International Finance Discussion Papers

Number 312

September 1987

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ABSTRACT

This paper addresses the question: do risk premia account for the observed time-varying discrepancies between forward and corresponding future spot exchange rates? A simple theoretical framework is used to derive testable restrictions on the parameters of a multivariate regression model. Using various econometric procedures and different estimation periods, the data reject the restrictions. In contrast to past investigations, the empirical results are inconsistent with a world in which time-varying risk premia are the sole determinants of observed deviations from the unbiased expectations hypothesis. Anticipated real exchange rate movements may explain the rejection.

The Pricing of Forward Exchange Rates

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Ross Levine[1]

Although an expanding empirical literature finds that forward exchange rates systematically differ from corresponding future spot prices, the source of this bias has not been convincingly identified. Frankel and Froot (1987) argue that agents systematically make mistakes in predicting exchange rates, and reject rational expectations. Krasker (1980), Lewis (1986) and Obstfeld (1987) suggest that even if expectations are fully rational ex ante, exchange rate forecasts may appear biased and serially correlated in the ex post sample if there is the possibility of a major policy change.[2] The most frequently advanced and thoroughly studied theoretical explanation for the observed discrepancies between forward and future spot exchange rates is the risk premia hypothesis. Empirical support for the risk premia hypothesis, however, is inconclusive.[3]

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1. The author is a staff economist in the International Finance Division. This paper represents the views of the author and should not be interpreted as reflecting those of the Board of Governors of the Federal Reserve System or other members of its staff. I have benefited from the comments of Maria Carkovic, Michael Darby, Sebastian Edwards, Edward Leamer, and workshop participants at the Board of Governors, Johns Hopkins University, the Kellogg Graduate School of Management, and the Wharton Finance Department.

2. This explanation is called the "peso problem" because there was a long time interval before the actual Mexican peso devaluation where an expectation of a devaluation persisted, and the forward exchange rate consistently undervalued the peso.

3. See Levich's (1985) review of the literature.

This paper uses an approach developed and implemented by Korajczyk (1985) to examine the validity of the risk premia hypothesis. This approach tests the predictions of a wide class of international asset pricing models concerning forward exchange rates. In particular, a diverse set of asset pricing paradigms [see Kouri (1977), Lucas (1982), and Solnik (1983), for example] predicts that forecastable deviations between forward and future spot exchange rates equal expected real return differentials on default free nominal bonds, where real returns are evaluated in the currency of issuance. This prediction imposes testable restrictions on the parameters of a multivariate regression system. In examining these restrictions, this paper tests whether the data are consistent with a world in which only time-varying risk premia on nominally riskless bonds explain the deviations between forward and future spot exchange rates. Although the tests performed in this paper are not tests of a particular asset pricing model, they do test the implications of a broad class of asset pricing models.

Korajczyk (1985) cannot reject the hypothesis that risk premia cause the observed deviations between forward and future spot prices. He, however, uses incorrectly matched forward and future spot exchange rate data which lead to unwarranted econometric procedures. More importantly, Korajczyk fails to test an important restriction suggested by theory and past research into the pricing of forward exchange rates. Using a number of econometric procedures and different estimation periods, the data reject this restriction and reverse Korajczyk's conclusion.

After deriving the testable restrictions and discussing the estimation methodology in Section I, Section II describes the data and presents the empirical results. Although ex ante real interest rate differentials are often significant explanatory variables of ex post differences between forward and future spot prices, the empirical results are inconsistent with a world in which only time-varying risk premia on default free bonds explain the forward exchange rate bias. Anticipated real exchange rate movements may explain this conclusion. Section III summarizes the results and suggests future research endeavors.

I. The Unbiased Expectations Hypothesis and Expected Real Interest Rates

The unbiased expectations hypothesis (UEH) states that the forward exchange rate equals the market prediction of the future spot exchange rate. In logarithmic form this suggests that

<1> $$E(s_{t+1} - f_t | \phi_t) = 0,$$

where

s_{t+1} is the logarithm of the spot exchange rate at time t+1 expressed, for example, in dollars per foreign currency;

f_t is the logarithm of the forward exchange rate set at time t, payable at t+1, and also expressed in dollars per foreign currency;

ϕ_t is the information set available at time t; and

E(.) is the expected value operator.

This UEH implies that information available at the time the forward contract is set should not be useful in explaining ex post discrepancies between forward and corresponding future spot exchange rates. This hypothesis can be tested by analyzing whether or not $\boldsymbol{\beta} = \mathbf{0}$ in the regression equation:

<2> $$\tilde{s}_{t+1} - f_t = X_t\boldsymbol{\beta} + \epsilon_{t+1},$$

where $E(\epsilon_{t+1}) = 0$, X_t is a subset of ϕ_t, and a tilde indicates a random variable at time t. The hypothesis that $\boldsymbol{\beta} = \mathbf{0}$ has been rejected by many authors [see, for example, Hansen and Hodrick 1980, 1983 and Hodrick and Srivastava 1984] using elements of X_t such as the forward premium, $f_t - s_t$, and lagged values of the forward rate forecast error, $s_t - f_{t-1}$. As discussed above, identifying the source of this rejection has proved difficult. In order to resolve this interpretational problem, I combine the Covered Interest Rate Parity (CIRP) condition, the Fisher equation, and the assumptions of rational expectations and ex ante relative purchasing power parity to derive an estimable expression for $E(s_{t+1} - f_t|\phi_t)$ which is fully consistent with the asset pricing models listed above. CIRP states that

<3> $$R_{t+1} = R^*_{t+1} + f_t - s_t$$

where R_{t+1} = the continuously compounded yield on a 1-period nominally riskless bond denominated in (for example) dollars (from t to t+1); and

R^*_{t+1} = the continuously compounded yield on a foreign (denominated) 1-period nominally riskless bond (from t to t+1).

