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# An empirical inquiry into the nature of the forward exchange rate bias

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This paper tests whether anticipated real exchange rate movements fully account for the systematic, time-varying discrepancies between forward and future spot exchange rates. The data do not reject this hypothesis. The results demonstrate that (1) real exchange rate changes are predictable; (2) anticipated real exchange rate changes are reflected in the forward bias; and (3) information available at the signing of the forward contract is useless in forecasting differences between forward and future spot prices beyond the information's ability to predict real exchange rate changes. The results emphasize the importance of real exchange rates in international asset pricing.

## 1. Introduction

It is widely recognized that there exist systematic, time-varying discrepancies between forward and corresponding future spot exchange rates. Empirical verification of any particular theory's explanation of the forward bias, however, has proven elusive.[1] Instead of testing the restrictions implied by a particular model's characterization of the forward bias, this paper examines the predictions of a broad class of models.

A variety of asset pricing models assume covered interest rate parity and rational expectations.[2] Consequently, they express the difference between forward and expected future spot exchange rates as being identically equal to the expected real interest rate differential plus the expected rate of change in the real exchange rate. A large subset of these models [e.g. Kouri (1977) and Hodrick (1981)], however, assume that real exchange rate movements are unpredictable. Consequently, these models equate the forecastable compo-

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[1]See the reviews by Hodrick (1987) and Meese (1989).

[2]See Levine (1989b) and citations therein.

nent of the forward bias with expected real interest rate differentials. Levine (1989a), however, rejects the hypothesis that expected real interest rate differentials fully explain the systematic discrepancies between forward and future spot rates. This implies that anticipated real exchange rate movements are important in the pricing of forward exchange rates.

This paper conducts a more powerful examination of the role of anticipated real exchange rate movements in the pricing of forward rates than previous work. In particular, I test the extreme hypothesis that anticipated real exchange rate changes *fully* account for the time-varying discrepancies between forward and future spot exchange rates. The data do not reject this 'anticipated real exchange rate hypothesis', implying that anticipated real exchange rate movements are the primary component of the forward bias, and establishing an empirical link between the forward bias and the implications of many theoretical models.

## 2. Theoretical framework

This paper uses a framework developed by Korajczyk (1985) that is based on three equations. The first equation is covered interest rate parity (CIRP):

$$i_t = i_t^* + f_t - s_t, \tag{1}$$

where $i_t$ is the continuously compounded yield on a one-period nominally riskless bond denominated in dollars (from $t$ to $t+1$); $i_t^*$ is the corresponding foreign yield; $s_t$ is the logarithm of the spot exchange rate at $t$ expressed in dollars per foreign currency; and $f_t$ is the logarithm of the forward exchange rate set at $t$, payable at $t+1$.

The second equation is a definition of the real exchange rate. The logarithm of the real exchange rate at time $t+1$, $d_{t+1}$, is defined as

$$d_{t+1} = p_{t+1}^* - p_{t+1} + s_{t+1}, \tag{2}$$

where $p_{t+1}$ and $p_{t+1}^*$ are the logarithms of U.S. and foreign price levels. $d_{t+1}$ is often called the logarithm of the deviation from absolute purchasing power parity.

Finally, a Fisher equation decomposes the nominal return on a nominally riskless asset into the expected real return and the expected inflation rate:

$$i_t = \mathrm{E}(r_{t+1} \mid \phi_t) + \mathrm{E}(\pi_{t+1} \mid \phi_t), \tag{3}$$

$$i_t^* = \mathrm{E}(r_{t+1}^* \mid \phi_t) + \mathrm{E}(\pi_{t+1}^* \mid \phi_t),$$

where $\phi_t$ is the information set at time $t$, $\mathrm{E}(\cdot)$ is the mathematical expectations operator, and $r_{t+1}$ [$r^*_{t+1}$] is the real return on a nominally riskless U.S. [foreign] bond maturing at $t+1$, where the real return is evaluated using the U.S. [foreign] inflation rate.

