THE JOURNAL OF FINANCE • VOL. XLVIII, NO. 4 • SEPTEMBER 1993

The Effect of Money Shocks on Interest Rates in the Presence of Conditional Heteroskedasticity

KEVIN B. GRIER and MARK J. PERRY*

ABSTRACT

Most current empirical work finds no evidence that money shocks lower interest rates. We show that these nonresults are mainly due to a failure to model the conditional heteroskedasticity of interest rates. Autoregressive conditional heteroskedasticity (ARCH) models find a significant liquidity effect where ordinary least squares (OLS) models do not. The existence of a liquidity effect is found using different models and sample periods when ARCH models are used in estimation, but never when OLS is employed.

A MAJOR UNRESOLVED ISSUE in financial economics is whether money shocks temporarily lower interest rates through the liquidity effect. In traditional Keynesian models, a liquidity effect is necessary for monetary policy to have real effects. Friedman (1968) includes a temporary liquidity effect in his monetarist framework. Recently, Lucas (1990), Feurst (1992), and Christiano and Eichenbaum (1991, 1992) have introduced general equilibrium models with heterogeneous agents where money shocks create liquidity effects. Most current empirical work (e.g., Mishkin (1981, 1982), Melvin (1983), Reichenstein (1987), Sims (1992), and Leeper and Gordon (1992)) shows little or no statistical evidence favorable to a liquidity effect when data from the 1970s and beyond are considered.

In this paper, we show that published results failing to support liquidity effects are due mainly to a failure to account for the conditional heteroskedasticity of interest rates. When this heteroskedasticity is explicitly modelled as an autoregressive conditional heteroskedasticity (ARCH) process, the results of liquidity effect tests change dramatically. We find consistent evidence that positive innovations in M1 growth significantly lower three- or six-month Treasury bill rates.

While our results are in no way an explicit test of the general equilibrium models of the term structure found in finance (e.g., Breeden (1986), Cox, Ingersoll, and Ross (1985a, 1985b), Longstaff and Schwartz (1992)), they do have implications for that literature.[1] The existence of a significant liquidity

* The authors are from George Mason University. We thank Tyler Cowen, Tim Sugrue, and Robert Tollison, along with René Stulz and an anonymous referee, for valuable comments and suggestions.

[1] Chan *et al.* (1992) derive a common statistical framework for these equilibrium models and test the restrictions associated with several specific models. However, even their unrestricted model does not allow monetary variables to affect the term structure.

effect implies that money growth innovations temporarily lower real interest rates. This phenomenon is inconsistent with these exclusively real factor models. Our results imply that any theory of interest rate determination needs to consider monetary factors.

Section I below briefly reviews the statistical evidence on liquidity effects. Section II discusses ARCH as a method of modelling conditional heteroskedasticity. Section III estimates new versions of the existing models, using ordinary least squares (OLS) and ARCH techniques. Section IV contains a discussion of the implications of our results.

I. The Disappearing Liquidity Effect

Early empirical studies of the liquidity effect (Cagan and Gandolfi (1969), and Gibson (1970)) regress short-term interest rate changes on changes in lagged money growth in a equation of the type,

$$\Delta R_t = \alpha_0 + \sum_{i=0}^{n} \beta_i(\Delta DM_{t-i}) + \epsilon_t. \tag{1}$$

Cagan and Gandolfi use monthly data from 1910 to 1967, and find that interest rates decline for a period of between four to nine months in response to an increase in money growth. However, later studies by Melvin (1983) and Reichenstein (1987) using the same methodology over more recent sample periods, find evidence of a positive relation between money growth and interest rates, especially during the 1970s. Melvin and Reichenstein both conclude that the liquidity effect vanishes (reverses) during the inflationary period of the 1970s as expected inflation effects start to dominate the liquidity effect.[2]