The CIRP condition merely states that two nominally riskless investments must have the same nominal rate of return when evaluated in the same currency. If CIRP did not hold, profitable arbitrage opportunities would exist. Frenkel and Levitch (1977) and McCormick (1979) present empirical support for the CIRP condition.

The nominal exchange rate may be expressed as

$$\langle 4\rangle \qquad s_t = p_t - p_t^* + d_t,$$

where p_t is the logarithm of the U.S. price level, p_t^* is the logarithm of the foreign price level, and d_t is the logarithm of the deviation from PPP at time t. d_t may be referred to as the logarithm of the real exchange rate because it represents the logarithm of the relative price of a bundle of U.S. goods for a bundle of foreign goods. Since this relative price may change intertemporally, the real return on the same nominally riskless asset may differ when evaluated in different currencies.

Combining equations <3> and <4> we obtain an expression for the ex post difference between $\tilde{s}_{t+1}$ and f_t:

$$\langle 5\rangle \qquad \tilde{s}_{t+1} - f_t = \tilde{I}_{t+1} - \tilde{I}_{t+1}^* + \tilde{d}_{t+1} - d_t - (R_{t+1} - R_{t+1}^*),$$

where $\tilde{I}_{t+1}$ is the domestic inflation rate from period t to t+1 and $\tilde{I}_{t+1}^*$ is the corresponding foreign inflation rate.

This expression can be simplified by using the Fisher equation which expresses nominal yields (on nominally riskless bonds) as the summation of expected real returns and expected inflation:

<6a> $$R_{t+1} = E(\tilde{r}_{t+1}|\phi_t) + E(\tilde{I}_{t+1}|\phi_t)$$

<6b> $$R^*_{t+1} = E(\tilde{r}^*_{t+1}|\phi_t) + E(\tilde{I}^*_{t+1}|\phi_t),$$

where $\tilde{r}_{t+1}$ is the real return on a nominally riskless bond maturing at time t+1. Equation <6a[b]> defines the expected real return on U.S. [foreign] bonds, where the real value is evaluated in dollars [foreign currency]. It is important to notice that the expected real return on a foreign bond held by a foreign resident may differ from the expected real return on a foreign bond held by a U.S. resident because of anticipated real exchange rate changes. For example, if $E(\tilde{r}^*_{t+1}) = E(\tilde{r}_{t+1})$, then a U.S. resident would expect a higher yield from holding foreign bonds than from holding U.S. bonds if the dollar's real value is expected to depreciate.[4]

Darby (1975) shows how the Fisher equations should be modified to incorporate the effect of taxes. The "Darby effect" would add an additional term to each equation. For simplicity, this effect is ignored in the theoretical presentation; however, it is considered in the empirical estimation.

Combining equations <5>, <6a>, <6b> and assuming rational expectations, the expected deviation of $\tilde{s}_{t+1}$ from f_t, conditional on ϕ_t, is

<7> $$E[(\tilde{s}_{t+1} - f_t)|\phi_t] = E[(\tilde{r}^*_{t+1} - \tilde{r}_{t+1})|\phi_t] + E[(\tilde{d}_{t+1} - d_t)|\phi_t].$$

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4. Notice that implicit in this discussion is a definition of residency. A U.S. resident is someone who purchases his goods in the U.S. and deflates nominal returns by the U.S. price level.

The CIRP condition merely states that two nominally riskless investments must have the same nominal rate of return when evaluated in the same currency. If CIRP did not hold, profitable arbitrage opportunities would exist. Frenkel and Levitch (1977) and McCormick (1979) present empirical support for the CIRP condition.

The nominal exchange rate may be expressed as

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where $\tilde{I}_{t+1}$ is the domestic inflation rate from period t to t+1 and $\tilde{I}_{t+1}^*$ is the corresponding foreign inflation rate.

This expression can be simplified by using the Fisher equation which expresses nominal yields (on nominally riskless bonds) as the summation of expected real returns and expected inflation:

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<6b> $$R^*_{t+1} = E(\tilde{r}^*_{t+1}|\phi_t) + E(\tilde{I}^*_{t+1}|\phi_t),$$

where $\tilde{r}_{t+1}$ is the real return on a nominally riskless bond maturing at time t+1. Equation <6a[b]> defines the expected real return on U.S. [foreign] bonds, where the real value is evaluated in dollars [foreign currency]. It is important to notice that the expected real return on a foreign bond held by a foreign resident may differ from the expected real return on a foreign bond held by a U.S. resident because of anticipated real exchange rate changes. For example, if $E(\tilde{r}^*_{t+1}) = E(\tilde{r}_{t+1})$, then a U.S. resident would expect a higher yield from holding foreign bonds than from holding U.S. bonds if the dollar's real value is expected to depreciate.[4]

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Combining equations <5>, <6a>, <6b> and assuming rational expectations, the expected deviation of $\tilde{s}_{t+1}$ from f_t, conditional on ϕ_t, is

<7> $$E[(\tilde{s}_{t+1} - f_t)|\phi_t] = E[(\tilde{r}^*_{t+1} - \tilde{r}_{t+1})|\phi_t] + E[(\tilde{d}_{t+1} - d_t)|\phi_t].$$

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4. Notice that implicit in this discussion is a definition of residency. A U.S. resident is someone who purchases his goods in the U.S. and deflates nominal returns by the U.S. price level.

