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The Determinants of the Treasury Security Yield Curve

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ABSTRACT

Investors' security demands and two points on the yield curve are jointly determined using a disaggregated structural model of the U.S. Treasury securities market. The empirical results indicate that the structural model is capable of accurately explaining Treasury yields and that changes in a variety of nonyield variables affect the yield curve. Among these nonyield variables are Treasury security supplies, which are found to have significant but somewhat volatile impacts depending on investors' wealth flows. The within-sample predictions from the structural model are also compared to those of a naive model.

MOST EMPIRICAL STUDIES OF the term structure of interest rates have relied on single-equation models of interest rate determination to identify the underlying determinants of long-term bond yields. The methodologies used in these studies may be grouped into two broad classifications. First, researchers have frequently specified yield curve relationships based predominately on the "expectations hypothesis" associated with Hicks [23] and Lutz [26] and found that current and past short-term interest rates provide accurate within-sample "forecasts" of long-term interest rates. (See, for example, Meiselman [28], Wood [54], and Dobson, Sutch, and Vanderford [8].) Within this framework, Modigliani and Sutch [33, 34] and Modigliani and Shiller [32] have additionally examined the potential effects resulting from changes in relative asset supplies—due to the market segmentation effects suggested by Culbertson [7]—and risk premiums. As a whole, the empirical research using the expectations hypothesis as a starting point indicates that nonyield variables are not significant determinants of long-term bond yields. Furthermore, in tests involving the significance of lagged changes in short-term interest rates, Hamburger and Latta [21] and Elliott and Baier [11] among others have found that only contemporaneous changes in short-term interest rates significantly influence changes in long-term bond yields.

Second, other researchers have used unrestricted reduced-form equations based on loanable funds or liquidity-preference theories of interest rate determination. (See, for example, Okun [35], Scott [48], Sargent [46], Pierson [39], Feldstein and

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Eckstein [12], and Echols and Elliott [10].) Using this approach, subsets of nonyield variables have been included which may properly appear in the structural representation of the financial sector.[1] However, the estimation of unrestricted reduced-form equations may suffer from misspecification and multicollinearity arising from the large number of potential determinants. (See, for example, Wallace [53] and Friedman and Roley [18].) Recent studies by Pesando [37] and Mishkin [30] have cast further doubt on the significance of both nonyield variables and lagged values of short-term interest rates appearing in these unrestricted reduced-form equations. Under the joint hypothesis of efficient markets and the pure expectations theory, these authors have again shown that contemporaneous innovations in short-term interest rates statistically dominate other potential determinants of long-term bond yields. However, recent empirical evidence presented by Friedman [14] supports Kessel's [24] finding that term premiums depend on the level of interest rates—a result that is inconsistent with the pure expectations hypothesis. Furthermore, Shiller [49] and Singleton [51] have demonstrated that the observed volatility of bond holding-period yields is inconsistent with the joint hypothesis of rational expectations and the pure expectations theory.

Structural models of interest rate determination are logical alternatives to single-equation models based either on the expectations hypothesis or the unrestricted reduced-form approach. In the supply-demand market-clearing models estimated by Hendershott [22], Friedman [13], and Backus, Brainard, Smith, and Tobin [1], the outcomes associated with either of the single-equation approaches may be replicated conditional on the degree of asset substitutability in investors' portfolios.[2] Furthermore, by using the highly developed theory of portfolio behavior to specify investors' demands, the constrained reduced-form equations implicit in structural models are less likely to be subject to multicollinearity, spurious correlation, and misspecification inherent in single-equation models.

The purpose of this paper is to investigate the determinants of the term structure of interest rates within the context of the structural model methodology. This subject is examined using a disaggregated structural model of the Treasury securities market, where the demand side of the market consists of 10 disaggregated categories of investors. In addition, two nonoverlapping maturity classes of Treasury securities are used. By including market-clearing identities equating aggregate demand with supply for each maturity class, two points on the Treasury security yield curve are simultaneously determined. Simulation experiments are then used to investigate the economic significance of a set of potential underlying determinants of Treasury security yields. The predicted values of the two endogenously determined yields are further examined in light of the recent criticisms of approaches not based on the pure expectations hypothesis and efficient markets

[1] Nonyield variables appearing in these studies include currency, demand deposits, time deposits, financial wealth, personal income, gross national product, bank earning assets, and security supply variables.

[2] Other researchers have estimated systems of disaggregated structural demand equations, but the resultant models do not rely on market-clearing identities to determine security yields. Instead, term structure equations are typically included to close the model. See, for example, Goldfeld [19], Silber [50], and Bosworth and Duesenberry [4].

paradigm. In particular, the within-sample predictions are tested to determine whether they are dominated by innovations in short-term interest rates and whether the implied prediction errors exhibit significant serial correlation.

The first section of this paper presents the short-run portfolio adjustment models used in specifying the demand side of the model. Following Friedman [13], the short-run demand equations emphasize the role played by net wealth flows in the adjustment of portfolios toward their desired long-run composition. The second section contains the estimation results for the individual equations, with a discussion of the determinants of the two demand equations estimated for each investor category. In the third section, the individual demands are combined with two market-clearing identities—one for each maturity class—to determine the corresponding Treasury security yields. The complete model is also examined in this section in terms of the effects of changes in selected exogenous variables and its predictive ability relative to a "naive" model. The final section summarizes the main conclusions of the paper.

I. Specification, Data, and Estimation Techniques

In the disaggregated structural model presented in this paper, the Treasury security demands of individual categories of investors are used to investigate the determinants of the Treasury security yield curve. The specifications of these Treasury security demands are consistent with the theory of portfolio selection in which the most general case involves investors' decisions concerning both the size and composition of their portfolios within a multiperiod investment horizon. (See, for example, Merton [29], Samuelson [45], and Hakansson [20].) However, derivations of asset demands from portfolio selection models with such complications as multiperiod horizons and simultaneous size and composition portfolio decisions, not to mention transactions costs and other relevant factors, generally lead to specifications which are not empirically tractable and which may even obscure the predominant determinants of portfolio selection behavior. Therefore, the methodology used here to investigate the determinants of Treasury security demands involves the more limited objective of considering the allocation, within a one-period horizon, of existing portfolio wealth together with a given net wealth flow. This approach is implemented through the use of portfolio adjustment models which form short-run asset demands from expressions representing desired long-run proportional asset holdings[3]:

$$\underset{\sim}{\alpha}_t^* = \underset{\sim}{A}_t^*/W_t = \underset{\sim}{b} + B_1\underset{\sim}{\mu}_t + B_2\underset{\sim}{\sigma}_t \tag{1}$$

[3] Linear homogeneous asset demands as in (1) follow from expected utility maximization when either the argument of the utility function is portfolio rate of return or investors exhibit constant relative risk aversion. For derivations of the latter case in both continuous- and discrete-time models, see Friedman and Roley [17]. The expression for desired proportional asset holdings (1) follows from the linearization of asset demands derived from these expected utility maximization models. As such, the coefficient matrices $\underset{\sim}{b}$, B_1, and B_2 are functions of variances and covariances of security yields. Instead of the usual assumption of variance and covariance stationarity (e.g., Parkin [36]), the demands are linearized to take account of variance nonstationarity to allow for the possible risk premium effects postulated by Modigliani and Shiller [32].

where

$\underset{\sim}{\alpha}_t^* = N \times 1$ vector of the investor's desired proportional holdings of assets at time t ($\underset{\sim}{\alpha}_t^{*\prime}\underline{1} = 1$);

$\underline{A}_t^* = N \times 1$ vector of the investor's desired holdings of assets at time t ($\underline{A}_t^{*\prime}\underline{1} = W_t$);

$W_t =$ the investor's total portfolio size (wealth) at the end of time t;

$\underset{\sim}{\mu}_t = N \times 1$ vector of expected holding-period yields at time t;

$\underset{\sim}{\sigma}_t = N \times 1$ vector of variances of holding-period yields at time t;

$\underset{\sim}{b}, B_1, B_2 = N \times 1$ vector and $N \times N$ matrices of coefficients, respectively

The usual "adding-up" properties imply $\underline{1}'\underset{\sim}{b} = 1$, $\underline{1}'B_1 = \underline{0}$, and $\underline{1}'B_2 = \underline{0}$. In addition, most derivations of desired asset holdings consistent with (1) imply non-negative coefficients on expected own-yields and coefficients on competing asset yields with signs that are unknown a priori.[4]

A. Short-Run Portfolio Adjustment Models

Portfolio adjustment models are used to specify the less than instantaneous adjustment to desired asset proportions due to transaction costs. Because of the diverse institutional and behavioral characteristics of the categories of investors included in the disaggregated structural model, several versions of a general portfolio adjustment model are applied. The most general form of the adjustment model includes four properties which are additional to those of the standard stock adjustment model: (1) new investable financial flows have distinct effects on portfolio adjustment; (2) the allocation of new investment financial flows depends on the holding-period yields of the endogenous assets in the portfolio; (3) new investable financial flows affect the reallocation of assets already in the portfolio; and (4) positive and negative new investable financial flows have asymmetric effects.[5] With one exception, all of the adjustment models utilized for the investor categories included in the disaggregated structural model may be classified by a subset of these properties.[6] In addition, each adjustment model includes Properties (1) and (2).

