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The pricing of forward exchange rates

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This paper tests the hypotheses that (1) risk premia fully account for the observed systematic discrepancies between forward and future spot exchange rates; and (2) the 'efficient markets version' of PPP holds. A simple theoretical framework is used to derive testable restrictions on the parameters of a multivariate regression model. The data reject the restrictions and each hypothesis. In contrast to past investigations, the empirical analysis strongly suggests that forward exchange rates incorporate anticipated real exchange rate movements.

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 (1988), and Obstfeld (1986) 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. Korajczyk (1985), Levine (1989), and Huang (1987) note that if agents anticipate real exchange rate movements, then forward rates will predictably differ from future spot rates. The most frequently advanced and thoroughly studied explanation for the observed discrepancies between forward and future spot exchange rates is that purchasing power risk introduces a risk premium. Empirical support for the risk premia hypothesis, however, is inconclusive.[1]

This paper uses an approach developed by Korajczyk (1985) to examine the validity of the risk premia hypothesis and the role of real exchange rates in the pricing of forward exchange rates. Korajczyk (1985) notes that a diverse set of asset pricing models predicts that the forecastable deviations between forward and future spot exchange rates should be identically equal to the risk premia reflected in real interest rate differentials on default-free nominal bonds.[2] This prediction imposes testable restrictions on the parameters of a multivariate regression system. In examining these restrictions, this paper tests the hypothesis that only time-varying risk premia on nominally riskless bonds explain the systematic deviations between

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forward and future spot exchange rates. Two important maintained hypotheses in this test are that

1. Agents are rational.
2. Real exchange rate changes are unpredictable, *i.e.*, Roll's (1979) 'efficient market version of PPP' (EPPP) is assumed to hold.[3]

Korajczyk (1985) cannot reject the hypothesis that only risk premia cause the observed deviations between forward and future spot prices. However, he uses incorrectly matched forward and future spot exchange rate data and fails to test an important restriction suggested by theory and past empirical research. Using a number of econometric procedures and estimation periods, this paper rejects this additional restriction and reverses Korajczyk's conclusion. Furthermore, the data reject the EPPP hypothesis and suggest that anticipated real exchange rate movements are important in the pricing of forward exchange rates.

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 forward forecast errors. Additional testing implies that anticipated real exchange rate movements help 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

$$\langle 1 \rangle \qquad E(s_{t+1} - f_t | \phi_t) = 0,$$

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 $\beta = 0$ in the regression equation:

$$\langle 2 \rangle \qquad \tilde{s}_{t+1} - f_t = X_t \beta + \tilde{\varepsilon}_{t+1},$$

where $E(\varepsilon_{t+1}) = 0$; X_t is a subset of ϕ_t; and a tilde indicates a random variable at time t. The hypothesis that $\beta = 0$ has been rejected by many authors (see, for example, Hansen and Hodrick, 1980; Fama, 1984; 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 forecast error, $s_t - f_{t-1}$.

As discussed above, identifying the source of the rejection of the UEH has proven difficult. In order to resolve this interpretational problem, I derive an estimable expression for $E(s_{t+1} - f_t | \phi_t)$.

The Covered Interest Rate Parity (CIRP) condition states that

$$\langle 3 \rangle \qquad R_{t+1} = R^*_{t+1} + f_t - s_t,$$

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 Levich (1975) and McCormick (1979) present empirical support for the CIRP condition.

The logarithm of 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 US 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. Here d_t is referred to as the logarithm of the real exchange rate because it represents the logarithm of the relative price of a bundle of US 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 $\langle 3 \rangle$ and $\langle 4 \rangle$, 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:

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

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

where $\tilde{r}_{t+1}$ is the real return on a nominally riskless bond maturing at time $t+1$. Equation $\langle 6a \rangle$ defines the expected real return on US bonds and equation $\langle 6b \rangle$ defines the expected real return on foreign bonds, where the real values are evaluated in home country consumption units. 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 US resident because of anticipated real exchange rate changes. For example, if $E(\tilde{r}^*_{t+1}) = E(\tilde{r}_{t+1})$, then a US resident would expect a higher yield from holding foreign bonds than from holding US bonds if the dollar's real value is expected to depreciate.[4]

Darby (1975) shows that the Fisher equations should be modified to incorporate tax effects. The 'Darby effect' would add a term to each equation. For simplicity, this effect is ignored in the theoretical presentation; however, it is considered in the empirical estimation.

