STEPHEN M. MILLER
University of Connecticut
Storrs, Connecticut

*Disequilibrium Macroeconomics, Money as a Buffer Stock, and the Estimation of Money Demand**

Standard explanations of the seeming instability of the money demand in the post-1973 period usually link to stories about financial innovation and deregulation. I propose an alternative hypothesis: Much of the seeming instability occurs because of shifts in monetary policy, either explicit or implicit, in an environment where the Federal Reserve controls a more "exogenous" money stock. My econometric analysis modifies existing methods for estimating markets in disequilibrium and incorporates newly developed cointegration and error-correction modeling. My findings provide support for the buffer-stock interpretation of the money market.

1. Introduction

Students of macroeconomic theory are familiar with the recent extensive debate concerning macroeconomic modeling. A part of the debate considers disequilibrium or non-market clearing macroeconomic models (Clower 1965; Patinkin 1965; Leijonhufvud 1968; and Barro and Grossman 1971, 1976), which failed to capture a significant following, at least in the United States. This failure to attract much attention probably stems from the absence of convincing arguments for price rigidities.[1]

One aspect of the disequilibrium macroeconomic literature focuses on money as a buffer stock or shock absorber. Laidler (1984) surveys the theoretical bases for, and empirical analyses of, money as a buffer stock and concludes that "the theoretical basis of the

*The comments of F.W. Ahking, D.E.W. Laidler, and two anonymous referees are gratefully acknowledged. This research was completed while the author was a Principal Analyst (visiting) at the Congressional Budget Office. The views expressed are mine and do not necessarily reflect those of the Congressional Budget Office or its staff.

[1]Barro (1979) criticizes disequilibrium models because of their "non-theory of price rigidities." And Barro (1979) and Grossman (1979) recant their initial enthusiasm for disequilibrium models, questioning their usefulness. Howitt (1979), in contrast, provides a more sympathetic evaluation.

Journal of Macroeconomics, Fall 1990, Vol. 12, No. 4, pp. 563–586

0164-0704/90/$1.50

buffer stock to monetary analysis is well developed and simple, and it has already withstood a good deal of empirical testing" (32).[2]

Most econometric analyses of money demand recognize, at least implicitly, the possibility of disequilibrium. The standard stock (supply)-adjustment model (Chow 1966 and Goldfeld 1973) differentiates between short- and long-run demands. But this specification possesses some peculiarities if the money supply is exogenous (Walters 1965; Starleaf 1970; Artis and Lewis 1976; Laidler 1980; Carr and Darby 1981; Coats 1982; and Andersen 1985). For example, a change in the money supply requires that the interest rate, real income, and the price level overshoot their long-run values in the short run (Starleaf 1970 provides extensive discussion). Judd and Scadding (1982b) compare supply- and demand-adjusting specifications, concluding that the demand-adjusting models outperform the supply-adjusting models, both for within-sample fit (that is, 1959:*i* to 1974:*ii*) and for out-of-sample forecasting (that is, 1974:*iii* to 1980:*iv*).

Judd and Scadding (1982b) note that even for the best-performing equation (that is, Coats 1982), the out-of-sample simulation encounters the ". . . well-known shift in the demand for money in 1975–76 . . ." (28). Post-1973 econometric analysis of money demand also suggests implausibly slow speeds of adjustment (Judd and Scadding 1982a). The emergence of high levels of autocorrelation and seeming parameter instability in the post-1973 period causes some researchers to search for model misspecifications (for example, Gordon 1984 and Rose 1985). A popular explanation states that money demand shifted down between 1974 and 1976 and again between 1979 and 1981 because of financial innovation (Judd and Scadding 1982a). More recently, explanations state that money demand shifted up between 1982 and 1983 (Gordon 1984; Hetzel 1984; and Miller 1986) and again between 1985 and 1986 (Miller 1989) because of financial deregulation.

I propose a tentative alternative hypothesis to explain post-1973 events: much of the shifting of money demand reflects shifts in money supply (that is, a shift in monetary policy in the sense of Poole 1975) rather than money demand.[3] Significant decelerations

[2]Some authors (White 1981) question the buffer-stock approach to money, arguing that since money is, by definition, the most liquid and flexible asset, a disequilibrium in the money market is untenable. Such criticism, by its nature, must question the modeling of the short-run money demand as well.

[3]Examining seven industrial countries, OECD (1984) finds that the adoption of money-stock targeting associates with money demand shifts.

(accelerations) in money-stock growth are incorrectly interpreted as downward (upward) shifts in short-run money demand. If the shifts in money demand noted in the previous paragraph were actually shifts in monetary policy, then my hypothesis suggests contractionary monetary policy during the first two periods and expansionary policy during the latter two. Moreover, these policy shifts need not have been planned. The first two periods correspond roughly to inflation build-ups after oil-price shocks. If oil-price shocks generate unexpected inflation, then a given monetary policy becomes more contractionary (less expansionary) *ex post.* In addition, the latter two periods correspond to a softening of oil prices and of domestic inflation. In sum, sustained deviations of money-stock growth from its trend generate money-market disequilibria; the demand for money adjusts to the new policy regime as the interest rate, real income, and the price level change.

In the next section, I describe the econometric procedures developed for handling market disequilibria and show how these procedures can be modified to address buffer stocks in a macroeconomic setting. Inferences concerning the nature of the high autocorrelation in post-1973 estimates of money demand emerge from this discussion. I then incorporate relatively new econometric procedures, cointegration and error-correction modeling, before moving to my empirical analysis. Section 3 discusses the data and evaluates the estimation results. Finally, Section 4 concludes the paper.

2. Methodology

Estimating Markets in Disequilibrium

Expanding on the analysis of Fair and Jaffee (1972), a number of authors estimate markets in disequilibrium (for example, Fair and Kelejian 1974; Maddala and Nelson 1974; Laffont and Garcia 1977; and Quandt and Rosen 1978), usually the mortgage market. The key assumption asserts that, when the market is in disequilibrium, the observed quantity reflects the minimum of demand and supply quantities at the given price (that is, the short-side rule). Determining whether a demand or supply observation occurs depends on the direction of movement in the market price. If the observed price exceeds the market-clearing level, then the price falls and the observed quantity presumably lies on the demand curve and vice versa.