The model in its most general form, incorporating all four of the properties listed above, may be written as

$$\begin{aligned}\Delta A_{it} = {} & \textstyle\sum_k^N \Theta_{ik}(\alpha_{kt}^* W_{t-1} - A_{k,t-1}) \\ & + \textstyle\sum_k^N \Psi_{ik}'(\Delta W_t'/W_{t-1})(\alpha_{kt}^* W_{t-1} - A_{k,t-1}) \\ & + \textstyle\sum_k^N \Psi_{ik}''(\Delta W_t''/W_{t-1})(\gamma_{kt}^* W_{t-1} - A_{k,t-1}) \\ & + \alpha_{it}^*\Delta W_t' + \gamma_{it}^*\Delta W_t'', \qquad i = 1, \cdots, N, \quad (2)\end{aligned}$$

[4] Again interpreting the desired proportional asset holdings (1) as linearizations of asset demand equations derived from expected utility maximization, Blanchard and Plantes [2] show that positive covariances for all pairs of security yields are necessary but not sufficient for gross substitutability. Furthermore, Roley [43] shows that symmetry of the B_1 matrix implies a particular type of risk averse behavior which does not generally hold for all classes of utility functions.

[5] The portfolio adjustment models used by Brainard and Tobin [5], Modigliani [31], and Bosworth and Duesenberry [4] exhibit the first property. Friedman [13] developed and implemented a model with properties (1) and (2).

[6] The portfolio adjustment model applied to commercial banks is the one exception. This adjust-

where ΔA_{it} represents net purchases of the i^{th} asset; the indices i and k ($i, k = 1, \cdots, N$) are associated with endogenous assets; Θ_{ik}, Ψ'_{ik}, and Ψ''_{ik} are fixed coefficients of adjustment; and α^*_{kt} and γ^*_{kt} are desired proportional holdings of assets conditional on positive and negative investable financial flows, respectively.[7] In addition, the positive and negative investable financial flows are written as

$$\Delta W'_t = \begin{cases} \Delta W_t, & \text{if } \Delta W_t > 0 \\ 0, & \text{otherwise} \end{cases}$$

$$\Delta W''_t = \begin{cases} \Delta W_t, & \text{if } \Delta W_t < 0 \\ 0, & \text{otherwise} \end{cases}$$

The portfolio wealth constraint implies $\sum_i^N \Theta_{ik} = \bar{\Theta}$, $\sum_i^N \Psi'_{ik} = \bar{\Psi}'$, and $\sum_i^N \Delta''_{ik} = \bar{\Psi}''$, for all k.

The terms in (2) relate to various sources of portfolio adjustment. The first term describes standard stock adjustment. The second and third terms incorporate the effects of financial flows on the reallocation of assets already in the portfolio dependent on the sign and magnitude of the financial flows. The final two terms involve the marginal allocation of investable financial flows according to desired proportional asset holdings (1), with the inclusion of asymmetric effects from positive and negative flows. The various submodels—involving zero constraints on the Ψ'_{ik} and Ψ''_{ik} parameters and equality constraints on the α^*_{it} and γ^*_{it} parameters—applied to particular investor categories are determined on the basis of statistical tests.

B. Data and Estimation Techniques

The demands for two maturity classes of Treasury securities by 10 categories of investors are included in the model. The investor categories are indicated—with respect to total Treasury securities outstanding as of year-end 1975—in Table I. The 10 investor categories marked with asterisks are those with endogenous asset demands in the model of the Treasury securities market. These 10 investor groups hold 95 percent of the outstanding Treasury securities net of Federal Reserve System and foreign holdings.[8] Apart from commercial banks,

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ment model considers the allocation of individual exogenous components of the new investable financial flow in addition to properties (1) through (4). Because this adjustment model has been examined in detail elsewhere, it will not be further considered here. See Roley [42].

[7] The γ^*_{kt} differ from the α^*_{kt} in that the former explicitly represent desired short-run portfolio holdings conditional on negative financial flows. That is, the γ^*_{kt} are included to allow for possible asymmetric effects of expected holding-period yields and variances of holding-period yields associated with positive and negative financial flows. These asymmetric effects may result from different transactions costs associated with purchasing and selling assets, and from different behavior regarding unrealized capital gains and losses on existing assets in the portfolio. Furthermore, the γ^* vector is analogous to (1) except that expected holding-period yields enter as reciprocals—e.g., $1/\mu_i$. For the own-yield on asset $i(\mu_i)$, for example, this implies that for negative financial flows, the ***higher*** the own-yield, the ***less*** the amount of asset i sold. Alternatively, if the own-yield was not entered in reciprocal form, then the ***higher*** the own-yield, the ***greater*** the amount of asset i sold.

[8] The modeling of foreign purchases of U.S. Treasury securities involves areas well outside the scope of the study. Therefore, foreign purchases are taken as exogenous. The supply of U.S. Treasury securities is determined by fiscal policy and the government budget constraint; and monetary policy

Table I

U.S. Treasury Securities Outstanding as of Year-end 1975[a]

Securities Held By[b]:	Total Amount[c]	Percentage
Federal Reserve System	87.9	23.5
Commercial Banks*	84.6	22.6
Foreign	66.5	17.8
Households*	49.0	13.1
State and Local Government General Funds*	30.6	8.2
Nonfinancial Corporate Businesses*	14.3	3.8
Private Pension Funds*	7.9	2.1
Savings and Loan Associations*	5.4	1.4
Credit Unions	5.0	1.3
Life Insurance Companies*	4.7	1.3
Mutual Savings Banks*	4.7	1.3
Other Insurance Companies*	4.7	1.3
Sponsored Credit Agencies	3.4	1.0
State and Local Government Retirement Funds*	2.2	0.6
Security Brokers and Dealers	2.1	0.6
Investment Companies	1.1	0.3
Total[d]	374.1	100.0

[a] Source: Board of Governors of the Federal Reserve System [3]. Agency issues and non-negotiable savings bonds are excluded.

[b] Groups marked by asterisk are endogenous in the U.S. Treasury securities market model.

[c] Amounts are in billions of dollars.

[d] Detail may not add to total because of rounding.

households, and state and local government general funds, the individual investor categories typically do not hold large amounts of Treasury securities. However, average absolute values of net purchases of Treasury securities are significant in comparison to average absolute values of net acquisitions of financial assets for each of these investor categories. This property is due to the fact that Treasury securities serve as a principal type of liquid asset in the portfolios of these investors. Treasury securities are ideally suited for this purpose since they are more liquid than other financial assets of similar maturities due to a highly developed secondary market and their risk characteristics. Thus, for all of these investor categories, Treasury securities are important in short-run portfolio selection.

The primary data source of the disaggregated structural model is the Federal Reserve System's flow-of-funds accounts [3]. Quarterly observations are used, with the sample period beginning in 1960:I and ending in 1975:IV. The data for Treasury securities consist of four weighted maturity classes of Federal debt that are consistent with the flow-of-funds accounts. (See Taylor and Wood [52].) The data are defined in terms of four "definite" areas and three "borderline" areas. The definite areas include the following maturities: (1) within one year (short-term); (2) two to four years (short-intermediate-term); (3) six to eight years (long-intermediate-term); and (4) over 12 years (long-term). Treasury securities with

determines the Federal Reserve System's total holdings. This results in the net amount of U.S. Treasury securities to be purchased by private investors.

maturities in the borderline areas are allocated to the definite classifications according to a weighting scheme. In particular, if n is the number of months in a borderline area, then the securities are allocated to the immediately preceding and successive definite maturity classes according to the following pairs of weights:

$$\left(\frac{n}{n+1}, \frac{1}{n+1}\right), \left(\frac{n-1}{n+1}, \frac{2}{n+1}\right), \ldots, \left(\frac{1}{n+1}, \frac{n}{n+1}\right)$$

where maturity is increasing from left to right.[9] The principal advantage of this procedure is that it avoids the otherwise perverse effects which occur when large debt issues cross fixed maturity boundaries.

Financial flow variables corresponding to the individual assets of the 10 investor categories are defined in terms of seasonally adjusted net changes during the quarter. The wealth flow variables are generally defined as quarterly net acquisitions of financial assets, seasonally adjusted.[10] Financial stock variables, including individual asset stocks and total portfolio wealth, are formed by decrementing seasonally adjusted quarterly flows from the value of year-end outstandings in 1975:IV. This procedure serves to guarantee the mutual consistency of the asset stock and flow data throughout the sample period. When asset stock data contain market valuation changes, these components are included without seasonal adjustment. The two endogenous yields correspond to the short-intermediate-term and long-term maturity classes of Treasury securities. These yields are represented by the published series for the 3- to 5-year Treasury security yield and the long-term (10-years and over) Treasury security yield.[11]

The estimated demand equations correspond to various submodels embodied in (2). Because yields on securities are jointly dependent variables along with investors' demands, the use of ordinary least squares estimation would result in inconsistent estimates. Thus, a simultaneous equations estimation technique is used. In particular, the application of an instrumental variables technique described by Brundy and Jorgenson [6] is used to gain consistent estimates of the structural equations. The direct application of 2*SLS* is not possible here because of the undersized sample problem—i.e., more predetermined variables than sample observations.