Combining $\langle 5 \rangle$, $\langle 6a \rangle$, and $\langle 6b \rangle$ and assuming rational expectations, we can express the expected deviation of $\tilde{s}_{t+1}$ from f_t, conditional on ϕ_t, as:

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

Equation ⟨7⟩ demonstrates that forward exchange rates are not unbiased predictors of future spot exchange rates 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]

Condition (i) will not hold if national currencies have different purchasing power risks and agents are risk averse. In order to hold the bond denominated in the more risky currency, investors must be compensated with a risk premium in the form of higher expected real returns. Since a forward contract is an agreement to exchange the future payoffs on nominal bonds denominated in the two currencies, any factors affecting the expected real value of these bonds will be incorporated into forward prices. Thus, if country price levels have different stochastic properties, bonds will be priced to reflect those differences, and the forward exchange rate will not equal the expected future spot price. Mishkin (1984) and Merrick and Saunders (1986) show empirically that *ex ante* real interest rates are not equal internationally. Therefore, we should not expect the UEH to hold.

Condition (ii) is Roll's 'efficient market version of PPP' (EPPP). The EPPP assumption states that the $E[\tilde{d}_{t+1} - d_t] = 0$, and implies that *ex ante* real returns are independent of residence. When there are non-zero expected real exchange rate movements, however, expected real returns on nominally riskless bonds depend upon the currency in which real returns are evaluated.[6] 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 EPPP is violated.

Although it is clear that exact PPP does not hold (*i.e.*, $d_t = 0$, for all t), the empirical evidence is generally supportive of the EPPP hypothesis.[7] This paper tests the EPPP hypothesis, and analyzes the importance of anticipated real exchange rate movements in the pricing of forward exchange rates.

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

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

where X_t is a subset of ϕ_t. Equation ⟨8⟩ implies that the forecastable difference between $\tilde{s}_{t+1}$ and f_t *equals* the expected real return differential 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 (1977), Hodrick (1981), Stulz (1981), and Lucas (1982). 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:

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

where 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 forecast error should enter *insignificantly* once $E[(\tilde{r}^*_{t+1} - \tilde{r}_{t+1})|X_t]$ is included. Rejection of any of these restrictions constitutes evidence against the null hypothesis that risk premia on nominally riskless bonds are the only source of systematic 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 *important* source of 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 $\boldsymbol{\delta}$:

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

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 are used to construct inflation series, and are obtained from the *International Financial Statistics*.

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 rates 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.[8]

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 *not* 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 data that are correctly matched in this fashion.

II.B. Ex ante *Real Interest Rates and the Forward Bias*

This subsection tests whether the data are consistent with a world in which the only systematic 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 similar to those used by Korajczyk (1985) 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 USA and the foreign country.
4. A proxy for nominal interest rate variability.[9]
5. The lagged value of the real return differential.
6. The forward premium at time t.

Instrument two was chosen because Fama and Gibbons (1984) demonstrate that it explains US 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 Fama (1976) finds that nominal interest rate volatility explains risk premia in the US Treasury bill market. 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 US 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 0.24 to 0.49, and the mean is 0.38 (over the period April 1974 to December 1985). Only for the United Kingdom do the data not reject the hypothesis that all non-intercept parameters are zero.

TABLE 1. Unrestricted 3SLS.

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

Country	δ_0	A. Estimates δ_1	$F(\delta_0=0,\ \delta_1=1)$	D.W.
NE	−0.001	1.45*	2.39	2.11
	(0.003)	(0.20)		
UK	0.002	2.23*	2.09	1.92
	(0.003)	(0.59)		
FR	−0.001	1.49*	0.55	2.19
	(0.003)	(0.46)		
WG	−0.001	1.28*	0.56	2.07
	(0.002)	(0.29)		
SW	0.000	1.06	0.01	1.99
	(0.004)	(1.29)		

B. System tests

Test	F	P-value
$\delta_0=0$; all equations	0.43	0.71
δ_1: equal across equations	0.52	0.72
$\delta_1=1$; all equations	1.78	0.11
$\delta_0=0,\ \delta_1=1$; all equations	1.02	0.42

Weighted $R^2=0.24$ April 1974 to 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 0.05 level.

