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TEMPORAL VARIATION IN THE INTEREST-RATE RESPONSE TO MONEY ANNOUNCEMENTS

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ABSTRACT

A number of studies find significant temporal variation in the interest-rate response to money announcement surprises. An unresolved question, however, is whether the response changes immediately as different policy regimes are adopted, or whether the change is gradual reflecting the establishment of Federal Reserve credibility. This paper conducts tests that allow for both discrete shifts in the interest-rate response to money announcements and a gradual evolution in this response. The evidence is consistent with the hypothesis that temporal variation in the interest-rate response is limited to discrete shifts in October 1979, October 1982, and February 1984.

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1. Introduction

Lucas (1976) argues that empirical economic relations can change when different policy rules are adopted. How rapidly these relations change to reflect new regimes, however, is an unanswered question. The transition will be gradual if it takes time for policymakers to establish credibility. On the other hand, if policymakers are credible, economic relations can change abruptly. Even if policymakers are credible, however, the transition can be gradual if agents require time to learn the empirical implications of the new regime [Taylor (1975) and Friedman (1979)].

The behavior of the interest-rate response to money announcements across Federal Reserve policy regimes provides an example of the Lucas critique. Roley (1982, 1983) and Cornell (1983) find evidence that the response of the 3-month Treasury bill yield rises after the announced policy change in October 1979. Similarly, Roley (1986) finds evidence that the response falls after the announced policy change of October 1982. Finally, Gavin and Karamouzis (1984) and Roley (1986) find that the bill-yield response falls following the announced policy change of February 1984.

These policy regimes can be characterized by three factors [Roley and Walsh (1985) and Roley (1987)]: the type of operating procedure -- federal funds rate, nonborrowed reserves, or borrowed reserves; the degree of desired monetary control; and the type of reserve requirements system

-- lagged or contemporaneous. One can use these three factors to explain the temporal variation in the bill yield's response under the policy anticipation hypothesis [Grossman (1981) and Urich and Wachtel (1981)], the expected inflation hypothesis [Cornell (1983)], or some combination of these two hypotheses [Hardouvelis (1985)]. Under the policy anticipation hypothesis, goods prices are sticky in the short run implying that the interest-rate response arises from movements in the real rate. In contrast, under the expected inflation hypothesis, goods prices are perfectly flexible implying that the response reflects changes in the inflation premium embedded in nominal yields. Regardless of the hypothesis, however, the empirical tests described above assume that the market adjusts immediately to a policy regime change.

Several recent studies question whether the interest-rate response changes immediately following a policy regime change. Belongia, Hafer, and Sheehan (1988) and Hardouvelis and Barnhart (1989), for example, use a Kalman filtering procedure to estimate time series of interest-rate responses to money surprises. They conclude from the smooth appearance of these time series that the Federal Reserve was unable to establish credibility immediately following the October 1979 and October 1982 announced policy changes. Instead, they argue that their results illustrate a gradual evolution in Federal Reserve credibility. The basis for their argument is the belief that the Kalman filter setup is more general than a model that allows for a few discrete shifts in the interest-rate response. This belief is incorrect. Response innovations in the Kalman filter model are normally distributed. Thus the model makes scenarios with a few large shifts in the interest-rate response extremely unlikely. To illustrate this, we conduct bootstrap simulations using a model in which the interest-rate response undergoes three discrete shifts. Time series of Kalman filter response estimates computed using these data appear smooth. That is, the Kalman filter procedure does not reveal discrete shifts in the interest-rate response.[1] It is also true, however, that models that allow only for discrete shifts cannot reveal evidence of gradual change in the interest-rate response.

We conduct tests in this paper that allow for both discrete shifts and gradual change in the interest-rate response to money surprises as different monetary policy regimes are announced. Thus the tests enable one to determine whether the response shifted immediately following the announced policy changes of October 1979, October 1982, and February 1984. Our results are generally consistent with the hypothesis that temporal variation in the interest-rate response to money surprises is limited to discrete shifts immediately following these three announced policy changes.

We also test whether the dates of estimated regime changes differ significantly from the dates of the announced policy changes. We use the Quandt procedure to estimate the dates of regime changes. Loeys (1985) uses a variant of this procedure to estimate the dates of shifts in the interest rate-money surprise relation. He identifies October 1979 and August 1981 as the most likely dates of breaks in the relation. He does not, however, use these estimates to conduct significance tests. We use a longer time series and identify breaks in March 16, 1978, September 6, 1979, and October 22, 1982. Two of these three dates are close to the announced policy changes of October 6, 1979 and October 5, 1982. On the other hand, the third date is very different from the announced policy change of February 1, 1984. To judge the significance of these results we conduct bootstrap simulations. The results of the simulations indicate that the Quandt procedure is unreliable in identifying regime changes. Based on the simulated distribution of identified regime changes, we cannot reject the hypothesis that regime changes occurred on the announced policy changes of October 6, 1979, October 5, 1982, and February 1, 1984. As a whole, therefore, the results of our tests are consistent with the hypothesis that empirical economic relations change immediately following Federal Reserve policy changes. The simulation evidence also indicates, however, that the power of these tests is low.