[9] This procedure is applied by the Federal Reserve System to monthly data. Quarterly observations are formed by taking the arithmetic means of seasonally adjusted monthly data.

[10] Preliminary estimation results indicated that the portfolio selection behavior of mutual savings banks and savings and loan associations may be best represented by considering mortgage holdings separately from other financial asset holdings. Thus, for these investor categories, wealth flows are defined as the total net acquisition of financial assets less mortgages. This dichotomy could be interpreted as implying that the decisions relating to the assets treated as endogenous are residual to the decisions concerning mortgages. Commercial banks are treated in a similar manner. (See Roley [42].)

[11] Observed market yields are entered directly into the structural demand equations. The use of observed market yields is consistent with the martingale property of bond yields which renders *unconditional* forecasts of bond yields—given an appropriate information set at time $t(\phi_t)$—equal to observed market yields. (See, for example, Pesando [38].) That is, $E_t(r_{i,t+1} \mid \phi_t) = r_{i,t}$. The yields solved from the structural model $(r_{i,t+1})$ are conditional forecasts based on the information set in time $t+1$ (ϕ_{t+1}). Thus, the yields solved from the model are not required to follow a martingale to be consistent with the unconditional forecasts of investors.

II. Determinants of the Demand for Treasury Securities

Equations separately representing the net purchases of short-intermediate-term and long-term Treasury securities by 10 categories of investors are estimated.[12] The two maturity classes chosen for the empirical work serve to illustrate the joint determination of market yields on two nonoverlapping maturity classes of Treasury securities. The equations are estimated over 64 quarterly observations beginning in 1960:I and ending in 1975:IV using the instrumental variables procedure.[13]

The short-run demands for Treasury securities by the individual categories of investors—with the exception of commercial banks—are specified by applying a version of the portfolio adjustment model (2) to the expression for desired long-run portfolio composition (1). The adjustment model is applied without any constraints to nonfinancial corporate businesses. The adjustment model with $\Psi''_{ik} = \Psi'_{ik}$ and $\gamma^*_{kt} = \alpha^*_{kt}$, for all i and k, is applied to households and state and local general funds.[14] Mutual savings banks and savings and loan associations use the adjustment model with $\Sigma''_{ik} = \Psi'_{ik} = 0$, and for all i and k. The adjustment model with $\Psi''_{ik} = \Psi'_{ik} = 0$ and $\gamma^*_{kt} = \alpha^*_{kt}$, for all i and k, is applied to life insurance companies, other insurance companies, private pension funds, and state and local government retirement funds. This latter portfolio adjustment scheme is identical to Friedman's [13] "optimal marginal adjustment" model. This model, along with that applied to mutual savings banks and savings and loan associations, allows the identification of the term representing desired long-run portfolio composition α^*_{it}.

The choice of the particular version of the general adjustment model applied to each investor category was based on preliminary tests using ordinary least squares estimation. In particular, in each case the general adjustment model (2) was tried, and successively more restrictive models were adopted until an additional constraint could be rejected statistically. The different adjustment models found applicable to the various investor categories accentuate the importance of disaggregation.

A summary of the estimation results is presented in Table II.[15] The estimation results provide support for the short-run portfolio selection model specified in the previous section. As indicated by the multiple correlations ($\bar{R}^2$), these equations explain much of the variation of the volatile net purchases of Treasury securities. The multiple correlations range from 0.40 for the demand for short-intermediate-term securities by state and local government retirement funds to

[12] Because of the small holdings of long-term securities by nonfinancial corporate businesses, only their demand for short-intermediate-term Treasury securities is estimated.

[13] Preliminary ordinary least squares estimates indicated the presence of a structural shift in the demand for long-term Treasury securities by commercial banks. The midpoint of this apparent shift occurred during the introduction of the Federal Reserve System's Regulation F and other related regulations. As a result, two separate equations are estimated. The first equation is estimated for 1960: I through 1965:I, and the second equation is estimated for 1965:II through 1975:IV.

[14] In the case of households, the α^* in (2) represents the desired proportion of assets from two different sources. Following Duesenberry [9], the two sources represent the demands for liquid and nonliquid assets. Personal consumption expenditures are used as a scale variable to determine the proportions of portfolio wealth devoted to these two classifications of assets.

[15] The complete set of estimation results is available from the author upon request.

0.92 for the demand for long-term securities by life insurance companies, with a median value of 0.67. These statistics also indicate that the net purchases of each maturity class are modeled with approximately equal success. The root-mean-square errors of the estimated equations are additionally reported to indicate the accuracy of the estimated equations in dollar amounts. The root-mean-square errors are computed by replacing the variables being instrumented with their actual values, and simulating using historical values in each period.

Individual parameter estimates also support the short-run portfolio selection models as well as indicate the determinants of Treasury security demands. First, in each case the coefficients on the own-yields for the short-intermediate-term (r_2) and long-term (r_4) maturity classes have the theoretically anticipated signs in their respective demand equations and virtually all are highly statistically significant. Furthermore, for six categories of investors, either the "optimal marginal adjustment" model or its slight variant incorporating asymmetric effects from positive and negative investable financial flows is used to describe portfolio adjustment. As indicated above, the application of either of these models is sufficient to identify the effects of changes in expected holding-period yields on the desired equilibrium portfolio from the coefficients appearing on multiplicative terms involving yields and investable financial flows ($\alpha^*_{it}\Delta W_{it}$). These equilibrium responses are reported in Table II where the reported values correspond to a one percentage point increase in the respective own-yields. For example, a one percentage point increase in the yield on short-intermediate-term Treasury securities would cause life insurance companies to increase their equilibrium proportional holdings of these securities by 2.99 percentage points. For the short-intermediate-term maturity class as a whole, the values range from one percentage point for state and local government retirement funds to 11 percentage points for other insurance companies, with all corresponding t-ratios greater than 2.5. For the long-term maturity class, the values range from less than one percentage point for savings and loan associations to 19 percentage points for state and local government retirement funds, with all corresponding t-ratios greater than 1.6. The magnitudes of these values appear to be reasonable, with the possible exception of the largest value for each maturity class.

The second group of individual parameter estimates reported in Table II consists of the estimated coefficients on the lagged own-stocks for the two maturity classes of Treasury securities. For the short-intermediate-term maturity class, estimated values for the standard own-stock adjustment parameter range from .1056 for state and local government retirement funds to .5515 for savings and loan associations, with all t-ratios greater than 1.7. For the long-term maturity class, these values range from .0546 for the state and local government general funds to .6437 for households, with all t-ratios greater than 1.9. This latter adjustment parameter for households is most likely too high in comparison to other investor groups. The other estimated values may be considered reasonable for a quarterly model. The complete set of estimated demand equations also reveals that cross-adjustment parameters are statistically significant determinants of Treasury security demands.

Other individual parameter estimates indicating the determinants of Treasury security demands include statistically significant coefficients on competing yields

Table II

Summary of Estimation Results for Treasury Security Demand Equations[a]

Investor Category		$\bar{R}^2$	RMSE	Equilibrium Own-Yield Response	Standard Stock Adjustment Component	Competing Yields	Selected Non-yield Variables	Respecified Equations R^2	Respecified Equations RMSE
Commercial Banks[b]	$\Delta US2^C$	.69	616	—	.1501 (5.4)	r_T	V_I, V_2	.24	985
	$\Delta US4^C$	.64	61	—	.2575 (6.5)	r_T, r_S	V_4	.10	68
Households	$\Delta US2^H$	.79	355	—	.3377 (6.4)	r_P	V_I, V_4	.35	672
	$\Delta US4^H$	.66	132	—	.6437 (8.1)	r_P, r_S	$\%\Delta P, V_C$	.08	260
Life Insurance Companies	$\Delta US2^L$	.82	19	.0299 (5.1)	.1399 (2.4)	r_P, r_4	V_2, V_E	.52	30
	$\Delta US4^L$	.92	35	.0136 (4.0)	.1908 (3.8)	r_C	V_4, V_C	.05	127
Mutual Savings Banks	$\Delta US2^M$	.69	47	.0746 (2.5)	.2460 (5.4)	r_p, r_4	V_I	.49	59
	$\Delta US4^M$	.71	47	.0039 (1.6)	.4226 (6.3)		V_I	.00	89
Nonfinancial Corporate Businesses	$\Delta US2^N$	.80	148	—	.2548 (6.6)	r_P		—	—
Other Insurance Companies	$\Delta US2^O$	.54	53	.1107 (4.1)	.2012 (5.4)	r_C	V_4	.45	55
	$\Delta US4^O$	.65	22	.0158 (2.2)	.3149 (4.7)		$\%\Delta P$	.35	30
Private Pension Funds	$\Delta US2^P$	.75	42	.0239 (2.5)	.1346 (1.7)	r_C, r_D	V_4, V_E	.64	52
	$\Delta US4^P$	.80	35	.0158 (2.9)	.3053 (4.4)	r_T, r_D		.33	63
Savings and Loan Associations	$\Delta US2^{SL}$	.57	146	.0732 (2.7)	.5515 (6.2)	r_T	$\%\Delta P, V_I$	.32	190
	$\Delta US4^{SL}$	.67	47	.0023 (1.7)	.5466 (6.2)			.23	71
State-Local General Funds	$\Delta US2^{SG}$	.41	174	—	.1886 (3.9)	r_T	V_S	.00	217
	$\Delta US4^{SG}$	.50	95	—	.0546 (2.3)		$\%\Delta P, V_I, V_S$	.03	142
State-Local Retirement Funds	$\Delta US2^S$	.40	24	.0091 (2.6)	.1056 (2.6)		V_E	.28	26
	$\Delta US4^S$	.63	104	.1912 (4.2)	.0935 (1.9)	r_2	V_4, V_C	.38	133

