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MONEY DEMAND AND THE TERM STRUCTURE OF INTEREST RATES: SOME CONSISTENT ESTIMATES

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1. Introduction

The demand for money is a crucial component in economic theory and in the formulation of economic policy. While there is general agreement that the demand for real money balances is related to a scale variable and some measure of the opportunity cost of holding money, the variables that best capture these theoretical constructs remain an unresolved empirical issue. A great deal of attention has been directed towards finding the best opportunity cost variables in recent studies. For example, Klein (1974, 1977) includes a short-term and a long-term interest rate into his long-run annual money demand equation. Goldfeld (1973, 1976) elects to include the interest rates on commercial paper and time deposits into his quarterly money demand equation. Hamburger (1977) presents evidence suggesting that the proper specification may include the yield on equities, in addition to a short-term and a long-term rate. [1/] If the decision to hold money is considered within a broader portfolio-decision framework, then there is no one interest rate that adequately captures the costs of holding money. Laidler (1977) and Feige and Pearce (1977), present this viewpoint in their surveys of the literature. However, the econometric difficulties that are encountered when more than a few interest rates are included in estimates of the money demand function precludes most research efforts to finding the best rate or rates.

Friedman (1977) focuses directly on the relevant information for the quantity of money demanded that is contained in the term structure of interest. [2/] Based on his theoretical analysis regarding the option between holding cash and securities, Friedman suggests that the characteristics of the term structure, i.e., its level, slope, and curvature, should be parameterized and included in a money demand function. 3/ Heller and Khan (1979) (hereafter HK) approximate the term structure by estimating a quadratic function of the various maturities for each point in time. The time-series of the regression coefficients from these equations, estimates of the level, slope, and curvature of the term structure, are then introduced into a money demand equation as the relevant opportunity cost measures. Using this specification of the money demand function, HK find that it yields a statistically stable relationship when estimated over the period 1960/III-1976/IV.

Two independent studies have found that the HK quadratic equations misspecified the maturity lengths of the various government securities. Allen, et. al. (1981) and Bilson and Hale (1980) (hereafter BH) report that HK entered the maturity of the respective obligation in an $i=1, \ldots, n$ fashion instead of setting the time variable equal to the maturity length of bond. Because of this error, the HK findings must be questioned.

The purpose of this paper is to present additional evidence concerning the effects on money demand estimates when the term structure information is included. In the next section we report evidence supporting the hypothesis that a cubic specification of the term structure is preferred to the quadratic approximation employed by HK and BH. Section 3 presents an empirical comparison of a conventional money demand equation and alternative term structure money demand specifications for the period 1960/II-1979/IV. Unlike the HK and BH studies, the regression results reported here employ the Hatanaka (1974) procedure to circumvent the serious econometric problems associated with the application of the Cochrane-Orcutt iterative technique in the presence of autocorrelated errors and a lagged dependent variable.

In this section, the statistical stability of the alternative money demand relationships is also examined. Concluding remarks are presented in Section 4.

2. The term structure

HK argue that because the term structure occasionally appears as a humped or U-shaped curve, a quadratic function is necessary to adequately capture its form. The quadratic function used by HK is

$$\ln R_{it} = \alpha_t^1 + \beta_{1t}^1 \gamma_i + \beta_{2t}^1 \gamma_i^2 + \varepsilon_\gamma \qquad (\gamma=1,\ldots,n) \qquad (1)$$

where the dependent variable is the logarithm of the i-th nominal interest rate of maturity γ, α and β_i (i=1,2) are parameters to be estimated, and ε_t is an independently distributed error term with zero mean and constant variance. In estimating equation (1), HK employ seven different securities: 3-, 6-, and 12-month Treasury bills; 3-, 5-, 10- and 20-year Government bonds. In their article, HK incorrectly specify the maturities as γ = 1,2, ..., 7. To correct this, the maturities in this paper are specified in months, i.e., γ = 3, 6, 12, 36, 70, 120, 240. 4/

An alternative quadratic function is suggested by BH. After correcting the error in the specification of the maturities, they note that the quadratic does a poor job in capturing the term structure's shape. This is because the slope of equation (1) ($\beta_{1t} + 2\beta_{2t}\gamma_i$) tends to infinity with the length of maturity (γ). Because little difference is generally observed between the long-maturity rates, β_{1t} and β_{2t} must be close to zero if the quadratic is used. BH show that the quadratic function is useful if the maturities are expressed in log form. Thus, the quadratic function utilized by BH is

$$\ln R_{it} = \alpha_t^2 + \beta_{1t}^2 \ln\gamma_i + \beta_{2t}^2 \ln\gamma_i^2 + \varepsilon_\gamma \qquad (2)$$

where all variables are defined as before. Examination of equation (2) indicates that as γ tends to infinity, the slope tends to zero. Consequently, BH argue that this form will better capture the shape of the term structure.