Equation <7> demonstrates that forward exchange rates are not unbiased predictors of future spot exchange rate unless (i) expected real returns on nominally riskless bonds are equal across currencies and (ii) the expected rate of change in the real exchange rate is zero.[5]

Since a forward foreign exchange contract is an agreement to exchange the future payoffs on nominal bonds denominated in the currencies of two countries, any factors affecting the expected real value of these bonds will be incorporated into forward prices. When real returns are evaluated in the currency of issuance, expected real returns on nominally riskless assets may differ if the two currencies have different price level risks. Thus, if country price levels have different stochastic properties and agents are risk averse, bonds will be priced to reflect those differences, and the forward exchange rate will not equal the expected future spot price. Empirical evidence suggests that ex ante real interest rates are not equal internationally [See: Mishkin 1984; Huizinga and Mishkin 1984; and Merrick and Saunders 1986]. Therefore, we should not expect the UEH to hold.

Condition (ii) implies that ex ante real returns are independent of residence, although ex post real returns on the same asset may differ

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5. As Korajczyk points out, the forward forecast error would also equal zero if the expected real return differential and expected rate of change in the real exchange rate are perfectly negatively correlated. This would be the case, for example, under a fixed exchange rate regime where the the probability of adjustment is zero. Since the empirical investigation will cover the floating exchange rate period, it is unlikely that $E[\tilde{r}^*_{t+1} - \tilde{r}_{t+1}]$ will equal $-E[\tilde{d}_{t+1} - d_t]$ for all t.

internationally.[6] When there are non-zero expected real exchange rate movements, expected real returns on nominally riskless bonds depend upon the currency in which real returns are evaluated. Consequently, anticipated real exchange rate movements affect the expected real value of default free bonds and will be reflected in forward exchange rates. This implies that forward exchange rates will not equal the market's prediction of future spot rates when there are anticipated real exchange rate movements.

Empirical evidence concerning condition (ii) is inconclusive. Although it is clear that exact PPP does not hold (i.e., $d_t = 0$, for all t), the evidence regarding Roll's (1979) "efficient market version of PPP" (i.e., $E[\tilde{d}_{t+1} - d_t] = 0$) is mixed.[7] The tests performed in this paper are designed to determine the relative importance of anticipated real exchange rate movements and expected real return differentials as explanations of the time-varying forward exchange rate bias.

Assuming that $E[(\tilde{d}_{t+1} - d_t)|\phi_t] = 0$, one obtains:

$$\text{<8>} \qquad E[(\tilde{s}_{t+1} - f_t)|X_t] = E[(\tilde{r}^*_{t+1} - \tilde{r}_{t+1})|X_t],$$

where X_t is a subset of ϕ_t. Equation <8> implies that the forecastable difference between $\tilde{s}_{t+1}$ and f_t <u>equals</u> the expected real return differential

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6. Condition (ii) does not rule out stochastic real exchange rates from entering the pricing of assets, even if the expected rate of change in the real exchange rate is zero. See Levine (1986).

7. Kravis and Lipsey (1978) and Isard (1977) show that exact PPP does not hold. Darby (1980), Cumby and Obstfeld (1984), Adler and Lehman (1983), Officer (1984), and Hsieh (1982) present conflicting evidence on the question of whether Roll's efficient market version of PPP holds.

on default free nominal bonds deflated by their home currency price levels. This equation is similar to the expression for foreign exchange market risk premia derived by Kouri (1979), Lucas (1982), Stulz (1981), and Solnik (1983). These models, however, explicitly characterize the term $E[(\tilde{r}^*_{t+1} - \tilde{r}_{t+1})|X_t]$.

Assuming that $E[(\tilde{r}^*_{t+1} - \tilde{r}_{t+1})|X_t]$ is observable, the following regression equation is testable:

$$\langle 9\rangle \qquad \tilde{s}_{t+1} - f_t = \theta_0 + \theta_1 E[(\tilde{r}^*_{t+1} - \tilde{r}_{t+1})|X_t] + \theta_2 Z_t + \eta_{t+1},$$

Z_t is a subset of X_t. The theory suggests that $\theta_0 = \theta_2 = 0$ and $\theta_1 = 1$. The variable Z_t is added in order to incorporate an additional testable implication from equation <8>. Information available at time t should not systematically explain the ex post difference between forward and future spot rates beyond the information's ability to predict real return differentials. Consequently, theory predicts that variables which have been shown to be statistically significant explanatory variables of the forward exchange rate bias should enter <u>insignificantly</u> once $E[(\tilde{r}^*_{t+1} - \tilde{r}_{t+1})|X_t]$ is included. Rejection of any of these restrictions would constitute evidence against the null hypothesis that risk premia on nominally riskless bonds are the only source of bias in the forward exchange market. Assuming rational expectations, rejection of the null hypothesis supports the notion that anticipated real exchange rate changes are an <u>important</u> cause of the observed discrepancies between forward and future spot prices.

