

# ECONOMETRICS OF THE FORWARD PREMIUM PUZZLE

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## ABSTRACT

This paper explores from a new perspective the forward premium puzzle, i.e., why a regression of the change in the future spot exchange rate on the forward premium paradoxically yields a coefficient that is frequently negative. This traditional specification is compared theoretically and empirically to a "level" regression of the future spot rate on the current forward rate, which does not display the puzzle. We explore both non-rationality and risk premium explanations. The general conclusion is that, with non-rationality, any modest deviation from unity in the level coefficient becomes greatly magnified in the forward premium coefficient because of the stationary/nonstationary properties of the relevant variables, thereby generating the puzzle.

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## 1. Introduction

The Forward Premium Puzzle is an empirical paradox in the foreign exchange market that continues to pose a challenge to international economists. A regression of the future change in the log of the spot exchange rate on the forward premium (the log of the forward exchange rate minus the log of the spot exchange rate) is expected with efficient markets to yield a coefficient of unity. Instead, regression estimates of this "forward premium" specification yield a coefficient that is significantly less than unity and frequently negative! Much of the burgeoning literature attempting to solve the puzzle has focused on explanations involving a risk premium in the forward exchange market, with quite mixed findings.<sup>1</sup>

A second specification involving spot and forward exchange rates, referred herein as the "level" specification, was pursued early in this literature -- a regression of the log of the future spot exchange rate on the log of the current forward exchange rate.<sup>2</sup> Although not without econometric concerns, this regression typically yields a coefficient close to unity, a finding which seems consistent with efficient markets. Comparing estimates from these two similar specifications suggests a related puzzle -- how can a small insignificant deviation of the coefficient from unity in the level specification

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<sup>1</sup> For discussion about the forward premium puzzle, see Froot and Thaler (1990) and Obstfeld and Rogoff (1997, pp. 588-91). For surveys of the research, with focus on the risk premium approach, see Lewis (1995) and Engel (1996).

<sup>2</sup> For some early papers, see Cornell (1977), Levich (1979), and Frenkel (1980); for a recent discussion, see Zivot (2000).

become so greatly magnified that it causes a sign reversal in the forward premium specification? The focus of this paper, which we believe is novel in the literature, is to find a satisfactory answer to this related puzzle. In addition, the analysis sheds light on a probable explanation why there is a deviation in the coefficient from unity in either specification relating spot and forward exchange rates.

Is the level form or the forward premium form more appropriate to evaluate market efficiency? The most obvious choice would seem to be the level form since it is a direct approach. However, the variables in the level form (the future spot and current forward exchange rates) are non-stationary  $I(1)$  variables, which implies that regressing one of them on the other may lead to inconsistency given the well-known unit root problem in time series regression.<sup>3</sup> The forward premium form involves stationary  $I(0)$  variables (the future change in the spot exchange rate and the forward premium), so the resulting regression coefficient is consistent, which explains the literature's almost universal reliance on this specification.<sup>4</sup> More recently, Evans and Lewis (1993) demonstrate that the variables in the level specification, the future spot and the current forward exchange rates, are cointegrated, implying that the level regression is in fact super consistent<sup>5</sup>. If so, the level form is indeed legitimate to evaluate market efficiency and one need not focus only on the traditional forward premium specification.

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<sup>3</sup> For an early statement, see Granger and Newbold (1974). For a full treatment of the unit root problem, see Hamilton (1994, 557-562).

<sup>4</sup> The forward premium regression is a popular test for market efficiency. The contention is that if the market is efficient then the agents have full information and make unbiased predictions about the future exchange rate. Hence, with an efficient market the forward premium regression would result in a slope coefficient of unity.

<sup>5</sup> See Engle and Granger (1987) and Hamilton (1994, 571-629) for general development on cointegration and super consistency. For related applications of cointegration to spot and forward exchange rates, see Hakkio and Rush (1989), Hai, Mark, and Wu (1997), and Zivot (2000).