One problem with the quadratic function is that, because it allows for only one turning point, it will not yield an accurate description of the term structure when it takes on a humped appearance. Given the occurence of humped term structures during 1960, 1966, 1970, 1973, 1974, 1978, and 1979, a more general functional form may be useful. Allen, et. al. present evidence for the period 1960/I-1976/IV suggesting that a cubic function provides a significantly better fit vis-á-vis the HK quadratic functional form. 5/ Thus, again specifying maturity in months, we shall also utilize the logged cubic function

$$\ln R_{it} = \alpha_{1t}^{3} + \beta_{1t}^{3} \ln \gamma_i + \beta_{2t}^{3} \ln\gamma_i^2 + \beta_{3t}^{3} \ln\gamma_i^3 + \varepsilon_\gamma . \qquad (3)$$

Equations (1) - (3) were estimated for each quarter during the 1960/III - 1979/IV period. Summary evidence of the relative abilities of the alternative equations to capture the shape of the term structure through time is presented in table 1. A comparison of either R^2s or $\bar{R}^2$s indicates that the cubic functional form provides a better overall fit than either quadratic specification. This outcome is not suprising upon examination of the individual quarterly regression results because, in over twenty-five percent of the quarterly estimates, the estimated coefficient for the $\ln \gamma_i^3$ term ($\hat{\beta}_{3t}^{3}$) is statistically significant.

The lower half of table 1 provides some additional evidence on the efficacy of employing the cubic equation. The general superiority of the cubic form is evident in a comparison of these quarterly $\bar{R}^2$s. The most striking contrast occurs in 1973/II and 1974/III, quarters characterized by hump-shaped term structures. In each of these periods, the cubic specification yielded an $\bar{R}^2$ significantly larger than either quadratic approach. Thus, the empirical evidence indicates that the cubic specification provides a better statistical approximation of the term structure than the HK or BH quadratic equations.

3. Money demand estimation results

In this section we compare the 1960/III-1979/IV sample period results obtained from estimating a conventional short-run money demand function that employs only two short-term interest rates and three money demand equations resulting from the incorporation of the relevant data from the estimated term structure equations (1)-(3). Before these estimation results are presented, it is necessary to discuss the estimation procedure used.

3.1. Estimation procedures

The conventional Goldfeld money demand specification is used as a benchmark. This equation is

$$\ln m_t = a_0 + a_1 \ln y_t + a_2 \ln CPR_t + a_3 \ln RTD_t + a_4 \ln m_{t-1} + \epsilon_t \qquad (4)$$

where m_t represents the nominal money stock (using the narrow M1 definition) deflated by the implicit GNP deflator (1972=100), y_t is real GNP ($1972), CPR_t is measured by the 4-6 month prime commercial paper rate, RTD_t equals a weighted average of commercial bank passbook rates, and ϵ_t is an error term.[7/]

To determine the effect of incorporating the term structure information into the money demand equation, the α and β terms from equation (1) - (3) are used to replace CPR and RTD in equation (4). Thus, the equations to be estimated in addition to (4) are

$$\ln m_t = a_o + a_1 y_t + a_2 \hat{\alpha}_t^1 + a_3 \hat{\beta}_{1t}^1 + a_4 \hat{\beta}_{2t}^1 + a_5 \ln m_{t-1} + \mu_{1t} , \tag{5}$$

$$\ln m_t = a_o + a_1 y_t + a_2 \hat{\alpha}_t^2 + a_3 \hat{\beta}_{1t}^2 a_4 \hat{\beta}_{2t}^2 + a_5 \ln m_{t-1} + \mu_{2t} , \tag{6}$$

and

$$\ln m_t = a_o + a_1 y_t + a_2 \hat{\alpha}_t^3 + a_3 \hat{\beta}_{1t}^3 + a_4 \hat{\beta}_{2t}^3 + a_5 \hat{\beta}_{3t}^3 + a_6 \ln m_{t-1} + \mu_{3t} . \tag{7}$$

Equation (5) corresponds to the corrected HK term structure money demand equation; equation (6) is the BH formulation; and (7) is the money demand equation that results from incorporating the data from the cubic specification of the term structure equation.