Another approach to testing for a liquidity effect is the efficient market-rational expectation approach of Mishkin (1981, 1982). This method starts from the efficient markets theory insight that only new information will change asset values. Innovations in interest rates are derived from the term structure, and relevant economic variables are decomposed into expected and surprise components with forecasting equations. A typical interest rate equation would be,

$$R_t - E_{t-1}R_t = \alpha_0 + \sum_{i=1}^{n} \alpha_i(X_{it} - E_{t-1}X_{it}) + \epsilon_t. \tag{2}$$

Mishkin finds a positive and significant relation between unanticipated money growth and unanticipated changes in interest rates in a variety of equations. In Mishkin's studies, M1 and M2 growth are investigated, short- and long-term interest rates are tested and both univariate and multivariate

[2] Melvin uses first differences of monthly M2 growth and a commercial paper rate over a 1951 to 1979 sample, which he breaks into several subsamples. Reichenstein uses differenced monthly M1 growth and the three-month Treasury bill rate over a 1975 to 1983 sample.

models are used for forecasting equations. In all cases money growth and interest rates are positively related between 1959 and 1976. Mishkin's results are supported by Grier (1986) and Reichenstein (1987) in similar models.[3] Empirical tests using the efficient markets model show no evidence of a liquidity effect.

Vector autoregression (VAR) models are also used to test for a liquidity effect. Sims (1992) estimates four- and six-variable VAR systems with fourteen lags using monthly data over the 1957 to 1991 period in five countries. Using impulse-response functions to then test for a liquidity effect, Sims finds a positive relation between money (M1) and short-term interest rates in the United States, Japan, and France.[4] Christiano and Eichenbaum (1991, 1992) also use VARs and replicate Sims's results when the monetary measure is M0 or M1. However, when Nonborrowed Reserves (NBRs) and the Federal Funds rate are used in a VAR, a significant liquidity effect is found over the 1959 to 1990 period in the United States using both monthly and quarterly data.[5]

The studies cited in this section use different samples, variables, and statistical methods. However, one common feature is a disregard for the well-known existence of volatility clustering in interest rates. Engle, Lillien, and Robbins (1987) find significant time dependence in the variance of Treasury bill rates over the 1959 to 1984 period. The following section describes the ARCH model as a method of estimating relations with time-varying conditional variances.

II. ARCH

Robert Engle (1982, 1983) introduced the ARCH model as a way to parameterize the time-varying conditional variances commonly observed in stock prices, interest rates, exchange rates, and other economic variables. ARCH and related models are now widely used. In a recent review, Bollerslev, Chou, and Kroner (1992) cite over 200 articles using ARCH techniques in a wide variety of finance applications.

[3] Mishkin uses quarterly data and regresses interest rate surprises on money growth, output, and inflation shocks. Grier extends Mishkin's sample through 1984 and confirms the positive effect of money growth shocks on interest rate innovations. Reichenstein uses the change in the Treasury bill rate rather than the difference between the Treasury bill and forward rates over a monthly 1965 to 1983 sample, but still finds a positive coefficient on money shocks. Mishkin estimates the forecasting and interest rate equations simultaneously, while Grier and Reichenstein use a two-step technique.

[4] Results for the United Kingdom and Germany show a very small liquidity effect. Sims uses a short interest rate, some M1 money measure, a consumer price index, and an industrial production index, in his four-variable model and adds an exchange rate and a world commodity price index for the six-variable model. Variables are entered as log levels except for the interest rate.

[5] We consider Christiano and Eichenbaum's results in more detail below. Showing a negative relationship between the quantity of NBRs and their interbank overnight lending rate is quite different from what most researchers mean by a liquidity effect. Also, Cochrane (1989) uses filtered weekly M1 data from mid 1979 through mid 1983 and reports a significant short lived negative correlation between money and interest rates.

