coefficients in the first subsample

b'_{ij}(i=1,...,6; j=0,1) = estimated coefficients in the third subsample

$UM_{i,t}$(i=1,...,6) = six different types of unanticipated changes in money corresponding to Table 5

N_1, N_2, N_3 = number of observations in the first, second, and third subsamples, respectively.

and the change in random volatility. The first of these sources merely equals the observed volatility of the bill yield in the first period. The second is due to the rise in the volatility of unanticipated money, and shifts in the relation of money growth to the long-run range from the first to third periods. The change in the market's response refers to the differences in the estimated coefficients across subsamples, as reported in Table 5. The final term—the change in random volatility—is defined as the difference in the mean of the sum of squared residuals in the estimated equations from the first to third periods in Table 5.

The results of this volatility decomposition are presented on the bottom of Table 6 for both measures of the expected change in money. As shown in the table, the volatility of the bill yield in the first period amounts to only 2.5 percent of the third period's volatility. In contrast, with the revised expectation measure, the change in the volatility and type of unanticipated money comprises about 26 percent of the bill yield's volatility in the third period. Similarly, the change in the market's response accounts for about 29 percent of the increase. While the estimated contribution of the change in the market's response is similar to that found in previous studies using simple linear models, the impact of the volatility of unanticipated money is much larger than that reported previously. In particular, previous estimates of the impact of the volatility of unanticipated money range from about 10 to 20 percent of that attributed to changes in the market's response. (See Evans [4] and Roley [16].)

IV. Summary of Conclusions

The empirical results presented in this paper suggest several conclusions. First, in modeling the effect of unanticipated weekly changes in money on short-term interest rates, the basic linear model used in previous studies does not take several significant factors into account. These factors include the different responses of short-term yields depending on the relation of money growth to the Federal Reserve's monetary targets, and nonlinear responses to money surprises.

Second, the response of the 3-month Treasury bill yield to weekly money surprises is significantly different in the pre- and post-October 1979 periods. Indeed, the empirical results indicated that the Federal Reserve's adoption of a new monetary control procedure in October 1979 has led to sharper fluctuations in short-term yields for a given money surprise when money growth is outside the long-run target range. Thus, the market apparently views the new procedures as part of a greater commitment by the Federal Reserve to control money growth.

Finally, the increased responsiveness of the bill yield to unanticipated weekly changes in money since October 1979 accounts for about 29 percent of the volatility of this yield during the 1 1/2 hours spanning weekly money announcements. About an equal amount of the bill yield's volatility is due to the increased volatility of unanticipated weekly changes in money, which accounts for 26 percent.

Footnotes

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1. To be precise, the variance of the change in the 3-month Treasury bill yield from 3:30 p.m. to 5:00 p.m. on the day of a money announcement is 0.0016 for the September 29, 1977 to October 4, 1979 period, and 0.0543 for the October 11, 1979 to November 20, 1981 period. These data are further discussed in the first section of this paper.

2. The variance of weekly announced changes in the money stock has increased from 4.329 in the September 29, 1977-October 4, 1979 period to 7.128 in the October 11, 1979-November 20, 1981 period. In addition, with the market survey data used here to represent the market's expected announced change in money, the variance of unanticipated changes in money has increased from 2.374 to 4.995 over the same two periods. These data are further discussed in the first section.

3. For applications of the efficient markets model to weekly money announcements, see Berkman [1], Cornell [2], Grossman [8], and Urich and Wachtel [20]. For a discussion of the general implications of the efficient markets hypothesis, see Fama [5].

4. Note that this specification also implies that short-term interest rates follow a random walk over the time interval spanning a money announcement. If this interval is short in comparison to the maturity of the security, and if the expectations hypothesis describes equilibrium yields, then this result follows from Pesando [14]. Even if short-term yields contain time-varying term premiums (see Jones and Roley [9]), the random-walk model would be expected to approximate yield changes over short intervals. In any event, the random-walk specification is tested below in this section.

5. In contrast to these studies, Evans [4] uses weekly averages of average daily yields which make his results difficult to interpret. In addition to this problem, he excludes innovations in other relevant variables during the week, and includes current and future levels of the federal funds rate which most likely causes simultaneity bias in his estimates. It should also be noted that Mishkin [11] considers a different problem than that examined here, but the underlying models are identical.