Previous empirical investigations of equations (4) -(7) have, for the most part, relied upon the Cochrane-Orcutt iterative technique to correct for apparent first-order serial correlation in the residuals. Application of such procedures, however, yields coefficient estimates that are biased and inefficient. These undesirable characteristics arise because of the joint presence of autocorrelated errors and a lagged dependent variable.

We shall employ Hatanaka's residual-adjusted Aitken estimator which has been shown to yield coefficient estimates that are consistent and asymptotically efficient.[8/] The estimation procedure suggested by Hatanaka is a two-step process that initially requires consistent estimates of the regression coefficients. This is accomplished by applying the instrumental variables method to the regression equation.

Thus, for equation (4), instrumental variables estimates are used to obtain consistent estimates of $\hat{a}_0$, $\hat{a}_1$, $\hat{a}_2$, $\hat{a}_3$, and $\hat{a}_4$.[9/] These coefficient estimates are then used to calculate a consistent estimate of the serial correlation coefficient, given by

$$\hat{\rho} = \sum_t \hat{\varepsilon}_t \hat{\varepsilon}_{t-1} \Big/ \sum_t \hat{\varepsilon}_{t-1}^2 \tag{8}$$

where

$$\hat{\varepsilon}_t = \ln m_t - \hat{a}_0 - \hat{a}_1 \ln y_t - \hat{a}_2 \ln CPR_t - \hat{a}_3 \ln RTD_t - \hat{a}_4 \ln m_{t-1}.$$

Once the consistent estimate of $\hat{\rho}$ is obtained, the original regression equation, here equation (4), is transformed in the manner

$$\begin{aligned} \ln m_t - \hat{\rho} \ln m_{t-1} = {} & a_0 (1-\hat{\rho}) + a_1(\ln y_t - \hat{\rho} \ln y_{t-1}) \\ & + a_2 (\ln CPR_t - \hat{\rho} \ln CPR_{t-1}) + a_3 (\ln RTD - \hat{\rho} \ln RTD_{t-1}) \\ & + a_4(\ln m_{t-1} - \hat{\rho} \ln m_{t-2}) + \hat{\phi}\varepsilon_{t-1} + \mu_t \quad . \end{aligned} \tag{9}$$

This transformed equation is then estimated using ordinary least squares.[10/] The coefficient estimates that emerge from equation (9) are unbiased and asymptotically efficient. Because existing term structure money demand investigations are subject to the econometric problems discussed above, we estimate equations (4)-(7) using the Hatanaka procedure. These estimation results are presented in the following section.

3.2 Estimation results

Equations (4)-(7) are estimated for the U.S. for the period 1960/III - 1979/IV using the narrow definition of money (M1).[11/] The results for the conventional money demand equation are

$$\ln m_t = -0.281 + 0.053 \ln y_t - 0.020 \ln CPR_t$$
$$(2.42) \quad (2.49) \qquad (3.67)$$
$$-0.049 \ln RTD_t + 1.018 \ln m_{t-1}$$
$$(2.18) \qquad (19.82)$$

$$\bar{R}^2 = 0.902,\ D.W. = 2.00,\ rho = 0.369,\ SEE(X10^{-3}) = 5.57$$

where absolute values of t-statistics are presented in parentheses. Relative to regression results estimated through the mid-1970s (see Hafer and Hein (1980b)), the 1960/III-1979/IV results suggest a significant change in the underlying economic relationship. For example, the estimated short-run income elasticity is quite small compared to previous estimates, even though it is statistically different from zero at the five percent significance level. The most discouraging result is the estimated value obtained on the lagged dependent variable. Because this coefficient does not differ statistically from unity, economic interpretation of the stock-adjustment mechanism as well as the deviation of any long-run elasticities is meaningless.[12/]

The regression results from estimating the term structure money demand equations are reported in table 2 and reveal that the level, slope, and curvature measures are significant at the five percent level in every instance. These results are broadly consistent with the estimates of HK and BH. For example, HK report that a uniform 1 percent upward shift in the term structure (as indicated by α coefficient) reduces the demand for money by 0.052 percent in the short-run. Based on the results presented in table 2, the response of money demand to such a shift in the term structure lies in the range of a 0.037 percent reduction for the corrected HK specification to a 0.051 percent reduction for the BH model. The findings for the estimated slope and curvature elasticities indicate that an increase in the slope of the term structure (long rates exceeding short rates) will, *ceteris paribus*, reduce the demand for real money balances. For example our cubic specification suggests that a one percent increase in the slope of the term structure will lead to a 0.222 percent decline in money demand in the short run. In addition, the significantly negative coefficients on the curvature variables suggests that greater curvature in the term structure will reduce money demand, *ceteris paribus*.[13/]

The summary statistics suggest that incorporating the term structure information into the short-run money demand equation yields a improved estimating equation. Although a direct comparison is not possible due to the different error structures of the equations, the standard errors of the different regressions suggest that the equation incorporating the relevant information from a cubic specification of the term structure is preferred. It should also be noted that the cubic term (β_{3t}^{3}) from equation (7) is statistically significant at the one percent level. On this set of information, the cubic specification in the money demand equation appears preferable to one using either a quadratic term structure model or simply two short-term interest rates.