Rearranging (1)–(3) and taking expectations, we obtain an expression for the forecastable differences between forward and future spot prices:

$$E[(s_{t+1}-f_t)|\phi_t]=E[(d_{t+1}-d_t)|\phi_t]+E[(r^*_{t+1}-r_{t+1})|\phi_t]. \tag{4}$$

Eq. (4) implies that forward rates will be biased predictors of future spot rates unless: (a) expected real exchange rate movements equal zero; and (b) expected real interest rates are equal internationally.[3]

Condition (a), $E[(d_{t+1})|\phi_t]=d_t$, is the 'efficient market version of purchasing power parity' (EPPP). EPPP states that real exchange rate changes are unpredictable and implies that expected real asset returns are independent of investor nationality. EPPP has been tested by a number of authors. Roll (1979), Frenkel (1981), Darby (1983), and Adler and Lehman (1983) do not find a significant autocorrelation pattern in real exchange rates, leading some to conclude that real exchange rate changes are unpredictable. Cumby and Obstfeld (1984) present evidence inconsistent with EPPP by demonstrating that expected inflation differentials are not equal to expected exchange rate changes. Levine (1989a) *directly* rejects EPPP by showing that information available at time $t$ is useful in predicting the rate of change in the real exchange rate between $t$ and $t+1$.[4]

Condition (b), $E[(r^*_{t+1}|\phi_t]=E[(r_{t+1})|\phi_t]$, has also been tested. Cumby and Obstfeld (1984) reject the equality of expected real interest rates, implying that forward rates are biased predictors of future spot rates. But, Cumby and Obstfeld (1984) and Huang (1988) cannot reject the hypothesis that expected real rate differentials are constant for industrialized countries.

Thus, assuming that expected real interest rate differentials are a constant $k$, eq. (4) becomes:

$$E[(s_{t+1}-f_t)|\phi_t]=E[(d_{t+1}-d_t)|\phi_t]+k. \tag{5}$$

This formally expresses the *anticipated real exchange rate hypothesis of the*

[3]The anticipated discrepancy between forward and future spot prices would also equal zero if the expected real return differential and the expected rate of change in the real exchange rate were perfectly negatively correlated. Meese and Rogoff (1988) present evidence contrary to this proposition.

[4]Levine (1988) extends the sample used in Levine (1989a) and strongly rejects EPPP by showing that forward premia predict future real exchange rate movements. This corresponds well with this paper's conclusion that expected real interest rate differentials have little role in accounting for forward biases and the findings of Hodrick and Srivastava (1984) who show that forward premia significantly predict forward biases.

*forward bias*: except for a constant expected real interest differential the predictable difference between the forward exchange rate and the expected future spot rate equals the expected rate of change in the real exchange rate. If expected real interest rate differentials vary substantially, the data should reject the anticipated real exchange rate hypothesis. This formulation, along with the tests described below, will help determine the relative importance of expected real exchange rate movements and expected real interest rate differentials in explaining the evolution of the forward bias. As in Korajczyk (1985) and Levine (1989a), this paper may be viewed as testing for the importance of an omitted variable.

Assuming $\mathrm{E}[(d_{t+1}-d_t)|\phi_t]$ is observable and $Y_t$ is a subset of $\phi_t$, eq. (5) may be transformed into an estimable equation:

$$s_{t+1}-f_t=\alpha_0+\alpha_1\mathrm{E}[(d_{t+1}-d_t)|\phi_t]+\alpha_2 Y_t+u_{t+1}. \tag{6}$$

The anticipated real exchange rate hypothesis predicts that $\alpha_1=1$ and $\alpha_2=0$. Assuming rational expectations and covered interest rate parity, rejection of these restrictions suggests that anticipated real exchange rate movements are not the only systematic component of the forward bias and implies that time-varying expected real interest rate differentials are important factors in the forward bias. The null hypothesis, $\alpha_1=1$, expresses the prediction that anticipated real exchange rate changes are reflected directly in discrepancies between forward and expected future spot prices. The coefficient $\alpha_1$ will differ from one if expected real interest rate differentials are significantly correlated with anticipated real exchange rate movements. The null hypothesis, $\alpha_2=0$, formally expresses the prediction that information available at the signing of the forward contract should be useless in forecasting the differences between forward and future spot exchange rates beyond the information's ability to forecast real exchange rate movements. Thus, information that predicts the forward bias and information potentially correlated with expected real interest rate differentials should enter insignificantly in (6) once the information's ability to predict real exchange rate changes is considered. In the empirical work, variables are chosen for $Y_t$ that have been shown to be independent predictors of the forward bias and variables thought to be correlated with expected real interest rate differentials.