The rest of the paper is organized as follows. Section 2 describes the data. Section 3 provides the results of discrete shift tests, Kalman filter tests, tests that allow for discrete shifts and gradual change, and Quandt tests. Section 4 contains bootstrap simulations that investigate the use of Kalman filtering when there are discrete shifts, and that investigate the distribution of regime changes revealed by the Quandt procedure. Finally, section 6 provides conclusions.

2. Data

The data we use in estimating the interest-rate response to money announcement surprises begin on September 29, 1977, and end on May 26, 1988. The money stock data consist of announced weekly levels of the narrowly defined money stock M1, in billions of dollars, from the Federal Reserve's H.6 release. Before January 31, 1980, the announcements were made on Thursdays at 4:10 p.m. and corresponded to changes in "old M1." After this date the announcements were made at 4:10 p.m. on Fridays and corresponded first to M1-B and then to a definition of M1 equivalent to M1-B. Beginning on November 29, 1982, money announcements were made at 4:15 p.m. Finally, starting on February 16, 1984, money announcements were switched back to Thursdays, and since March 22, 1984, they have been made at 4:30 p.m.

Expected levels of the money stock are based on the survey data compiled by Money Market Services International. The survey data correspond to expected announced changes in M1, in billions of dollars. To construct expected levels, the survey value for the expected change is added to the previous week's announced level.[2] The money announcement surprise is then calculated as the difference in the logarithms of the announced and expected levels of M1.

The 3-month Treasury bill yield is the main focus of this study, but we also report results for the federal funds rate. Data for both of these yields are taken from the Federal Reserve's H.15 release. The change in the 3-month 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. Since money announcements were scheduled to occur at 4:10 p.m. or later, this change incorporates any new information from the announcement. The change in the federal funds rate is defined similarly, except that published data are daily-averaged figures. Nevertheless, quoted rates predominately reflect federal funds trading before 3:30 p.m.

3. Empirical results

We consider a standard efficient-markets specification of the interest-rate response to money announcement surprises:

$$\Delta r_t = \alpha_t + \beta_t(m_t^a - m_t^e) + \epsilon_t, \quad t = 1,2,..., T, \tag{1}$$

$$\epsilon_t \sim N\,(0, \sigma_t^2) \ ,$$

where Δr_t is the change, in percentage points, in either the 3-month Treasury bill yield or federal funds rate from 3:30 p.m. on the day of the announcement to 3:30 p.m. on the next business day, m_t^a and m_t^e are the logarithms of the announced and expected levels of M1, α_t and β_t are regression parameters, ϵ_t is a serially independent disturbance, and σ_t^2 is its variance. β_t represents the interest-rate response in percentage points at time t to the announcement of an unexpected one percent increase in M1. This section investigates how this response behaves over time.

First, we test for discrete shifts in the interest-rate response immediately following announced policy changes. After that we test a model in which the response evolves as a random walk. If there are relatively few large shifts in the response, however, these random walk tests are unlikely to uncover them. This is because response innovations in the random walk model are normally distributed. On the other hand, discrete shift tests cannot uncover gradual change in the interest-rate response. For these reasons, we also test models in which the interest-rate response evolves as a random walk, but can undergo large discrete shifts immediately following announced policy changes. These tests allow for both immediate and gradual changes in the interest-rate response following announced policy changes. Finally, we investigate whether breaks revealed by the Quandt procedure coincide with announced policy changes.

3.1. Discrete shift tests

Roley (1982, 1983, 1986), Cornell (1983), and Gavin and Karamouzis (1984) test for discrete shifts in the interest-rate response to money announcement surprises when policy regimes change. We update the results of their tests below. We assume that

$$\text{(A.1)} \quad \alpha_t = \alpha_k \, , \beta_t = \beta_k \, , \text{ and } , \sigma_t^2 = \sigma_k^2 \, , \qquad \text{for } t \in k \, ,$$

where k denotes the policy regime. Thus the regression parameters take on different values in each regime but do not vary within regimes. We choose four regimes on the basis of announced changes in Federal Reserve policy and interpret the effects of these changes in the framework of the policy anticipation hypothesis.[3]

The first regime begins on September 29, 1977, and ends on October 4, 1979. This regime is characterized by a federal funds rate operating procedure, some desire by the Federal Reserve to offset deviations of M1 from its target path, and lagged reserve requirements. With this characterization, the federal funds rate is fixed within a given week and should not respond to money announcement surprises. The 3-month bill yield should respond, however, as a positive money announcement surprise causes investors to increase their assessments about expected levels of the federal funds rate in future weeks. In particular, money announcement surprises correspond to money demand prediction errors under lagged reserve requirements. If these errors are highly persistent and the Federal Reserve offsets them at least partially in the future, expected future levels of the federal funds rate increase. Finally, under the expectations hypothesis of the term structure, the 3-month bill yield rises immediately.