Table 1 gives unrestricted 3SLS estimates of equation $\langle 10\rangle$ without Z_t. For four out of the five currencies the slope coefficient is significantly different from zero at a 0.05 significance level. More 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.
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 0.05 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 0.09 with most falling below 0.07. These statistics do not reject normality at a 0.05 significance level (see Powell, 1982).

Although real interest rate differentials explain only 18 per cent of the intertemporal variation in the forward forecast error, the results presented in Table 1 do not reject the hypothesis that risk premia on Eurocurrency bonds are the sole determinants of expected deviations between forward and future spot exchange rates.

If, however, risk premia on default-free nominal bonds are the only 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 (1985) 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 are similar. 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 2. Unrestricted 3SLS.

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

A. Estimates

Country	δ_0	δ_1	δ_2	$F(\delta_0=0, \delta_1=1, \delta_2=0)$	D.W.
NE	−0.001	1.36*	0.09	2.30	2.27
	(0.003)	(0.21)	(0.05)		
UK	0.003	2.60*	0.07	3.12*	2.02
	(0.003)	(0.56)	(0.07)		
FR	−0.000	1.68*	0.02	0.85	2.25
	(0.003)	(0.46)	(0.05)		
WG	−0.001	1.72*	0.05	2.23	2.19
	(0.003)	(0.32)	(0.05)		
SW	0.000	1.24	0.03	0.17	2.07
	(0.004)	(0.77)	(0.06)		

B. System tests

Test	F	P-value
$\delta_0 = 0$; all equations	0.39	0.71
$\delta_2 = 0$; all equations	1.00	0.42
$\delta_1 = 1$; all equations	2.90	0.01
$\delta_0 = 0$, $\delta_1 = 1$, $\delta_2 = 0$ all equations	0.44	0.82

Weighted $R^2 = 0.26$ April 1974 to December 1985

See note in Table 1.

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 $(f_t - s_t)$. It is important to remember that the instrument set used to form predictions of the real interest rate differentials includes the forward premium. The results strongly reject the hypothesis that forward premia enter 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. The system tests also strongly reject the null hypothesis,

Neither of the models presented in Tables 2 or 3 exhibits significant departures from the assumption of normally distributed regression residuals. Furthermore, the Durbin—Watson statistic and the test statistic derived by Godfrey (1978) fail to detect significant serial correlation.[10]

Taken together, Tables 1 through 3 demonstrate that although forward exchange rates incorporate risk premia, risk premia are not the only systematic components of forward exchange rates: the forward premium, which is available at the signing of the forward contract, significantly explains the discrepancy between forward and future spot rates beyond its ability to predict real return differentials.

II.C. The Forward Bias: Different Time Periods and Countries

Korajczyk (1985) estimates equation ⟨10⟩ using data from 1974 through 1980 for eight currencies paired with the US dollar. Using incorrectly matched forward and

TABLE 3. Unrestricted 3SLS.

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

			A. Estimates		
Country	δ_0	δ_1	δ_2	$F(\delta_0=0,\ \delta_1=1,\ \delta_2=0)$	D.W.
NE	0.002	0.40	−1.76*	11.90*	2.12
	(0.002)	(0.23)	(0.30)		
UK	−0.002	2.15*	−2.30*	5.13*	2.02
	(0.003)	(0.54)	(0.70)		
FR	0.003	2.95*	1.33*	2.75*	2.14
	(0.003)	(0.69)	(0.55)		
WG	0.002	0.75*	−1.25*	2.58	2.08
	(0.003)	(0.33)	(0.47)		
SW	0.013*	−0.78	−3.36*	5.53*	1.94
	(0.005)	(0.78)	(0.82)		

B. System tests		
Test	F	P-value
$\delta_0 = 0$; all equations	2.20	0.05
$\delta_2 = 0$; all equations	12.00	0.01
$\delta_1 = 1$; all equations	5.59	0.01
$\delta_0 = 0,\ \delta_1 = 1,\ \delta_2 = 0$ all equations	7.17	0.01

Weighted $R^2 = 0.24$ April 1974 to December 1985

See note in Table 1.

future spot prices, Korajczyk finds 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. With the constructed test statistics, Korajczyk is unable to reject the hypothesis that risk premia on default-free bonds are the sole systematic determinants of forward forecast errors.[11]

When correctly matched data are used, however, 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.