[a] Numbers in parentheses are ratios of estimated coefficients to their standard errors. Root-mean-square errors (RMSE) in millions of dollars.
[b] All estimation concerning the demand for long-term Treasury securities by commercial banks is performed from 1965:II through 1975:IV.

Definitions:

$\Delta US2^h$ = net purchases of short-intermediate-term Treasury securities by investor category h;
$\Delta US4^h$ = net purchases of long-term Treasury securities by investor category h;
$\%\Delta P$ = percentage change of the consumer price index (1967 = 100);
r_2 = yield on 3- to 5-year Treasury securities;
r_4 = yield on 10-year and over Treasury securities;
r_C = current yield on new issues of corporate bonds (Aa utilities);
r_D = Standard and Poor's dividend/price ratio;
r_P = yield on commercial paper;
r_S = municipal bond yield (Moody's Aaa);
r_T = yield on 3-month Treasury bills;
V_2 = lagged moving-average variance of the holding-period yield on short-intermediate-term Treasury securities;
V_4 = lagged moving-average variance of the holding-period yield on long-term Treasury securities;
V_C = lagged moving-average variance of the holding-period yield on corporate bonds;
V_E = lagged moving-average variance of the holding-period yield on equities;
V_I = lagged moving-average variance of inflation;
V_S = lagged moving-average variance of the holding-period yield on municipal bonds

and variances of yields multiplied by either investable financial flows or lagged wealth stocks. As shown in Table II, a variety of competing yields appears in the model. In each case, the coefficient on a competing yield is negative if it is multiplied by only a new investable financial flow (ΔW) or a lagged wealth stock (W_{-1}). In cases where a competing yield is multiplied by both a wealth flow and a wealth stock, the identifiable coefficient on the term with the wealth flow is always negative. Thus, in contrast to single equation models of Treasury security yield curve determination, the disaggregated structural model indicates the mechanism by which yields on other financial assets affect Treasury security yields. In particular, the substitutability among assets apparent in these demand equations accounts for the widely observed phenomenon that security yields generally move in the same direction. For example, increases in the yields on commercial paper (r_P), Treasury bills (r_T), corporate bonds (r_C), municipal bonds (r_S), and equity (r_D) all result in a reduction in the aggregate demand for the two maturities of Treasury securities considered in the model. As a result, the yields on these Treasury securities rise with increases in other market yields.

Nonyield variables—including variances of yields and the level of price inflation—appear as statistically significant determinants of Treasury security demands in 14 of the 19 estimated equations. (See Table II.) Using the interpretation of coefficient signs given immediately above, own-yield variances have negative impacts on Treasury security demands and competing-yield variances have positive impacts as expected. Thus, as the mean-variance portfolio selection theory suggests, variances of asset yields are important determinants of portfolio selection behavior. Variables representing the level of price inflation ($\%\Delta P$) are statistically significant with negative impacts in three of the estimated long-term Treasury security demand equations. Thus, the disaggregated structural model describes the processes by which both relative risk premiums—associated with relative yield variances—and inflation premiums are incorporated into the Treasury yield curve.[16]

Another important set of nonyield variables appearing in the model consists of investors' lagged wealth stocks and contemporaneous wealth flows. Both measures are important determinants of Treasury security demands in the model in contrast to the empirical evidence provided by single equation models. Furthermore, in the case of commercial banks, the separate components of the liability side of the balance sheet as well as certain categories of exogenous assets are important determinants of both the size and composition of holdings of Treasury securities. For example, net contemporaneous flows of demand deposits, time deposits, government deposits, loans, and other assets and liabilities have statistically significant impacts on commercial banks' short-run demands for Treasury securities. Thus, the Treasury yield curve is directly affected by these disaggregated components of the commercial banking sector's balance sheet.

The final area of investigation in this section involves the substitutability of the two different maturity classes of Treasury securities. To judge the degree of substitutability, the demand equations are respecified by switching the set of

[16] The inflation premium process inherent in the model conforms to that found by Friedman [15] in his disaggregated structural model of the U.S. corporate bond market.

predetermined variables between the two maturity classes. In particular, the demand for short-intermediate-term securities is estimated using the specification for long-term securities, and vice versa. This allows a judgmental examination of the appropriateness of applying the same specification, without any constraints on the coefficients, to both maturity classes within an individual investor category. For each estimated equation, the coefficient of determination adjusted for degrees of freedom ($\bar{R}^2$) and the root-mean-square error of the forecasted values (*RMSE*) are included in Table II.[17] If investors view short-intermediate-term and long-term Treasury securities as perfect or even close substitutes, then the separate demands should have similar subsets of predetermined variables. Thus, under this hypothesis, there should be little loss of fit from switching the specifications between maturity classes. However, the application of similar specifications to both maturity classes leads, in general, to a substantial loss of fit. In terms of the root-mean-square errors of the forecasted values, the smallest difference between actual and respecified equations for short-intermediate-term securities is an increase of eight percentage points for state and local government retirement funds. The largest increase for short-intermediate-term securities is 89 percentage points for households. The corresponding extreme values for long-term securities are 11 percentage points for commercial banks and 363 percentage points for life insurance companies. Thus, on the basis of this subjective analysis, it appears that the perfect substitutes hypothesis can be rejected.

III. Short-Run Determination of the Treasury Security Yield Curve

This section examines the short-run determination of the Treasury security yield curve using the estimated structural demand equations. In the model the two endogenous yields are simultaneously determined by combining the 19 estimated demand equations with two market-clearing identities which place aggregate demands equal to the exogenous supplies of the two maturity classes of Treasury securities. In the short run, the determinants of the yields include items from both desired long-run portfolio composition (1) and short-run portfolio adjustment (2). In the long run, however, the yields depend exclusively on desired long-run portfolio composition. Because the expressions describing long-run portfolio selection are consistent with expected utility maximizing behavior, the long-run equilibrium yields are therefore consistent with the capital asset pricing model (CAPM) approach used, for example, by Roll [44] and McCallum [27] to investigate interest rate determination.

Selected simulation results of the model are reported in Table III. In particular, summary measures are computed for static (or one-period) single-equation simulations, separate dynamic simulations for each maturity class, and the joint dynamic simulation that includes the two maturity classes simultaneously. In the static single-equation simulations, the individual demand equations—with the

[17] The instrumental variables estimation procedure is again used in forming the reported results. The root-mean-square errors are obtained by replacing the fitted values from the first-stage regressions by actual values, and then simulating each equation separately.

exception of those for commercial banks—do not have any significant forecast bias and the root-mean-square errors are about the same magnitude as estimated standard errors. The bias in each equation for commercial banks results from the relatively large number of variables being instrumented in the estimation procedure.

The results from the separate dynamic simulations of the two sets of equations—corresponding to the two maturity classes—are reported in the third and fourth columns of Table III. For the yields on short-intermediate-term and long-term Treasury securities, the root-mean-square errors are 33 and 20 basis points, respectively. Thus, as expected, this measure is higher for the yield on short-intermediate-term securities due to the greater volatility of short-term yields. However, the magnitudes of both of these values indicate that the structural modeling methodology is capable of a high degree of accuracy. The results for the separate dynamic simulations also show no evidence of any bias in the individual equations. In addition, irregularities in the root-mean-square errors are not apparent in these results.