Estimation of the money market in disequilibrium differs in two important respects. First, the short-side rule breaks down; the quantity of money observed *always* falls on the money supply. Second, no unique price of money exists from which market-disequilibria signals emanate. Rather, money-market disequilibria generate adjustments of varying degrees and with different timing in the interest rate, real income, and the price level. If the monetary authorities increase the money supply, then the economy holds too much money. Individuals reduce their holding of money by increased spending on goods, services, and assets. If asset demands rise, then interest rates fall. If goods and service demands rise, then real income and the price level rise. A consensus exists on the timing of these effects; the interest rate adjusts first, followed in order by real income and the price level. As the price level finally adjusts, the interest rate and real income movements attenuate; many argue that in the long run, the price level absorbs all of the adjustment.[4]

To illustrate, assume that the demand for money takes the following form:

$$\ln M_t^D = \alpha_0 + \alpha_1 \ln r_t + \alpha_2 \ln y_t + \alpha_3 \ln P_t + \epsilon_t \,, \tag{1}$$

where M^D is the nominal quantity of money demanded, r is the market interest rate, y is real income, P is the price level, ln is the natural logarithm operator, and ϵ is a random error. The demand is specified in nominal terms and can be written in real terms only if $\alpha_3 = 1$. The quantity of money demanded becomes observable only in equilibrium when it equals the money supply (M^S).

In formulating adjustments to disequilibrium, I develop a modification of the Fair-Jaffee (1972) quantitative method. They assume that the market price adjusts to the difference between the quantities demanded and supplied. That is,

$$Dq_t = \Phi(Q_t^D - Q_t^S) \,, \tag{2}$$

where q is the market price of Q, Q^D and Q^S are quantities demanded and supplied, D is the first-difference operator, and Φ is the speed of adjustment. Thus, if Q^D is greater (less) than Q^S, then q rises (falls).

[4]Osagie and Osayimwese (1981) discuss the ideas of disequilibrium in the money market and how the Fair-Jaffee (1972) technique can be used to estimate the money market. They also discuss the issue of what price to use for identifying disequilibria, but assume incorrectly that the short-side rule operates. Finally, they do not perform any econometric tests.

An additional timing issue must be resolved. Laffont and Garcia (1977) suggest two possibilities.

$$Dq_t = q_t - q_{t-1} = \Phi(Q_t^D - Q_t^S)\,, \tag{3a}$$

or

$$Dq_t = q_{t+1} - q_t = \Phi(Q_t^D - Q_t^S)\,. \tag{3b}$$

Equation (3a) assumes that the price-setting mechanism operates within the period but does not succeed in clearing the market. Equation (3b) assumes that Q^D and Q^S are determined by the price at the beginning of the period (that is, q_t) and that the price adjusts over the period in response to this period's excess demand resulting in next period's price (that is, q_{t+1}). My analysis adopts Equation (3b).

Money-market disequilibrium spills into financial and goods markets. Let δ_1 and $\delta_2 = (1 - \delta_1)$ represent the fractions of the excess supply of money (that is, $\ln M^S - \ln M^D$) that spill into the financial and goods markets. Spillovers into financial markets cause adjustments in the interest rate, while spillovers into the goods markets cause adjustments in nominal income. Let Φ_1 and Φ_2 equal the speeds of adjustment of the interest rate and nominal income to the fraction of the excess supply of money spilling into the financial and goods markets. Thus, the following adjustment equations emerge.

$$D \ln r_t = -\Phi_1\delta_1(\ln M_t^S - \ln M_t^D)\,, \tag{4}$$

and

$$D \ln(Py)_t = \Phi_2(1 - \delta_1)(\ln M_t^S - \ln M_t^D)\,. \tag{5}$$

Dividing Equations (4) and (5) by Φ_1 and Φ_2, respectively, and then subtracting Equation (4) from Equation (5) yields

$$\ln M_t^S - \ln M_t^D = -(1/\Phi_1)D \ln r_t + (1/\Phi_2)D \ln(Py)_t\,. \tag{6}$$

Since the economy always holds the money stock, the money demand is never observed, unless the money market clears. Thus, substituting for $\ln M_t^D$ from Equation (1) produces

$$\ln M_t^S = \alpha_0 + \alpha_1 \ln r_t + \alpha_2 \ln y_t + \alpha_3 \ln P_t - (1/\Phi_1)D \ln r_t + (1/\Phi_2)D \ln(Py)_t + \epsilon_t\,. \tag{7}$$

Equation (7) does not separate the effect of the excess supply of money into movements in real income and the price level. Allowing for these differential effects, Equation (5) becomes

$$D \ln y_t = \Phi_{21}(1 - \delta_1)(\ln M_t^S - \ln M_t^D) , \tag{5a}$$

and

$$D \ln P_t = \Phi_{22}(1 - \delta_1)(\ln M_t^S - \ln M_t^D) , \tag{5b}$$

where $\Phi_2 = \Phi_{21} + \Phi_{22}$. Now, dividing Equations (4), (5a), and (5b) by Φ_1, Φ_{21}, and Φ_{22}, respectively, and then subtracting twice Equation (4) from the sum of Equations (5a) and (5b) gives

$$\ln M_t^S - \ln M_t^D = -(1/\Phi_1)D \ln r_t + (1/2\Phi_{21})D \ln y_t + (1/2\Phi_{22})D \ln P_t . \tag{6a}$$

And finally, substituting from Equation (1) results in

$$\ln M_t^S = \alpha_0 + \alpha_1 \ln r_t + \alpha_2 \ln y_t + \alpha_3 \ln P_t - (1/\Phi_1)D \ln r_t + (1/2\Phi_{21})D \ln y_t + (1/2\Phi_{22})D \ln P_t + \epsilon_t . \tag{7a}$$

Now, first-differencing Equation (1) yields

$$\ln M_t^D - \ln M_{t-1}^D = \alpha_1 D \ln r_{t-1} + \alpha_2 D \ln y_{t-1} + \alpha_3 D \ln P_{t-1} + \epsilon_t - \epsilon_{t-1} , \tag{8}$$

where Equation (3b) defines the adjustments in the interest rate, real income, and the price level. Substituting into Equation (8) from Equations (4), (5a), and (5b) generates

$$\ln M_t^D - \ln M_{t-1}^D = \Omega(\ln M_{t-1}^S - \ln M_{t-1}^D) + \epsilon_t - \epsilon_{t-1} , \tag{9}$$

where

$$\Omega = -\alpha_1 \Phi_1 \delta_1 + (\alpha_2 \Phi_{21} + \alpha_3 \Phi_{22})(1 - \delta_1) . \tag{10}$$

Equation (9) represents, not surprisingly, a demand-adjusting formulation in the tradition of Starleaf (1970), Artis and Lewis (1976), and Coats (1982).[5]

Gordon (1984) states that two major problems face monetary economists—the large coefficients of lagged money and the high autocorrelations in post-1973 samples. Lagged money was originally introduced to account for sluggish portfolio adjustment (Chow 1966); but the post-1973 coefficients of lagged money suggest implausibly slow speeds of portfolio adjustment. Further, high autocorrelation may indicate model misspecification.