For completeness, Tables 4–6 present the 3SLS estimates and system tests over the period considered by Korajczyk (1985). When equation $\langle 10 \rangle$ is estimated without Z_t (Table 4), the system tests do not reject the null hypothesis that $\delta_0 = 0$ and $\delta_1 = 1$ 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 the forward premium may have biased Korajczyk's (1985) conclusions. None of these equations has regression residuals significantly different from the normal

TABLE 4. Unrestricted 3SLS.

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

A. Estimates

Country	δ_0	δ_1	$F(\delta_0=0,\ \delta_1=1)$	D.W.
NE	0.001	0.96*	0.11	2.23
	(0.004)	(0.20)		
UK	0.005	0.96*	1.38	1.76
	(0.003)	(0.47)		
FR	0.002	1.97*	1.76	2.28
	(0.003)	(0.56)		
WG	0.002	0.09	3.32*	2.12
	(0.002)	(0.35)		
SW	0.002	−0.17	0.49	1.98
	(0.005)	(1.29)		

B. System tests

Test	F	P-value
$\delta_0 = 0$; all equations	0.71	0.62
δ_1: equal across equations	2.74	0.03
$\delta_1 = 1$; all equations	2.20	0.05
$\delta_0 = 0,\ \delta_1 = 1$; all equations	1.52	0.13

Weighted $R^2 = 0.18$ April 1974 to December 1980

See note in Table 1.

TABLE 5. Unrestricted 3SLS.

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

A. Estimates

Country	δ_0	δ_1	δ_2	$F(\delta_0=0,\ \delta_1=1,\ \delta_2=0)$	D.W.
NE	0.002	0.36	0.10	3.77*	2.39
	(0.002)	(0.20)	(0.07)		
UK	0.004	0.83	0.24*	3.27*	2.16
	(0.003)	(0.44)	(0.09)		
FR	0.002	2.27*	0.03	2.14	2.22
	(0.003)	(0.55)	(0.07)		
WG	0.001	1.13*	0.07	0.50	2.29
	(0.004)	(0.34)	(0.06)		
SW	0.002	0.58	−0.02	0.12	1.99
	(0.005)	(1.34)	(0.08)		

B. System tests

Test	F	P-value
$\delta_0=0$; all equations	0.55	0.69
$\delta_2=0$; all equations	2.02	0.07
$\delta_1=1$; all equations	3.87	0.002
$\delta_0=0,\ \delta_1=1,\ \delta_2=0$ all equations	2.20	0.005

Weighted $R^2=0.16$ April 1974 to December 1980

See note in Table 1.

distribution, and both the Durbin–Watson and Godfrey (1978) statistics fail to detect significant serial correlation.

Tables 7–9 provide the system tests for the period January 1981 to December 1985 for all nine countries paired with the USA. The results in these tables confirm two important findings:

1. The data reject the hypothesis that only risk premia on Eurocurrency interest rates explain the forward forecast error.
2. The forward premium has significant explanatory power beyond its influence through real interest differentials.

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 misspecified, 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⟩,[12] but does not change the conclusions.

TABLE 6. Unrestricted 3SLS.

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

A. Estimates					
Country	δ_0	δ_1	δ_2	$F(\delta_0=0,\ \delta_1=1,\ \delta_2=0)$	D.W.
NE	0.004	0.47*	−1.61*	8.05*	2.24
	(0.004)	(0.20)	(0.33)		
UK	0.001	1.02*	−1.34	1.61	1.78
	(0.005)	(0.45)	(0.92)		
FR	0.001	1.16	−0.50	0.60	2.28
	(0.003)	(0.68)	(0.65)		
WG	0.007	−0.50	−1.73*	5.23*	2.11
	(0.004)	(0.40)	(0.60)		
SW	0.023*	−3.19*	−4.21*	6.01*	1.89
	(0.007)	(1.37)	(1.11)		

B. System tests		
Test	F	P-value
$\delta_0=0$; all equations	2.20	0.05
$\delta_2=0$; all equations	6.83	0.01
$\delta_1=1$; all equations	4.06	0.01
$\delta_0=0,\ \delta_1=1,\ \delta_2=0$ all equations	3.06	0.01

Weighted $R^2=0.23$ April 1974 to December 1980

See note in Table 1.