In this paper, we mainly use simple first-order ARCH or ARCH-M models, defined as:

$$Y_t = X_t\beta + \epsilon_t; \qquad \epsilon_t \sim N(0, \sigma_t^2) \tag{3}$$

$$Y_t = X_t\beta + \delta(\log(\sigma_t)) + \epsilon_t \tag{3'}$$

$$\sigma_t^2 = \alpha_0 + \alpha_1(\epsilon_{t-1}^2) \tag{4}$$

Equations (3) and (4) are the basic ARCH(1) model. Equation (4) shows the explicit time dependence of the conditional error variance through the parameter α_1.[6] Equations (3′) and (4) are the ARCH(1)-M model, introduced by Engle, Lilien, and Robbins (1987). ARCH-M allows the mean to be a function of the conditional error variance and is especially useful for measuring time-varying risk premia in the term structure.[7] These ARCH models are estimatible with iterative, nonlinear maximum likelihood methods.

When conditional heteroskedasticity is present, but not correctly modelled, results from an OLS regression will be unbiased. However, the nonlinear maximum likelihood estimator will produce efficiency gains that can be very large.[8] In the next section, we reestimate the liquidity effect models discussed above showing both that there is significant conditional heteroskedasticity in the OLS residuals, and that using a simple ARCH model significantly changes the OLS results.[9]

III. Results

A. Efficient Markets Models

Here we estimate an efficient markets model using seasonally adjusted end of quarter data from 1960.3 through 1991.4. Interest rate surprises are the difference between the three-month Treasury bill rate in period t and the three-month forward rate for period t based on rates in $t - 1$, i.e, $TB3_t - {}_{t-1}FR3_t$. The regressors are surprises in M1 money growth, output growth, and

[6] ARCH(1) allows only one-period persistence in the variance. We investigated other models, most notably the GARCH(1, 1) model of Bollerslev (1986), which assumes the variance follows an ARMA (1, 1) process. The simple ARCH(1) fits the data as well as any of the more complicated variance models. The persistence parameter α_1 must be greater than zero but less than one for the conditional variance to be stationary. Unlike Engle, Lillien, and Robbins, our regressions all have stationary conditional variances.

[7] There are a variety of possible functional forms for entering the conditional variance as a regressor in the mean equation. We use the log of the standard deviation. Engle, Lillien, and Robbins found this to be the best fitting variable of the ones they considered.

[8] See Engle (1982, pp. 998–999) for a discussion of potential efficiency gains.

[9] Leeper and Gordon (1992) also critique the empirical liquidity effects literature, although from a completely different perspective. They concentrate on testing the exogeneity of money and on coefficient stability over a number of subsamples Their work also uses OLS, and is subject to the criticisms laid out in this paper. A comprehensive analysis of coefficient stability with ARCH models is beyond the scope of this paper.

inflation.[10] Mishkin, Grier, and Reichenstein all find a positive correlation between money growth surprises and interest rate surprises using this basic method.

Equation (1) in Table I reports the constant variance (OLS) results over the full sample. Output and inflation surprises significantly raise interest rates, but money growth surprises have no significant effect. However, there is significant conditional heteroskedasticity in these data. Equation (5) below shows the temporal dependence in the squared errors (t-statistics in parentheses):

$$\hat{e}_t^2 = \underset{(2.83)}{0.569} + \underset{(4.9)}{0.404}\ (\hat{e}_{t-1}^2) \qquad (N = 125,\ R^2 = 0.164). \tag{5}$$

The Lagrange Multiplier (LM) test for first-order ARCH effects is $N \times R^2$, which is distributed as a χ^2, with 1 degree of freedom. The value from equation 5 is 20.5, which is significant at the 0.001 level. Equation (2) of Table I reestimates the efficient markets model as an ARCH(1) process. Output and inflation surprises are still positive and significant, but now money growth surprises are negative and significant. Modelling the conditional heteroskedasticity inherent in these data dramatically changes the results. The efficient markets ARCH model clearly supports the existence of a liquidity effect.[11] When the output growth and inflation surprise variables are excluded from the ARCH model, the coefficient on money shocks is virtually unchanged (-0.046 rather than -0.044) but its significance level rises from 0.05 to 0.01.

