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INTERTEMPORAL ASSET PRICING AND THE TERM STRUCTURES OF EXCHANGE RATES AND INTEREST RATES: THE EUROCURRENCY MARKET*

by

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ABSTRACT

The primary purpose of this investigation is to test a model of the term structure of forward exchange rates. The approach taken in the paper consists of developing a unified framework within which this term structure is studied in conjunction with that of interest rates. Econometric analysis of data from the eurocurrency market generally indicates that the term structure implications of a lognormal version of the (consumption-based) intertemporal asset pricing model are statistically rejected at usual significance levels.

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I. Introduction

Each trading day, foreign exchange markets determine a complete schedule of forward exchange rates across maturities. Econometric analysis of this term structure can provide useful information about the empirical validity of alternative asset pricing theories, the market's anticipations of future events, and the existence of intertemporal profit opportunities. Yet, despite the availability of data, there are only a few published studies on this subject.[1] Most of these studies have relied on a certainty framework and have stipulated a number of assumptions, like uncovered interest parity and the "expectations hypothesis" of the term structure of interest rates, that have not been supported by recent empirical work.[2] Thus, it is worthwhile to investigate the term structure of exchange rates within a framework that a-priori does not impose these assumptions. The intertemporal asset pricing model analyzed below is one such framework.

The primary purpose of this investigation is to test a model of the term structure of forward exchange rates. The approach taken in the paper consists of developing a unified framework within which this term structure is studied in conjunction with that of interest rates. This has the potential of resulting in a more informative and powerful test of the model considered, and of giving a common basis for comparing findings across exchange and interest rates. Moreover, the findings reported below on the term structure of interest rates are useful from the standpoint of the voluminous literature on this topic, in that the present work uses a different data set from that of most previous studies.

Section II of the paper develops a version of an intertemporal asset pricing model whose foundations rely on previous work by Lucas (1978, 1982), Cox, Ingersoll, and Ross (1978), Breeden (1979), and others. Using the first order conditions of the model, the analysis deduces its implications for the term structures of exchange rates and interest rates.[3] Combining this analysis with a set of auxiliary assumptions yields a joint null hypothesis that can be tested using exchange rate and interest rate data alone. This hypothesis asserts that the difference (in logs) between the return on a long term asset and that of a corresponding sequence of short term assets is equal to a time invariant risk premium plus a forecast error.

Section III discusses the data set, econometric methods, and empirical results. The Eurocurrency market is chosen as the territory within which to test the model for two main reasons. First, this market is perhaps the most obvious example of joint term structure determination for exchange rates and interest rates. Second, assets within this market are comparable in terms of issuer, political and default risk, and other aspects except currency or denomination. The orthogonality restrictions imposed by the model are tested using a method similar to the one advanced by Hansen and Hodrick (1980, 1983). Interpretation of the findings and concluding remarks are included in Section IV.

II. The Model

a. Structure and First Order Conditions

Consider a representative consumer choosing consumption and investment plans so as to maximize expected utility subject to a sequence of budget constraints. With a view towards the empirical implementation that follows, it is assumed that the consumer can invest in Eurocurrency deposits denominated in different currencies as well as in forward contracts of foreign exchange. These assets are assumed to have maturities of 1, 3, 6, and 12 months, and their currencies of denomination are referred to as domestic (U.S. dollars) and foreign (Deutschemark and U.K. pound).[4] Since the model is familiar from previous literature, a more complete description of its basic setup is left to Appendix 1.

Assuming that the consumer takes all prices as well as exchange and interest rates as given, his optimal plans of investment in Eurocurrency forward contracts and deposits must satisfy the first order conditions:

$$E_t[\lambda_{t+j+i}(S_{t+j+i} - F_{it+j+i})] = 0, \tag{1}$$

$$- E_t\lambda_{t+j} + \beta^i E_t[R_{it+j+i}\lambda_{t+j+i}] = 0, \tag{2}$$

$$- E_t[\lambda_{t+j}S_{t+j}] + \beta^i E_t[R^*_{it+j+i}S_{t+j+i}\lambda_{t+j+i}] = 0, \tag{3}$$

$$i = 1, 3, 6, 12,$$

$$j = 0, 1, 2, \ldots, 11,$$

where E_t = conditional expectation based on time t information,

β = subjective discount factor ($0 < \beta < 1$),

$\lambda_t = U'(c_t)/P_t$; i.e., the marginal utility derived from allocating one unit of domestic currency to consumption,

U = strictly concave utility function,

c_t = consumption during period t,

P_t = domestic currency price of one unit of c_t,

S_t = spot exchange rate at time t,

F_{it+j+i} = i-months forward exchange rate, set at time t+j,

R_{it+j+i} = the date t+j+i payoff from investing at time t+j one unit of domestic currency in an i-months domestic Eurocurrency deposit,

R^*_{it+j+i} = the date t+j+i payoff from investing at time t+j one unit of foreign currency in a foreign Eurocurrency deposit.

Variables dated t or eariler are assumed to be included in the time t information set. Any variable with an index "it+h" is known as of time t+h-i.

Equations (1) - (3) have standard interpretations. Condition (1) requires that the expected marginal utility of profits from forward foreign exchange contracts equals zero; this reflects the assumption that engaging in forward contracts does not require resources from the investor at time t.[5] Equations (2) and (3) involve the margin of choice between consumption and investment plans for periods t+j and t+j+i.[6] They imply that the cost in terms of foregone current consumption of investing one unit of domestic (foreign) currency in a domestic (foreign) asset equals the expected future consumption benefit resulting from the asset's payoff.