The second regime begins on October 11, 1979, and ends on

October 1, 1982. This regime is characterized by a nonborrowed reserves operating procedure, an increased desire to offset deviations of M1 from its target path, and lagged reserve requirements. In this case, both the federal funds rate and the 3-month bill yield should respond to money announcements, and the bill yield's response should be greater than before. The federal funds rate responds because nonborrowed reserves are held fixed in the current week and the money announcement surprise provides information about the current week's demand for reserves. With nonborrowed reserves fixed, any change in the demand for reserves is met through the discount window, which requires a change in the federal funds rate relative to the discount rate. The response of the 3-month bill yield is greater because of this increase in the funds rate and the Federal Reserve's desire to offset money demand shocks more quickly.

The third regime spans the October 8, 1982-January 27, 1984 period. This period is characterized by a borrowed reserves operating procedure, a decreased desire to offset deviations of M1 from its target path, and lagged reserve requirements. With a positive money announcement surprise, for example, the demand for reserves will rise. Under the borrowed reserves operating procedure, however, nonborrowed reserves are increased to maintain the federal funds rate-discount rate spread. This spread is maintained to achieve the borrowed reserves target. Thus the federal funds rate does not respond. This effect on the current week's funds rate, along with a decreased desire to offset money demand shocks, causes the bill-yield response to decline.

The final regime begins on February 3, 1984, and spans the remainder of the overall sample to May 26, 1988. This regime is characterized by a borrowed reserves operating procedure, a further decline in the desire to offset deviations of M1 from its target path, and contemporaneous reserve requirements.[4] Once again, the federal funds rate should not respond to money announcement surprises as the Federal Reserve accomodates any changes in the demand for reserves to maintain the federal funds rate-discount rate spread. The decreased desire to offset money announcement surprises most likely causes the bill-yield response to decline further.[5]

Estimates of the interest-rate response for the federal funds rate and the Treasury bill yield in each regime are reported in panel A of Table 1. Consistent with the predictions outlined above, the federal fund rate's response is significantly different from zero at the 5 percent level only for the October 1979-October 1982 period. During this period, a one percent money announcement surprise increases the federal funds rate by about 35 basis points. The response of the Treasury bill yield is also consistent with the predictions. In particular, the response increases in the October 1979-October 1982 period, and then declines in each of the two remaining periods. The last column in panel A reports test statistics for the hypothesis that the responses across all four regimes are equal.

This hypothesis can be rejected at less than the one percent significance level for each interest rate. Moreover, the hypothesis that the bill yield's response is the same across any pair of adjacent regimes can be rejected at less than the 1 percent level in every instance.[6]

One should note, however, that the pattern of the Treasury bill yield's response is also consistent with the expected inflation hypothesis. Under this hypothesis, the bill yield's response increases in October 1979 because the Federal Reserve loses credibility as an inflation fighter. Any positive money surprise, for example, signals that the Federal Reserve has adopted a higher money growth path. One can interpret the declining responses in the last two regimes as the Federal Reserve gaining increased credibility by offsetting money surprises to achieve an unchanged long-run money path. In any event, the responses of the bill yield across the four regimes are statistically different, regardless of the underlying theory.

3.2. Random walk tests

Belongia, Hafer, and Sheehan (1988) and Hardouvelis and Barnhart (1989) test a model in which the interest-rate response to money announcement surprises evolves as a random walk. Following these authors, we assume that:

(A.2) $\alpha_t = \alpha$, $\sigma_t^2 = \sigma^2$, $\beta_t = \beta_{t-1} + \eta_t$, and , yield response is rejected at the one percent significance level, the hypothesis of temporal stability in the funds-rate response cannot be rejected at the 5 percent level. The stronger evidence of instability in the bill-yield response than in the funds-rate response mimics the results of panel A. On the other hand, the evidence of instability in the funds-rate response is stronger in panel A than in panel B. This result is consistent with the hypothesis that the funds-rate response shifts immediately following policy regime changes. This is because panel A's tests are likely to be more powerful than panel B's tests in detecting this particular departure from the null hypothesis.

Figure 1 plots the smoothed estimates of the bill-yield response against time. This figure, like those provided by Belongia, Hafer, and Sheehan (1988) and Hardouvelis and Barnhart (1989), appears to suggest that the bill-yield response changes only gradually with time. The estimation procedure, however, almost guarentees this appearance. The assumption that response innovations are normally distributed makes a few large shifts extremely unlikely. In the next section we illustrate this property using simulations.