To illustrate the robustness of the result, equations (3) and (4) of Table 1 estimate the OLS and ARCH(1) models over a 1973.1 to 1991.4 subsample. We choose this period because Melvin, Reichenstein, and Leeper all claim the liquidity effect vanishes in regressions starting around 1973. In equation (3) (OLS), money surprises are insignificant, but in the ARCH(1) model (equation(4)), money surprises are again negative and signfiicant.[12]

In these efficient markets regressions, the intercept is the negative of the risk premium, here assumed to be constant over time. Mishkin operationalized a moving risk premium by using the following regressor:

$$v_t = \left(\sum_{i=1}^{8} abs(TB3_{t-i} - TB3_{t-i-1}) \right) \Big/ 8 \tag{6}$$

[10] The forward rate is given by ${}_{t-1}FR3_t = ((1 + R6_{t-1})^2/(1 + R3_{t-1})) - 1$. M1 growth is predicted with an AR(5) model, inflation with an AR(3), and industrial production growth with an MA(1).

[11] Consistent with the implications of efficient markets theory, when the predicted values of our three macro variables are added to equation (2) of Table 2, they are insignificant, both individually and as a group.

[12] Over the 1979 to 1991 subsample, the estimated ARCH(1) process is no longer stationary (i.e., the coefficient on lagged squared errors is slightly greater than 1.0). When we use an integrated GARCH(1, 1) model over this period, the coefficient on money shocks is -0.065 with a t-statistic of 3.02. Money shocks remain insignificant using OLS. See Bollerslev, Chou, and Kroner (1992) for details on the I-GARCH model.

Table I

Efficient Market Tests for the Liquidity Effect Using OLS and ARCH

The dependent variable is interest rate surprises, measured as the difference between the end-of-quarter three-month Treasury bill rate and the corresponding three-month forward rate derived from the term structure; ${}_{t-1}FR3_t = [(1 + TB6_{t-1})^2/(1 + TB3_{t-1})] - 1$. The independent variables are surprise movements in money growth, output growth, and inflation. Expected money growth ($E_{t-1}DMt$) is predicted by an AR(5) regression, expected output growth ($E_{t-1}DY_t$) by an MA(1), and expected inflation ($E_{t-1}DP_t$) by an AR(3). Results are not sensitive to the exact forecasting equations used. Data on three- and six-month Treasury bills are from Salomon Brothers. Money growth (DM_t) is M1 growth (FM1 from CITIBASE), output growth (DY_t) is industrial production growth (IPD from CITIBASE) and inflation (DP_t) is consumer price index growth (PUNEW from CITIBASE). The independent variables are all measured end of quarter. Equations (1) and (3) are OLS results showing no liquidity effect. Equations (2) and (4) use the ARCH(1) model and find a significant liquidity effect. The ARCH variance equations are shown below the main regression results. Equations (1) and (2) cover the full 1960.3 to 1991.4 ($N = 126$) sample. Equations (3) and (4) cover 1973.1 to 1991.4 ($N = 76$). It is in this post-1973 period that the liquidity effect is alleged to have disappeared. Numbers in parentheses are t-statistics. The χ^2 tests indicate that the ARCH parameters are significant at the 0.01 level.

	1960.3 to 1991.4		1973.1 to 1991.4	
Variable	1. OLS	2. ARCH(1)*	3. OLS	4. ARCH(1)**
Constant	−0.3238	−0.3207	−0.2937	−0.3490
	(3.24)	(4.97)	(2.11)	(3.67)
$DM_t - E_{t-1}DM_t$	−0.0258	−0.0440	−0.0325	−0.0607
	(0.80)	(2.49)	(0.87)	(2.25)
$DY_t - E_{t-1}DY_t$	0.0763	0.0312	0.0995	0.0398
	(5.68)	(3.58)	(5.35)	(2.73)
$DP_t - E_{t-1}DP_t$	0.1831	0.0848	0.1996	0.1274
	(4.71)	(2.61)	(3.31)	(2.86)
R^2	0.33	—	0.39	—
χ^2 (no ARCH)		71.6		34.0