To explore why the forward premium specification greatly magnifies (with a frequent sign reversal) any coefficient deviation from unity in the level specification, we decompose the slope coefficients in both specifications into a combination of risk premium and non-rationality terms, and then express the coefficients as variances and covariances of the relevant variables. The theoretical analysis leads to stark empirical predictions, which are then tested using data on spot and forward exchange rates between the US dollar and three other major currencies. The general conclusion is that the dramatic magnification in the coefficient deviation from unity and possible sign reversal shifting from the level to the forward premium specification can be explained by the variance-covariance properties of the relevant I(0) and I(1) variables in the two specifications, i.e., the fact that the variables are stationary in the forward premium form and non-stationary in the level form. The paper also concludes that the key reason the coefficients in either form deviate from unity is non-rationality of agents in the foreign exchange market. This finding does not rule out the possibility of the existence of a risk premium, but does indicate that the puzzle is not solely a consequence of a risk premium.

The next section develops the theoretical decomposition of the coefficients as variances and covariances of the relevant variables in a combined model of risk aversion and non-rationality. Section 3 presents estimation results, and section 4 concludes.

## **2. Level and Forward Premium Models**

The "level" specification of the relationship between the forward exchange rate  $F_t$  and the future spot exchange rate  $s_{t+1}$ , where both exchange rates are defined as the dollar price of foreign exchange and expressed in logarithms, is the following:

$$s_{t+1} = \delta + \gamma F_t + \psi_{t+1} \quad (1)$$

where  $\delta$  is the intercept,  $\gamma$  is the slope coefficient, and  $\psi$  is a random error term. The key null hypothesis for market efficiency is that the slope coefficient  $\gamma$  is unity. The ordinary least squares (OLS) estimator of  $\gamma$  is  $\hat{\gamma}$ :

$$\hat{\gamma} = \frac{Cov(s_{t+1}, F_t)}{V(F_t)} \quad (2)$$

where V and Cov are the sample variance and covariances, respectively.

The traditional "forward premium" specification is

$$\Delta s_{t+1} = \alpha + \beta(F_t - s_t) + u_{t+1} \quad (3)$$

where  $\alpha$  is the intercept,  $\beta$  is the slope coefficient, and  $\mu$  is a random error term. The null hypothesis for market efficiency in this form is that the slope coefficient  $\beta$  is unity.

Similarly, the OLS estimate of  $\beta$  is  $\hat{\beta}$ :

$$\hat{\beta} = \frac{Cov(\Delta s_{t+1}, F_t - s_t)}{V(F_t - s_t)} \quad (4)$$

The forward premium puzzle is that  $\hat{\beta}$  is significantly less than unity, and in the majority of studies is negative.

### ***General Model***

Suppose first that agents are risk averse. In this case, the forward rate is their expected value of the future spot rate minus a premium they are willing to forego in order to eliminate foreign exchange risk. Thus,

$$E_t[s_{t+1}] = F_t + RP_t \quad (5)$$

where  $E_t[s_{t+1}]$  is the expected value in period t of the spot rate in period t+1, and  $RP_t$  is the risk premium in period t. Next, suppose that agents are not rational and make systematic forecast errors in period t+1, denoted  $e_{t+1}$ . As a consequence,

$$s_{t+1} = E_t[s_{t+1}] + e_{t+1} \quad (6)$$

Combining eq. (5) and eq. (6) we obtain

$$s_{t+1} = F_t + RP_t + e_{t+1} \quad (7)$$

Next, subtract  $s_t$  from both sides of eq. (7):

$$\Delta s_{t+1} = (F_t - s_t) + RP_t + e_{t+1} \quad (8)$$

Combining eq. (2) and eq. (7) yields

$$\hat{\gamma} = 1 + \frac{\text{Cov}(RP_t, F_t)}{V(F_t)} + \frac{\text{Cov}(F_t, e_{t+1})}{V(F_t)} \quad (9)$$

Similarly, combining eq. (4) and eq. (8) yields

$$\hat{\beta} = 1 + \frac{\text{Cov}(RP_t, F_t - s_t)}{V(F_t - s_t)} + \frac{\text{Cov}(F_t - s_t, e_{t+1})}{V(F_t - s_t)} \quad (10)$$

Thus, in general, risk aversion and/or non-rationality offer plausible explanations why OLS estimates of  $\gamma$  and  $\beta$  may differ from unity. To see this, consider the special case of risk neutrality and rational expectations. With risk neutrality,  $RP_t = 0$ , and the second term on the right-hand side of eqs. (9) and (10) becomes zero. In addition, if agents possess rational expectations, then the forecast error  $e_{t+1}$  is uncorrelated with the information set in period  $t$  (including  $F_t - s_t$ ), which implies that the third term in eqs. (9) and (10) is also zero. Thus, with risk neutrality and rational expectations, eqs. (9) and (10) collapse to  $\hat{\gamma} = \hat{\beta} = 1$ .