3.3. Random walk tests that allow for discrete shifts

To allow for both immediate and gradual changes in the interest-rate response following announced policy changes we assume that:

(A.3) $\alpha_t = \alpha$, $\sigma_t^2 = \sigma^2$, $\beta_t = \beta_{t-1} + \eta_t$, and ,

$$\eta_t \sim N\left(\sum_{k=1}^{3} \delta_k D_{kt}, \sigma^2 P\right), \quad P \geq 0, \quad t=1, 2, \ldots, T,$$

where D_{kt} is a dummy that equals one at the kth announced policy change, and zero otherwise, and δ_k is the expected shift in the interest-rate response at the kth policy change. Once more we use the Kalman filtering procedure and a grid search to produce maximum likelihood estimates of δ_1, δ_2, and δ_3, and P.

Estimates of the shift and random walk parameters appear in panel A of table 2. The maximum likelihood estimate of the random walk parameter P is zero irrespective of whether the funds rate or bill yield is used. Consequently, likelihood ratio tests do not reject the hypothesis P = 0 (no stochastic variation) given the presence of discrete shifts at the announced policy changes. On the other hand, likelihood ratio tests easily reject the hypothesis of no discrete shifts at the announced policy changes given stochastic variation at conventional significance levels.[8] Thus the results in panel A are consistent with the hypothesis that temporal variation in the interest-rate response to money surprises is limited to discrete shifts immediately following announced policy changes.

Assumption (A.3) restricts the variance of the disturbance ϵ_t to be constant across the four regimes. Roley (1986), however, provides evidence against this restriction. To relax the restriction we also conduct random walk tests regime by regime. Panel B provides the results of these tests. The maximum likelihood estimate of the random walk parameter for the funds rate is zero in each regime. On the other hand, two of the bill-yield parameter estimates are positive. Only the parameter estimate in the first regime, however, is significantly different from zero. Thus panel B's results provide little evidence of within-regime variation in the interest-rate response.

The tests reported in table 2 will lack power if the interest-rate response follows a process other than a random walk. For this reason, we also conducted tests within each regime of a model in which the interest-rate response follows a stationary autoregressive process. Again, likelihood ratio tests only reject the hypothesis of a constant response for the bill yield in the first regime.

3.4. Quandt tests

The Quandt (1958) procedure provides a way to estimate the timing of discrete shifts in the interest rate-money surprise relation. The idea behind the procedure is to find breaks that maximize the likelihood function. Loeys (1985) uses a variant of this procedure recursively to find breaks in the interest-rate response to money surprises between November 1977 and December 1983. For the 3-month Treasury bill yield, the first break Loeys finds is October 1979. Given this break, the second break he finds is August 1981. Thus he finds that the interest-rate response declined over a year before the October 1982 announced change in monetary policy.

This procedure has also been used in similar applications. For example, Huizinga and Mishkin (1986) use the Quandt procedure to find the optimal two breaks in an ex post real interest rate regression using monthly data from January 1953 to December 1984. They find that choosing breaks in October 1979 and October 1982 maximizes the likelihood function, although they note that the function is quite flat. Antoncic (1986) also uses a variant of the Quandt procedure to determine the optimal break in the variance of the real rate from January 1965 to December 1984. She finds the optimal break to be April 1980.

Here we use the Quandt procedure to find breaks in the interest rate-money surprise relation. The procedure we use differs in three ways from Loeys'. First, because of the larger sample, we search for three breaks, not two. Loeys' sample does not include the announced policy change of February 1984. Second, the three breaks are found simultaneously instead of recursively. Recursive searches do not guarantee a global maximum for the likelihood function. Third, the Quandt procedure is followed exactly in that residual variances from the subperiod regressions are allowed to change at the breaks. This assumption is more appropriate given existing evidence that interest-rate volatility differs across policy regimes [Roley (1986)].

The objective function is

$$\sum_{k=1}^{4} T_k \log\left(\sum_{t\in k} \frac{\left[\Delta r_t - \alpha_k - \beta_k \left(m_t^a - m_t^e\right)\right]^2}{T_k} \right), \qquad (5)$$

where T_k is the length of the kth regime. Minimizing (5) with respect to α_k, β_k, and T_k, k = 1, 2, 3, 4 maximizes the likelihood function.[9] In finding the global minimum of the objective function with respect to the three breaks simultaneously, over 25 million different combinations of subsamples are considered to evaluate all possible regimes.

Using the bill-yield we find breaks at observations 25, 102, and 265, which correspond to regimes ending on March 16, 1978, September 6, 1979, and October 22, 1982. Two of these three breaks are fairly close to the policy regime changes of October 4, 1979 (observation 106) and October 1, 1982 (observation 262). The third assumed break on January 27, 1984 (observation 331), however, is not found using this estimation procedure. Instead, a break is estimated in early 1978.