6. Starting in 1981, M1-B was adjusted by the Federal Reserve to reflect the introduction of nationwide NOW accounts. While the target range for shift-adjusted M1-B was emphasized by the Federal Reserve, weekly announced changes were not shift adjusted.

7. I am indebted to Mr. Raul A. Nicho, who is a vice president with Money Market Services, Inc., for making the survey data available for this project. For descriptions of the various methods used by market participants to form their weekly money forecasts, see Sivesind [17].

8. These tests are reported for only the third subsample. Grossman [8] and Urich and Wachtel [19] conduct similar tests for the pre-October 1979 period, and the results generally support the rationality of the survey data. These tests were replicated with the data used here, and the results were found to be virtually the same as those reported previously.

9. If relevant variables are excluded from the information set, this test is still valid because the bias will be the same in each autoregression under the null hypothesis. Also note that the single-equation efficiency test specified here is equivalent to testing the hypothesis that money surprises are uncorrelated with previously announced changes in money. For other applications of the efficiency test, see Pesando [14] and Friedman [7].

10. See for example, Pearce [13] for an analysis of the forecast performance of the Livingston inflation survey data.

11. The lower marginal significance level in the first subsample is not surprising. In particular, prior to October 1979, trading in the Treasury bill market was thin after 4:00 p.m., which may account for Urich and Wachtel's [20] decision to use 10:30 a.m. rates on the day following a money announcement. Nevertheless, as discussed below, their estimated impact of unanticipated money is roughly the same as that reported here. Thus, it appears that the 5:00 p.m. quotes embody the new information obtained in money announcements.

12. The former of the two subsamples includes only 17 observations, and is not considered further in subsequent sections. In addition to the problem posed by the sparcity of data, it may also be desirable to exclude some period of time after the change in policy regimes to allow adjustment by market participants. In particular, this 17-week period may be characterized as one of transition, and therefore may not provide an accurate guide to ultimate market behavior. This learning behavior is consistent with the rational expectations models presented, for example, by Taylor [18] and Friedman [6].

13. To avoid potential problems associated with heteroscedasticity, the equations in each of the three periods are weighted by the reciprocals of their estimated standard errors.

14. The sample sizes used in the replications were inferred from information in these studies. The samples vary according to the treatment of holidays and discount rate changes. Bid data are used to replicate Grossman's estimates, and average bid-ask quotes are used to replicate Urich and Wachtel's estimates.

15. However, using Grossman's point estimates, the test that the estimates are the same has an F-statistic of $F(3,96) = 0.2328$, implying a marginal significance level of 0.8729.

16. The estimation results of models specified in terms of surprises in money stock levels are not reported in the remaining tables in this paper due to the apparent lack of statistical significance of these terms. The statistical significance of surprises in money stock levels was nevertheless examined in the context of the nonlinear model, and the hypothesis that coefficients on both linear and nonlinear terms equal zero could not be rejected at the 5 percent significance level in each period. In contrast, the analogous null hypothesis involving surprises in announced changes could be rejected in each period at the 5 percent level.

17. Prior to 1979, annual long-run ranges were set each quarter, and they spanned the current and next three quarters. From the third quarter of 1977 through the third quarter of 1978, the growth ranges were set each quarter at 5 to 6 1/2 percent for M1. Thus, despite the fact that the public was not informed about these ranges until at least one month after they were set, it is assumed that throughout this period the market accurately assessed the ranges because of their rather lethargic nature. In the fourth quarter of 1978, the Federal Reserve departed from its 4 to 6 1/2 percent range as a consequence of the introduction of the automatic transfer service (ATS). In this case, it is again assumed that the market correctly assessed the long-run range for narrowly defined money prior to its public availability. Since 1979, the Federal Reserve has set a single long-run range for each monetary and credit aggregate, with the ranges spanning an entire calendar year. These ranges are announced each February, and the Federal Reserve has the opportunity to change them each July. Moreover, preliminary ranges for the subsequent year are announced in July. Thus, with this information, the market may be expected to form fairly accurate assessments of the long-run ranges. In determining the relation of money growth to the long-run ranges, it was assumed that the base quarter's average money stock occurred in the middle week of the quarter. Ranges for each week were then computed using this base week, and announced weekly levels were compared to the upper and lower limits.

18. In the tests, the equations in each of the periods are weighted by the reciprocals of the estimated standard errors reported on the top of Table 5.

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