The implications of these first order conditions for the term structure vector of exchange and interest rates -- i.e., $[F_{it+i}, R_{it+i}, R^*_{it+i}]$ for i = 1, 3, 6, 12 -- can now be derived.

b. The Term Structure of Exchange Rates

At each point in time t the market determines the forward exchange rates F_{it+i}, for i = 1, 3, 6, 12. In order to characterize this term structure the analysis proceeds by establishing the link between these rates and: (i) expected future short forward rates, and (ii) expected future spot rates.

Using eq. (1), with $j = 0$ and with $i = 1$, $j \neq 0$, yields the following relation:

$$F_{it+i} = E_t F_{1t+i} + \frac{Cov_t(\lambda_{t+i}, F_{1t+i})}{E_t \lambda_{t+i}}, \qquad (4)$$

$$i = 3, 6, 12,$$

where Cov_t denotes conditional covariance. This term structure representation links long forward rates at time t to expected future short (one period) forward rates. Consider an agent demanding foreign exchange for period t+i. Among his options, he can purchase at t a forward contract that delivers foreign exchange at t+i, or he can wait and purchase a one period forward contract at t+i-1. Equation (4) relates these two options. It indicates that the (nominally riskless) forward rate set at time t for delivery of foreign exchange at t+i is equal to the conditional expectation of the (risky) one period forward rate to be set at t+i-1 plus a risk premium term whose sign depends on that of the conditional covariance between the marginal utility λ_{t+i} and the forward rate F_{1t+i}. All risk premiums to be derived below have a general form that is similar to that in eq. (4). They are given by the ratio of the conditional covariance between marginal utility of consumption and an asset's payoff to the conditional expectation of marginal utility of consumption; a characterization that is known from consumption based asset pricing theories.

Another term structure representation can be obtained by using Eq. (1) with $j = 0$, thus relating forward to expected future spot rates:

$$F_{it+i} = E_t S_{t+i} + \frac{Cov_t(\lambda_{t+i}, S_{t+i})}{E_t \lambda_{t+i}}, \qquad (5)$$

$$i = 1, 3, 6, 12.$$

According to eq. (5) each one of the (nominally riskless) forward rates set at time t is equal to the conditional expectation of the pertinent future (risky) spot rate plus a risk premium term.[7]

The restrictions imposed by Eqs. (4) and (5) on the temporal comovement of short and long forward rates and spot rates are empirically examined in section III below. Before proceeding, however, it is worthwhile to discuss the connection between the analysis up to this point and previous work, as well as to point out some of the potential contributions of the present investigation. This discussion centers around three sets of remarks.

First, notice that eq. (4) involves only forward rates of different maturities (as well as λ_{t+i}). Examining empirical versions of this equation can help assess the relative advantages, e.g. from an expected profit/risk standpoint, of using forward contracts with long versus short maturities for a given terminal or delivery date. Also this would be a convenient and informative way of testing the implications of the underlying asset pricing model for the behavior of forward rates alone. However, this approach based on confronting short to long forward rates has not been previously implemented. Second, eq. (5) is well known from the literature on foreign exchange market efficiency. By placing it in the term structure context of the present study, the analysis can determine the sensitivity of empirical findings across different maturities. Although a priori one would expect to find similar patterns of empirical results (e.g. rejection of the model's null hypothesis) for eqs. (4) and (5), empirically this need not be the case and such a comparison remains to be seen below.

Third, by invoking certainty assumptions previous studies on this subject have focused on testing empirical versions of the following expression for the term structure of forward premiums:

$$\frac{F_{it+i}}{S_t} = \frac{F_{1t+1}}{S_t} \prod_{j=1}^{i-1} E_t\left(\frac{F_{1t+j+1}}{S_{t+j}}\right), \qquad i = 3, 6, 12.$$

The derivation of this equation typically relies on assumptions like covered and/or uncovered interest parity, and the "expectations hypothesis" of interest rates' term structure. Yet, since some of these assumptions have been rejected in previous empirical work, it would seem desirable to derive the term structure of forward premiums within a framework that does not necessarily impose them. Combining eqs. (4) and (5) yields one such derivation:

$$\frac{F_{it+i}}{S_t} = \frac{F_{1t+1}}{S_t} \cdot \prod_{j=1}^{i-1} \left[\frac{E_t F_{1t+j+1} + Cov_t(\lambda_{t+j+1}, F_{1t+j+1})}{E_t S_{t+j} + Cov_t(\lambda_{t+j}, S_{t+j})}\right],$$

an expression that holds as long as agents' decisions about forward contracts satisfy the first order condition (1).

c. The Term Structure of Interest Rates

Using first order conditions (2) and (3), with $j = 0$ and with $i = 1$, $j \neq 0$, the following representations are obtained for domestic and foreign interest rates:

$$R_{it+i} = R_{1t+1} \prod_{j=1}^{i-1} \left[E_t R_{1t+j+1} + \frac{Cov_t(\lambda_{t+j+1}, R_{1t+j+1})}{E_t \lambda_{t+j+1}}\right], \tag{6}$$

$$R^*_{it+i} = R^*_{1t+1} \prod_{j=1}^{i-1} \left[E_t R^*_{1t+j+1} + \frac{Cov_t(\lambda_{t+j+1} S_{t+j+1}, R^*_{1t+j+1})}{E_t(\lambda_{t+j+1} S_{t+j+1})}\right] \tag{7}$$

$$i = 3, 6, 12.$$

These equations link long rates to current and expected future short rates. They imply that in general there will be a nonzero differential between a long payoff and the corresponding sequence of expected future short payoffs. This differential, commonly referred to as the term premium, captures differences in the riskiness of long vs. short investment strategies; and riskiness is related to the signs and magnitudes of the pertinent $Cov_t(\cdot)/E_t(\cdot)$ ratios. Thus, as is known, eqs. (6) and (7) are at variance with the popular "expectations hypothesis" of the term structure,[8] advanced by Fisher (1930) and Lutz (1940), which stipulates (for domestic interest rates e.g.) that

$R_{it+i} = R_{1t+1} \prod_{j=2}^{i} E_t R_{1t+j}$. This equation holds only as a special case of the more general expressions (6) and (7).