The asymptotic distribution of the breaks identified by the Quandt procedure is unknown. Consequently, we conduct bootstrap simulations to judge significance. The results of these simulations are reported in the next section. The results indicate that the Quandt procedure often identifies breaks at dates that differ substantially from the dates of true breaks. Based on the simulated distribution of estimated breaks, we cannot reject the hypothesis that regime changes occurred at the announced policy changes of October 4, 1979, October 1, 1982, and January 27, 1984.

4. Simulation results

We conduct bootstrap simulations in this section to demonstrate that plots of smoothed response estimates against time are unlikely to reveal discrete shifts in the interest-rate response. We also use simulations to show that the Quandt procedure is unreliable in correctly identifying breaks.

4.1. Random walk tests

2,500 time series of bill-yield changes are constructed using a model in which there are only discrete shifts in the interest-rate response. We choose parameter values to match estimates reported in panel A of table 1, and within each regime generate disturbances by sampling from the regime's residual vector with replacement. For each time series we produce smoothed response estimates. Figure 2 plots the model interest-rate response against time, while figure 3 plots the mean smoothed response estimate against time. Table 3 reports summary statistics for the estimated innovation in the response over the three regime changes. This table and figures 2 and 3 together show that when there are discrete shifts in the interest-rate response, plots of smoothed response estimates against time are unlikely to identify these shifts. The reason for this is that the response innovations in figure 2 are not normally distributed. Three of these innovations are large, while the remainder are zero. The estimated response innovations, however, are by construction normally distributed. Thus the estimation procedure guarentees that large discrete shifts will be eliminated, and the time series will appear smooth.

4.2. Quandt tests

We also use the same discrete-shift model to investigate the accuracy of the Quandt procedure in identifying breaks in the interest rate-money surprise relation. Because of the large number of computations required to find the global minimum of the objective function (5), however, we conduct only 100 replications. As before, the estimated subperiod relations summarized in panel A of Table 1 are taken as the true relations, and within each regime disturbances are sampled with replacement from the regime's residual vector.

The simulation results are summarized in Table 4. In the first row, the probability of identifying all three breaks correctly is estimated to be 4 percent. Similarly, the probability of identifying any two of the three breaks correctly, but not the third, is 25 percent. Of more interest, however, are the subsequent rows, which estimate the probabilities of obtaining the correct breaks within a range of values. In the fourth row, for example, the probability of correctly identifying the three breaks to within 10 weeks is shown to be 39 percent. The probability of finding at least two breaks within 10 weeks is, however, 97 percent (0.39 + 0.58). The last row indicates that one of the three breaks may sometimes differ substantially from its true value. In particular, the probability that the third break is different from its correct value by at least 80 weeks is 21 percent. The results in this table suggest that the Quandt procedure is unreliable in correctly identifying three breaks in the interest rate-money announcement surprise relation.

5. Conclusions

Several recent studies concerning the interest-rate response to money announcement surprises challenge the assumption that the effect of different monetary policy regimes can be characterized by discrete breaks in the response, specified on the basis of Federal Reserve statements. Two reasons are frequently cited to support this challenge. First, some events not captured by the October 1979, October 1982, and February 1984 breaks may have altered the interest-rate response. Second, adjustment to changes in Federal Reserve policy may be gradual, and changes in policy may occur at times other than those indicated by Federal Reserve statements.

The question of whether changes in the interest rate-money surprise relation are gradual or immediate following policy regime changes is empirical. It is obvious that tests for a small number of discrete shifts in the interest-rate response cannot reveal evidence of a gradual evolution in this response. It is less obvious, but nevertheless true, that tests of models in which the response follows a random walk cannot reveal evidence of discrete shifts. This is because response innovations in the random walk model are normally distributed, and this limits the frequency with which relatively large innovations can occur. Thus time series of response estimates produced using this model will inevitably appear smooth, whether or not there are discrete shifts.[10]

This paper conducts tests that allow for both discrete shifts and gradual change in the interest-rate response to money surprises as policy changes are announced. We find little evidence against the hypothesis that temporal variation in the response is limited to discrete shifts. A further question is whether regime changes occur at announced policy changes or at other dates. We use the Quandt procedure to identify the dates at which the interest rate-money surprise relation changes. While two of the three dates identified are close to the announced policy changes of October 1979 and October 1982, the third date differs substantially from the announced policy change of February 1984. Simulations we conduct, however, show that the Quandt procedure is unreliable in correctly identifying breaks. Thus our results are consistent with the hypothesis that the interest rate-money surprise relation shifted immediately following announced changes in policy.