Next, consider the conditions required to generate the forward premium puzzle, i.e.,  $\hat{\beta}$  less than unity and often negative. For  $\hat{\beta}$  to be less than unity, it follows from eq. (10) that

$$\frac{Cov(RP_t, F_t - s_t)}{V(F_t - s_t)} + \frac{Cov(F_t - s_t, e_{t+1})}{V(F_t - s_t)} < 0 \quad (11)$$

which implies that at least one of the two terms on the left-hand side of eq. (11) must be negative, and their sum must be negative. For  $\hat{\beta}$  to be negative, it follows from eq. (10) that

$$\frac{Cov(RP_t, F_t - s_t)}{V(F_t - s_t)} + \frac{Cov(F_t - s_t, e_{t+1})}{V(F_t - s_t)} < -1. \quad (12)$$

### ***Risk Premium***

Within the forward premium specification, first suppose that agents have rational expectations, i.e.,  $Cov(F_t - s_t, e_{t+1}) = 0$ , but that agents possess a risk premium, i.e.,  $Cov(RP_t, F_t - s_t) \neq 0$ . In order for  $\hat{\beta} < 1$ , it follows from eq. (10) in this case that  $Cov(RP_t, F_t - s_t) < 0$ . Thus, when the forward premium  $F_t - s_t$  is positive, the risk premium term  $RP_t$  must be negative (and vice-versa) in the majority of the cases.

However, when  $F_t - s_t$  is positive, there is a positive return on purchasing foreign currency. If agents are risk-averse, they would be willing to accept a smaller sure return. In this case, the forward premium must be less than the change in the exchange rate when both are positive. Since on average  $\Delta s_{t+1} = (F_{t+1} - s_t) + RP_t$ , then the risk premium on average must be positive when the forward premium is positive. And the converse is true when the forward premium is negative. As a consequence, if agents are risk averse, then it must follow that  $Cov(RP_t, F_t - s_t) > 0$ <sup>6</sup>. Hence, the risk-premium

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<sup>6</sup> This result is not new. Fama (1984) and Engel (1996) demonstrate the same result but analytically differently.

approach alone does not seem sufficient to explain the puzzle of  $\hat{\beta} < 1$ , which requires  $Cov(RP_t, F_t - s_t) < 0$ . Thus, in this paper we focus on a non-rationality approach.

### ***Non-rationality***

Alternatively, assume that agents are risk neutral, i.e.,  $Cov(RP_t, F_t - s_t) = 0$ , but that expectations are not rational, i.e.,  $Cov(F_t - s_t, e_{t+1}) \neq 0$ . Thus, the forecast error in the next period is correlated with information this period, and agents make systematic errors in prediction of the spot exchange rate. In order for  $\hat{\beta} < 1$ , it follows from eq. (10) in this case that  $Cov(F_t - s_t, e_{t+1}) < 0$ . Since it is not possible a priori to predict the sign of this covariance, non-rationality can potentially explain the puzzle of  $\hat{\beta} < 1$ . If there also exists a risk premium, then from the previous subsection the effect of non-rationality must dominate the effect of the risk premium in order for the net bias in  $\hat{\beta}$  to remain negative.

### ***Comparing the Level to the Forward Premium Specification***

Suppose that agents are risk-neutral, and that non-rationality is the only source of bias in eqs. 9 and 10. Thus, from eq. 9 the bias in  $\hat{\gamma}$  in the level specification is

$$\frac{Cov(F_t, e_{t+1})}{V(F_t)}, \text{ and from eq. 10 the bias in } \hat{\beta} \text{ in the forward premium specification is}$$

$$\frac{Cov(F_t - s_t, e_{t+1})}{V(F_t - s_t)}. \text{ Evidence discussed in the introduction suggests that, paradoxically,}$$

the bias in the level specification is minimal, yet the bias in the forward premium specification is strongly negative, causing a frequent sign reversal in the coefficient

estimate  $\hat{\beta}$ . A plausible resolution to this paradox can be found by exploring the stationary-nonstationary properties of the relevant variables in the two bias terms.