The existing literature has several things to say about these two issues. Goodfriend (1985) argues that the money market can clear each period and that lagged money does not belong theoretically in money demand. Measurement errors in the exogenous variables can explain the significance of the coefficient of lagged money and the high autocorrelation. Laidler (1985) and Gordon (1984) argue that money demand regression equations represent semi-reduced-form equations. That is, the parameters of the money demand regressions combine the parameters from the money demand and other equations of the macroeconomy.

I offer a competing explanation for these problems based on Equations (1), (7), (7a), and (9). The post-1973 money market experienced significant disequilibrium. But the dynamic adjustment is of the demand-, rather than the supply-, adjusting type. Equation (9) shows how my formulation of money-market adjustment conforms with the demand-adjusting view. Now, a well-behaved (that is, white-noise) error structure in Equation (1) implies a well-behaved error structure in Equations (7) and (7a) but a moving-average error structure with a unit root in Equation (9). If, alternatively, the partial-adjustment equation possesses a well-behaved error structure, then Equations (1), (7), and (7a) exhibit autocorrelated

[5]Equations (7a) and (9) are comparable to Starleaf's (1970, 751–52) Equations (3.4) and (3.5) after several adjustments. First, Starleaf assumes that the adjustment equation (that is, [3.4]) does not involve a random error. Equation (9) includes a random error due to different model design. Second, Starleaf assumes that the demand for money and the demand-adjustment equation are in real terms. Thus, the price terms appearing in Equation (7a) disappear in Starleaf's specification. Third, Starleaf assumes that this period's demand for money adjusts to the difference between this period's money supply and last period's money demand. Equation (9) has last period's money supply instead of this period's. Starleaf's adjustment equation results when Equation (3a) is adopted rather than Equation (3b) as the disequilibrium adjustment specification. Finally, to derive Starleaf's Equation (3.5) from Equation (7a), assume that $\Omega = \alpha_1\Phi_1 = \alpha_2\Phi_{21}$.

error structures with unit roots. In sum, a well-behaved demand-adjusting partial-adjustment model of the money market implies an autoregressive error structure with a unit root for estimated money demand equations, potentially explaining the high autocorrelation in the post-1973 money demand regressions.[6]

Estimation of Equations (7) and (7a) present several econometric problems. First, the equations contain right-side endogenous variables. The rates of change in the interest rate, nominal and real income, and the price level, since they are based on Equation (3b), follow, in a timing sense, the other variables in the equations, including the left-hand-side money stock. Thus, two-stage estimation appears appropriate, assuming that the rate of change variables are endogenous. But, such an approach implies an exogenous left-hand-side variable. Cointegration and error-correction modeling, considered in the next section, provide a possible solution to these problems.[7]

Cointegration and Error-Correction

Econometric method precedes econometric practice, sometimes with a substantial lead. For example, the possibility of spurious co-movement between variables has been acknowledged for a long time (for example, Jevons 1884, 3), with Yule (1926) conducting the first formal analysis (Hendry 1986 provides more details). Nonetheless, econometricians continued to use standard time-series regressions with little concern for whether the relationships were real or spurious. Spurious regression can occur when the regression

[6]Such a dichotomy does not occur with the supply-adjusting model, where the error structures of the partial-adjustment and estimating equations are identical. Gordon (1984, 414) introduces the error term into the partial-adjustment, rather than the demand, equation with little effect, since the final error structure of the estimating equation is unaffected. Such is not the case for the demand-adjusting framework.

[7]Estimation also assumes constant parameters, inviting the Lucas (1976) criticism. The speeds of adjustment (that is, Φ_1, Φ_2, Φ_{21}, and Φ_{22}) are especially open to this criticism, since they measure how the interest rate, nominal and real income, and the price level respond to disequilibria in the money market. Laidler (1985) makes this point as it applies to the estimation of standard post-1973 money demand functions. In addition, exogenous oil-price shocks cause temporary perturbations in the price-level adjustment process. For example, as the price level rises in response to previous excess supplies of money, oil-price increases (decreases) cause larger (smaller) changes in $D \ln P$ than are indicated by previous money-market disequilibria. As a consequence, the estimates of Φ_2 and Φ_{22} are biased upward (downward) during the time when the oil-price shock is being transmitted to the domestic price level.

adjusted coefficient of determination (R^2) exceeds the Durbin-Watson statistic (Granger and Newbold 1974 and Plosser and Schwert 1978).

Cointegration analysis addresses the spurious regression problem, attempting to identify conditions for which regression relationships are not spurious (Engle and Granger 1987; Granger 1986; and Hendry 1986). When two time-series variables are cointegrated, their secular trends move subject to an equilibrium constraint, and the cyclical components of the series conform to a dynamic specification in the class of error-correction models.

The problem of spurious regression emerges because most economic time series exhibit non-stationary tendencies. Thus, the high R^2 may reflect correlated trends rather than underlying economic relationships; the low Durbin-Watson statistic may indicate non-stationary residuals. One specification check for spurious regression involves first-differenced regressions. That specification check probably produces stationary residuals. The question emerges as to whether relationships found in regressions on levels remain under the first-differenced specification. But, first-differencing removes the low-frequency (long-run) information. Cointegration and error-correction modeling reintroduces the low-frequency information into first-differenced regressions in a statistically acceptable way.

Consider two time-series x_t and y_t that are non-stationary in their levels but stationary in their first differences. The series are cointegrated when a factor β exists, such that $z_t = y_t - \beta x_t$ is stationary. If it does exist, then the cointegration factor must be unique in the two-variable case, since altering it to $(\beta + \delta)$ introduces an additional term $(-\delta x_t)$, which is non-stationary by definition. Since the temporal characteristics of z_t and its components are so different, a special relationship exists between cointegrated variables. To wit, y_t and βx_t must exhibit low-frequency (long-run) components that cancel, producing a stationary series z_t. The long-run (equilibrium) relationship may emerge from economic theory, where z_t measures short-term deviations from the trend (equilibrium) relationship.