Since the $\mathrm{E}[(d_{t+1}-d_t)|\phi_t]$ is unobservable, predetermined variables are used to form predictions of the rate of change in the real exchange rate. The model is estimated jointly using three-stage least squares and treating the auxiliary equations describing expectations formation as part of the system:

$$\begin{aligned} s_{t+1}-f_t&=\alpha_0+\alpha_1(d_{t+1}-d_t)+\alpha_2 Y_t+u_{t+1},\\ d_{t+1}-d_t&=\delta I_t+\varepsilon_{t+1}, \end{aligned} \tag{7}$$

where $I_t$ are instrumental variables used to predict real exchange rate changes, and $\varepsilon_{t+1}$ is a white noise error term.[5]

## 3. Evidence

This section examines the empirical validity of the anticipated real exchange rate hypothesis. I examine two hypotheses: (a) anticipated real exchange rate changes are fully reflected in the forward bias; and (b) information available at the setting of the forward exchange rate is useless in forecasting the forward bias beyond its ability to predict real exchange rate changes. If the data do not reject (a) and (b), then we cannot reject the anticipated real exchange rate hypothesis.

### *3.1. Data*

Spot exchange rates, one-month forward rates, and one-month Eurocurrency interest rates come from Data Resources Incorporated. End-of-month forward rates are matched with future spot rates, accounting for holidays and weekends [see Levine (1989a)]. Other data are from the *International Financial Statistics*. The data cover the period July 1974 through January 1988 for the United States (US), the Netherlands (NE), the United Kingdom (UK), West Germany (WG), and Switzerland (SW).[6]

### *3.2. The forward bias and anticipated real exchange rate changes*

The instruments for the expected rate of change in the real exchange rate, $I_t$, were chosen on the basis of their theoretically and empirically documented relationship with real exchange rates. The instrumental variables are: (1) a constant; (2) the one-month lagged rate of change in the real exchange rate; (3) the difference between the average rate of change in the two stock market indices over the past six months (line 62 in the IFS); (4) the one-

[5]Eq. (7) is based on linear approximations. Although the precise effects on the empirical results are uncertain, two points may be noted: (1) the results are so strong that it is difficult to believe that second-order terms will overturn them; and (2) general tests for mis-specification (see footnote 9) do not suggest any problems.

[6]The analysis was also conducted with Italy and France, but capital controls induce CIRP deviations for parts of the sample. When the tests are conducted with France and Italy when CIRP holds, the results are unchanged. Also, only after 1981 does DRI have Eurocurrency interest rates for Canada, Japan, and Belgium. When tests are run over the later period with these countries the results are unchanged. See Levine (1988).

Table 1

Unrestricted 3SLS: $s_{t+1}-f_t=\alpha_0+\alpha_1(d_{t+1}-d_t)+u_{t+1}$.

| Country | $\alpha_0$ | $\alpha_1$ | $F(\alpha_1=1)$ |
|---|---|---|---|
| NE | −0.001 (0.001) | 0.94[a] (0.03) | 0.60 |
| UK | −0.001 (0.001) | 1.00[a] (0.03) | 0.01 |
| WG | −0.001 (0.001) | 0.99[a] (0.02) | 0.02 |
| SW | −0.002[a] (0.001) | 1.04[a] (0.02) | 0.28 |

*System tests*

| Test | $F$ | $P$-value |
|---|---|---|
| $\alpha_1$: equal across equations | 0.49 | 0.70 |
| $\alpha_1=1$: all equations | 0.37 | 0.83 |

| | |
|---|---|
| Weighted $R^2=0.23$ | July 1974–January 1988 |

[a]Significantly different from the null hypothesis at the 0.05 level.

*Note:* Standard errors in parentheses. $F(\alpha_1=1)$ represents the $F$-statistic for the null hypothesis that $\alpha_1=1$.

month lagged growth rate in the U.S. terms of trade; (5) the one-month lagged growth rate in the foreign country's terms of trade (lines 74 and 75); (6) the one-month lagged growth rate in the U.S. trade balance; (7) the one-month lagged growth rate in the foreign country's trade balance (lines 70 and 71); and (8) the forward premium. Instrumental variables (1) and (2) are chosen based on the time-series properties of sample real exchange rates. Since the productivity differential approach to real exchange rate determination is an important model of real exchange rate movements [e.g. Balassa (1964), Hsieh (1982), and Meese and Rogoff (1988)], instrumental variable (3) is included. Variables (4)–(7) are included based on empirical studies of real exchange rate determination [e.g. Barro (1983)], while variable (8) is chosen because of the results in Levine (1989a).[7] The unadjusted $R^2$ statistics for the first-stage regressions used to form the predicted rate of change in the real exchange rate range between 0.20 and 0.26, and the data reject the hypothesis that the instruments are jointly insignificant.