First, consider the bias term in the level specification,  $\frac{Cov(F_t, e_{t+1})}{V(F_t)}$ . Assume

that the forward exchange rate  $F_t$  is a non-stationary variable and the forecast error  $e_{t+1}$  is stationary, conjectures supported by empirical evidence presented below. Given these statistical properties of  $F_t$  and  $e_{t+1}$ , it can be shown that  $p \lim[Cov(F_t, e_{t+1})] = 0$ ,

$p \lim[V(F_t)] = \infty$ ,  $p \lim[\frac{Cov(F_t, e_{t+1})}{V(F_t)}] = 0$ , and  $p \lim \hat{\beta} = 1$ . Thus, the bias term in the

level specification  $\frac{Cov(F_t, e_{t+1})}{V(F_t)}$  is likely to be relatively "small" for samples of at least

moderate size. Furthermore, since it depends on the sample size, the bias term should decline in absolute value moving from quarterly data to monthly data for a fixed number of years in the sample. These implications of the level model are tested below.

Next, consider the bias term in the forward premium specification:

$\frac{Cov(F_t - s_t, e_{t+1})}{V(F_t - s_t)}$ . Since estimates of  $\hat{\beta}$  are significantly less than unity and often

negative, this bias term is expected to be relatively "large" in magnitude and negative,

and in the majority of cases we should find that  $\frac{Cov(F_t - s_t, e_{t+1})}{V(F_t - s_t)} < -1$ . Assume that the

variables  $F_t - s_t$  and  $e_{t+1}$  are stationary, conjectures also supported by our data. Given

these statistical properties of  $F_t - s_t$  and  $e_{t+1}$ , then it can be shown that

$p \lim[Cov(F_t - s_t, e_{t+1})] = k1$ ,  $p \lim[V(F_t - s_t)] = k2$ ,  $p \lim[\frac{Cov(F_t - s_t, e_{t+1})}{V(F_t - s_t)}] = k3$ , and

$p \lim \hat{\beta} = 1 + k_3$ , where  $k_1$ ,  $k_2$ , and  $k_3$  are finite numbers. Thus, the bias term in the forward premium form  $\frac{Cov(F_t - s_t, e_{t+1})}{V(F_t - s_t)}$  may have any finite magnitude and is not systematically related to sample size, implications also tested below. However, the sign of the covariance term is ambiguous without placing restrictions on the source of the non-rationality.

To summarize, the theoretical analysis shows that, assuming non-rationality, the bias term in the level specification is small in magnitude and declines as the sample size increases given the non-stationary properties of  $F_t$  and  $s_{t+1}$ . However, the bias term in the forward premium specification becomes greatly magnified given the stationary properties of its variables. Thus, non-rationality combined with the stationary/nonstationary properties of the relevant variables offers a potential explanation for the apparent puzzle of little or no bias in the level specification between the spot and forward exchange rates, yet a dramatic negative bias with frequent sign reversal in the traditional forward premium specification.

### **3. Evidence**

The sample is three exchange rates -- the US dollar price of the UK pound-sterling, the French Franc and the Japanese Yen (the data are from Harris Bank's Weekly Review). The data are both monthly and quarterly, and include spot exchange rates, and one and three-month forward rates. Monthly data are from March 1973 to August 1992, and quarterly data are from 1973-quarter 1 to 1992-quarter 2 for the French Franc, and 1973-quarter 1 to 1994-quarter 1 for the UK pound-sterling and Japanese Yen. The data

are drawn from the last Fridays of the calendar month for monthly data, and the calendar quarter for quarterly data.<sup>7</sup>

### *Cointegration of the Level Specification*

Valid estimation of the level specification requires cointegration between the future spot and current forward exchange rates. With cointegration, the unit roots in the variables will not lead to inconsistent parameter estimates; in fact, regression estimates will be super consistent. To test this cointegration requirement, Johansen's test is applied to the three exchange rates using both monthly and quarterly data in our sample. The future spot rate is proxied by the spot rate on the last Friday one-month ahead for monthly data, and three-months ahead for quarterly data.