In sum, cointegration and error-correction modeling is a two-step procedure. The first step estimates the cointegration equation, which captures the long-run (trend) relationships, if any, between the variables of interest. The errors from the cointegration regression are then used in the second step to estimate the error-correction model, which captures the short-run (cyclical) relationships among the variables.

This discussion applies directly to the present problem of estimating money demand, since the buffer-stock view implies that the money market exhibits short-run departures from long-run equilibrium.[8] Equation (1), therefore, represents the long-run (equilibrium) money demand, where each variable refers to the trend of the observed series. Cointegration analysis allows the estimation of the long-run relationship with observed time-series, where the residuals measure the short-run deviations from long-run equilibrium.

Second, modification of the Fair-Jaffee quantitative procedure for estimating markets in disequilibrium suggests that the rates of change in the interest rate, nominal and real income, and the price level depend on short-run deviations from long-run equilibrium. That is, the residuals from the cointegration regression can be used to estimate directly Equations (4), (5), (5a), and (5b), solving one of the previously mentioned econometric problems.

Third, the cointegration regression uses simple ordinary least squares, where all variables are potentially endogenous. The error-correction model emerges as a restricted vector autoregression. As seen below, the estimation of Equations (4), (5), (5a), and (5b) are contained within the class of error-correction models, although with further restrictions.

3. Empirical Analysis

Considerable debate surrounds the choice of variables to use in the money demand function.[9] Questions arise about the monetary aggregate, the interest rate, and the scale variable. I examine three alternatives for the monetary aggregate, M1, M1A, and M2; two alternatives for the interest rate, the four-to-six-month commercial-paper rate (r_c) and the dividend-to-price ratio (r_d); and one alternative for the scale variable, nominal gross national product (Y),

[8]Hendry (1980) and Motley (1988) employ error-correction models, unconstrained by cointegration equations, to study money demand. Trehan (1988) combines cointegration equations with error-correction models to examine West German money demand, but does not link the analysis to the estimation of markets in disequilibrium.

[9]The data are from the Federal Reserve Board Quarterly Econometric Model data base. Precise definitions of variables are in the Appendix. The sample covers 1959:*i* to 1987:*iv*. All statistical analysis is performed with the aid of RATS, version 2.03, October 9, 1986.

that is decomposed into real gross national product (y) and the implicit price deflator (P).[10]

Cointegration and error-correction modeling proceeds as follows. First, determine the orders of integration for each of the variables under consideration. Second, estimate cointegration equations with ordinary least squares, using variables with the same order of integration. Third, test for stationary residuals of the cointegration equations. And finally, construct the error-correction models.

Testing for Stationary Series

Table 1 reports Dickey-Fuller (DF) and adjusted Dickey-Fuller (ADF) tests for stationarity of the natural logarithm of each variable (Fuller 1976 and Dickey and Fuller 1979). For levels of the series, none reject the null hypothesis of non-stationarity at either the 5% or 10% levels. After first differencing, each series, save one, rejects non-stationarity at the 5% level. The test of the natural logarithm of the implicit price deflator (that is, ln P), the exception, rejects non-stationarity by the DF test, but not by the ADF test.

Further analysis of the implicit price deflator suggests that first differencing probably induces stationarity. The DF and ADF tests on second differences indicate over differencing, since the coefficients of the lagged level (that is, the first difference of the series) are significantly less than minus one. Also, examination of autocorrelation and partial autocorrelation charts reveals that first differencing leaves a highly autocorrelated series with a slowly declining autocorrelation function and significant partial autocorrelation spikes of 0.76 and 0.34 at lags one and two, but that second differencing produces only one significant spike in the autocorrelation and partial autocorrelation functions at lag one of -0.43, suggesting possible over differencing.

In sum, the evidence suggests that each series is stationary in first differences.

Cointegration Equations

Engle and Granger (1987) consider whether alternative monetary aggregates and nominal gross national product are cointe-

[10]These choices are not exhaustive, but do reflect frequently examined variables. Since I find a set of co-integrated variables, I search no further. M1 and M2 are the current Federal Reserve definitions, and M1A subtracts other checkable deposits from M1. Renewed interest surrounds M1A (Darby, Mascaro, and Marlow 1989). Hamburger (1987) supports the use of the dividend-price ratio.

TABLE 1. *Tests for Stationarity*

	DF Test		ADF Test	
	Levels	1st-Differences	Levels	1st-Differences
Variable (x_t)				
ln M1	6.758	−6.096*	3.461	−3.193*
ln M1A	1.345	−7.132*	0.115	−3.143*
ln M2	2.182	−5.136*	0.430	−3.662*
ln y	−1.425	−8.215*	−0.964	−4.485*
ln P	3.406	−3.856*	−0.517	−1.774
ln r_c	−1.871	−7.813*	−1.935	−3.974*
ln r_d	−1.652	−6.875*	−2.000	−5.215*

NOTES: The augmented Dickey-Fuller (ADF) test is based on the following regression:

$$Dx_t = \alpha + \sigma x_{t-1} + \sum_{i=1}^{4} \Phi_i Dx_{t-i} + e_t ,$$

where D is the first-difference operator, and e_t is a stationary random error. The null hypothesis is that x_t is a non-stationary series, and it is rejected when σ is significantly negative. The Dickey-Fuller (DF) test deletes the summation from the equation. The sample period runs from 1959:*i* to 1987:*iv*.

*significant at the 5% level.
**significant at the 10% level.

grated. They examine four measures of the money stock—M1, M2, M3, and liquid assets (*L*)—from 1959:*i* to 1981:*ii*. They conclude that the money stock and nominal gross national product (GNP) are not cointegrated with the possible exception of M2, which passes the ADF test when the natural logarithm of M2 is regressed on the natural logarithm of GNP. In other words, the velocity of circulation is generally non-stationary.[11]

The absence of cointegration between the money stock and nominal GNP does not rule out cointegration in some higher order system, including the money stock and nominal GNP. The omission of relevant variables may lead to the non-cointegration finding. The demand for money literature provides the avenue for a logical extension, since velocity potentially depends on nominal income and the interest rate.