The two sets of equations may be combined to jointly determine Treasury security demands and two points on the yield curve. The corresponding dynamic simulation results are given in the last two columns of Table III. The results for

Table III

Simulation Results for 1960:I-1975:IV[a]

	Single Equation Forecasts		Separate Dynamic		Joint Dynamic	
Variable	ME	RMSE	ME	RMSE	*ME*	*RMSE*
r_2	—	—	0.01	0.33	−0.01	0.34
r_4	—	—	−0.01	0.20	−0.02	0.20
$\Delta US2^C$	−30.5	616	−1.7	334	−0.4	337
$\Delta US4^C$	31.4	116	0.4	120	0.8	123
$\Delta US2^H$	0.0	355	3.4	348	3.0	348
$\Delta US4^H$	0.0	132	−0.3	190	0.5	196
$\Delta US2^L$	−0.1	19	−0.1	29	−0.4	31
$\Delta US4^L$	0.0	35	0.0	37	−0.1	39
$\Delta US2^M$	0.0	47	−0.2	50	−0.4	50
$\Delta US4^M$	0.0	47	0.4	49	0.4	48
$\Delta US2^N$	0.0	148	−0.2	205	−0.6	206
$\Delta US2^O$	0.2	53	−0.1	55	−0.2	55
$\Delta US4^O$	0.0	22	−0.1	24	0.0	25
$\Delta US2^P$	−0.2	42	−0.2	46	0.2	43
$\Delta US4^P$	−0.1	35	−0.1	37	0.2	37
$\Delta US2^{SL}$	0.0	146	−4.2	164	−4.3	164
$\Delta US4^{SL}$	0.0	50	−0.7	56	−1.1	63
$\Delta US2^{SG}$	0.0	174	3.5	165	3.4	164
$\Delta US4^{SG}$	−0.6	95	−0.2	94	0.4	96
$\Delta US2^S$	0.0	24	−0.1	25	−0.3	26
$\Delta US4^S$	−0.4	104	0.5	94	−0.9	119

[a] For variable definitions, see Table II. *ME* and *RMSE* are mean error and root-mean-square error, respectively.

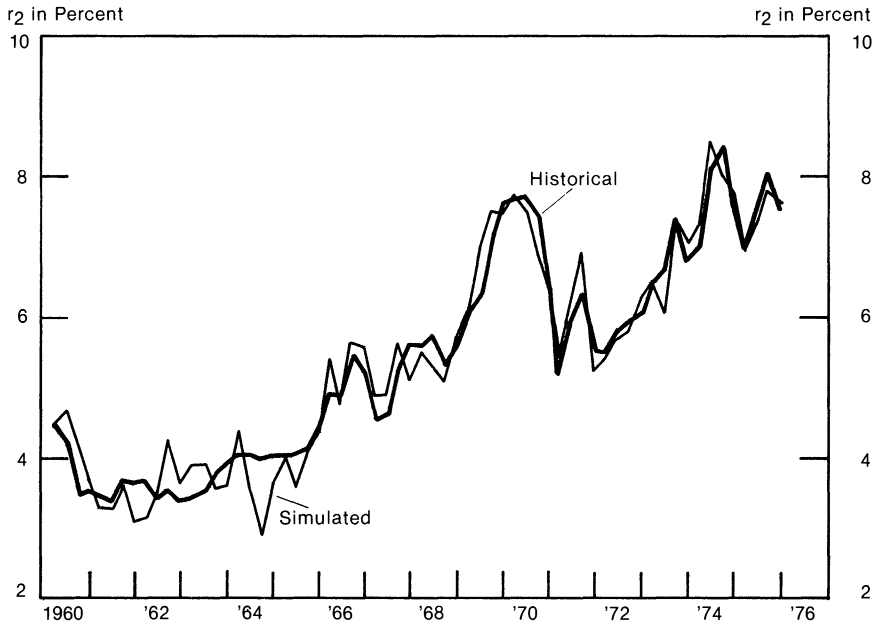

Figure 1. Dynamic Simulation Results for 3-5 Year Treasury Security Yield

the yields are also illustrated in Figures 1 and 2, where plots of actual and simulation values are given. For each endogenous variable, the results are similar to those of the separate dynamic simulations. For the yields, the root-mean-square errors are 34 and 20 basis points for the short-intermediate-term and long-term maturity classes, respectively. Again, the yields are explained with an unexpectedly high degree of accuracy. Furthermore, as indicated in Figures 1 and 2, the model performs somewhat better in more recent periods despite the greater volatility of actual market yields.

A. Short-Run Elasticities of Selected Variables

Although the individual Treasury security demand equations indicate a number of statistically significant determinants of Treasury security yields, the economic significance of these determinants must be examined in the context of the complete model. The significance of a subset of these variables in the short-run determination of the Treasury security yield curve is analyzed here in terms of the short-run eleasticities implied by the model. The short-run elasticities are derived by separately increasing the exogenous variables by 1 percent and then simulating the model. Because of the nonlinear form of the model, the experiments are performed for three different time periods—1961:IV, 1968:IV, and 1975:IV, using six exogenous variables.

The short-run elasticities of the two endogenous yields (r_2, r_4) with respect to the six exogenous variables are reported in Table IV. The results indicate that

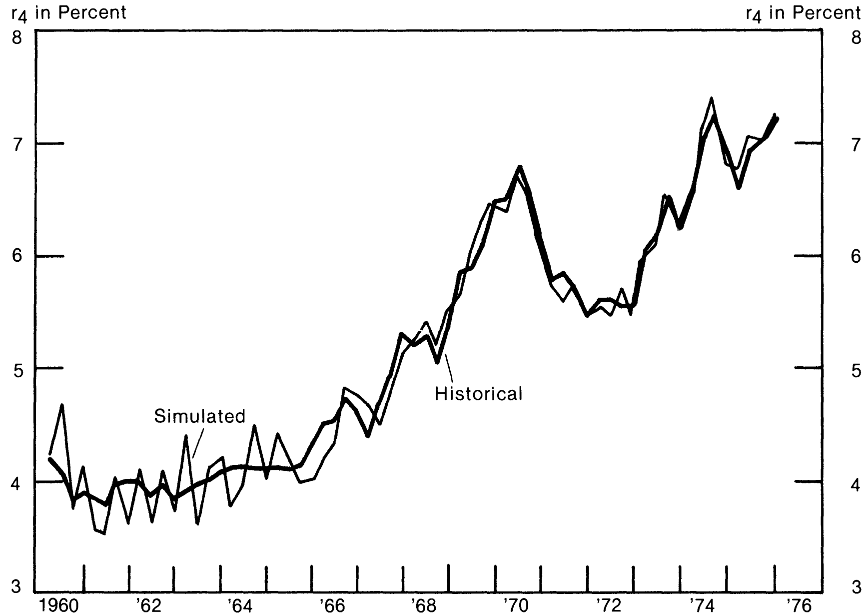

Figure 2. Dynamic Simulation Results for Long-Term Treasury Security Yield

the two Treasury security yields are quite responsive to changes in Treasury security supplies. For example, a 1 percent increase in the supply of short-intermediate-term Treasury securities ($US2^0$) implies a 1.7 percent increase in the short-intermediate-term yield (r_2) in 1975:IV. The results also indicate that the two endogenous yields are responsive to changes in personal consumption expenditures, reflecting the role of liquid assets in household portfolio selection. Increases of 1 percent in the remaining variables—the Treasury bill yield, the variance of the holding-period yield on long-term Treasury securities, and the net change in demand deposits—all lead to absolute changes of less than 1 percent in the yields. Nevertheless, all of the elasticities have the expected sign, with the short-intermediate-term yield exhibiting the most responsiveness to changes in these variables. Furthermore, although the elasticity of the short-intermediate term yield with respect to demand deposit flows appears to be small, its reported value of −0.11 in 1975:IV implies that a $0.5 billion increase in demand deposits would lead to a fairly substantial decline of 39 basis points in the short intermediate-term yield.

B. A Closer Look at Treasury Security Supply Effects

The results presented in Table IV concerning the responsiveness of Treasury security yields to supply changes are in sharp contrast to the results of other researchers who have studied the determinants of Treasury security yields. Thus, the elasticities of the two Treasury security yields with respect to changes in

Table IV

Selected Short-Run Elasticities

Yield Elasticity with Respect to:	Short-Intermediate-Term Yield (r_2)			Long-Term Yield (r_4)		
	1961:IV	1968:IV	1975:IV	1961: IV	1968: IV	1975: IV
$US2^O$	8.838	2.642	1.734	.253	.276	.166
$US4^O$	.066	.041	.025	3.393	2.091	.616
r_T	.091	.225	.386	.017	.070	.066
V_4	−.125	−.097	−.061	.007	.022	.014
CE	−2.673	−1.209	−1.199	1.781	1.868	1.214
DD^C	—	−.034	−.114	—	−.014	−.004

Definitions:
$US2^O$ = supply of short-intermediate-term Treasury securities;
$US4^O$ = supply of long-term Treasury securities;
r_T = yield on Treasury bills;
V_4 = variance of the holding-period yield on long-term Treasury securities;
CE = personal consumption expenditures;
DD^C = net change in demand deposits

Treasury security supplies are more closely examined in Table V, where summary statistics for these elasticities as well as aggregate demand elasticities are computed for the complete sample period. These latter elasticities are of interest since researchers finding only small Treasury security supply effects have sometimes explained their results by appealing to large yield elasticities of demand. (See, for example, Lang and Rasche [25].)