$$^{*}\sigma_t^2 = \underset{(5.29)}{0.246} + \underset{(3.67)}{0.749}\,(\epsilon_{t-1}^2)$$

$$^{**}\sigma_t^2 = \underset{(2.59)}{0.361} + \underset{(2.77)}{0.774}\,(\epsilon_{t-1}^2)$$

which he found to consistently be significant. By contrast, the ARCH model produces a parametric estimate of the moving conditional variance of the interest rate. Equations (7) and (8) below estimate the efficient markets model as an ARCH(1)-M process, allowing for a variable risk premium (t-statistics in parentheses).

$$\begin{aligned} TB3_t - {}_{t-1}FR3_t = &- \underset{(6.3)}{0.66} - \underset{(3.8)}{0.051}\,(DM1_t - E_{t-1}DM1_t) \\ &+ \underset{(2.3)}{0.019}\,(DY_t - E_{t-1}DY_t) + \underset{(3.4)}{0.101}\,(DP_t - E_{t-1}DP_t) \\ &- \underset{(3.6)}{0.316}\,(\mathrm{Log}(\sigma_t)) + \epsilon_t \end{aligned} \tag{7}$$

$$\sigma_t^2 = \underset{(4.6)}{0.22} + \underset{(3.9)}{0.769}\,(\epsilon_{t-1}^2) \tag{8}$$

The variable risk premium, measured as the log of σ_t, is significant at the 0.01 level. In addition, money surprises are now negative and significant at the 0.01 level and the coefficient is larger than in the constant risk premium model. Using the ARCH(1) − M model, a one standard deviation money growth shock lowers the Treasury bill rate about 20 basis points.

To again check for generality, we reestimate the efficient market model as a GARCH(1, 1)-M process. As noted above, this model allows for increased persistence in the volatility clustering by assuming that the conditional error variance is given by,

$$\sigma_t^2 = \alpha_0 + \alpha_1(e_{t-1}^2) + \alpha_2(\sigma_{t-1}^2). \tag{9}$$

This experiment produces the following results (t-statistics in parentheses):

$$\begin{aligned} TB3_t - {}_{t-1}FR3_t = & -\underset{(3.7)}{0.52} - \underset{(2.29)}{0.036}\,(DM1_t - E_{t-1}DM1_t) \\ & + \underset{(2.7)}{0.023}\,(DY_t - E_{t-1}DY_t) + \underset{(2.7)}{0.084}\,(DP_t - E_{t-1}DP_t) \\ & - \underset{(1.8)}{0.194}\,(\mathrm{Log}(\sigma_t)) + \epsilon_t \end{aligned} \tag{10}$$

$$\sigma_t^2 = \underset{(1.6)}{0.09} + \underset{(3.0)}{0.543}\,(\epsilon_{t-1}^2) + \underset{(2.36)}{0.36}\,(\sigma_{t-1}^2) \tag{11}$$

Money surprises are still negative and significant, the conditional variance is still stationary, and the maximized value of the likelihood function is not significantly higher than the ARCH(1) case.

In efficient markets tests, modelling the conditional variance of interest rates changes results. There is robust evidence of a significant liquidity effect from efficient markets models when ARCH models are employed.

B. Reduced Form Models

Consider now a reduced form model where interest rate changes are regressed on lags of changes in money growth. The sample is monthly data from 1960 through 1991 on the six-month Treasury bill rate and M1 growth. Because the ARCH program used will only accept 10 variables, we examine models with nine lags of money.[13] Table II, equation (1) shows the full-sample results from a constant variance (OLS) model. The first six lags of money are positive and significant. This result confirms what others have found, namely that OLS reduced form regressions do not show a liquidity effect. Again, though, there is massive volatility clustering in these data. Equation (12) below shows the temporal dependence in the squared errors (t-statistics in parentheses):

$$\hat{e}_t^2 = \underset{(3.9)}{0.149} + \underset{(7.7)}{0.367}\,(\hat{e}_{t-1}^2) \qquad (N = 383,\ R^2 = 0.135). \tag{12}$$

[13] We are using a univariate FORTRAN program called GARCH kindly supplied to us by Ken Kroner.