[11]Gould and Nelson (1974), Gould, Miller, Nelson, and Upton (1978), and Ahking (1984) also find velocity to be generally non-stationary.

As a first step, I examine tri-variate cointegration regressions of the natural logarithm of the money stock onto the natural logarithms of real GNP and the implicit price deflator. The results appear in Table 2.[12] The high adjusted coefficent of determination and low Durbin-Watson statistics suggest possible spurious regression and make the cointegration investigation a fruitful exercise (Hendry 1986). The DF and ADF tests do not reject the null hypothesis of non-stationary errors in any case, although consistent with Engle and Granger (1987), the M2 series comes closest. The DF and ADF statistics for cointegration regressions with three or more variables are given in Engle and Yoo (1987).

As a second step, I introduce sequentially the four-to-six-month commercial-paper rate and the dividend-price ratio to form four-variable cointegration regressions. The results also appear in Table 2. Now, the M2 equations reject non-stationary errors for the DF test when the four-to-six-month commercial-paper rate is added and for the ADF test when the dividend-price ratio is added, each at the 10% level. Further, deleting insignificant coefficients from the lagged differences in the ADF tests produces a significant ADF statistic (that is, -4.22) for the M2 equation including the four-to-six-month commercial-paper rate.

I conclude that the natural logarithms of M2, y, P, and r_c are cointegrated. The cointegration equation measures the long-run equilibrium relationship between the variables. The residuals from the cointegration equation measure the short-run deviations from long-run equilibrium.

Table 3 reports the errors (that is, actual M2 minus its fitted value from the cointegration regression) for the post-1973 period, where shifting money demand considerations emerge. For purposes of comparison, the errors for the M1 cointegration regression also appear. Several observations emerge. First, the much discussed missing money (that is, long-run equilibrium money demand exceeding the available money stock) during 1974 and 1975 does not appear; positive errors occur through 1975:*iii*. Second, much evidence exists of the money stock falling short of long-run equilibrium money demand in the late 1970s and early 1980s—negative errors from 1978:*ii* through 1981:*iv*. Third, the available money stock exceeds the long-run equilibrium demand during the early and mid-1980s—positive errors with one exception from 1982:*i* through

[12]The table does not report standard t-statistics, since the standard errors are misleading in cointegration equations (Engle and Granger 1987).

TABLE 2. *Cointegration Regressions*

		Coefficients of							
	CONST	ln y	ln P	ln r_c	ln r_d	R^2	DW	DF	ADF
Variable									
ln M1	−1.04	0.407	0.856	—	—	0.99	0.03	1.95	−0.90
ln M1A	−2.41	0.784	0.440	—	—	0.99	0.09	−1.85	−1.98
ln M2	−5.55	1.080	0.953	—	—	0.99	0.15	−1.95	−2.99
ln M1	−2.12	0.575	0.855	−0.125	—	0.99	0.11	−0.54	−1.79
ln M1A	−2.64	0.821	0.439	−0.270	—	0.99	0.09	−1.92	−2.07
ln M2	−6.35	1.204	0.952	−0.092	—	0.99	0.53	−4.21**	−3.00
ln M1	−0.28	0.283	1.010	—	−0.300	0.99	0.30	−2.18	−3.10
ln M1A	−2.44	0.790	0.433	—	0.014	0.99	0.09	−1.86	−2.03
ln M2	−5.23	1.028	1.018	—	−0.128	0.99	0.34	−3.32	−3.77**

NOTES: The errors from the cointegration equations are recovered to perform the augmented Dickey-Fuller non-stationarity tests based on the following regression:

$$D\epsilon_t = \delta\epsilon_{t-1} + \sum_{i=1}^{4} \pi_i D\epsilon_{t-i} + \mu_t ,$$

where ϵ_t is the error from the cointegration equation, μ_t is a stationary random error, and the null hypothesis of non-stationarity is rejected when δ is significantly negative. The Dickey-Fuller (DF) tests for non-stationarity delete the summation. R^2 is the adjusted coefficient of determination, and DW is the Durbin-Watson statistic.

*significant at the 5% level.

**significant at the 10% level.

TABLE 3. *Short-Run Disequilibria in Money Market*

Date	Error M1	Error M2	Date	Error M1	Error M2
74:1	13.1509	11.3584	81:1	−61.7334	−71.8368
74:2	22.2887	19.0593	81:2	−32.8256	−44.9324
74:3	25.9008	29.8321	81:3	−30.3126	−38.1445
74:4	6.1038	17.5078	81:4	−24.4134	−21.4593
75:1	−3.9263	6.3670	82:1	30.9629	38.1170
75:2	−4.5163	1.7710	82:2	31.7449	39.0233
75:3	0.8009	6.4324	82:3	44.0344	56.1784
75:4	−16.9934	−10.5750	82:4	23.6385	26.0725
76:1	−34.3567	−30.2302	83:1	78.0244	76.9354
76:2	−15.8218	−12.0907	83:2	69.7091	59.5572
76:3	−7.6018	−4.8660	83:3	73.7713	58.8806
76:4	−9.4554	0.0340	83:4	44.3360	32.1397
77:1	−12.9621	4.2227	84:1	2.4403	−3.5882
77:2	−17.1918	0.1581	84:2	17.1096	12.2908
77:3	−19.9091	0.2609	84:3	24.3861	16.8943
77:4	5.6313	26.2002	84:4	7.2771	7.2674
78:1	1.5981	28.0690	85:1	18.8408	15.5524
78:2	−48.9288	−24.5324	85:2	2.7867	1.4798
78:3	−45.8349	−27.7916	85:3	8.5054	7.0519
78:4	−38.7536	−22.4725	85:4	7.4682	1.3424
79:1	−44.3260	−28.6224	86:1	−13.2705	−29.5663
79:2	−46.6318	−28.8984	86:2	0.4234	−21.9828
79:3	−43.0815	−29.2594	86:3	12.1440	−4.8920
79:4	−17.0707	−7.6395	86:4	50.1401	36.0378
80:1	−29.4776	−24.1690	87:1	41.2841	6.3737
80:2	−44.4363	−28.9025	87:2	53.0456	6.8887
80:3	−38.2878	−30.7980	87:3	25.4535	−33.7998
80:4	−8.4928	−21.7644	87:4	13.3300	−10.1328

NOTE: The errors measure the difference between the actual money stock and the fitted money demand from the cointegration equations, including the four-to-six-month commercial-paper rate, for M1 and M2 contained in Table 2.