Using notation consistent with the estimation results reported previously, the aggregate own- and cross-yield elasticities of demand in a given period may be represented as

$$\eta_{mn}^{D} = (\partial USm/\partial r_n)(r_n/USm),\ m, n = 2, 4$$

where

$$USm = \sum_h USm^h,\ m = 2, 4,$$

and h (h = 1, . . . , 10) corresponds to the categories of investors. Summary statistics for these elasticities (η_{22}^D, η_{44}^D, η_{24}^D, η_{42}^D) are reported in the upper portion of Table V. Two aspects of the reported results are of particular interest. First, the magnitudes of the sample means are consistent with the view that absolute or relative changes in Treasury securities do affect the Treasury yield curve. Second, as indicated by the sample standard deviations as well as the minimum and maximum values, the elasticities have been highly variable over the sample period. This variability refelects the importance of short-run wealth or cash flows in the short run determination of Treasury security demands.

The short-run elasticities of Treasury security yields with respect to changes in Treasury security supplies may be directly represented in terms of the aggregate demand elasticities. In particular, own-elasticities may be expressed as

$$\eta^S_{mm} = (\partial r_m/\partial USm^0)/(USm^0/r_m) = [\eta^D_{nn}/(\eta^D_{mm}\cdot\eta^D_{nn} - \eta^D_{mn}\cdot\eta^D_{nm})], \quad (m, n) = (2, 4), (4, 2), \quad (4)$$

and cross-elasticities may be expressed as

$$\eta^S_{mn} = (\partial r_m/\partial USn^0)(USn^0/r_m) = [-\eta^D_{mn}/(\eta^D_{nn}\cdot\eta^D_{mm} - \eta^D_{mn}\cdot\eta^D_{nm})], \quad (m, n) = (2, 4)\ (4, 2), \quad (5)$$

where USm^0 (m = 2, 4) are exogenous supplies. Summary statistics for these elasticities (η^S_{22}, η^S_{44}, η^S_{24}, η^S_{42}) are reported in the middle of Table V. The results indicate that changes in Treasury security supplies affect Treasury security yields, and the impacts are highly variable over the sample period. If, for example, the supply of long-term Treasury securities is increased by 1 percent, then, based on sample means, the long-term Treasury security yield would increase by 2.5 percent and the short-intermediate-term yield would increase by 0.1 percent. However, to emphasize the variability of these elasticities, there are 17 quarterly observations in the sample where the elasticity η^S_{44} has a value less than unity.

The computed elasticities may also be used to determine the effectiveness of discretionary Federal debt management policy in changing the Treasury yield curve. For example, if the supply of short-intermediate-term Treasury securities is *increased* by the same amount that the supply of long-term Treasury securities

Table V

Summary Statistics for Short-Run Aggregate Demand and Yield Elasticities (1960:I-1975:IV)

	Mean	Standard Deviation	Minimum[a]	Maximum[a]
η^D_{22}	.422	.339	.087	2.180
η^D_{44}	.697	.550	.114	2.279
η^D_{24}	−.009	.007	−.002	−.303
η^D_{42}	−.058	.052	−.008	−.177
η^S_{22}	3.557	2.241	.459	11.435
η^S_{44}	2.452	1.606	.440	8.783
η^S_{24}	.060	.099	.010	.804
η^S_{42}	.238	.123	.054	.752
$\eta^S_{2,DM}$	.430	2.207	0.429	11.387
$\eta^S_{4,DM}$	−2.344	1.556	−0.391	−8.464

[a] Ranked according to absolute values.

Definitions:

$\eta^D_{mn} = (\partial USm/\partial r_n)(r_n/US_m)$, $m, n = 2, 4$;

$\eta^S_{mn} = (\partial r_m/\partial USn^0)(USn^0/r_m)$, $m, n = 2, 4$

is *decreased*, then the elasticities of Treasury security yields with respect to debt management operations of this type are

$$\eta^S_{2,DM} = \eta^S_{22} - \eta^S_{24} \cdot (US2^0/US4^0) \tag{6}$$

$$\eta^S_{4,DM} = -\eta^S_{44} + \eta^S_{42} \cdot (US4^0/US2^0) \tag{7}$$

As indicated in Table V, Federal debt management is, on average, capable of changing the Treasury yield curve.[18] Because of the substantial within-sample variability, the same qualifications as before are relevant. The results do indicate, however, that researchers using unrestricted reduced-form equations may obscure the potential effects of Federal debt management if only uniform responses from changes in Treasury security supplies are tested over a given sample period.[19]

C. A Comparison of the Structural Model With a Naive Model

Unrestricted reduced-form models of interest rate determination have been subject to an increasing amount of criticism in recent studies on bond-market efficiency. For example, Pesando [37] found that contemporaneous innovations in short-term interest rates statistically dominate nonyield determinants commonly used in previous studies in explaining changes in bond yields. Contemporaneous innovations in short-term interest rates were also found to statistically dominate lagged values of interest rates. Furthermore, the degree of serial correlation evident in virtually all single-equation models of interest rate determination is inconsistent with usual notions of market efficiency.

The long-term Treasury security yield solved from the restricted reduced form of the structural model is examined in Table VI in light of these recent criticisms.[20] The endogenously determined values of the long-term yield are taken from a joint *static* simulation. In contrast to the dynamic simulation reported in the previous subsection, the static simulation uses actual values for all lagged endogenous variables in each period. Thus, the complete information set of the model is used in each period to predict the long-term Treasury security yield. The predicted values obtained from the simulation are tested to determine whether they are

[18] Again, the values in Table V correspond to the initial impact of a Federal debt management operation. In a simulation experiment using the model, a permanent shift in the composition of the Federal debt was shown to have a permanent impact on the Treasury yield curve. In particular, a shift of \$2.5 billion from short-intermediate-term to long-term Treasury securities beginning in 1959: IV decreases the short-intermediate-term yield by an average of 36 basis points and increases the long-term yield by an average of 51 basis points. See Roley [41].

[19] The study by Lang and Rasche [25] does not suffer from this pitfall. They report elasticities on an annual basis, and also find substantial variation over the sample period beginning in 1967 and ending in 1976. Their longest computed elasticity—roughly corresponding to $\eta^S_{4,,DM}$—appears to be approximately 0.85. Lang and Rasche do not, however, disaggregate the demand side of the Treasury securities market.

[20] Empirical results for the 3- to 5-year Treasury security yield are similar to those reported for the long-term yield in Table VI. However, empirical comparisons of the type reported in Table VI are more straightforward to implement and interpret for long-term interest rates than for short-term interest rates. This is because the longer the maturity of a security, the more closely the martingale approximation represents security yields if the expectations hypothesis is valid. Thus, regressions similar to those in Table VI with the 3- to 5-year yield as the dependent variable are not discussed further here.

Table VI

An Empirical Comparison of Models (1960:I-1975:IV)

$r_{4t} = a + b_1 \cdot r^p_{4,t} + b_2 \cdot r_{4,t-1} + b_3 \cdot (r_{T,t} - r_{T,t-1}) + \epsilon_t$

	Coefficient Estimates[a]				Summary Statistics		
	a	b_1	b_2	b_3	$\bar{R}^2$	SE	DW
1.	0.1283 (1.1)	0.9756 (42.7)	0	0	.97	.20	2.31
2.	0	0.9992 (207.5)	0	0	.97	.21	2.37
3.	0.0431 (2.1)	0	1	0.2135 (6.0)	.98	.17	1.97
4.	0	0	1	0.2162 (5.9)	.98	.17	1.84
5.	0	0.3857 (5.5)	0.6199 (8.8)	0.1466 (4.6)	.98	.14	1.94
6.	0	0.0102 (2.1)	1	0	.97	.21	1.71
7.	0	0.0096 (2.5)	1	0.2137 (6.1)	.98	.17	2.01
8.	0	0.9952 (127.5)	0	0.0555 (0.8)	.91	.33	1.61
9.	0	0.5121 (6.9)	0.4925 (6.6)	0	.98	.16	1.82

[a] Individual entries consisting of either 0's or 1's correspond to constraints imposed on the estimated equations. Numbers in parentheses are t-statistics.

Definitions:

$r_{4,t}$ = yield on 10-year and over Treasury securities;

$r^p_{4,t}$ = static simulation prediction of $r_{4,t}$;

$r_{T,t}$ = yield on 3-month Treasury bills

biased, whether they imply serially correlated errors, and whether they are dominated by innovations in short-term interest rates. A set of regressions is also reported in a further attempt to identify the value added of the structural model over less complicated models comprised of the lagged long-term yield and the innovation in the short-term yield. In all of the relevant regressions, the innovation in the short-term yield is defined as the change in the 3-month Treasury bill yield. While this yield is already included in the structural model, it is constrained by the underlying demand equations and therefore its impact on the yield curve may be understated if arbitrage forces are not fully incorporated into the demands.