Since $E[(\tilde{r}^*_{t+1} - \tilde{r}_{t+1})|X_t]$ is unobservable, proxies must be used. Wickens (1982) demonstrates that consistent and asymptotically efficient parameter estimates may be obtained using instrumental variables techniques in which expected variables are replaced by their realized values, exogenous variables are used as instruments, and the model is estimated jointly treating the auxiliary equations describing expectations formation as part of the system. Consequently, three stage least squares (3SLS) is used to obtain consistent and asymptotically efficient estimates of $\boldsymbol{\delta}$:

$$\langle 10\rangle \qquad \tilde{s}_{t+1} - f_t = \delta_0 + \delta_1(\tilde{r}^*_{t+1} - \tilde{r}_{t+1}) + \delta_2 Z_t + \xi_{t+1},$$

$$\tilde{r}^*_{t+1} - \tilde{r}_{t+1} = \boldsymbol{\gamma} Y_t + e_{t+1},$$

where Y_t is the set of instrumental variables used to predict real interest rate differences, and e_{t+1} is a white noise error term. Although the implications drawn from using the instrumental variables methodology are contingent upon the instruments containing the information sets employed by economic agents in forming expectations, Wickens (1982) demonstrates that even if a subset of agents' information sets is used to construct expectations in the first stage regressions, the 3SLS estimator will remain consistent though not asymptotically efficient. The instruments are described below.

II. Estimation

II.A. The Data

Daily observations on spot exchange rates, 1-month forward exchange rates, and 1-month Eurocurrency interest rates were obtained from Data Resources Incorporated. The ten countries in the sample are the United States, Belgium, Canada, France, Italy, Japan, the Netherlands, Switzerland, the United Kingdom, and West Germany. The data cover the period July 1973 through April 1986 for most time series. Eurocurrency interest rate data for Belgium, Canada, Italy, and Japan, however, do not begin until January 1981. Monthly observations of the consumer price index (CPI) are used to construct inflation series, and are obtained from the International Monetary Fund's IFS tape (line 64).

Past investigations into the nature of the forward exchange rate bias have typically matched forward exchange rates sampled on the last Friday of the month with spot exchange rate sampled on the last Friday of the following month to obtain the forward forecast error, or forward rate bias, $s_{t+1} - f_t$. This is not, however, the way the foreign exchange market matches forward and corresponding future spot exchange rates.

In order to correctly match forward and future spot exchange rates, it is important to understand the mechanics of the spot exchange market. It takes two working days to settle a spot contract. Thus, a spot contract written on contract day Thursday, March 25 is for settlement on the spot value day Monday, March 29. A forward contract written on contract day Thursday, March 25 is dated in the following manner. First, find the spot value date (Monday, March 29) corresponding to the contract date (Thursday, March 25). Second, go one month forward from the spot value date. If April 29 is a working day then April 29 is the future value date. If, however, April 29 is a holiday in either country then go forward until the first working day is found in order to identify the future value day. If, however, by going forward from April 29 we go into the next month, then go backward from April 29 until the first working day is identified in order to find the future value date. The future value day is the day on which the one-month forward contract written on March 25 is settled. Note, however, that the future value day is <u>not</u> the date of the expected future spot rate corresponding to the forward contract. The reason is that it takes two working days to clear spot transactions. Therefore, to find the corresponding future spot exchange rate, the day two working days before the future value day must be chosen. This paper uses correctly matched data.

II.B. Small Sample Properties and Regression Residuals

Korajczyk estimates equation <10> using data from 1973 through 1980 for eight currencies paired with the U.S. dollar. He points out that there may be reasons for concern regarding the distribution of various test statistics because of small sample size and possible deviations from normality in the regression residuals. Using incorrectly matched forward and future spot prices, Korajczyk presents evidence that the regression residuals have distributions significantly different from the normal distribution. This induces Korajczyk to construct alternative test statistic distributions using a bootstrap procedure. These constructed distributions yield different results from those implied by the test statistics' asymptotic distributions. When correctly matched data are used, the Kolmogorov-Smirnov test does not reject the hypothesis of normally distributed regression residuals. Moreover, even with the degrees of freedom corrections suggested by Box and Watson (1962) for hypothesis testing when regression residuals are not normally distributed, or using the χ^2- distribution when conducting cross equation tests as recommended by Judge et al. (1980), this paper's conclusions are unchanged.

Even if the regression errors are normally distributed, we know only the asymptotic distribution of the test statistics in the 3SLS models when the variance-covariance matrix is estimated. For this reason Korajczyk uses Monte Carlo simulations to construct alternative test statistic distributions. Again, these alternative distributions yield different conclusions from those implied by the statistics' asymptotic distributions.