Most previous empirical work on this subject has tested the "expectations hypothesis" using U.S. interest rates. The present paper reports econometric analysis of versions of eqs. (6) and (7) applied to Eurocurrency interest rates.[9] By comparing the results of this analysis with those of eqs. (4) and (5), it will be possible to determine the extent to which assessments on the term-structure empirical validity of the underlying asset pricing model depend on the specific set of payoffs (exchange vs. interest rates) that are used.

d. Testing a Lognormal Version of the Model

Equations (4) - (7) form the basis for the econometric tests of the term structure implications of the model. In principle, it is possible to test these implications using consumption data. However, given the well known limitations of aggregate consumption data as well as the international nature of the Eurocurrency market, the tests below involve exchange and interest rate data alone. In order to conduct these tests, some auxiliary assumptions are required. Specifically, it is assumed that $\{\log F_{1t+j}, \log S_{t+j}, \log R_{1t+j}, \log R^*_{1t+j}, \log \lambda_{t+j}\}$ is a time invariant and normally distributed process. Thus, only a specific (and partial) version of the model above is used in the empirical analysis. Under the lognormality assumption, using the definition of conditional covariance, taking logs in eqs. (4) - (7), and replacing (assuming rational expectations) expected values by actual values minus forecast errors gives:

$$Z(F)_{it+i} \equiv \log F_{it+i} - \log F_{1t+i} = K_i(F) + \mu(F)_{it+i}, \tag{8}$$

$$Z(S)_{it+i} \equiv \log F_{it+i} - \log S_{t+i} = K_i(S) + \mu(S)_{it+i}, \tag{9}$$

$$Z(R)_{it+i} \equiv \log R_{it+i} - \sum_{j=1}^{i} \log R_{1t+j} = K_i(R) + \mu(R)_{it+i}, \tag{10}$$

$$Z(R^*)_{it+i} \equiv \log R^*_{it+i} - \sum_{j=1}^{i} \log R^*_{1t+j} = K_i(R^*) + \mu(R^*)_{it+i}, \tag{11}$$

where

$$K_i(F) = \tfrac{1}{2}\, \hat{Var}_t(\log F_{1t+i}) + \hat{Cov}_t(\log F_{1t+i}, \log \lambda_{t+i}),$$

$$K_i(S) = (\tfrac{1}{2})\, \hat{Var}_t(\log S_{t+i}) + \hat{Cov}_t(\log F_{it+i}, \log \lambda_{t+i}),$$

$$K_i(R) = \sum_{j=2}^{i} [(\tfrac{1}{2})\hat{Var}_t\, (\log R_{1t+j}) + \hat{Cov}_t(\log R_{1t+j}, \log \lambda_{t+j}],$$

$$K_i(R^*) = \sum_{j=2}^{i} [(\tfrac{1}{2})\, \hat{Var}_t(\log R^*_{1t+j}) + \hat{Cov}_t(\log R^*_{1t+j}, \log \lambda_{t+j} S_{t+j})],$$

and

$$\mu(F)_{it+i} = \hat{E}_t \log F_{1t+i} - \log F_{1t+i},$$

$$\mu(S)_{it+i} = \hat{E}_t \log S_{t+i} - \log S_{t+i},$$

$$\mu(R)_{it+i} = \sum_{j=2}^{i} [\hat{E}_t \log R_{1t+j} - \log R_{1t+j}],$$

$$\mu(R^*)_{it+i} = \sum_{j=2}^{i} [\hat{E}_t \log R^*_{1t+j} - \log R^*_{1t+j}],$$

$i = 3, 6, 12$ [for Eq. (9), i also equals 1].

$\hat{E}_t$, $\hat{V}ar_t$, and $\hat{Cov}_t$ are expectation, variance, and covariance terms conditional on a subset of agents' information set.

Equations (8) - (11) are testable versions of (4) - (7). They give the model's restrictions on the time series behavior of exchange rates and deposits' payoffs. Each Z-variable[10] can be interpreted as a measure of the ex post excess return from holding a long term asset whose nominal return is known with certainty as of time t, versus holding a sequence of short term assets whose returns are uncertain at time t. Each such excess return includes two components. The first is a time invariant term, K_i, that captures the model's risk premium.[11] From the definition of the latter, it can be seen that there is no simple relation between the premiums on assets which differ in terms of maturity and/or currency of denomination. This reflects, to an important extent, the partial equilibrium nature of the present analysis. The second component of Z is the random term μ_{it+i}, a rational forecast error that is assumed to be orthogonal to components of the "^" information set.

The model is tested using a methodology similar to the one proposed and implemented by Hansen and Hodrick (1980, 1983) in their studies of foreign exchange market efficiency. Specifically, the ex-post excess return variable Z_{it+i} is regressed against a vector of information set components denoted by $\underline{x}_{it}$:

$$Z_{it+i} = K_i + \underline{b}_i' \underline{x}_{it} + \mu_{it+i}. \qquad (12)$$

The null-hypothesis is given by the orthogonality condition $\underline{b}_i' = \underline{0}$. A test of this condition can help detect economically meaningful departures of the sample information from the model's hypothesis. As the latter is a joint hypothesis, rejection of the model would indicate (i) the existence of a time varying risk premium, which arises due to violation of one of the following assumptions: stationarity, lognormality, constant preferences and discount factor, and/or (ii) violation of the present version of rational expectations, which would be captured by non-orthogonality of the forecast error with respect to information set components.