TABLE 7. Unrestricted 3SLS. All nine currencies against the dollar.

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

System tests		
Test	F	P-value
$\delta_0=0$; all equations	1.50	0.14
$\delta_1=1$; all equations	17.32	0.01
$\delta_0=0,\ \delta_1=1$; all equations	8.94	0.01

Weighted $R^2=0.35$ January 1981 to December 1985

See note in Table 1.

II.D. The EPPP Hypothesis

The last section rejected the hypothesis that risk premia on default-free bonds are the sole determinants of the systematic difference between forward and future spot prices: the forward premium (f_t-s_t) significantly explains forward forecast errors beyond its ability to predict real interest rate differentials. As discussed above, one explanation for rejecting the risk premia hypothesis is that agents forecast real exchange rate movements and these predictions are incorporated into forward prices. This section shows that the forward premium is also an important predictor of real exchange rate movements.

TABLE 8. Unrestricted 3SLS. All nine currencies against the dollar.

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

System tests		
Test	F	P-value
$\delta_0=0$; all equations	3.67	0.01
$\delta_2=0$; all equations	6.36	0.01
$\delta_1=1$; all equations	30.89	0.01
$\delta_0=0,\ \delta_1=1,\ \delta_2=0$ all equations	12.94	0.01
Weighted $R^2=0.41$	January 1981 to December 1985	

See note in Table 1.

TABLE 9. Unrestricted 3SLS. All nine currencies against the dollar.

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

System tests		
Test	F	P-value
$\delta_0=0$; all equations	1.49	0.15
$\delta_2=0$; all equations	2.37	0.05
$\delta_1=1$; all equations	16.74	0.01
$\delta_0=0,\ \delta_1=1,\ \delta_2=0$ all equations	5.95	0.01
Weighted $R^2=0.36$	January 1981 to December 1985	

See note in Table 1.

Tables 10 and 11 present seemingly unrelated regression estimates (SURE) of the equation:

$$\langle 11\rangle \qquad \tilde{d}_{t+1}-d_t = \alpha_0+\alpha_1(f_t-s_t)+u_{t+1}.$$

The EPPP hypothesis states that $E[(\tilde{d}_{t+1}-d_t)|\phi_t]=0$. In terms of equation $\langle 11\rangle$, the EPPP hypothesis is that $\alpha_0=\alpha_1=0$. Table 10 presents the regression results for five countries paired with the USA over the period April 1974 through December 1985. For the United Kingdom and Switzerland, the forward premium in period t is a significant explanatory variable of the rate of change in the real exchange rate between periods t and $t+1$. Furthermore, the system tests strongly reject the hypothesis that $\alpha_0=\alpha_1=0$. Table 11 presents the results for nine countries paired with the USA over the shorter estimation period. The results are similar: five of the nine forward premia are significant, and the system tests strongly reject the EPPP hypothesis.

III. Summary and Conclusions

This paper investigates the observed time-varying discrepancies between forward and future spot exchange rates. In order to determine whether rejection of the UEH is due only to risk premia, a theoretical framework is developed which yields

TABLE 10. SURE.

$$\tilde{d}_{t+1} - d_t = \alpha_0 + \alpha_1(f_t - s_t) + u_{t+1}$$

A. Estimates			
Country	α_0	α_1	D.W.
NE	−0.002	−0.12	1.98
	(0.116)	(0.15)	
UK	−0.005	−2.23*	1.91
	(0.003)	(0.65)	
FR	−0.001	0.40	2.05
	(0.003)	(0.37)	
WG	−0.002	−0.27	1.99
	(0.003)	(0.36)	
SW	0.007	−1.68*	1.98
	(0.004)	(0.65)	

B. System tests		
Test	F	P-value
$\alpha_1 = 0$	4.00	0.01
$\alpha_0 = \alpha_1 = 0$	2.42	0.01

Weighted $R^2 = 0.03$ April 1974 to December 1985

See note in Table 1.

restrictions on the parameters of a multivariate regression model. The 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 equal the expected real return differentials 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. The data reject these predictions. More specifically, the data reject the hypotheses that

1. Expected real interest rate differences are the only systematic component of forward forecast errors.
2. Real exchange rate movements are unpredictable.