Table II

Reduced-Form Tests for the Liquidity Effect Using OLS and ARCH

The dependent variable is the change in the six-month Treasury bill rate (FYGM6 from CITIBASE). The independent variables ($\Delta dm1_{-t}$, $t = 1$–9) are changes in M1 growth (FM1 from CITIBASE). Equations (1) and (3) are OLS results showing no liquidity effect. Equations (2) and (4) use the ARCH(1) model and support the liquidity effect. The ARCH variance equations are shown below the main regression results. Equations (1) and (2) cover the full 1960.01 to 1991.12 ($N = 384$) sample. Equations (3) and (4) cover 1973.1 to 1991.12 ($N = 228$). It is in this post-1973 period that the liquidity effect is alleged to have disappeared. Numbers in parentheses are t-statistics. The χ^2 tests indicate that the ARCH parameters are significant at the 0.01 level.

	1960.01 to 1991.12		1973.01 to 1991.12	
Variable	OLS	ARCH(1)*	OLS	ARCH(1)**
Constant	−0.0039	0.0556	−0.0061	0.0378
	(0.14)	(3.48)	(0.16)	(1.36)
$\Delta dm1_{-1}$	0.0278	0.0053	0.0348	0.0091
	(7.16)	(1.94)	(5.23)	(1.73)
$\Delta dm1_{-2}$	0.0303	−0.0093	0.0381	0.0051
	(6.23)	(3.18)	(4.95)	(0.83)
$\Delta dm1_{-3}$	0.0254	−0.0082	0.0371	0.0041
	(5.11)	(2.64)	(4.23)	(0.67)
$\Delta dm1_{-4}$	0.0161	−0.0058	0.0255	0.0021
	(2.83)	(2.21)	(2.81)	(0.34)
$\Delta dm1_{-5}$	0.0151	−0.0012	0.0240	−0.0029
	(2.78)	(0.41)	(2.48)	(0.41)
$\Delta dm1_{-6}$	0.0198	−0.0024	0.0314	−0.0047
	(4.04)	(0.85)	(3.36)	(0.67)
$\Delta dm1_{-7}$	−0.0014	−0.0025	0.0070	−0.0182
	(0.38)	(2.71)	(0.78)	(3.26)
$\Delta dm1_{-8}$	−0.0035	−0.0061	0.0011	−0.0163
	(0.72)	(3.55)	(0.14)	(3.22)
$\Delta dm1_{-9}$	−0.0020	0.0012	0.0005	−0.0087
	(0.45)	(0.51)	(0.08)	(2.56)
R^2	0.14	—	0.18	—
χ^2 (no ARCH)		185.4		95.8

$$^{*}\sigma_t^2 = \underset{(10.8)}{0.062} + \underset{(6.65)}{0.969}\,(\epsilon_{t-1}^2)$$

$$^{**}\sigma_t^2 = \underset{(6.93)}{0.103} + \underset{(4.71)}{0.837}\,(\epsilon_{t-1}^2)$$

The LM test statistic has a value of 51.7, which is significant at the 0.001 level. Equation (2) in Table II reestimates the reduced form equation as a first-order ARCH model. There is again a dramatic effect on the results. Seven out of the nine coefficients are now negative and five of those seven are significant.