III. Empirical Investigation

a. Data

The model is implemented using data from the Eurocurrency market, which is primarily a short term market for deposits (and loans). The distinguishing feature of this market is that it is a nondomestic financial intermediary, in which banks and other financial institutions accept time deposits (and make loans) in currencies other than that of the country in which they are located. Since Eurocurrency assets are comparable in terms of issuer, political and default risk, and other aspects except currency of denomination, they offer an appropriate testing ground for the model developed in Section II.

The sample period is May 1973 to April 1984, and the data source is the Harris Bank of Chicago publication - "Weekly Review: International Money Markets and Foreign Exchange Rates". The interest rate data are London Eurocurrency (Friday closing) bid rates for 1, 3, 6, and 12 months deposits denominated in U. S. dollars, U. K. pounds and deutschemarks. To approximate monthly data, the Friday closest to the beginning of the month was chosen.[12] The exchange rate data consist of spot rates and 1, 3, 6, and 12 months forward rates for the U. K. pound and deutschemark (relative to the U. S. dollar); all these are Friday closing bid rates. Table 1 gives the average value of each return and exchange rate, as well as their standard deviations.

b. Econometric Methods

Equations (8) - (11) impose an orthogonality restriction on eq. (12): $\underline{b}_i' = \underline{0}$. Before testing this restriction, two econometric issues must be addressed: the estimation procedure, and the specification of the information set variables $\underline{x}_{it}$.

Several versions of eq. (12) were estimated by OLS, which under the null-hypothesis is a consistent estimator of $\underline{b}_i'$. However, since maturity (and hence the forecast interval) is often greater than the monthly sampling interval, the μ_{it+i} errors may be serially correlated;[13] these errors may also be heteroscedastic. Although serially correlated and heteroscedastic disturbances invalidate standard hypothesis testing, Hansen (1982) and White (1980) have shown how to correct the standard errors under these conditions.[14] After estimating the parameters by OLS, corrected estimates of the covariance matrix were used in the statistical tests reported below; see Appendix 2. OLS estimations and corrections were made using the RATS computer package.

In order to test the model, the information set - $\underline{x}_{it}$ - must be specified. Three alternative sets are considered. The three sets are somewhat restrictive in that interest rate excess returns are regressed on interest rate variables and exchange rate excess returns are regressed on exchange rate variables. A fourth information set was investigated but it is not reported due to computational problems. This fourth information set consisted of the current values of all thirteen excess returns.[15]

The first information set consists of the current and first lag of the excess return. That is, the following regression was run:

$$Z(Q)_{it+i} = K_i(Q) + b_{i1}Z(Q)_{it} + b_{i2}Z(Q)_{it-1} + \mu(Q)_{it+i}, \qquad (13)$$

where $Q = R, R^*, S$, and F, and $i = 3, 6$, and 12; (for $Q = S$, there is also an equation with $i = 1$). Tests of $b_{i1} = b_{i2} = 0$ are reported in column (1) of Tables 2 and 3.

The second information set consists of a "long" rate and a "short" rate. The long rate is the variable with the longest maturity in the definition of Z. For example, for $Z(R)_{6t+6}$ the long rate is R_{6t+6}. The short rate is the variable with the shortest maturity. For regressions involving $Z(F)$, $Z(R)$, and $Z(R^*)$ the short rates are F_{1t+1}, R_{1t+1}, and R^*_{1t+1} respectively; for regressions involving $Z(S)$, the short rate is S_{1t}. Denoting the long rate by Q^L and the short rate by Q^S, the following regression was estimated:

$$Z(Q)_{it+i} = K_i(Q) + b_{i1}\log Q^L_{it+i} + b_{i2}\log Q^S_{1t+1} + \mu(Q)_{it+i}, \tag{14}$$

where Q and i are defined above (below Eq. (13)). Tests of $b_{i1} = b_{i2} = 0$ are reported in column (2) of Tables 2 and 3.

The third information set is a restricted version of the previous information set. In this case, x_{it} consists of the forward premium, denoted $FP(Q)_{it+i}$. For interest rates and exchange rates the forward premium is defined by:

$$\log FP(R)_{3t+3} = \log R_{3t+3} - 3\log R_{1t+1},$$

$$\log FP(R)_{6t+6} = \log R_{6t+6} - 2\log R_{3t+3},$$

$$\log FP(R)_{12t+12} = \log R_{12t+12} - 2\log R_{6t+6},$$

$$\log FP(S)_{it+i} = \log FP(F)_{it+i} = \log F_{it+i} - \log S_t.$$

With these definitions, the following equation was estimated:

$$Z(Q)_{it+i} = K_i(Q) + b_{i1}\log FP(Q)_{it+i} + \mu(Q)_{it+i}. \tag{15}$$

Tests of $b_{i1} = 0$ are reported in column (3) of Tables 2 and 3.

c. Empirical Results

This subsection reports estimates of eqs. (13) - (15) and tests of the model's orthogonality restrictions. As indicated, data are available from May 1973 to April 1984. However, due to the leads and lags for the Z variables each regression is estimated from 1974-6 to 1983-3. Tables 2 and 3 report marginal significance levels, for testing the null hypothesis, for the U S. dollar/U. K. pound and U. S. dollar/deutschemark respectively. Note that marginal significance levels close to zero represent evidence against the null hypothesis.