1985:*iv*. For M1 a similar story is told, except that the oversupply of the money stock in the early and mid-1980s becomes more dramatic in magnitude and in persistence—generally larger and positive errors from 1982:*i* through 1987:*iv*.

Splitting the sample in 1973 and testing for structural changes in money demand has become standard procedure. This suggests estimating cointegration equations for the two sub-samples, and testing for structural shifts. Such a procedure is problematic because the standard errors from the cointegration regressions are misleading. Nonetheless, Table 4 does report results from estimating the cointegration equation for the 1959:*i* to 1973:*iv* and 1974:*i* to 1987:*iv* periods. I also report the full-sample results from Table 2 to facilitate comparisons.

Several observations emerge. First, neither of the sub-sample regressions pass the DF or the ADF tests for stationary errors, suggesting non-cointegration. The DF and ADF statistics are in the neighborhood of the 10% significance level, however. Furthermore, visual inspection of the autocorrelation and partial autocorrelation functions suggest stationary error structures; the auto-correlation declines quickly while the partial autocorrelation functions have spikes (of around 0.65) at lag one only. Second, the price and interest rate elasticities increase in the latter period. Numerous authors argue that the interest rate elasticity increased because of financial innovation and deregulation. Finally, the real income elasticity falls in the latter period.

Error-Correction Modeling

The final stage in the model building process involves the construction of error-correction models. The standard procedure in-

TABLE 4. *Cointegration Regressions: Sub-Samples*

		Coefficients of						
	CONST	ln y	ln P	ln r_c	R^2	DW	DF	ADF
1959:i–1987:iv								
ln M2	−6.35	1.204	0.952	−0.092	0.99	0.53	−4.21**	−4.22*
1959:i–1973:iv								
ln M2	−6.56	1.265	0.876	−0.079	0.99	0.74	−3.63	−3.35
1974:i–1987:iv								
ln M2	−5.22	1.011	1.054	−0.104	0.99	0.57	−3.53	−3.58

NOTES: See Table 2. For the ADF test, lagged first-differences of the error term are included only if significant.

*significant at the 5% level.

**significant at the 10% level.

volves estimating a vector-autoregressive system of the first difference of each variable in the cointegration equation onto lagged values of the first differences of all of the variables plus the lagged value of the error-correction term (that is, the error term from the cointegration regression).

The discussion of money as a buffer stock and estimation of the money market in disequilibrium suggests some restrictions on the error-correction model. The simplest possible error-correction model regresses the first difference of the variables in the cointegration regression onto the error-correction term only; no lagged first differences are included. This is precisely the form of Equations (4), (5), (5a), and (5b).

Such a simplistic formulation of the adjustment process may be inappropriate, especially if the adjustment of the variables is distributed over time; that is, this period's error affects several future periods' rates of change in the interest rate, real and nominal income, and the price level. A modest extension assumes that such lagged adjustment to disequilibria does occur and that this period's error causes a perturbation in the adjustment path already in the pipeline for each variable because of previous periods' errors. In sum, the rates of change of a particular variable depend on lagged rates of change in itself and the lagged error-correction term.

Table 5 reports the results of the second approach, estimation of Equations (4), (5), (5a), and (5b) with the inclusion of significant lagged rates of change in the dependent variable. Several interesting observations emerge. First, the coefficients of the error-correction terms all have the expected sign.[13] Moreover, these coefficients are all significantly different from zero at the 5% or 10% levels in the full-sample regressions.

Second, the sub-sample regressions suggest that the pre- and post-1973 adjustment processes differ. Real and nominal income respond significantly to the error-correction term before 1973. (The price level responds significantly at the 15% level.) The interest rate does not respond significantly to the error-correction term. Roles reverse after 1973; only the interest rate responds to the error-correction term.

[13]The error-correction term measures the difference between the actual money stock and the fitted values and, for the full (pre-1973, post-1973) sample period, corresponds to the errors from the cointegration equation reported on the first (second, third) line of Table 4.

TABLE 5. *Error-Correction Regressions*

Variable (x)	CONST	Coefficents of EC_{-1}	x_{-1}	x_{-2}	x_{-3}	R^2	DW
1959:i–1987:iv							
$D \ln r_c$	—	−1.010*	0.480*	−0.405*	0.210*	0.22	1.95
		(1.72)	(5.11)	(4.31)	(2.26)		
$D \ln Py$	0.011*	0.108*	0.265*	0.180**	—	0.10	1.97
	(4.38)	(1.92)	(2.80)	(1.94)			
$D \ln y$	0.005*	0.144*	0.281*	—	—	0.12	1.99
	(4.91)	(2.90)	(3.17)				
$D \ln P$	—	0.038**	0.548*	0.423*	—	0.62	2.13
		(1.59)	(6.37)	(4.90)			
1959:i–1973:iv							
$D \ln r_c$	—	−0.417	0.558*	—	—	0.19	1.85
		(0.41)	(3.90)				
$D \ln Py$	0.018*	0.246*	—	—	—	0.12	1.46
	(15.03)	(2.99)					
$D \ln y$	0.009*	0.238*	—	—	—	0.15	1.72
	(8.76)	(3.32)					
$D \ln P$	—	0.052	0.517*	0.480*	—	0.43	2.21
		(1.27)	(4.29)	(3.86)			
1974:i–1987:iv							
$D \ln r_c$	—	−3.507*	0.390*	−0.371*	—	0.30	1.82
		(3.44)	(3.21)	(3.19)			
$D \ln Py$	0.014*	0.021	0.335*	—	—	0.07	2.01
	(4.36)	(0.23)	(2.46)				
$D \ln y$	0.004*	0.032	0.365*	—	—	0.10	2.00
	(2.53)	(0.37)	(2.77)				
$D \ln P$	—	0.022	0.538*	0.408*	—	0.70	2.05
		(0.62)	(4.60)	(3.48)			

NOTES: See Table 2. The numbers in parentheses under parameter estimates are t-statistics. EC is the error-correction term determined from the corresponding cointegrations reported in Table 4. The negative subscripts refer to lags. Tests are two-tailed except for the coefficients of EC, where they are one-tailed.

*significant at the 5% level.