Equation (3) and (4) in Table II demonstrate that the coefficient reversals also occur over the 1973.01 to 1991.12 subperiod. The OLS regression again shows the first six lags of money to be positive and significant. However, in the ARCH model, there are no significant positive coefficients and the last three lags of money growth changes are negative and significant at the 0.01 level. Just as in the efficient markets tests, modelling the conditional variance makes an important difference in the reduced form equation results. In this case, regressions showing a strong positive relation between money growth and interest rates under OLS change to show a modest but significant liquidity effect using ARCH methods.[14]

C. M1 vs. Nonborrowed Reserves

Sims finds no evidence of a liquidity effect in his VAR work using M1 as the monetary aggregate. However, Christiano and Eichenbaum provide empirical support for their theoretical liquidity model by replacing M1 with NBRs in VARs where the included interest rate is the Fed Funds rates. They show impulse-response simulations where innovations in NBRs significantly lower the Fed Funds rate. While this work is virtually the only current evidence of significant liquidity effects, it uses OLS and is therefore susceptible to the same inference problems due to unmodelled conditional heteroskedasticity that we have documented above.[15]

Further, Christiano and Eichenbaum's financial variables are not ones usually associated with the liquidity effect. The Fed Funds rate is the rate on interbank, overnight reserve borrowing. NBRs are the main components of what is available for interbank lending. Christiano and Eichenbaum's results can be easily thought of as tracing out a downward sloping demand curve for interbank reserve borrowing.[16] It is doubtful that the classic tradeoff between inflation expectations and liquidity can be very important in an overnight loan market. Below we briefly investigate the effect of NBRs on longer term market rates using the ARCH model.

Consider the effect of NBR surprises in the efficient markets model of the three-month Treasury bill rate. Adding NBR surprises to the ARCH-M model presented in equations (7) and (8) above produces the following results (t-statistics in parentheses):

$$TB3_t - {}_{t-1}FR3_t = \underset{(5.1)}{-\ 0.65} - \underset{(2.9)}{0.008}\ (DNBR_t - E_{t-1}DNBR_t)$$

[14] As was the case in the efficient markets regressions, starting the sample in 1979 causes ARCH(1) or GARCH(1, 1) variances to become nonstationary. A comparison of OLS vs. I-GARCH(1, 1) results over this period basically supports the results in Table II.

[15] We have estimated four-variable VAR systems with nine lags of each variable in each equation, and replicated both the Sims and Christiano and Eichenbaum results. When we test these equations for ARCH, we find significant temporal dependence in the squared errors. For interest rates, output, and the price level, the ARCH effect is significant at the 0.01 level. For the monetary aggregates, the significance level varies between 0.05 and 0.10.

[16] Christiano and Eichenbaum also point out that borrowed reserve are positively correlated with the Fed Funds rate. This too, can be seen as a mechanical relationship. Holding the discount rate (the price of borrowing reserves from the Fed) constant, whenever the Fed Funds rate (the price of borrowing reserves from another bank) rises, reserve borrowers will tend to go to the Fed, thus increasing borrowed reserves.

$$
\begin{aligned}
&- \underset{(2.2)}{0.035}\ (DM1_t - E_{t-1}DM1_t) + \\
&\underset{(2.3)}{0.018}\ (DY_t - E_{t-1}DY_t) \\
&+ \underset{(3.8)}{0.11}\ (DP_t - E_{t-1}DP_t) - \underset{(2.5)}{0.266}\ (\mathrm{Log}(\sigma_t)) + \epsilon_t \quad (13)
\end{aligned}
$$

$$
\sigma_t^2 = \underset{(4.9)}{0.21} + \underset{(3.2)}{0.714}\ (\epsilon_{t-1}^2). \quad (14)
$$

NBR surprises are negative and significant. However,M1 surprises remain negative and significant as well, indicating that the NBR component of M1 is not the only component that affects interest rates. On the basis of this experiment, NBR does not dominate M1 as the variable that creates a liquidity effect when broader market interest rates are considered.[17]

IV. Conclusion

The major implication of our work is simply that, contrary to recent reports, the liquidity effect has strong statistical support. Money growth innovations do temporarily lower interest rates. Efficient market models of interest rate suprises show significant liquidity effects when estimated as ARCH processes. Similar results are found for reduced form lag models. OLS estimation implies money growth innovations raise rates, but ARCH models find a significant liquidity effect. Our results hold up well over different sample periods and different specifications of the ARCH process. The pervasive conditional heteroskedasticity of interest rates makes OLS an inefficient technique for estimating financial models. ARCH models are theoretically appropriate and can make an important difference in the results obtained. Further, the ARCH-M model provides a good way to capture variable risk premia in interest rate equations.