Before discussing the specific results, an overview of the organization of these tables would be useful. The Z variables can be divided into two broad categories: the term structure of exchange rates and the term structure of interest rates. In the tables, the exchange rate group corresponds to rows 1 - 7 and the interest rate group to rows 8 -13. Within the first group, there is a term structure of forward exchange rates (rows 1 - 3, corresponding to eq. (8)) and one of forward relative to future spot rates (rows 4 - 7, corresponding to eq. (9)). Within the second group, there are term structure equations for domestic interest rates (rows 8 - 10, corresponding to eq. (10)) and for foreign interest rates (rows 11 - 13, corresponding to eq. (11)).

Consider first the results in Table 2 for the U.S. dollar and the U.K. pound. The test results for the exchange rate Z-variables (rows 1 - 7) are very similar across columns (1) - (3) and across maturities. Out of 21 reported entries, only one marginal significance level is greater than 0.08. This is a rejection of the model's null-hypothesis for the dollar/pound exchange rate variables.

In the case of the term structure of interest rates,[16] rows 8 - 13, the test results are very sensitive to the particular specification of the information set that is adopted. When the information set includes logs of "short" and "long" returns known at time t, as in column (2), the null hypothesis is strongly rejected in almost all cases. However, to the extent that the information set includes only current and one-lag own values of the pertinent Z variable, as in column (1), or only the log forward premium, as in column (3), the results do not generally reject the null hypothesis. Given that short and long rates are public knowledge at time t, these results imply an overall rejection of the null hypothesis. That is, "short" and "long" returns have significant explanatory power in predicting future Z excess (interest rate) returns. These findings hold for all the maturities considered, and are consistent with available evidence, based on U. S. interest rates, against the "expectations theory" of the interest rates term structure.

The results for the U.S. dollar and deutschemark, reported in Table 3, can be compared to those of the U.S. dollar and the U.K. pound in Table 2. For the exchange rate Z-variables, the results in Table 3 differ from those in Table 2. Out of the 21 reported entries, only two have marginal significance levels less than 10%. In other words, the null hypothesis is generally not rejected for the dollar/deutschemark exchange rate. However, rows 8 - 13 indicate a rejection of the null hypothesis for the term structure of interest rates.

The spot/forward exchange rate results, rows 4 - 7, can be compared to the results by Hansen and Hodrick (1980, 1983) and Hodrick and Srivastava (1984). Although their investigations used somewhat different sample periods, data sets, and estimation methods, they tested orthogonality restrictions similar to those of this paper. In general, the present findings indicate nonrejection of the null hypothesis for the dollar/deutschemark rate and rejection for the dollar/pound rate. These results are in line with those reported by Hodrick and Srivastava (1984); yet they are at variance with the general pattern of findings reported by Hansen and Hodrick (1980, 1983). Specifically, the latter reject their null-hypothesis more frequently for the dollar/deutschemark rate than for the dollar/pound exchange rate. The extent to which these differences in findings can be accounted for by differences in sample periods, estimation techniques, information set specifications and other factors remains to be determined.

Are the results reported in Tables 2 and 3 sensitive to the choice of the sample period? To partially answer this question, the sample period was split at October 1979 and two subperiods were considered: June 1974 to September 1979 and October 1979 to March 1983. The results of this sample split are somewhat mixed, and are available from the authors upon request. For the group of exchange rate variables, the evidence in the pre-October 1979 sample is more supportive of the model's null hypothesis, in terms of generating slightly higher marginal significance levels, than that for the second subperiod. However, the marginal significance levels pertinent to the group of interest rate variables do not exhibit any clear patterns of variation across the two periods. Overall, then, it seems safe to provide a negative answer to the question above.

Tables 4 and 5 report the b_i parameter estimates for eqs. (13) - (15) for the entire sample period. Recall that marginal significance levels for these b_i's were given in columns (1) - (3) of Tables 2 and 3. Since the findings reported in column (2) of these tables characterized the general pattern of results, the discussion here focuses on the b_i estimates that correspond to this column. Several facts stand out in column (2) - Table 4. First, the parameter on the log of the "long" rate generally is not significantly different from 1.0. Second, the parameter on the log of the "short" rate is negative in all cases. In many of these cases, this parameter is not significantly different from -1.0. Perhaps these findings are not surprising given that in constructing the Z's, the "long" rate enters with a coefficient of 1.0 and "short" rates appear with coefficients of -1.0. However, notice that the dates on these rates generally differ across the dependent and explanatory variables in the regressions. Combining these findings yields, in some cases, additional interesting implications. As an example, consider the regression result for $Z(F)_{3t+3}$ (Table 4):

$$Z(F)_{3t+3} \equiv \log F_{3t+3} - \log F_{1t+3} = \underset{(.041)}{-.032} + \underset{(.343)}{.779} \log F_{3t+3} - \underset{(.338)}{.756} \log F_{1t+1} .$$

Since the coefficients on $\log F_{3t+3}$ and $-\log F_{1t+1}$ are insignificantly different from 1.0, and the constant is insignificantly different from zero, the above equation can be rearranged to yield

$$E_t \log F_{1t+3} = \log F_{1t+1} .$$

That is, the current one month forward rate is an unbiased (rational) predictor of the one month forward rate to be determined two months hence. Put differently, under rational expectations the above equality amounts to a restriction on the stochastic process followed by the "short" forward rate.

The results reported in Table 5 - column (2) are as follows. For interest rate variables, the parameter estimates have similar properties to those reported in the previous table. However, the exchange rate results show b_1 and b_2 coefficients that do not significantly differ from zero, a finding that differs from those of Table 4.