An important consideration in the investigation of incorporating a spectrum of interest ratios into a money demand equation is the stability of the estimated relationship. Indeed, this represents a major portion of the HK piece and is a problematic area of money demand studies that has not been resolved since the appearance of Enzler, Johnson and Paulus (1976) and Goldfeld. HK use the stability test procedures suggested by Brown, Durbin, and Evans (1975). Using several variants of this test--the cusum, cusum squares, and time trend regressions--HK cannot reject the null hypothesis of stability for the money demand function using the quadratic specification of the term structure over the period 1960/III-1976/IV. These findings, unfortunately, are marred by several problems. First, the stability tests are based on equation estimates that are neither unbiased nor efficient (see above). Second, because the Brown-Durbin-Evans tests are constructed for situations where no serial correlation exisits amongst the residuals, HK are forced to transform all of the data in the manner

$$X' = \log X_t - \hat{\rho} \log X_{t-1} \qquad (10)$$

where $\hat{\rho}$ is the Cochrane-Orcutt estimate of the serial correlation coefficient and X' is the transformed variable. It was noted above that this estimate of rho is not consistent: hence, the procedure given by equation (10) may lead to spurious data transformations. Finally, the power of the cusum and cusum-squares tests have been evaluated critically by Garbade (1977) and Farley, Hinich, and McGuire (1975). Because of these problems, the stability finding by HK may be questioned.[14/]

We have chosen to employ the more commonly used Chow and likelihood-ratio tests. The difficulty with these tests is the *a priori* specification of the regime change. To examine the stability issue, the fourth quarter of 1973 was chosen as the break point because it represents one of recent concern with regard to out-of-sample simulations and is essentially the break point at which the Quandt log-likelihood ratio reached a minimum value in HK's study. The null hypothesis tested in each case is that all of the estimated coefficients remained unchanged across the 1960/III-1979/IV sample period.

The calculated F and X^2 statistics pertinent to testing the stability hypothesis are reported in table 3. The results which emerge from these tests indicate that the null hypothesis is rejected at the five percent significance level for each equation examined. This finding, based on two standard tests for structural change, contrast sharply with that of HK. Indeed, the results presented in table 3 indicate that substituting an approximation of the term structure of interest rates for some vector of rates in a short-run money demand equation does not alleviate the problem of unstable coefficient estimates.

4. Conclusion

A number of studies have sought to determine the interest rate appropriate in a money demand framework. Recently, Friedman has argued that a more viable approach to solving this dilemma may be to empirically capture the position and shape of the term structure of interest rates and to enter this information directly into the money demand function. Following this insight, Heller-Khan and Bilson-Hale have empirically tested this approach by specifying a quadratic approximation of the term structure during each quarter over the sample 1960/III-1976/IV. In this paper it is demonstrated that, over a longer period (1960/II-1979/IV), a cubic specification of the term structure is superior to the quadratic approximation. The information thus obtained (i.e., the intercept, slope, and curvature of the term structure) is entered directly into a short-run money demand function, replacing the conventional short-term interest rates.

The analysis in this paper improves upon previous investigations of incorporating the spectrum of interest rates into a money demand function in that unbiased and efficient regression results are obtained though the use of Hatanaka's residual-adjusted Aitken estimation procedure. Our findings suggest that the money demand function using the cubic approximation of the term structure is preferable to alternative equations that employ two short-term interest rates or a quadratic approximation of the term structure. More important to the current money demand literature is the result that emerges from the stability tests. Using the Chow test and Quandt's likelihood-ratio test, the null hypothesis of structural stability is strongly rejected for each specification examined. This finding contrasts directly with that of HK and suggests that purging the conventional short-run money demand equation of its two short-term rates in favor of a term structure approximation does not correct for the persistent problem of coefficient instability.

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FOOTNOTES

1. Klein (1977), Barro and Santomero (1972), and Becker (1975) also have attempted to incorporate a non-pecuniary return on money into a demand-for-money function. Santomero (1979) incorporates a transactions cost variable along with an implicit return variable.

2. Friedman also notes that the expected yield structure for equities and physical goods will influence the public's demand for real money balances.