There are, however, important problems with using Monte Carlo simulations to construct alternative distributions. "Monte Carlo studies in econometrics often have been criticized for imprecision present in estimating the underlying finite sample properties investigated and for the specificity of the results from the particular parameter values and sample sizes chosen, so making any conclusions very tentative at best." (Ericsson 1984, p. 691) In simultaneous systems there is the additional problem that Monte Carlo techniques typically assume that the regressors are exogenous. In the Monte Carlo procedure, a new set of regressors is constructed by sampling from a normal distribution and adding these errors to the regressors whose coefficients are given by the null hypothesis. "If the regressors are merely predetermined endogenous variables, such a technique does not generate new future right-hand-side variables whose values would be simultaneously determined with realizations of the current errors." (Hodrick and Srivastava 1986, p.31) These problems make suspect Korajczyk's conclusions based on Monte Carlo simulations.[8]

II.C. Ex Ante Real Interest Rates and the Forward Bias

This subsection tests whether the data are consistent with a world in which the only source of bias in forward exchange rates arises from risk premia on Eurocurrency bonds. Assuming (i) rational expectations and (ii) $E[(\tilde{d}_{t+1} - d_t)|\phi_t] = 0$, Section I defined the null hypothesis, and described the 3SLS estimation procedure. The instrumental variables for predicting real interest rate differentials are the same as those used by Korajczyk and are chosen on the basis of their documented ability to predict future real interest rates. The instruments are : (1) a constant; (2) the average real return differential over the preceding twelve months; (3) the lagged difference in the inflation rates between the U.S. and the foreign country;

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8. In addition to increasing the sample size from 88 to 149 observations, which may reduce small sample problems, this study constructed alternative test statistic distributions based on Monte Carlo simulations. Although these results are not presented because of the problems discussed in the text, it is important to note that while conclusions concerning specific parameter values based on the Monte Carlo distributions are different from those based on the asymptotic distributions, this paper's null hypothesis is rejected using either distribution.

(4) a proxy for nominal interest rate variability;[9] (5) the lagged value of the real return differential; and (6) the forward premium at time t. Instrument two was chosen because Fama and Gibbons (1982) demonstrate that it explains U.S. real interest rates (as an approximation to an ARIMA [0,1,1]). Instruments three and six were included since Mishkin (1984) shows that they are significant explanatory variables of real interest rate differentials. Instrument four was added because nominal interest rate volatility explains risk premia in the U.S. Treasury bill market [Fama 1976]. Since I could obtain appropriate data for the time period April 1974 through December 1985 for only the United States, the United Kingdom, West Germany, France, Switzerland, and the Netherlands, my sample uses these five currencies paired with the U.S. dollar. Beginning in 1981, the data set also has relevant figures for Belgium, Canada, Italy, and Japan. As will be demonstrated below, using these additional countries over the shorter time period does not alter the results.

The unadjusted R^2 statistics for the first stage regressions of the real return differential on the instrument set range from .24 to .49, and the mean is .38 (over the period April 1974 - December 1985). Only for the United Kingdom do the data not reject the hypothesis that all non-intercept parameters are zero.

Table 1 gives unrestricted 3SLS estimates of equation <10> without Z_t. For four out of the five currencies the slope coefficient is significantly different from zero at a .05 significance level. More

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9. Korajczyk uses the difference between the sample standard deviations of nominal interest rates over the preceding 26 weeks. Since I have daily observations, I use the difference between the sample standard deviations on one-month interest rates (with daily observations) over the preceding month as a measure of nominal interest rate variability.

TABLE 1

UNRESTRICTED 3SLS

$$s_{t+1} - f_t = \delta_0 + \delta_1(\tilde{r}^*_{t+1} - \tilde{r}_{t+1}) + \epsilon_{t+1}$$

A. Estimates

Country	δ_0	δ_1	$F(\delta_0=0, \delta_1=1)$	D.W.
NE	-.001 (.003)	1.45* (.20)	2.39	2.11
UK	.002 (.003)	2.23* (.59)	2.09	1.92
FR	-.001 (.003)	1.49* (.46)	0.55	2.19
WG	-.001 (.002)	1.28* (.29)	0.56	2.07
SW	.000 (.004)	1.06 (1.29)	.01	1.99

B. System Tests

Test	F	P-Value
$\delta_0 = 0$; all equations	.43	.71
δ_1: equal across equations	.52	.72
$\delta_1 = 1$; all equations	1.78	.11
$\delta_0 = 0$, $\delta_1 = 1$; all equations	1.02	.42

Weighted R^2 = .24 April 1974 - December 1985

Note: Standard errors in parentheses. $F(\delta_0 = 0, \delta_1 = 1)$ represents the F-statistic for the null hypothesis for $\delta_0 = 0$ and $\delta_1 = 1$.

*Significantly different from the null at the .05 level.

importantly in no individual country is the null hypothesis that $\delta_0 = 0$ and $\delta_1 = 1$ rejected. The test statistics for joint hypotheses across equations are provided in part B of the table. The four tests in Table 1 are: (1) the constant term is zero in all equations; (2) the slope coefficients are equal across equations; (3) all the slope coefficients equal one; and (4) the intercepts are zero and the slope parameters equal one for all cross sections. None of these joint system tests is rejected by the data at the .05 significance level.

Using the Kolmogorov-Smirnov normality test, one cannot reject the null hypothesis of normally distributed regression residuals. The largest Kolmogorov-Smirnov statistic of the five equations is .09 with most falling below .07. These statistics do not reject normality at a .05 significance level [See Powell 1982].

Although real interest rate differentials explain only 18 percent of the intertemporal variation in the forward forecast error, the results presented in Table 1 are consistent with a world in which the risk premia on Eurocurrency bonds are the sole determinant of expected deviations between forward and future spot exchange rates.