In a recent contribution, Fama (1983) has indicated how, under some assumptions, b_1 coefficients like those reported in column (3) of Tables 4 and 5 (which correspond to the log forward premium) can be used to split variation in a given forward rate into parts attributable to time variation in its two components: a premium and the expected future spot rate. Fama finds that these b_1's are greater than unity for exchange rate data, and are between zero and one for U. S. interest rates data. Interestingly, the results in Tables 4 and 5 are consistent with Fama's.

IV. Interpretations and Concluding Remarks

This paper investigated the time-series implications of an intertemporal asset pricing model for the term structure of exchange and interest rates. A key testable hypothesis derived from the model and a set of auxiliary assumptions is that the excess return from holding a long term asset relative to holding a sequence of short term assets is equal to a time invariant risk premium plus a rational forecast error.

The empirical work used Eurocurrency exchange and interest rate data. The reported findings for the term structure of exchange rates do not appear to be sensitive to whether this term structure is studied by focusing on the relation between short and long forward rates, or on the link between future spot rates and the pertinent forward rates. While tests' results indicate rejection of the model's null hypothesis for U.S. dollar/U.K. pound exchange rates, nonrejections were generally found for U.S. dollar/deutschemark rates. Regarding the term structure of interest rates, the results were less ambiguous, mostly indicating rejection of the null hypothesis. These rejections imply that exchange and interest rate information that is available to agents at a point in time can generally be used to predict future values of excess returns.

In interpreting these results, it is important to emphasize that the equations tested ((8) - (11)) represent a joint null-hypothesis consisting of:

(i) the model's first order conditions and their underlying assumptions (like constancy of the discount factor, and time separability of the utility function);

(ii) the assumption of rational expectations (under which information currently available cannot help predict future forecast errors);

(iii) the joint lognormality and stationarity distriubtional assumptions.

Rejections of the model may be due to violation of one or several of these assumptions in the sample information. For example the discount factor used by agents may be changing through time. There may also be time variation in the variances and covariances entering the risk premium term, thus giving rise to a time varying premium. In addition, in a world of changing policy and institutional regimes, a strict version of rational expectations (as the one applied here) need not hold. Unfortunately, it is not possible to use the present framework to detect the specific sources for rejections of the model.

The foregoing analysis enhances the interest on future work in at least two directions. First, from the standpoint of asset pricing theories the results reinforce the motivation for developing more general empirical specifications than those used above. In particular, incorporating some time variation in the risk premium may result in less frequent rejections of the null hypothesis. Second, it would be useful to quantitatively assess the risk/return tradeoffs that arise from using available economic information in order to predict future excess returns, and from taking portfolio positions on the basis of these predictions.[17]

Table 1: Sample Averages and Standard Deviations

1973-5 to 1983-3

Variable	U.S. Dollar	U.K. Pound	Deutschemark
R_{1t+1}	1.008	1.010	1.005
	(.003)	(.003)	(.002)
R_{3t+3}	1.025	1.031	1.016
	(.008)	(.007)	(.007)
R_{6t+6}	1.052	1.064	1.034
	(.017)	(.013)	(.013)
R_{12t+12}	1.105	1.130	1.070
	(.031)	(.024)	(.025)
S_t		2.058	.443
		(.274)	(.063)
F_{1t+1}		2.053	.445
		(.273)	(.063)
F_{3t+3}		2.044	.447
		(.271)	(.064)
F_{6t+6}		2.033	.451
		(.268)	(.066)
F_{12t+12}		2.011	.458
		(.264)	(.069)

Note: The first number reported is the sample average, while the number in parenthesis is the standard deviation.

Table 2: U.S. Dollar and U.K. Pound, 1974-6 to 1983-3

Row	Dependent Variable	Marginal Significance Level (1)	(2)	(3)
1	$Z(F)_{3t+3}$	.048	.067	.032
2	$Z(F)_{6t+6}$	.027	.045	.024
3	$Z(F)_{12t+12}$	.000	.001	.042
4	$Z(S)_{1t+1}$	.080	.051	.018
5	$Z(S)_{3t+3}$	.597	.046	.037
6	$Z(S)_{6t+6}$	.003	.041	.022
7	$Z(S)_{12t+12}$	.000	.000	.042
8	$Z(R)_{3t+3}$	.146	.001	.004
9	$Z(R)_{6t+6}$	.424	.003	.113
10	$Z(R)_{12t+12}$	.497	.003	.869
11	$Z(R^*)_{3t+3}$	.626	.108	.375
12	$Z(R^*)_{6t+6}$	.317	.004	.139
13	$Z(R^*)_{12t12}$	.558	.000	.713

Notes: Each entry gives the marginal significance level for testing $\underline{b}_i' = 0$ for a given regression. Let H be a chi-square distributed random variable and let h be the test statistic. The marginal significance level is then defined as Prob $(H > h)$ under the null hypothesis. Column (1) corresponds to eq. (13); column (2) to eq. (14); and column (3) to eq. (15).

Table 3: U.S. Dollar and Deutschemark 1974-6 to 1983-3

Row	Dependent Variable	Marginal Significance Level (1)	(2)	(3)
1	$Z(F)_{3t+3}$	.135	.272	.328
2	$Z(F)_{6t+6}$	.805	.202	.139
3	$Z(F)_{12t+12}$	.113	.295	.248
4	$Z(S)_{1t+1}$	.254	.166	.058
5	$Z(S)_{3t+3}$	.135	.219	.317
6	$Z(S)_{6t+6}$	.403	.232	.169
7	$Z(S)_{12t+12}$	.035	.250	.229
8	$Z(R)_{3t+3}$	.146	.001	.004
9	$Z(R)_{6t+6}$	.424	.003	.113
10	$Z(R)_{12t+12}$	.497	.003	.869
11	$Z(R^*)_{3t+3}$	.392	.009	.254
12	$Z(R^*)_{6t+6}$	.080	.002	.035
13	$Z(R^*)_{12t+12}$	.306	.000	.215

Notes: See Table 2.