[17] We use the change in NBR growth in a reduced form equation for interest rate changes analogous to the M1 results in Table II. However, only two of the nine lagged NBR coefficients are negative and significant (using an ARCH(1) model) compared to five in the reported M1 results.

REFERENCES

Bollerslev, T., 1986, Generalized autoregressive conditional heteroskedasticity, *Journal of Econometrics* 31, 307–327.

———, R. Chou, and K. Kroner, 1992, ARCH modeling in finance: A review of the theory and empirical evidence, *Journal of Econometrics* 52, 5–60.

Breeden, D. T., 1986, Consumption, production, inflation and interest rates, *Journal of Financial Economics* 16, 3–39.

Cagan, P., and A. Gandolfi, 1969, The lag in monetary policy as implied by the time pattern of monetary effects on interest rates, *American Economic Review* 59, 277–84.

Chan, K., G. Karolyi, F. Longstaff, and A. Sanders, 1992, An empirical comparison of alternative models of the short-term interest rate, *Journal of Finance* 47, 1209–1227.

Christiano, L. J., and M. Eichenbaum, 1991, Identification and the liquidity effect for a monetary policy shock, National Bureau of Economic Research Working Paper No. 3920.

———, 1992, Liquidity effects and the monetary transmission mechanism, *American Economic Review* 82, 346–353.

Cochrane, J. H., 1989, The return of the liquidity effect: A study of the short-run relation between money growth and interest rates, *Journal of Business and Economic Statistics* 7, 75–83.

Cox, J., J. Ingersoll, and S. Ross, 1985a, An intertemporal general equilibrium model of asset prices, *Econometrica* 53, 363–384.

———, 1985b, A theory of the term structure of interest rates, *Econometrica* 53, 385–407.

Engle, R., 1982, Autoregressive conditional heteroskedasticity with estimates of the variance of U.K. inflation, *Econometrica* 50, 987–1008.

———, 1983, Estimates of the variance of U.S. inflation based upon the ARCH model, *Journal of Money, Credit and Banking* 15, 286–301.

———, D. Lilien, and R. Robins, 1987, Estimating time varying risk premia in the term structure: The ARCH-M model, *Econometrica* 55, 391–407.

Friedman, M., 1968, The role of monetary policy, *American Economic Review* 53, 3–17.

Fuerst, T., 1992, Liquidity, loanable funds and real activity, *Journal of Monetary Economics* 29, 3–24.

Gibson, W., 1970, The lag in the effect of monetary policy on income and interest rates, *Quarterly Journal of Economics* 84, 288–300.

Grier, K., 1986. A note on unanticipated money growth and interest rate surprises, *Journal of Finance* 41, 981–985.

Leeper, E., and D. Gordon, 1992, In search of the liquidity effect, *Journal of Monetary Economics*, 29, 341–369.

Longstaff, F. A., and E. Schwartz, 1992, Interest rate volatility and the term structure: A two-factor general equilibrium model, *Journal of Finance* 47, 1259–1282.

Lucas, R. E., 1990, Liquidity and interest rates, *Journal of Economic Theory* 50, 237–264.

Melvin, M., 1983, The vanishing liquidity effect of money on interest rates: Analysis and implications for policy, *Economic Inquiry* 21, 188–202.

Mishkin, F., 1981, Monetary policy and long term interest rates: An efficient markets approach, *Journal of Monetary Economics* 7, 29–55.

———, 1982, Monetary policy and short-term interest rates: An efficient markets–rational expectations approach, *Journal of Finance* 37, 63–72.

Reichenstein, W., 1987, The impact of money on short-term interest rates, *Economic Inquiry* 25, 67–82.

Sims, C. A., 1992, Interpreting the macroeconomic time series facts: The effects of monetary policy, *European Economic Review* 36, 975–1000.