I first test whether anticipated real exchange rate movements are fully reflected in the forward bias by estimating (7) without the 'nuisance' variable $Y_t$. The anticipated real exchange rate hypothesis predicts that $\alpha_1=1$. Table 1

[7]Other instruments were tried: money growth rates, deficit to GNP ratios, lagged real interest rate differentials, proxy variables for nominal interest rate variability, and industrial production growth rates, without changing the results.

shows that for each of the four currencies paired with the dollar, the data do not reject the hypothesis that $\alpha_1 = 1$, but the data strongly reject the hypothesis that this coefficient is zero. In the system tests given in the bottom part of table 1, the data do not reject the hypotheses that the slope coefficients are equal across currencies or that all of the slope coefficients equal one.

To evaluate the reliability of the results, I perform a number of diagnostic tests. Since the model includes lagged values of the dependent variables, Godfrey's (1978) statistic is used to test for serial correlation at orders 1, 6, and 12. The residuals do not exhibit significant serial correlation. Similarly, Engle's (1982) test does not detect ARCH in the residuals at orders 1, 6, and 12. The Jarque–Bera (1980) and Kolmogorov–Smirnov tests fail to detect significant departures from normality at the 0.05 level. Tests for parameter constancy also did not uncover important problems. The test involved using a 'rolling' systems estimation technique where the system was estimated and the null hypothesis tested using the first four years of data. Then each month was added and the estimation and tests were conducted. Finally, to test for general system mis-specification, each country's two-equation system was estimated separately. The results are unaltered [Levine (1988)].[8]

I now test whether or not information available at the setting of the forward exchange rate is useful in forecasting the ex post differences between forward and future spot exchange rates beyond the information's ability to predict real exchange rates, i.e. are the data consistent with a world in which *only* anticipated real exchange rate movements explain the time-varying wedge between forward and expected future spot rates? Formally, the null hypothesis is $H_0:(\alpha_1,\alpha_2)=(1,0)$.

The nuisance variables, $Y_t$, were chosen based on two criteria: (1) documented ability to predict the forward bias; and (2) potential correlation with expected real interest rate differentials. Hansen and Hodrick (1980) find that the forward bias is significantly autocorrelated. Consequently, table 2 presents 3SLS results of (7) with $Y_t = s_t - f_{t-1}$. The data do not reject the hypotheses $\alpha_1 = 1$ and $\alpha_2 = 0$ for any country or the system as a whole. Since Hodrick and Srivastava (1984) and others find that the forward premium independently predicts the forward bias, table 3 presents the system results with $Y_t = f_t - s_t$. Again, the data do not reject the anticipated real exchange rate hypothesis. In table 4, $Y_t$ is set equal to the average real interest rate differential over the preceding twelve months ($ARRD_t$) because Fama and Gibbons (1984) demonstrate that *ARRD* did a reasonable job of tracking

[8]Since the data do not reject the hypothesis that the slope coefficients are equal across countries, (7) was estimated imposing this constraint. The results are unaffected. See Levine (1988) for the complete array of unrestricted and restricted results.

Table 2

Restricted 3SLS:
$s_{t+1}-f_t=\alpha_0+\alpha_1(d_{t+1}-d_t)+\alpha_2(s_t-f_{t-1})+u_{t+1}$.

| Country | $\alpha_0$ | $\alpha_1$ | $\alpha_2$ | $F(\alpha_1=1)$ | $F(\alpha_1=1,\alpha_2=0)$ |
|---|---|---|---|---|---|
| NE | −0.001 | 0.99[a] | 0.03 | 0.03 | 0.22 |
| | (0.001) | (0.02) | (0.01) | | |
| UK | −0.001 | 0.99[a] | −0.02 | 0.03 | 0.09 |
| | (0.001) | (0.02) | (0.02) | | |
| WG | −0.001 | 0.99[a] | −0.01 | 0.03 | 0.01 |
| | (0.001) | (0.02) | (0.01) | | |
| SW | −0.002[a] | 0.99[a] | 0.02 | 0.03 | 0.13 |
| | (0.001) | (0.02) | (0.01) | | |

*System tests*

| Test | | F | P-value |
|---|---|---|---|
| $\alpha_1=1$: | all equations | 0.01 | 0.99 |
| $\alpha_2=0$: | all equations | 0.30 | 0.88 |
| $\alpha_1=1,\ \alpha_2=0$: | all equations | 0.16 | 0.99 |
| Weighted $R^2=0.24$ | | July 1974–January 1988 | |

[a]See note in table 1.