If, however, risk premia on default free nominal bonds are the cause of the forward bias, information available at the signing of the forward contract should not systematically explain the forward forecast error beyond the information's usefulness in predicting real interest rate differentials. Consequently, even variables which have been shown to significantly explain the forward forecast error should enter insignificantly once the real return differential is incorporated. Lagged values of the forward forecast error, $s_t - f_{t-1}$, and the forward premium, $f_t - s_t$ are two elements of the information set available at the setting of the forward price which have traditionally been used in studying the UEH. Korajczyk considers lagged values of the dependent variable but not the forward premium. This turns out to have important implications.

The results from estimating equation <10> where $Z_t = s_t - f_{t-1}$ are presented in Table 2. For no individual country is Z_t significantly different from zero, and only for the United Kingdom, do the data reject the null hypothesis that $\delta_0 = 0$, $\delta_1 = 1$, and $\delta_2 = 0$. In addition, the coefficient on the real return differential is significantly different from zero in four out of the five currencies considered. The system tests tell a similar story. Although inclusion of lagged forecast errors results in rejection of the joint hypothesis that the real return differential coefficients are one for all cross sections, the hypothesis that $\delta_0 = 0$, $\delta_1 = 1$, and $\delta_2 = 0$ for all currencies is not rejected. Table 2 shows that $(s_t - f_{t-1})$ has little explanatory power beyond its influence through real return differentials.

Table 3, however, tells a different story. Table 3 gives the results from estimating equation <10> with Z_t set equal to the forward premium $(f_t - s_t)$. The results strongly reject the hypothesis that Z_t enters with a zero coefficient. For all five currencies δ_2 is significantly different from zero and the data reject the hypothesis that $\delta_0 = 0$, $\delta_1 = 1$, and $\delta_2 = 0$ for each individual currency. In addition, once the forward premium is included, the slope coefficient on the real return differential is no longer significant for the Netherlands. The system tests also strongly reject the hypothesis that information available at the signing of the forward contract is **only** useful in explaining the forward exchange rate bias to the extent that that information is useful in forecasting real return differentials. Neither of the models, whose

TABLE 2

UNRESTRICTED 3SLS

$$s_{t+1} - f_t = \delta_0 + \delta_1(\tilde{r}^*_{t+1} - \tilde{r}_{t+1}) + \delta_2(s_t - f_{t-1}) + \epsilon_{t+1}$$

A. Estimates

Country	δ_0	δ_1	δ_2	$F(\delta_0=0, \delta_1=1, \delta_2=0)$	D.W.
NE	-.001 (.003)	1.36* (.21)	.09 (.05)	2.30	2.27
UK	.003 (.003)	2.60* (.56)	.07 (.07)	3.12*	2.02
FR	-.000 (.003)	1.68* (.46)	.02 (.05)	0.85	2.25
WG	-.001 (.003)	1.72* (.32)	.05 (.05)	2.23	2.19
SW	.000 (.004)	1.24 (.77)	.03 (.06)	.17	2.07

B. System Tests

Test	F	P-Value
$\delta_0 = 0$; all equations	.39	.71
$\delta_2 = 0$; all equations	1.00	.42
$\delta_1 = 1$; all equations	2.90	.01
$\delta_0=0$, $\delta_1=1$, $\delta_2=0$ all equations	.44	.82

Weighted $R^2 = .26$ April 1974 - December 1985

See note in Table 1.

TABLE 3

UNRESTRICTED 3SLS

$$s_{t+1} - f_t = \delta_0 + \delta_1(\tilde{r}^*_{t+1} - \tilde{r}_{t+1}) + \delta_2(f_t - s_t) + \epsilon_{t+1}$$

A. Estimates

Country	δ_0	δ_1	δ_2	$F(\delta_0=0, \delta_1=1, \delta_2=0)$	D.W.
NE	.002	.40	-1.76^*	11.9^*	2.12
	(.002)	(.23)	(.30)		
UK	-.002	2.15^*	-2.30^*	5.13^*	2.02
	(.003)	(.54)	(.70)		
FR	.003	2.95^*	1.33^*	2.75^*	2.14
	(.003)	(.69)	(.55)		
WG	.002	$.75^*$	-1.25^*	2.58	2.08
	(.003)	(.33)	(.47)		
SW	$.013^*$	-.78	-3.36^*	5.53^*	1.94
	(.005)	(.78)	(.82)		

B. System Tests

Test	F	P-Value
$\delta_0 = 0$; all equations	2.20	.05
$\delta_2 = 0$; all equations	12.00	.000
$\delta_1 = 1$; all equations	5.59	.000
$\delta_0=0$, $\delta_1=1$, $\delta_2=0$ all equations	7.17	.000

Weighted R^2 = .24 April 1974 - December 1985

See Note in Table 1.

results are presented in Tables 2 and 3, exhibits significant departures from the assumption of normally distributed regression residuals.

Taken together, Tables 1 - 3 demonstrate that risk premia on Eurocurrency bonds are incorporated into forward exchange rates. The data also suggest that risk premia on Eurocurrency bonds are not the only systematic component of the forward rate forecast errors. Past information is useful in explaining the time-varying discrepancy between forward and future spot exchange rates beyond that information's usefulness in predicting real return differentials.