**significant at the 10% level.

4. Conclusion

Monetary theorists have lived through turbulent events in the post-1973 period. The seeming breakdown of the cherished stability of the money demand function generated a reassessment of fundamental beliefs. One area of reassessment, and my focus, examines the implications of assuming that money is a buffer stock or shock absorber. This hypothesis rejects the assumption that the money market clears each period in an ex ante sense.

I link the theoretical notion of money as a buffer stock with the econometric literature on estimating markets in disequilibrium and on cointegration and error-correction modeling. The process of integrating the theory of money as a buffer stock with the estimation of markets in disequilibrium generates two problems that need resolution. One, the standard short-side rule of disequilibrium econometrics breaks down; in the money market, the economy always holds the money stock and never departs from the money supply. Two, an explicit price of money does not exist. Therefore, signals about money-market disequilibria, which come from market price movements in the disequilibrium econometric literature, must flow from other sources. Money-market disequilibria cause adjustments in the interest rate, real income, and the price level. Therefore, the standard disequilibrium econometric specification requires modification to allow adjustments in several variables rather than one unique price.

Consideration of the estimation techniques for markets in disequilibrium when applied to the money market generates adjustment equations that resemble simple error-correction models. New advances in econometrics suggest the examination of cointegration between the determinants of money demand prior to the formulation of error-correction models. Cointegration analysis has attractive features, since the technique focuses on long-run, trend (equilibrium) relationships among economic time series. The literature has long considered the distinction between the long-run and short-run demand for money (for example, Chow 1966), where short-run adjustment is important because the economy need not lie on the long-run money demand period-by-period.

My maintained hypothesis is that the seeming instability in the post-1973 money demand results partly from trend shifts in monetary policy rather than shifting money demand. The movement to flexible exchange rates and the redirection of monetary policy toward monetary-aggregate targeting has given the monetary authorities more independence and has made the money stock more "exogenous." As a consequence, movements in the money stock lead, rather than follow, money demand, and money-market disequilibria result more from policy action than endogenous economic events.

My econometric results are consistent with the maintained hypothesis. First, the cointegration results imply a long-run trend relationship between the natural logarithms of M2, real GNP, the implicit price deflator, and the four-to-six-month commercial paper rate. Such a finding extends the work of Engle and Granger (1987), who find that M2 comes closest to being cointegrated with nominal GNP.

Second, the error-correction equations imply that the interest rate, real and nominal income, and the price level all adjust in the theoretically expected manner. A difference exists in the adjustment patterns between pre- and post-1973 samples. Prior to 1973, real and nominal income respond; after 1973, the interest rate responds.

Finally, my findings offer some insight as to the reliability of monetary aggregates as indicators of monetary policy. Numerous studies examine the choice between the various monetary aggregates as guides to monetary policy (for example, Motley 1988 and Darby, Mascaro, and Marlow 1989). My results show that M2, but not M1 or M1A, is cointegrated with the simple determinants of money demand.

Received: January 1988
Final version: January 1990

References

Ahking, Francis W. "The Predictive Performance of the Time-Series Model and the Regression Model of the Income Velocity of Money: Evidence from Five EEC Countries." *Journal of Banking and Finance* 8 (September 1984): 389–415.

Andersen, Palle S. "The Stability of Money Demand Functions: An Alternative Approach." Bank of International Settlements *Economic Papers* 14 (April 1985): 1–72.

Artis, M.J., and M.K. Lewis. "The Demand for Money in the United Kingdom." *Manchester School* 44 (June 1976): 147–81.

Barro, Robert J. "Second Thoughts on Keynesian Economics." *American Economic Review* 69 (May 1979): 54–59.

Barro, Robert J., and Herschel I. Grossman. "A General Disequilibrium Model of Income and Employment." *American Economic Review* 61 (March 1971): 82–93.

———. *Money, Employment and Inflation.* Cambridge: Cambridge University Press, 1976.

Carr, Jack, and Michael R. Darby. "The Role of Money Supply Shocks in the Short-Run Demand for Money." *Journal of Monetary Economics* 8 (September 1981): 183–200.

Chow, Gregory C. "On the Long-Run and Short-Run Demand for Money." *Journal of Political Economy* 74 (April 1966): 111–31.

Clower, Robert W. "The Keynesian Counterrevolution: A Theoretical Appraisal." In *The Theory of Interest Rates,* edited by Frank H. Hahn and Frank P.R. Brechling. London: MacMillan, 1965.

Coats, Warren L., Jr. "Modeling the Short-Run Demand for Money with Exogenous Supply." *Economic Inquiry* 20 (April 1982): 222–39.

Darby, Michael R., Angelo R. Mascaro, and Michael L. Marlow. "The Empirical Reliability of Monetary Aggregates as Indicators: 1983–1987." *Economic Inquiry* 27 (October 1989): 555–85.

Dickey, David A., and Wayne A. Fuller. "Distribution of Estimates of Autoregressive Time Series with Unit Root." *Journal of the American Statistical Association* 74 (June 1979): 27–31.

Engle, Robert F., and C.W.J. Granger. "Co-Integration and Error Correction: Representation, Estimation, and Testing." *Econometrica* 55 (March 1987): 251–76.

Engle, Robert F., and Byang Sam Yoo. "Forecasting and Testing in Co-Integrated Systems." *Journal of Econometrics* 35 (May 1987): 143–59.

Fair, Ray C., and Dwight M. Jaffee. "Methods of Estimation for Markets in Disequilibrium." *Econometrica* 40 (May 1972): 497–514.

Fair, Ray C., and Harry H. Kelejian. "Methods of Estimation for Markets in Disequilibrium: A Further Study." *Econometrica* 42 (January 1974): 177–90.

Fuller, Wayne A. *Introduction to Statistical Time Series.* New York: Wiley, 1976.

Goldfeld, Stephen M. "The Demand for Money Revisited." *Brookings Papers on Economic Activity,* no. 3 (1973): 577–638.

Goodfriend, Marvin. "Reinterpreting Money Demand Regressions." In *Understanding Monetary Regimes,* Carnegie-Rochester Conference Series, edited by Karl Brunner and Allen H. Meltzer, vol. 22, 207–41. Amsterdam: North-Holland, 1985.

Gordon, Robert J. "The Short-Run Demand for Money: A Reconsideration." *Journal of Money, Credit, and Banking* 16, pt. 1 (November 1984): 403–34.