Moreover, the same information that is useful in explaining differences between forward and future spot prices beyond that information's ability to predict real interest rate differentials is also useful in forecasting real exchange rate changes. These findings strongly suggest that anticipated real exchange rate changes are incorporated into forward exchange rates. Future analysis of the time-varying differences between forward and future spot prices should concentrate on constructing and estimating an intertemporal, international asset pricing model which includes real exchange rate movements.

TABLE 11. SURE.

$$\tilde{d}_{t+1} - d_t = \alpha_0 + \alpha_1 (f_t - s_t) + u_{t+1}$$

A. Estimates			
Country	α_0	α_1	D.W.
NE	0.005	−2.91*	1.89
	(0.005)	(0.74)	
UK	−0.007	−5.39*	2.29
	(0.004)	(1.28)	
FR	−0.004	0.63	1.83
	(0.005)	(0.40)	
WG	0.002	−2.11*	1.82
	(0.005)	(0.72)	
SW	0.011	−2.92*	1.86
	(0.006)	(0.93)	
CA	−0.001	−1.69	2.16
	(0.002)	(1.07)	
JA	0.013	−3.13*	1.92
	(0.006)	(1.18)	
BE	−0.007	0.03	1.87
	(0.005)	(0.67)	
IT	−0.012*	−0.20	1.92
	(0.005)	(0.41)	

B. System tests		
Test	F	P-value
$\alpha_1 = 0$	5.38	0.01
$\alpha_0 = \alpha_1 = 0$	4.87	0.01

Weighted $R^2 = 0.08$ January 1981 to December 1985

See note in Table 1.

Notes

1. See Levich's (1985) review of the literature.
2. See Kouri (1977), Hodrick (1981), Stulz (1981), and Lucas (1982).
3. The 'peso problem' discussed by Krasker (1980), Lewis (1988), and Obstfeld (1986) is a small-sample problem. Although potentially important, this paper does not examine the empirical importance of the 'peso problem.'
4. Implicit in this discussion is a definition of residency: a US resident is someone who purchases his goods in the USA and deflates nominal returns by the US price level.
5. The forward forecast error would also equal zero if the expected real return differential and the expected rate of change in the real exchange rate are perfectly negatively correlated.
6. Even if the expected rate of change in the real exchange rate is zero, condition (ii) does not rule out stochastic real exchange rates from entering the pricing of assets (Levine, 1989).
7. Kravis and Lipsey (1978) and Isard (1977) show that exact PPP does not hold. Roll (1979), Darby (1983), Cumby and Obstfeld (1984), Adler and Lehman (1983), and Huang (1987) present evidence concerning EPPP.
8. See Riehl and Rodriguez (1983) and Hodrick and Srivastava (1987).
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.

10. Godfrey's (1978) Lagrange-multiplier test permits testing of any order autocorrelation, and is valid for models with lagged dependent variables or weakly exogenous regressors. The Durbin–Watson statistic is not valid in these cases.
11. Even if the regression errors are normally distributed, we know only the asymptotic distribution of the test statistics in the estimated 3SLS models. Consequently, Korajczyk (1985) uses Monte Carlo simulations to construct alternative test statistic distributions. These distributions yield different conclusions from those implied by the statistics' asymptotic distributions. Hodrick and Srivastava (1987) argue, however, that there are important problems in using Monte Carlo techniques in a simultaneous setting where some of the regressors are endogenous. Although the direction in which these problems bias the results is unknown, they make suspect Korajczyk's conclusions based on the Monte Carlo simulations. Furthermore, when the sample is extended from Korajczyk's (1985) 88 observations to 149 observations, the results are unchanged.
12. Darby (1975) modifies the Fisher equations so that:

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

where τ and τ^* are the marginal tax rates in the USA and foreign country respectively. Given these equations, $\langle 10 \rangle$ becomes

$$\langle 10' \rangle \qquad \begin{aligned} \tilde{s}_{t+1} - f_t = \gamma_0 + \gamma_1 E[\tilde{r}^*_{t+1} - \tilde{r}_{t+1}] + \gamma_2[\tau^*/(1-\tau^*)]E(\tilde{I}^*_{t+1}) \\ -\gamma_3[\tau/(1-\tau)]E(\tilde{I}_{t+1}) + \gamma_4 Z_t + \zeta_{t+1}. \end{aligned}$$

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.

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