Footnotes

1. Loeys (1985) uses rolling regressions to examine temporal variation in the interest-rate response. As he notes, the results of these regressions also cannot reveal discrete shifts in the response. Others have investigated whether economic variables explain temporal variation in the interest-rate response. Strongin and Tarhan (1990), for example, construct a measure of monetary policy tightness to explain temporal variation in the reponse, and suggest that their results are plausible because they mimic those obtained from rolling regressions. Hardouvelis and Barnhart (1989) use inflation, but find it is not a significant determinant of the bill yield's response. Roley (1982, 1983) uses deviations from the Federal Reserve's monetary target ranges as a determinant of the response within policy regimes. He finds evidence that the response differs within a policy regime depending on whether observed M1 is above, within, or below the M1 target range, and whether the money surprise is positive or negative. Since these differing responses are represented by discrete jumps, however, they are unlikely to be detected by procedures that smooth the responses over time.

2. We use the reported survey measure of announced money for two reasons. First, most of the studies mentioned at the outset use the

reported measure. Second, the adjusted survey measure proposed by Roley (1983) is typically calculated for separate policy regimes which are assumed to be known. Since part of this study concerns the identification of breaks, this procedure could bias the results in favor of the previously assumed regimes. Moreover, while the adjusted measure corrects for biases in the survey data, hypothesis tests about interest-rate responses are relatively unaffected [Roley (1983)].

3. The predictions about the responses of interest rates discussed below are considered in detail by Roley (1987).

4. During the last part of this regime, it may be more accurate to characterize the operating procedure as a federal funds rate procedure. The predicted responses are, however, the same in this case [Roley (1987)].

5. The bill yield's response does not unambiguously decline under contemporaneous reserve requiements because the error process in the demand for reserves equation also affects the response. If this error process is more highly serially correlated than money demand errors, however, the response unambiguously declines [Roley (1987)].

6. In the tests across the four regimes, as well as in the tests across adjacent pairs of regimes, the equations in each regime are weighted by the reciprocals of their estimated standard errors to correct for heteroscedasticity. The F-statistics and p-values for the tests that the Treasury bill yield's response is the same in periods 1 and 2, 2 and 3, and 3 and 4 are $F_{1,258} = 18.767$ (0.000), $F_{1,221} = 4.926$ (0.027), and $F_{1,291} = 21.365$ (0.000), respectively, where p-values are in parentheses.

7. Chow (1983) reviews the use of the Kalman filtering procedure.

8. We conducted bootstrap simulations to investigate the properties of the likelihood ratio statistics in table 2. Inferences based on the simulated distributions do not differ substantially from the inferences we report. An earlier version of the paper also contained Lagrange multiplier test statistics. With one exception, inferences based on these statistics do not differ from inferences we report. The exception concerns tests of the hypothesis of no shifts given stochastic variation. Table 2 shows that, for both the funds rate and bill yield, likelihood ratio tests reject this hypothesis. Lagrange multiplier statistics, on the other hand, do not reject the hypothesis. Bootstrap simulations we conducted indicate that the reason for this difference lies in the powers of the two tests. The

results of these simulations indicate that likelihood ratio tests of the hypothesis are substantially more powerful than Lagrange multiplier tests.

9. We also restrict regime lengths to be at least three to avoid having a regime's sum of squared residuals equal zero.

10. Similar problems arise in interpreting the results of rolling regressions [Loeys (1985)]. Rolling regression plots of interest-rate responses can appear smooth because a single estimate can use data from different regimes. On the other hand, these plots can display substantial variation because rolling regression estimates generally use fewer data than, for example, Kalman filter estimates. We used rolling regressions to test the hypothesis of no response variation within regimes. Although response estimates varied substantially within regimes, their large standard errors ensured that we were unable to reject the hypothesis.