Table 4: Parameter Estimates, U.S. Dollar and U.K. Pound, 1974-6 to 1983-3

Dependent Variable	(1) b_1	(1) b_2	(2) b_1	(2) b_2	(3) b_1
$Z(F)_{3t+3}$	.229*	-.087*	.779*	-.756*	1.460*
	(.094)	(.119)	(.343)	(.338)	(.680)
$Z(F)_{6t+6}$	.243*	.060*	.971*	-.899	1.796*
	(.188)	(.194)	(.410)	(.401)	(.795)
$Z(F)_{12t+12}$	.643*	-.380*	.913*	-.694*	1.729*
	(.203)	(.408)	(.423)	(.468)	(.850)
$Z(S)_{1t+1}$	.172*	.097*	1.045*	-1.038*	1.982*
	(.096)	(.081)	(.431)	(.427)	(.841)
$Z(S)_{3t+3}$	.073	.095	1.079	-1.037*	2.007*
	(.154)	(.142)	(.479)	(-.475)	(.964)
$Z(S)_{6t+6}$	.219*	.129*	1.073*	-.982*	2.002*
	(.163)	(.250)	(.454)	(.444)	(.876)
$Z(S)_{12t+12}$	.728*	-.480*	.962*	-.713*	1.833*
	(.222)	(.421)	(.445)	(.501)	(.902)
$Z(R)_{3t+3}$	.180	-.113	1.035*	-2.985*	.942*
	(.107)	(.101)	(.274)	(.774)	(.324)
$Z(R)_{6t+6}$	.020	-.185	1.108*	-5.988*	.754
	(.179)	(.146)	(.331)	(1.756)	(.476)
$Z(R)_{12t+12}$	.117	.069	1.053*	-10.485	.074
	(.243)	(.347)	(.329)	(3.651)	(.449)
$Z(R^*)_{3t+3}$	.017	.091	.388	-.954	.237
	(.109)	(.099)	(.242)	(.709)	(.267)
$Z(R^*)_{6t+6}$	.160	-.116	.559*	-2.360*	.465
	(.113)	(.163)	(.195)	(1.282)	(.315)
$Z(R^*)_{12t+12}$	-.077	-.103	.882*	-5.505*	.245
	(.223)	(.174)	(.159)	(2.301)	(.666)

Notes: Standard errors, corrected for serial correlation and robust to heteroscedasticity, are reported in parentheses. Columns labeled (1) - (3) correspond to columns (1) - (3) of Table 2. "*" denotes a marginal significance level less than 0.10 for the test $\underline{b} = 0$.

Table 5: Parameter Estimates, U.S. Dollar and Deutschemark, 1974-6 to 1983-3

Dependent Variable	(1) b_1	(1) b_2	(2) b_1	(2) b_2	(3) b_1
$Z(F)_{3t+3}$	.231	-.068	.809	-.696	1.000
	(.116)	(.123)	(2.090)	(2.128)	(1.023)
$Z(F)_{6t+6}$	.044	.049	1.422	-1.118	1.763
	(.251)	(.154)	(2.208)	(2.296)	(1.193)
$Z(F)_{12t+12}$	.197	.103	.031	.740	1.640
	(.263)	(.172)	(3.367)	(3.716)	(1.419)
$Z(S)_{1t+1}$	.130	.078	5.638	-5.630	3.091*
	(.101)	(.078)	(3.686)	(3.710)	(1.631)
$Z(S)_{3t+3}$	.274	-.237	.653	-.449	1.413
	(.164)	(.156)	(2.652)	(2.694)	(1.413)
$Z(S)_{6t+6}$	-.006	.173	1.156	-.758	1.960
	(.229)	(.173)	(2.739)	(2.839)	(1.424)
$Z(S)_{12t+12}$	.125*	.195*	.147	.702	1.863
	(.283)	(.206)	(3.745)	(4.132)	(1.548)
$Z(R)_{3t+3}$	.180	-.113	1.035*	-2.985*	.942*
	(.107)	(.101)	(.274)	(.774)	(.324)
$Z(R)_{6t+6}$	.020	-.185	1.108*	-5.988*	.754
	(.179)	(.146)	(.331)	(1.756)	(.476)
$Z(R)_{12t+12}$	.117	.069	1.053*	-10.485	.074
	(.243)	(.347)	(.329)	(3.651)	(.449)
$Z(R^*)_{3t+3}$	-.036	.193	.237*	-.621*	.201
	(.145)	(.150)	(.163)	(.511)	(.176)
$Z(R^*)_{6t+6}$	.369*	.025*	.653*	-3.620*	.710
	(.184)	(.128)	(.234)	(1.507)	(.336)
$Z(R^*)_{12t+12}$	.510	-.379	1.171*	-11.925*	.772
	(.332)	(.315)	(.305)	(3.747)	(.634)

Notes: See Table 4. Columns (1) - (3) here correspond to the same columns in Table 3.

Appendix 1

This appendix states the consumer's optimization problem that gives rise to first order conditions (1) - (3) discussed in the text.