All of the tests mentioned above may be implemented by imposing sets of constraints on the equation:

$$r_{4,t} = a + b_1 \cdot r^p_{4,t} + b_2 \cdot r_{4,t-1} + b_3 \cdot (r_{T,t} - r_{T,t-1}) + \epsilon_t \qquad (8)$$

where the variables are defined as in Table VI. This equation gives the structural model result if $a = 0$, $b_1 = 1$, $b_2 = b_3 = 0$, and reduces to a naive model comprised of the innovation in the Treasury bill yield if $a = b_1 = 0$, $b_2 = 1$, $b_3 > 0$. In addition, the biases associated with each of these models may be examined by testing $a = 0$ and $b_1 = 1$ in the structural model case, and $a = 0$ in the naive model case. Estimated equations used for all of these tests are reported in Table VI. Tests for the presence of bias indicate that the null hypothesis of unbiased predictions cannot be rejected at the 5 percent level of significance for the structural model, but that it can be rejected for the naive model—Equation (3.) in Table VI. The Durbin-Watson statistics reported in Table VI indicate that the null hypothesis of serially uncorrelated residuals cannot be rejected in the naive model or the structural model. The fact that the restricted reduced-form expression of the long-term yield in the structural model has no significant serial correlation is in sharp contrast to most unrestricted reduced-form equations.

Tests concerning the hypothesis that either the structural model or the naive model best describes the evolution of long-term security yields are particularly interesting. Again in contrast to tests involving unrestricted reduced-form models, the null hypothesis that coefficients on predicted values from the structural model equal zero when they are included with the naive model—Equation (5.) vs. Equation (4.) in Table VI—can be rejected at the 5 percent level of significance. However, the null hypothesis that the coefficients on the innovation in the Treasury bill yield and the lagged value of the long-term yield equal zero—Equation (5.) vs. Equation (2.)—can also be rejected.

Further empirical results focusing on the additional explanatory power provided by the structural model are reported in the last four rows of Table VI. In Equation (6.), the predicted value of the long-term yield is included in the random walk model, and the empirical results indicate that the predicted value adds significant explanatory power.[21] In Equations (7.) and (8.), the innovation of the short-term yield is included with the predicted value of the long-term yield. These specifications differ in that one includes and the other excludes the lagged long-term yield. This pair of estimated equations indicates that the innovation in the short-term rate is statistically significant only in the case where the lagged long-term rate is included, while the predicted value is significant in both. This result simply reflects the notion that innovations in short-term yields relate more closely to changes in long-term yields than to their levels. Equation (9.) includes both the predicted and lagged values of the long-term yield without any constraints. As in Equation (5.), the coefficients on both of these variables are highly statistically significant. Moreover, in both of these equations, the hypothesis that $b_2 = 1 - b_1$ cannot be rejected at the 5 percent level of significance. By imposing this constraint, the equations reduce to a partial adjustment model with the long-term yield adjusting toward the value predicted by the structural model. With this interpretation, the predicted yield represents equilibrium yield, with observed yields adjusting over time to this equilibrium. Such behavior may imply that the model does not fully capture the stock-adjustment process in investors' portfolios

[21] However, the structural model includes information not known at time $t - 1$. Thus, the results associated with Equation (6.) should be interpreted in a manner similar to those involving the innovation in the short-term yield. To compare the structural model with the random walk model, optimal time-series predictors of exogenous variables could be used to form the structural model's prediction at time $t - 1$ for the yield in time t. This exercise is, however, beyond the scope of the present paper.

despite the attempt made here to model this process in a more general manner than in previous studies.[22]

As a whole, the empirical results in Table VI are not sufficient to judge which model of the long-term Treasury security yield is superior. The results instead indicate that some combination of the two models—including the predicted long-term yield, the lagged long-term yield, and the innovation in the short-term yield—achieves the lowest standard error. Under the hypothesis that the structural model is true, however, the statistical significance of the short-term yield in Equations (5.) and (7.) may simply reflect the simultaneity of short- and long-term security yields. In particular, in a structural model including all markets, a restricted reduced-form equation would also represent the short-term yield, and this equation's error term would almost certainly be correlated with the error term in the reduced-form expression of the long-term yield. Thus, by including the actual short-term yield with the predicted value of the long-term yield in the equations in Table VI, the correlation of the short-term yield and the error terms in these equations may explain its statistical significance.[23]

On the other hand, under the hypothesis that the expectations hypothesis is true, the empirical results associated with Equations (5.) and (7.) may reflect a failure to adequately model the innovation in the short-term yield. In particular, there is no reason why the short-term yield should follow a random walk. (See Pesando [38].) This may be tested by using the expectations hypothesis to initially write the long-term yield as:

$$r_{4,t} = 1/N[r_{T,t} + E_t(r_{T,t+1}) + \cdots + E_t(r_{T,t+N-1})] + a \tag{9}$$

where E is the expectations operator and N is the maturity in quarters of long-term Treasury securities. If the results in Table VI are actually consistent with the expectations hypothesis, expected short-term rates are formed according to:

$$E_t(r_{T,t+i}) = b_{1i}\cdot r^p_{4,t} + b_{2i}\cdot r_{4,t-1} + b_{3i}\cdot r_{T,t} + b_{4i}\cdot r_{T,t-1} \qquad i = 1, 2, \cdots, N-1 \tag{10}$$

where the general case with b_{3i} and b_{4i} unconstrained is used. Combining Equations (9) and (10), the expectations hypothesis implies

$$r_{4,t} = a + b'_1\cdot r^p_{4,t} + b'_2\cdot r_{4,t-1} + b'_3\cdot r_{T,t} + b'_4\cdot r_{T,t-1} \tag{11}$$

where

$$b'_j = 1/N \textstyle\sum_{i=1}^{N-1} b_{ji},\ j = 1, 2, 4$$

$$b'_3 = 1/N(1 + \textstyle\sum_{i=1}^{N-1} b_{3i})$$

To test the hypothesis that this model is consistent with Equation (5.) in Table

[22] Alternatively, the statistical significance of the lagged long-term yield may reflect an inadequate representation of expected holding-period yields. For example, an autoregressive specification of expected holding-period yields may be preferable to the specification used here. See Friedman and Roley [16].

[23] I am indebted to David Jones for this point as well as for his detailed comments and suggestions concerning the tests reported below in the text.

VI, the right-hand side of Equation (9) is used as the dependent variable in Equation (11), with observed future yields used in place of expected short-term rates.[24] This equation is then included in a 2-equation system with the unconstrained version of Equation (5.); i.e., $b_3 \neq -b_4$. FIML estimation is used to test the hypothesis that $b_j = b'_j$, $j = 1, \cdots, 4$. Because actual yields are used for expected short-term rates and $N = 40$, the estimation period begins in 1960:I and ends in 1965:IV. The results of this test indicate that the null hypothesis can be rejected at the 1 percent level of significance. In particular, the likelihood ratio test statistic takes a value of 16.2 and is asymptotically distributed as $\chi^2(4)$. Thus, the expectations hypothesis—at least as represented here—is not consistent with the "best" equation in Table VI.

To summarize, the empirical results in this section do not enable a clear-cut choice between the structural and naive models. On the basis of these tests, however, it is apparent that the structural model performs much better than previous unrestricted reduced-form models which have been shown to be statistically dominated by changes in short-term interest rates. Based on the suggestive results reported above, further tests concerning the relative performance of structural models appear to be a promising area for future research.

IV. Conclusions

Five main conclusions emerge from the empirical investigation in this paper. First, the disaggregated structural model presented here implies there is a variety of economically significant determinants of Treasury security yields. In particular, the determinants include yields on other types of securities, variances of yields, the level of price inflation, wealth flows and stocks, and lagged asset stocks associated with short-run portfolio adjustment behavior. Second, based on the empirical specifications of net purchases of short-intermediate-term and long-term Treasury securities by each investor category, it appears that these two maturity classes of Treasury securities may not be regarded as perfect or near perfect substitutes. Third, when market-clearing identities are added to the disaggregated structural demand equations, the model provides accurate within-sample "forecasts" of past short- and long-term Treasury security yields. Again, the joint determination of short- and long-term yields is in sharp contrast to most previous studies. Fourth, a change in Treasury security supplies, both in absolute and relative terms, has a short-run impact on the Treasury security yield curve, but the impact varies among time periods. Finally, a series of tests comparing the structural model with less complicated models based on the expectations hypothesis were somewhat inconclusive. Neither model statistically dominated the other in terms of their ability to explain the variation of long-term yields. Nevertheless, previous studies have reported that unrestricted reduced-form equations are typically dominated in similar tests.

[24] In principle, this methodology is similar to that used by Sargent [47], although restrictions are not placed on the set of expected short-term rates in (10). Furthermore, as expected this equation exhibited significant serial correlation. Through preliminary estimation a third-order autocorrelation correction was chosen to eliminate this problem.