II.D. Interest Rates, The Forward Bias, and Different Time Periods

As discussed above, Korajczyk conducts a similar study over the period April 1974 through December 1980. For completeness, Tables 4 - 6 present the 3SLS estimates and system tests for this period. None of these equations has regression residuals significantly different from the normal distribution. Note that when equation <10> is estimated without Z_t (Table 5), the system tests do not reject the null hypothesis that $\delta_0 = 0$, $\delta_1 = 1$, and $\delta_2 = 0$ for all currencies. Once lagged values of the dependent variables, or the forward premia, are included for Z_t, however, the joint null hypothesis that $\delta_0 = 0$, $\delta_1 = 1$, and $\delta_2 = 0$ is rejected. In particular, Table 6 shows that the forward premium enters significantly in three out of five currencies. Omission of this variable biased Korajczyk's (1985) conclusions.

Tables 7 - 8 provide the system tests for the period January 1981 through December 1985 for all nine countries paired with the U.S. The

TABLE 4

UNRESTRICTED 3SLS

$$s_{t+1} - f_t = \delta_0 + \delta_1(\tilde{r}^*_{t+1} - \tilde{r}_{t+1}) + \epsilon_{t+1}$$

A. Estimates

Country	δ_0	δ_1	$F(\delta_0=0, \delta_1=1)$	D.W.
NE	.001 (.004)	.96* (.20)	.11	2.23
UK	.005 (.003)	.96* (.47)	1.38	1.76
FR	.002 (.003)	1.97* (.56)	1.76	2.28
WG	.002 (.002)	.09 (.35)	3.32*	2.12
SW	.002 (.005)	-.17 (1.29)	.49	1.98

B. System Tests

Test	F	P-Value
$\delta_0 = 0$; all equations	.71	.62
δ_1: equal across equations	2.74	.03
$\delta_1 = 1$; all equations	2.20	.05
$\delta_0 = 0$, $\delta_1 = 1$; all equations	1.52	.13

Weighted $R^2 = .18$ April 1974 - December 1980

See Note in Table 1.

TABLE 5

UNRESTRICTED 3SLS

$$s_{t+1} - f_t = \delta_0 + \delta_1(\tilde{r}^*_{t+1} - \tilde{r}_{t+1}) + \delta_2(s_t - f_{t-1}) + \epsilon_{t+1}$$

A. Estimates

Country	δ_0	δ_1	δ_2	F(δ_0=0, δ_1=1, δ_2=0)	D.W.
NE	.002 (.002)	.36 (.20)	.10 (.07)	3.77*	2.39
UK	.004 (.003)	.83 (.44)	.24* (.09)	3.27*	2.16
FR	.002 (.003)	2.27* (.55)	.03 (.07)	2.14	2.22
WG	.001 (.004)	1.13* (.34)	.07 (.06)	.50	2.29
SW	.002 (.005)	.58 (1.34)	-.02 (.08)	.12	1.99

B. System Tests

Test	F	P-Value
δ_0= 0; all equations	.55	.69
δ_2= 0; all equations	2.02	.07
δ_1= 1; all equations	3.87	.002
δ_0=0, δ_1=1, δ_2=0 all equations	2.20	.005

Weighted R^2 = .16 April 1974 - December 1980

See Note in Table 1.

TABLE 6

UNRESTRICTED 3SLS

$$s_{t+1} - f_t = \delta_0 + \delta_1(\tilde{r}^*_{t+1} - \tilde{r}_{t+1}) + \delta_2(f_t - s_t) + \epsilon_{t+1}$$

A. Estimates

Country	δ_0	δ_1	δ_2	$F(\delta_0=0, \delta_1=1, \delta_2=0)$	D.W.
NE	.004 (.004)	.47* (.20)	-1.61* (.33)	8.05*	2.24
UK	.001 (.005)	1.02* (.45)	-1.34 (.92)	1.61	1.78
FR	.001 (.003)	1.16 (.68)	-.50 (.65)	.60	2.28
WG	.007 (.004)	-.50 (.40)	-1.73* (.60)	5.23*	2.11
SW	.023* (.007)	-3.19* (1.37)	-4.21* (1.11)	6.01*	1.89

B. System Tests

Test	F	P-Value
$\delta_0 = 0$; all equations	2.20	.05
$\delta_2 = 0$; all equations	6.83	.000
$\delta_1 = 1$; all equations	4.06	.001
$\delta_0=0$, $\delta_1=1$, $\delta_2=0$ all equations	3.06	.000

Weighted R^2 = .23 April 1974 - December 1980

See Note in Table 1.

results in these tables confirm the rejection of the hypothesis that only risk premia on Eurocurrency interest rates explain the deviations of forward rates from future spot prices.

The system of equations was tested using alternative estimation methodologies in order to examine the robustness of the conclusions. Since 3SLS yields inconsistent estimates of parameters in all equations if any equation is mis-specified, the system is estimated using two-stage least squares (2SLS). "2SLS is not as efficient as 3SLS, but only the incorrectly specified equation is inconsistently estimated if misspecification is present in the system." (Hausman 1978, p. 1265) The conclusions from the 2SLS estimations do not differ from the 3SLS results in any estimation period. I also consider tax effects. Using Darby's (1975) modified Fisher equation instead of equation <6> adds two terms to equation <10>,[10] but does not change the conclusions.