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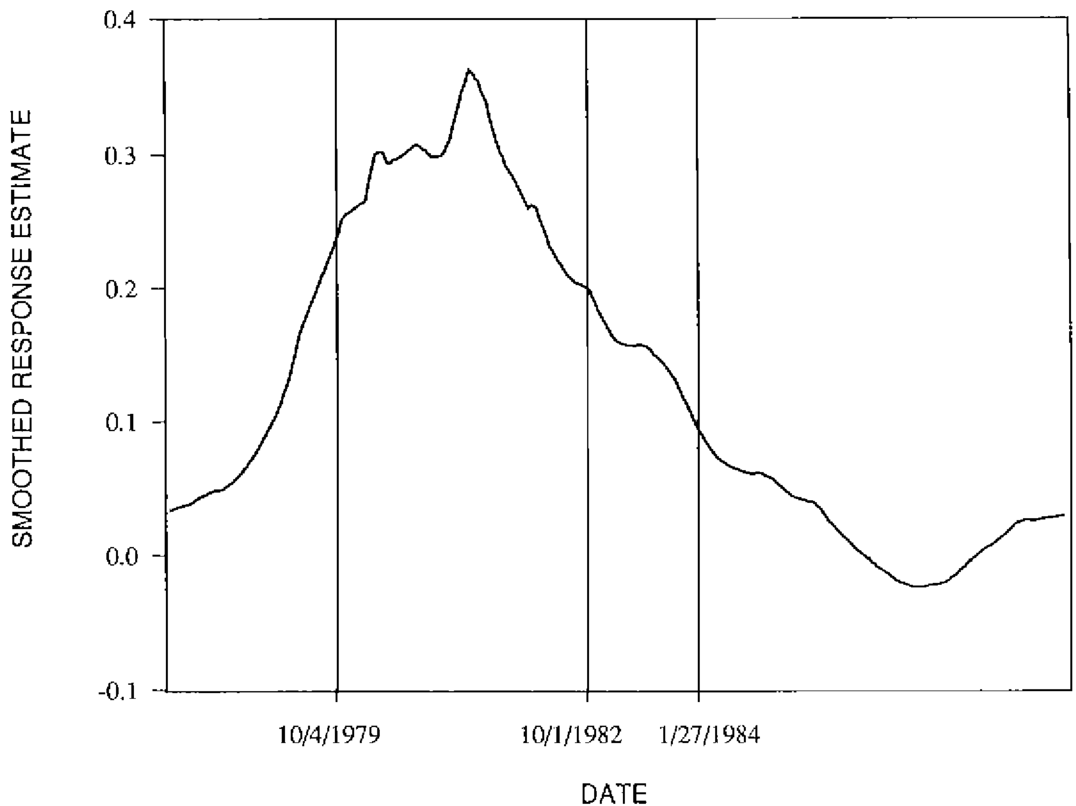

Fig. 1. Smoothed estimates of the bill-yield response, computed using data from 29 September 1977 to 26 May 1988, plotted against time.

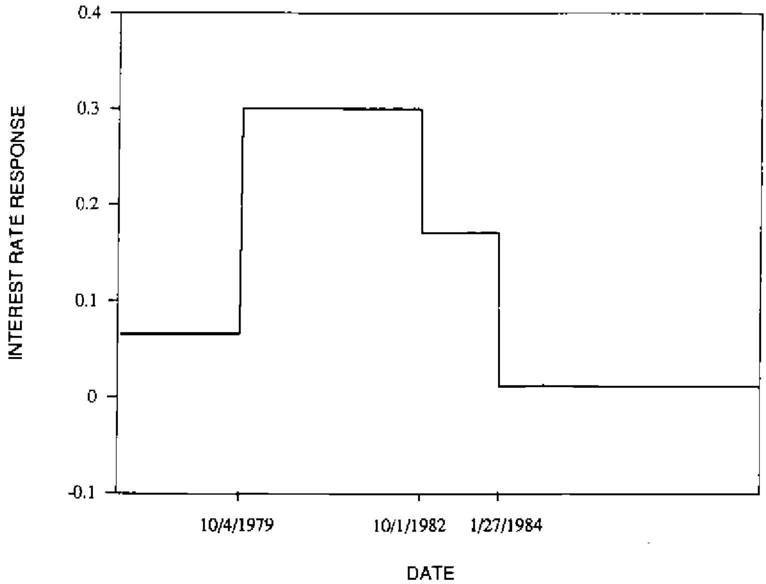

Fig. 2. Model interest-rate response plotted against time.

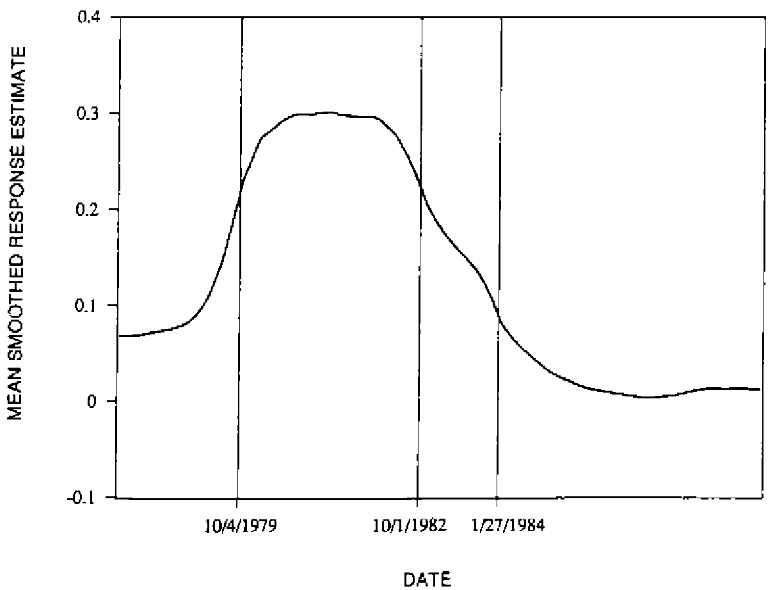

Fig. 3. Mean smoothed response estimate, computed from 2,500 replications, plotted against tim