Table 3

Restricted 3SLS:
$s_{t+1}-f_t=\alpha_0+\alpha_1(d_{t+1}-d_t)+\alpha_2(f_t-s_t)+u_{t+1}$.

*System tests*

| Test | | F | P-value |
|---|---|---|---|
| $\alpha_1=1$: | all equations | 0.15 | 0.96 |
| $\alpha_2=0$: | all equations | 0.64 | 0.63 |
| $\alpha_1=1,\ \alpha_2=0$: | all equations | 0.32 | 0.96 |
| Weighted $R^2=0.23$ | | July 1974–January 1988 | |

See note in table 1.

Table 4

Restricted 3SLS:
$s_{t+1}-f_t=\alpha_0+\alpha_1(d_{t+1}-d_t)+\alpha_2(ARRD_t)+u_{t+1}$.

*System tests*

| Test | | F | P-value |
|---|---|---|---|
| $\alpha_1=1$: | all equations | 0.03 | 0.99 |
| $\alpha_2=0$: | all equations | 0.74 | 0.56 |
| $\alpha_1=1,\ \alpha_2=0$: | all equations | 0.40 | 0.92 |
| Weighted $R^2=0.25$ | | July 1974–January 1988 | |

See note in table 1.

some nations' real interest rate differentials with the United States. This nuisance variable also failed to reject the null hypothesis.[9]

The results indicate that anticipated real exchange movements are reflected in the forward bias as many theoretical models suggest. Furthermore, information, even information shown by past investigators to be predictors of the forward bias and even information argued to be correlated with expected real interest rate differentials, enters insignificantly once account is taken of the information's ability to forecast real exchange rates. Although one may suggest incorporating ex ante real interest rate differentials into (7) and testing whether this variable also enters with a coefficient of one, this biases the parameters towards the null.[10]

## 4. Conclusions

Although the literature has devoted prodigious resources to linking the observed discrepancies between forward and future spot exchange rates to particular theoretical models, empirical verification of these models has been disappointing. Instead of testing a particular model, this paper examined the prediction of a broad class of models: anticipated real exchange rate movements should be reflected in systematic differences between forward and expected future spot exchange rates.

The results are two-fold: (1) anticipated real exchange rate changes are reflected in the forward bias as predicted by a class of asset pricing models; and (2) information available at the signing of the forward contract is useless in forecasting differences between forward and future spot prices beyond the information's ability to predict real exchange rate movements. Thus, the data do not reject the hypothesis that the time-varying wedge between forward and expected future spot exchange rates is *fully* explained by anticipated real exchange rate movements. The systematic, intertemporal variation between forward and future spot exchange rates seems to be primarily due to expected real exchange rate movements.

[9]Many other nuisance variables were tried. For example, variables used by Korajczyk (1985) to predict real interest rate differentials (e.g. lagged values of the real interest rate differential, lagged inflation differentials, and moving average measures of nominal interest rate variability) did not enter significantly; other countries' forward premia did not overturn the anticipated real exchange rate hypothesis; and, as a general test of mis-specification, when all of the variables used to form real exchange rate predictions are simultaneously and separately included as nuisance variables, the data do not reject the anticipated real exchange rate hypothesis [see Levine (1988)]. Furthermore, in all of the specifications the coefficients were tested for constancy, and the residuals were checked for autocorrelation, ARCH, and deviations from normality; no important departures from the standard null hypotheses were detected at the 0.05 significance level.

[10]Bob Korajczyk proved this to me; the proof is available on request. Nonetheless, incorporation of expected real interest rate differentials still yields a statistically significant coefficient of one on expected real exchange rate changes.

In conclusion, two clarifying statements are in order. First, no model is tested or examined in this paper. A simple framework based on an arbitrage condition and definitions is used to characterize the data. Thus, while this approach is not amenable to the type of precise economic interpretations we might garner from successfully estimating a general equilibrium asset pricing model, the resulting empirical characterization motivates a particular line of inquiry into the nature of the forward bias. Second, although the inability to reject the null hypothesis that the time-varying discrepancy between forward and expected future spot exchange rates equals the anticipated rate of change in the real exchange rate may not lead us to accept that null hypothesis, the empirical results strongly suggest that more careful attention needs to be given to the role of anticipated real exchange rates in the pricing of forward exchange rates.

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