---

10. Darby (1975) modifies the Fisher equations so that:

$$(2.6') \quad \begin{aligned} R_{t+1} &= E(\tilde{r}_{t+1}) + E(\tilde{I}_{t+1}) + [\tau/(1-\tau)]E(\tilde{I}_{t+1}) \\ R^*_{t+1} &= E(\tilde{r}^*_{t+1}) + E(\tilde{I}^*_{t+1}) + [\tau^*/(1-\tau^*)]E(\tilde{I}^*_{t+1}) \end{aligned}$$

where τ and τ^* are the marginal tax rates in the U.S. and foreign country respectively. Given these equations, <10> becomes

$$<10'> \quad \tilde{s}_{t+1} - f_t = \gamma_0 = \gamma_1 E[\tilde{r}^*_{t+1} - \tilde{r}_{t+1}] + \gamma_2[\tau^*/(1-\tau^*)]E(\tilde{I}^*_{t+1}) - \gamma_3[\tau/(1-\tau)]E(\tilde{I}_{t+1}) + \gamma_4 Z_t + \zeta_{t+1}.$$

The estimation is performed using an additional set of auxiliary equations to generate inflation predictions (an AR(6) process is used). The null hypothesis on γ_0, γ_1, and γ_4 is unchanged, and the data reject the null on these parameters when the inflation variables are included.

TABLE 7

UNRESTRICTED 3SLS

All Nine Currencies Against the Dollar

$$s_{t+1} - f_t = \delta_0 + \delta_1(\tilde{r}^*_{t+1} - \tilde{r}_{t+1}) + \epsilon_{t+1}$$

System Tests

Test	F	P-Value
$\delta_0 = 0$; all equations	1.50	.144
$\delta_1 = 1$; all equations	17.32	.0001
$\delta_0=0$, $\delta_1=1$, all equations	8.94	.0001

Weighted R^2 = .35 January 1981 - December 1985

TABLE 8

UNRESTRICTED 3SLS

All Nine Currencies Against the Dollar

$$s_{t+1} - f_t = \delta_0 + \delta_1(\tilde{r}^*_{t+1} - \tilde{r}_{t+1}) + \delta_2(f_t - s_t) + \epsilon_{t+1}$$

System Tests

Test	F	P-Value
$\delta_0 = 0$; all equations	3.67	.0002
$\delta_2 = 0$; all equations	6.36	.0001
$\delta_1 = 1$; all equations	30.89	.0001
$\delta_0=0$, $\delta_1=1$, $\delta_2=0$ all equations	12.94	.0001

Weighted R^2 = .41 January 1981 - December 1985

TABLE 9

UNRESTRICTED 3SLS

All Nine Currencies Against the Dollar

$$s_{t+1} - f_t = \delta_0 + \delta_1(\tilde{r}^*_{t+1} - \tilde{r}_{t+1}) + \delta_2(s_t - f_{t-1}) + \epsilon_{t+1}$$

System Tests

Test	F	P-Value
$\delta_0 = 0$; all equations	1.49	.145
$\delta_2 = 0$; all equations	2.37	.048
$\delta_1 = 1$; all equations	16.74	.0001
$\delta_0=0$, $\delta_1=1$, $\delta_2=0$ all equations	5.95	.0001

Weighted $R^2 = .36$

January 1981 - December 1985

III. Summary and Conclusions

This paper investigates the observed time-varying discrepancy between forward and future spot exchange rates. In order to determine whether rejection of the UEH is due to risk premia, a theoretical framework is developed which yields restrictions on the parameters of a multivariate regression model. This framework is consistent with a host of international asset pricing models which assume that expected real exchange rate changes are zero. These models predict that the forecastable deviations of the forward exchange rate from the future spot exchange rate equals the expected real return differential on default free nominal bonds, and that past information, beyond the information's ability to forecast real interest rates, should not significantly explain the intertemporal variation of the forward forecast error. Using various econometric procedures and different estimation periods, the data reject these predictions. More specifically, the data demonstrate that while anticipated real interest rate differentials are reflected in forward exchange rates, expected real interest rate differences are not the only systematic component of forward forecast errors. In particular, forward premia are useful in explaining differences between forward and future spot prices beyond that information's ability to predict real return differentials.

Anticipated real exchange rate movements may explain the rejection of the hypothesis that risk premia on default free nominal bonds are the only source of bias in forward exchange rates. If agents anticipated real exchange rate changes, these expectations will be incorporated into forward exchange rates.[11] Future research into the nature of time-varying differences between forward and future spot prices should concentrate on constructing and estimating an intertemporal, international asset pricing model which includes expected real exchange rate movements.

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11. At first glance, one may suggest incorporating ex ante real exchange rate movements into equation <10>, and testing whether or not it enters with a coefficient of one. This is done in Levine (1986). The data do not reject the hypothesis that the coefficients on expected real exchange rate changes and expected real interest rate differentials are equal to one and that past information, beyond its influence through these two variables, is useless in predicting the forward forecast error. There is, however, an econometric problem with this study because the coefficients on expected real return differences and anticipated real exchange changes are biased toward the null. The finding that past information does not enter significantly once these variables are incorporated, however, does support the belief that forward markets are efficient and that it is anticipated real exchange rate changes which leads to rejecting the hypothesis that $\delta_2 = 0$ in this paper.

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