REFERENCES

1. David Backus, William C. Brainard, Gary Smith, and James Tobin. "A Model of U.S. Financial and Nonfinancial Economic Behavior." *Journal of Money, Credit, and Banking* 12 (May 1980), 259–93.
2. Olivier J. Blanchard and Mary K. Plantes. "A Note on Gross Substitutability of Financial Assets." *Econometrica* 45 (April 1977), 769–71.
3. Board of Governors of the Federal Reserve System. *Flow of Funds Accounts 1946–1975.* Washington: 1975.
4. Barry Bosworth and James S. Duesenberry. "A Flow of Funds Model and its Implications." Federal Reserve Bank of Boston, *Issues in Federal Debt Management.* Boston: 1973.
5. William C. Brainard and James Tobin. "Pitfalls in Financial Model-Building." *American Economic Review* 57 (May 1968), 99–122.
6. James M. Brundy and Dale W. Jorgenson. "Efficient Estimation of Simultaneous Equations by Instrumental Variables." *Review of Economics and Statistics* 53 (August 1971), 207–24.
7. J. M. Culbertson. "The Term Structure of Interest Rates." *Quarterly Journal of Economics* 71 (November 1957), 485–517.
8. Steven W. Dobson, Richard C. Sutch, and David E. Vanderford. "An Evaluation of Alternative Empirical Models of the Term Structure of Interest Rates." *Journal of Finance* 26 (September 1976), 1035–66.
9. James S. Duesenberry. "The Portfolio Approach to the Demand for Money and Other Assets." *Review of Economics and Statistics* 45 (February 1963), 9–31.
10. Michael E. Echols and Walter J. Elliott. "Rational Expectations in a Disequilibrium Model of the Term Structure." *American Economic Review* 66 (March 1976), 28–44.
11. Walter J. Elliott and Jerome R. Baier. "Econometric Models and Current Interest Rates: How Well Do They Predict Future Rates?" *Journal of Finance* 34 (September 1979), 975–86.
12. Martin Feldstein and Otto Eckstein. "The Fundamental Determinants of the Interest Rate." *Review of Economics and Statistics* 52 (November 1970), 363–75.
13. Benjamin M. Friedman. "Financial Flow Variables and the Short-Run Determination of Long-Term Interest Rates." *Journal of Political Economy* 85 (August 1977), 661–89.
14. ———. "Interest Rate Expectations Versus Forward Rates: Evidence from an Expectations Survey." *Journal of Finance* 34 (September 1979), 965–73.
15. ———. "Price Inflation, Portfolio Choice, and Nominal Interest Rates." *American Economic Review* 70 (March 1980), 32–48.
16. ———. and V. Vance Roley. "Investors' Portfolio Behavior Under Alternative Models of Long-Term Interest Rates Expectations: Unitary, Rational, or Autoregressive." *Econometrica* 47 (November 1979), 1475–97.
17. ———. "A Note on the Derivation of Linear Homogeneous Asset Demand Functions." Mimeo: Harvard University, 1979.
18. ———. "Models of Long-Term Interest Rate Determination." *Journal of Portfolio Management* 6 (Spring 1980), 35–45.
19. Stephen M. Goldfeld. *Commercial Bank Behavior and Economic Activity.* Amsterdam: North-Holland Publishing Company, 1966.
20. Nils H. Hakansson. "Optimal Investment and Consumption Strategies Under Risk for a Class of Utility Functions." *Econometrica* 38 (September 1970), 587–607.
21. Michael J. Hamburger and Cynthia M. Latta. "The Term Structure of Interest Rates." *Journal of Money, Credit, and Banking* 1 (February 1969), 71–83.
22. Patric H. Hendershott. *Understanding Capital Markets: A Flow-of-Funds Financial Model* (*Volume 1*). Lexington, Mass.: D. C. Heath, 1977.
23. John R. Hicks. *Value and Capital.* London: Oxford University Press, 1939.
24. Reuben A. Kessel. "The Cyclical Behavior of the Term Structure of Interest Rates." Guttentag (ed.), *Essays on Interest Rates* (*Volume II*). New York: Columbia University Press, 1971.
25. Richard W. Lang and Robert H. Rasche. "Debt-Management Policy and the Own-Price Elasticity of Demand for U.S. Government Notes and Bonds." Federal Reserve Bank of St. Louis *Review* 59 (September 1977), 8–22.
26. Friedrich A. Lutz. "The Structure of Interest Rates." *Quarterly Journal of Economics* 54 (November 1940), 36–63.

27. John S. McCallum. "The Expected Holding Period Return, Uncertainty and the Term Structure of Interest Rates." *Journal of Finance* 30 (May 1975), 307–23.
28. David Meiselman. *The Term Structure of Interest Rates*. Englewood Cliffs: Prentice-Hall, 1962.
29. Robert C. Merton. "Lifetime Portfolio Selection Under Uncertainty: The Continuous-Time Case." *Review of Economics and Statistics* 51 (August 1969), 247–57.
30. Frederic S. Mishkin. "Efficient Markets Theory: Implications for Monetary Policy." *Brookings Papers on Economic Activity* (No. 3, 1978), pp. 707–52.
31. Franco Modigliani. "The Dynamics of Portfolio Adjustment and the Flow of Savings Through Financial Intermediaries." Gramlich and Jaffe (eds.), *Savings Deposits, Mortgages and Housing*. Lexington: D. C. Heath, 1972.
32. ———. and Robert J. Shiller. "Inflation, Rational Expectations and the Term Structure of Interest Rates." *Economica* 40 (February 1973), 12–43.
33. ———. and Richard Sutch. "Innovations in Interest Rate Policy." *American Economic Review* 56 (May 1966), 178–97.
34. ———. "Debt Management and the Term Structure of Interest Rates: An Empirical Analysis of Recent Experience." *Journal of Political Economy* 75 (August 1967), 569–89.
35. Arthur M. Okun. "Monetary Policy, Debt Management, and Interest Rates: A Quantitative Appraisal." Commission on Money and Credit, *Stabilization Policies*. Englewood Cliffs: Prentice-Hall, 1963.
36. Michael Parkin. "Discount House Portfolio and Debt Selection." *Review of Economic Studies* 38 (October 1970), 469–97.
37. James E. Pesando. "On the Efficiency of the Bond Market: Some Canadian Evidence." *Journal of Political Economy* 86 (December 1978), 1057–76.
38. ———. "On the Random Walk Characteristics of Short- and Long-Term Interest Rates in an Efficient Market." *Journal of Money, Credit, and Banking* 11 (November 1979), 457–66.
39. Gail Pierson. "Effect of Economic Policy on the Term Structure of Interest Rates." *Review of Economics and Statistics* 52 (February 1970), 1–11.
40. V. Vance Roley. *A Structural Model of the U.S. Government Securities Market*. Ph.D. Dissertation: Harvard University, 1977.
41. ———. "Federal Debt Management Policy: A Re-Examination of the Issues." Federal Reserve Bank of Kansas City *Economic Review* 63 (February 1978), 14–23.
42. ———. "The Role of Commercial Banks' Portfolio Behavior in the Determination of Treasury Security Yields." *Journal of Money, Credit, and Banking* 12 (May 1980), 353–69.
43. ———. "Symmetry Restrictions in a System of Financial Asset Demands: A Theoretical and Empirical Analysis." Mimeo: Federal Reserve Bank of Kansas City, 1980.
44. Richard Roll. *The Behavior of Interest Rates: An Application of the Efficient Market Model to U.S. Treasury Bills*. New York: Basic, 1970.
45. Paul A. Samuelson. "Lifetime Portfolio Selection by Dynamic Stochastic Programming." *Review of Economics and Statistics* 51 (August 1969), 239–46.
46. Thomas J. Sargent. "Commodity Price Expectations and the Interest Rate." *Quarterly Journal of Economics* 83 (February 1968), 127–40.
47. ———. "A Note on Maximum Likelihood Estimation of the Rational Expectations Model of the Term Structure." *Journal of Monetary Economics* 5 (January 1979), 133–43.
48. Robert Haney Scott. "Liquidity and the Term Structure of Interest Rates." *Quarterly Journal of Economics* 79 (February 1965), 135–45.
49. Robert J. Shiller. "The Volatility of Long-Term Interest Rates and Expectations Models of the Term Structure." *Journal of Political Economy* 87 (December 1979), 1190–219.
50. William L. Silber. "Portfolio Substitutability, Regulations, and Monetary Policy." *Quarterly Journal of Economics* 83 (May 1969), 197–219.
51. Kenneth J. Singleton. "Expectations Models of the Term Structure and Implied Variance Bounds." *Journal of Political Economy* 88 (December 1980), 1159–76.
52. Stephen P. Taylor and John Wood. "Federal Debt by Weighted Maturity Classes for Use in Flow-of-Funds Accounts." Mimeo: Board of Governors of the Federal Reserve System, 1963.
53. Neil Wallace. "The Term Structure of Interest Rates and the Maturity Composition of the Federal Debt." *Journal of Finance* 22 (May 1967), 301–12.
54. John H. Wood. "The Expectations Hypothesis, the Yield Curve, and Monetary Policy." *Quarterly Journal of Economics* 78 (August 1964), 457–70.