Consumers are assumed to maximize

$$E_o \left[\sum_{t=o}^{\infty} \beta^t U(c_t) \right],$$

subject to the sequence of budget constraints:

$$P_t c_t + d_{1t} + d_{3t} + d_{6t} + d_{12t} + S_t(d^*_{1t} + d^*_{3t} + d^*_{6t} + d^*_{12t}) + v_t \leq$$

$$Y_t + R_{1t} d_{1t-1} + R_{3t} d_{3t-3} + R_{6t} d_{6t-6} + R_{12t} d_{12t-12} +$$

$$+ S_t(R^*_{1t} d^*_{1t-1} + R^*_{3t} d^*_{3t-3} + R^*_{6t} d^*_{6t-6} + R^*_{12t} d^*_{12t-12}) +$$

$$+ (S_t - F_{1t}) a_{1t-1} + (S_t - F_{3t}) a_{3t-3} + (S_t - F_{6t}) a_{6t-6} + (S_t - F_{12t}) a_{12t-12},$$

where the notation generally corresponds to that in the text, with the following additions:

d_{it} = the size of the i-months deposit, denominated in domestic currency units, made at time t,

d^*_{it} = the size of the i-months deposit, denominated in foreign currency units, made at time t,

a_{it} = the size of the i-months forward purchase of foreign exchange, contracted at time t in foreign currency units,

Y_t = nominal income from labor and from assets other than d, d*, and a,

v_t = investment made at time t in assets other than d, d*, and a.

Equations (1) - (3) correspond to optimal choice of contingency plans for the sequences $\{a_{it}\}$, $\{d_{it}\}$, and $\{d^*_{it}\}$ respectively.

Appendix 2

This appendix briefly discusses the construction of the variance-covariance matrix used in the statistical tests. Consider the following regression

$$(A1) \qquad Y = X\beta + u,$$

where Y is $T \times 1$, X is $T \times k$, β is $k \times 1$, and u is $T \times 1$. Assume u is MA(P) and heteroscedastic. Let $\hat{\beta}$ denote the OLS estimate of β and let $\hat{u} = Y - X\hat{\beta}$. Define

$$(A2) \qquad (X'\hat{\Omega}X) = \sum_{\ell=-p}^{p} \hat{u}_t X_t' X_{t-\ell} \hat{u}_{t-\ell}' .$$

A consistent variance-covariance matrix for $\hat{\beta}$ is given by

$$(A3) \qquad (X'X)^{-1}(X'\hat{\Omega}X)(X'X)^{-1}.$$

This matrix is robust to heteroscedasticity of unknown form and corrects for the p-th order moving average error [see White (1980) and Hansen (1982)].

FOOTNOTES

[1]See Porter (1971) and Hakkio (1981).

[2]On uncovered interest parity, see Cumby and Obstfeld (1981), as well as the surveys by Adler and Dumas (1983) and Levich (1983). A selective list of empirical studies on the "expectations hypothesis" is provided by Kane (1983) and Shiller, Campbell, and Schoenholtz (1983).

[3]For recent term structure applications of variants of this model, see Dunn and Singleton (1983), Marsh (1983), and Leiderman and Blejer (1984). For a general approach for testing the implications of asset pricing models, see Hansen and Richard (1984).

[4]Although this definition of "domestic" and "foreign" is arbitrary, it has no effect on the empirical analysis that follows.

[5]This condition has been used in previous empirical studies by Frenkel and Razin (1980), Hansen and Hodrick (1983), and Hodrick and Srivastava (1984).

[6]Empirical applications of versions of eq. (2) to asset pricing are provided by Grossman and Shiller (1981) and Hansen and Singleton (1983).

[7]For recent empirical work on the relation between forward and expected future spot exchange rates, see e.g. Hansen and Hodrick (1980, 1983), Domowitz and Hakkio (1983), Hodrick and Srivastava (1984), and references therein. Some of the theoretical and empirical literature along these lines has been reviewed by Adler and Dumas (1983) and Levich (1983); see also references therein.

[8]Cox, Ingersoll, and Ross (1978, 1981) and Leroy (1982) give theoretical analyses of this and other term structure hypotheses.

[9]See Santomero (1975) for an earlier study of the term structure of Eurodollar interest rates.

[10]Notice that in the present case there are 13 Z-variables. For a complete list, see the "Dependent Variable" column of Table 2.

[11]This interpretation of K assumes a nonzero degree of risk aversion. In the case of risk neutrality, K captures a Jensen inequality term that need not be equal to zero. For a similar point in connection with eq. (5), see Frenkel and Razin (1980).

[12]This may result in a (hopefully minor) misalignment of the data.

[13]For example, $\mu(R)_{3t+3}$ is MA of order 1.

[14]See also Cumby, Huizinga, and Obstfeld (1983); the present equations can be interpreted as a special case of their analysis.

[15]Using the notation in the text, the fourth information set was the entire set of Z-variables dated t; that is, $\{Z(F)_{it}, Z(S)_{jt}, Z(R)_{it}, Z(R^*)_{it};$ $i = 3, 6, 12$ and $j = 1, 3, 6, 12\}$. Testing $b_1 = \ldots = b_{13} = 0$ in eq. (12) led to some computational difficulties. The estimated covariance matrix (under the assumption of heteroscedastic errors) was not positive definite. Two corrections were undertaken. First, non-zero lags in eq. (A2) of Appendix 2 were "damped" (that is, giving less weight to the lagged terms). The second correction assumed that the errors were homoscedastic. In general, the null hypothesis is rejected under the first correction and accepted under the second correction. The results are available from the authors.

[16]Notice that, by construction, the results in rows 8-10 are identical across Tables 2 and 3. They correspond to the term structure of U.S. dollar interest rates.

[17]For recent work on spot/forward foreign exchange speculation, along these lines, see Bilson and Hsieh (1983) and Hodrick and Srivastava (1984).

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