3. For example, Friedman argues that a steepening of the term structure's slope, implying higher long-term and lower short-term rates, will tend to reduce the demand for real money balances, *ceteris paribus*.

4. Bilson and Hale employ the monthly specification while Allen, et. al. employ a yearly specification where γ = .25, .50. 1.0, 3.0, 5.0, 10.0, 20.0. The two approaches are equivalent for the quadratic equation (1).

5. The empirical results of Allen, et. al., differ from those of equation (3) because they do not log the maturities (γ).

6. A curious finding is that the monthly specification and the yearly specification of the respective maturities do not yield identical results in a cubic term structure equation. The difference between the results obtained from the two specifications is minimal.

7. Although the evidence is mixed, a lagged dependent variable of the form $\ln(m_{t-1}/p_{t-1})$ is used. This type of lagged term is used also in the HK and BH studies. For a discussion of this lag specification and alternative approaches, see Goldfeld (1976), White (1978), and Hafer and Hein (1980a).

8. The Hatanaka procedure has not been widely used in the recent money literature. Two exceptions are Laumas and Spencer (1980) and Lieberman (1980).

9. The instruments used were: the independent variables lagged once, the money stock lagged twice, contemporaneous and once lagged values of the dividend price ratio, and the contemporaneous and lagged value of bank credit. These instruments are similar to those used by Laumas and Spencer.

10. Because the lagged residual estimate ($\hat{\epsilon}_{t-1}$) from instrumental equation (9), the final value of rho is determined by summing the estimate of ϕ, and ρ from equation 8. See Laumas and Spencer.

11. For purposes of comparison, we use the old M1 definition. Preliminary results (not reported here) indicate that the conclusions reached are not substantially affected by using the M1A or M1B definitions. Also, the beginning of the sample period, 1960/III, conforms with that of HK and BH.

12. A similar problem can be found in the HK and BH studies. Recall, however, that the HK and Bh estimates are biased.

13. Friedman, HK, and BH provide excellent discussions of the way in which changes in the term structure are reflected in the parameters of the money demand equation.

14. BH do not pursue the question of structural stability in their study.

TABLE 1

Estimates of Term Structure Equations
Sample Period: 1960/III - 1979/IV

Specification	$R^2 > .90$	$\bar{R}^2 > .90$
(1)	21%	11%
(2)	75%	69%
(3)	87%	77%

Sample of Quarterly $\bar{R}^2$s

Specification

Period	(1)	(2)	(3)
1973/I	0.704	0.987	0.991
1973/II	0.024	-0.250	0.844
1973/III	0.910	0.661	0.942
1973/IV	0.845	0.383	0.930
1974/I	0.866	0.453	0.836
1974/II	0.630	0.124	0.619
1974/III	0.088	-0.235	0.463
1974/IV	0.460	0.077	0.368
1975/I	0.773	0.911	0.882
1975/II	0.619	0.932	0.910
1975/III	0.340	0.822	0.800
1975/IV	0.740	0.975	0.967

TABLE 2
Estimates of Short-Run Money Demand Functions
Incorporating Term Structure of Interest Rates
1960/III - 1979/IV

	Coefficients[1]							Summary Statistics[2]			
Specification	Constant	$\ln y_t$	α	$\beta 1$	$\beta 2$	$\beta 3$	$\ln(M_{t-1}/P_{t-1})$	$\bar{R}^2$	D.W./Dh	rho	SEE($\times 10^{-3}$)
Heller-Khan	-0.275 (2.28)	0.049 (2.27)	-0.037 (2.98)	-10.345 (2.59)	-2985.53 (2.70)		0.995 (22.08)	0.925	2.21/-1.01	0.300	5.55
Bilson-Hale	-0.356 (2.78)	0.051 (2.82)	-0.051 (3.66)	-0.224 (2.80)	-1.401 (2.95)		0.988 (21.33)	0.921	2.13/-0.629	0.329	5.49
Allen-Hafer	-0.349 (2.84)	0.063 (2.85)	-0.049 (3.69)	-0.222 (2.84)	-1.391 (2.98)	-8.609 (3.12)	0.992 (22.81)	0.931	2.13/-0.6222	0.279	5.43

1. All equations are estimated using the Hatanaka estimation procedure. The numbers in parentheses are absolute values of t-statistics.

2. $\bar{R}^2$ is the coefficient of determination corrected for degrees of freedom, SEE is the standard error of the estimated equation, D.W. is the Durbin-Watson test statistic, Dh is the Durbin-h statistic, and rho is the Hatanaka estimate of the autocorrelation coefficient.