Table 1

Tests of the stability of the interest-rate response to money supply announcements

Panel A: Discrete shift tests

	Interest-rate response during [a]				
	first regime 9/29/1977 -10/4/1979	second regime 10/11/1979 -10/1/1982	third regime 10/8/1982 -1/27/1984	fourth regime 2/3/1984 -5/26/1988	F-test for stability [b]
Federal funds rate	0.016 (0.020)	0.351 (0.092)	0.070 (0.089)	0.002 (0.104)	4.335 (0.005)
Treasury bill rate	0.065 (0.022)	0.301 (0.050)	0.171 (0.031)	0.011 (0.016)	15.213 (0.000)

Panel B: Random walk tests

	Random walk parameter	Likelihood ratio test statistic [c]
Federal funds rate	0.001	2.839 (0.092)
Treasury bill rate	0.006	32.661 (0.000)

[a] Standard errors are in parentheses.

[b] The test statistic is $F_{3,\ 549}$ under the null hypothesis that the interest-rate response is the same in each regime; p-values are in parentheses.

[c] P-values are in parentheses and are calculated using tabulated values of the χ^2_1 distribution.

Table 2

Tests for discrete shifts and stochastic variation in the interest-rate response to money supply announcements

Panel A: Tests for discrete shifts and stochastic variation

Maximum likelihood estimates

	discrete shift at first regime change 10/4/1979-10/11/1979	discrete shift at second regime change 10/1/1982-10/8/1982	discrete shift at third regime change 1/27/1984-2/3/1984	random walk parameter
Federal funds rate	0.356	-0.304	-0.063	0.000
Treasury bill rate	0.257	-0.163	-0.138	0.000

Likelihood ratio statistics

	no stochastic variation given no shifts [a]	no shifts given no stochastic variation [b]	no stochastic variation given discrete shifts [a]	no shifts given stochastic variation [b]	no shifts and no stochastic variation [c]
Federal funds rate	2.839 (0.092)	13.145 (0.004)	0.000 (1.000)	10.306 (0.016)	13.145 (0.011)
Treasury bill rate	32.661 (0.000)	48.889 (0.000)	0.000 (1.000)	16.228 (0.001)	48.889 (0.000)

Panel B: Tests for stochastic variation within regimes

	first regime 9/29/1977 -10/4/1979	second regime 10/11/1979 -10/1/1982	third regime 10/8/1982 -1/27/1984	fourth regime 2/3/1984 -5/26/1988
Maximum likelihood estimates of random walk parameter				
Federal funds rate	0.000	0.000	0.000	0.000
Treasury bill rate	0.060	0.000	0.174	0.000
Likelihood ratio statistics [a]				
Federal funds rate	0.000 (1.000)	0.000 (1.000)	0.000 (1.000)	0.000 (1.000)
Treasury bill rate	4.882 (0.027)	0.000 (1.000)	1.155 (0.282)	0.000 (1.000)

[a] P-values are in parentheses and are calculated using tabulated values of the χ^2_1 distribution.

[b] P-values are in parentheses and are calculated using tabulated values of the χ^2_3 distribution.

[c] P-values are in parentheses and are calculated using tabulated values of the χ^2_4 distribution.

Table 3

Bootstrap simulation evidence on the behavior of smoothed estimates of the interest-rate response when there are discrete shifts

The results are based on 2,500 replications and a model in which there are discrete shifts in the interest-rate response at the announced policy changes of October 4, 1979, October 1, 1982, and January 27, 1984. Parameter values are chosen to match estimates for the Treasury bill yield reported in panel A of table 1.

		Maximum likelihood estimate			
Change in interest-rate response from	Model parameter	Mean	Standard deviation	Skewness	Kurtosis
10/4/1979-10/11/1979	0.236	0.005	0.004	2.845	17.470
10/1/1982-10/8/1982	-0.130	-0.003	0.004	-3.947	60.573
1/27/1984-2/3/1984	-0.160	-0.003	0.002	-3.588	28.327

Table 4

Bootstrap simulation evidence on the behavior of breaks identified by the Quandt procedure

The results are based on 100 replications and a model in which there are discrete shifts in the interest-rate response at the announced policy changes of October 4, 1979, October 1, 1982, and January 27, 1984. Parameter values are chosen to match estimates for the Treasury bill yield reported in panel A of table 1.

Probability that the procedure identifies	three break points	two break points	one break point	no break points
correctly	0.04	0.25	0.49	0.22
to within one week	0.07	0.55	0.35	0.03
to within 5 weeks	0.23	0.65	0.12	0.00
to within 10 weeks	0.39	0.58	0.03	0.00
to within 80 weeks	0.79	0.21	0.00	0.00