Gould, John P., and Charles R. Nelson. "The Stochastic Structure of the Velocity of Money." *American Economic Review* 64 (June 1974): 405–18.

Gould, John P., Merton H. Miller, Charles R. Nelson, and C. W. Upton. "The Stochastic Properties of Velocity and the Quantity

Theory of Money." *Journal of Monetary Economics* 4 (April 1978): 229–48.

Granger, C.W.J. "Developments in the Study of Cointegrated Economic Variables." *Oxford Bulletin of Economics and Statistics* 48 (August 1986): 213–28.

Granger, C.W.J., and P. Newbold. "Spurious Regression in Econometrics." *Journal of Econometrics* 2 (July 1974): 111–20.

Grossman, Herschel I. "Why Does Aggregate Employment Fluctuate?" *American Economic Review* 69 (May 1979): 64–69.

Hamburger, Michael J. "A Stable Money Demand Function." *Contemporary Policy Issues* 5 (January 1987): 34–40.

Hendry, David F. "Predictive Failure and Econometric Modelling in Macro-Economics: The Transactions Demand for Money." In *Economic Modelling,* edited by P. Omerod, 217–42. London: Heinemann Educational Books, 1980.

———. "Econometric Modelling with Cointegrated Variables: An Overview." *Oxford Bulletin of Economics and Statistics* 48 (August 1986): 201–12.

Hetzel, Robert L. "Estimating Money Demand Functions." *Journal of Money, Credit, and Banking* 16 (May 1984): 185–93.

Howitt, Peter. "Evaluating the Non-Market-Clearing Approach." *American Economic Review* 69 (May 1979): 60–63.

Jevons, W.S. *Investigations in Currency and Finance.* London: MacMillan, 1884.

Judd, John P., and John L. Scadding. "The Search for a Stable Money Demand Function." *Journal of Economic Literature* 20 (September 1982a): 993–1023.

———. "Dynamic Adjustment in the Demand for Money: Tests of Alternative Hypotheses." Federal Reserve Bank of San Francisco *Economic Review* (Fall 1982b): 19–30.

Laffont, Jean-Jacques, and Rene Garcia. "Disequilibrium Econometrics for Business Loans." *Econometrica* 45 (July 1977): 1187–1204.

Laidler, David E.W. "The Demand for Money in the United States: Yet Again." In *The State of Macroeconomics,* Carnegie Rochester Conference Series, edited by Karl Brunner and Allen J. Meltzer, vol. 12, 219–71. Amsterdam: North-Holland, 1980.

———. "The 'Buffer' Stock Notion in Monetary Economics." *Economic Journal* 94 (Supplement 1984): 17–34.

———. "The Missing Money and the Disappearing Phillips Curve—A Comment on Vance Roley." *Journal of Money, Credit, and Banking* 17, pt. 2 (November 1985): 647–53.

Leijonhufvud, Axel. *On Keynesian Economics and the Economics of Keynes.* London: Oxford University Press, 1968.

Lucas, Robert E., Jr. "Econometric Policy Evaluation: A Critique." In *The Phillips Curve and the Labor Market,* Carnegie-Rochester Conference Series, edited by Karl Brunner and Allen H. Meltzer, vol. 1. Amsterdam: North-Holland, 1976.

Maddala, G.S., and Forrest D. Nelson. "Maximum Likelihood Methods for Models of Markets in Disequilibrium." *Econometrica* 42 (November 1974): 1013–30.

Miller, Stephen M. "Financial Innovation, Depository Institution Deregulation, and the Demand for Money." *Journal of Macroeconomics* 8 (Summer 1986): 279–96.

———. "Money-Demand Instability: Has It Ended?" *Economic Letters* 30 (1989): 345–49.

Motley, Brian. "Should M2 Be Redefined?" Federal Reserve Bank of San Francisco *Economic Review* (Winter 1988): 33–51.

OECD. "La Demande de Monnaie et la Vitesse de Circulation Dans les Grands Pays de l'OCDE." Organization for Economic Cooperation and Development Working Paper No. 13, Paris, 1984.

Osagie, E. Ghosa, and Iz Osayimwese. "Conceptual, Measurement and Estimation Problems in the Demand for and Supply of Money." *Indian Economic Journal* 29 (July–September 1981): 73–81.

Patinkin, Don. *Money, Interest and Prices.* 2d ed. New York: Harper and Row, 1965.

Plosser, Charles I., and G. William Schwert. "Money, Income, Sunspots: Measuring Economic Relationships and the Effects of Differencing." *Journal of Monetary Economics* 4 (August 1978): 637–60.

Poole, William. "The Relationship of Monetary Decelerations to Business Cycle Peaks: Another Look at the Evidence." *Journal of Finance* 30 (June 1975): 697–712.

Quandt, Richard E., and Harvey S. Rosen. "Estimation of a Disequilibrium Aggregate Labor Market." *Review of Economics and Statistics* 60 (August 1978): 371–79.

Rose, Andrew K. "An Alternative Approach to the American Demand for Money." *Journal of Money, Credit, and Banking* 17, pt. 1 (November 1985), 439–55.

Starleaf, Dennis R. "The Specification of Money Demand/Supply Models Which Involve the Use of Distributed Lags." *Journal of Finance* 25 (September 1970): 743–60.

Trehan, Bharat. "The Practice of Monetary Targeting: A Case Study of the West German Experience." Federal Reserve Bank of San Francisco *Economic Review* (Spring 1988): 30–44.

Walters, Alan A. "Professor Friedman on the Demand for Money." *Journal of Political Economy* 73 (October 1965): 545–51.

White, William H. "The Case For and Against 'Disequilibrium' Money." International Monetary Fund *Staff Papers* 28 (September 1981): 534–72.

Yule, G.U. "Why Do We Sometimes Get Nonsense-Correlations Between Time-Series? A Study in Sampling and the Nature of Time-Series." *Journal of the Royal Statistical Society* 89 (1926): 1–64.

Appendix

The data come from the Federal Reserve Board's Quarterly Econometric Model data base. Data are as follows:

M1 = M1 definition of money supply,
M2 = M2 definition of money supply,
OCD = other checkable deposits,
M1A = M1 − OCD,
Y = gross national product in current dollars,
y = gross national product in 1982 dollars,
$P = Y/y$,
r_c = four-to-sixth-month commercial-paper rate,
r_d = dividend-to-price ratio.

Note that M1A and P are calculated while all other variables are collected directly from the data base.