Test results are presented in Table 1 for monthly data and Table 2 for quarterly data. In Tables 1 and 2, trace statistics indicate that cointegrating relations exist at the 5% level of significance between the future spot rate and the current forward rate for all three exchange rates with both monthly and quarterly data. In the case of the UK pound-sterling, two cointegrating relations exist at the 5% level for both monthly and quarterly data. Thus, the estimates in Tables 1 and 2 clearly indicate that the non-stationarity of the variables in the level specification does not lead to inconsistency in OLS estimation, but rather super consistency. As a consequence, a side-by-side comparison of both the level

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<sup>7</sup> We thank Nelson Mark for providing this data (originally from Harris Bank's Weekly Review), which he examined in Mark and Wu (1998). However, there are caveats with this data. The sample ignores the transactions costs of trading currencies due to the existence of bid-ask spreads and the delivery structure. Also, data are recorded on Fridays. When matching a forward rate with a corresponding spot rate in quarterly data, the delivery date for the forward transaction should be exactly three months from that day. By taking the last Friday of every month, this required delivery structure could be lost. These limitations with the data may introduce bias in the estimates. Fortunately, Bekaert and Hodrick (1993) argue that these data limitations seem unimportant in explaining the exchange rate statistics examined in this paper.

and forward premium coefficient estimates is feasible in order to determine why they are so dramatically different.

### *Estimates of the Level and Forward Premium Specifications*

We next test the theoretical implications derived in section 2 assuming non-rationality but risk neutrality using the same data. Estimates of the  $\hat{\gamma}$  coefficient from the level specification are presented in Table 3. The evidence seems very consistent with the theoretical predictions of section 2. First,  $\hat{\gamma}$  estimates in all six cases are not statistically different from unity, and are numerically close to unity.<sup>8</sup> This evidence suggests that the forward rate may be a reliable predictor of the future spot rate, and that there may be no significant deviation from rationality. In particular, the evidence does not suggest a pattern of coefficients that are significantly less than unity and even negative, as in the forward premium puzzle.

Another implication from Table 3 is that for all three exchange rates the coefficients increase in magnitude toward unity shifting from quarterly to monthly data. This is consistent with the prediction that the bias term  $\frac{Cov(F_t, e_{t+1})}{V(F_t)}$  decreases as the sample size increases, hence that the coefficient  $\hat{\gamma}$  tends to approach unity as the sample size increases.

Estimation results for  $\hat{\beta}$  from the forward premium specification are summarized in Table 4. This evidence also supports the theoretical predictions from section 2. First, the  $\hat{\beta}$  coefficients are significantly less than unity at the 1% level in five of the six cases, and in fact are numerically negative in all six cases, replicating the

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<sup>8</sup> However, a caveat is that the power of the test is low.

forward premium puzzle. In combination with evidence from Table 3, this evidence demonstrates that the modest deviation from unity in level form is sufficiently magnified to generate a negative  $\hat{\beta}$  in the forward premium form in all six cases.

Another observation is that the  $\hat{\beta}$  estimates do not change systematically with a change in the sample size, unlike in the level specification. The analysis in section 2 suggests that this is primarily a consequence of the stationarity property of the forward premium. The variance in the denominator should not explode with increasing sample size, hence the bias term  $\frac{Cov(F_t - s_t, e_{t+1})}{V(F_t - s_t)}$  should not change systematically.

### *Direct Estimates of the Bias*

Finally, we explore a more direct method of testing the theoretical predictions in Section 2. Table 5 presents, for the level model, estimates of the numerator and denominator of the bias term, i.e., estimates of the covariance between the forecast error and the forward rate, and the variance of the forward rate. Table 6 presents analogous estimates for the forward premium model. This evidence is consistent with that presented in Tables 3 and 4. The forward rate has a much larger variance in Table 5 compared to any other variance or covariance estimates in Tables 5 and 6, as predicted given its non-stationarity. Also, the covariance between the forward rate and the forecast error in Table 5 is very small, as predicted. Thus, the bias term in the level specification

$\frac{Cov(F_t, e_{t+1})}{V(F_t)}$  is small in magnitude. The numerator and denominator terms for the

forward premium specification in Table 6 are also small and are roughly of the same

order of magnitude. Consequently, the bias term  $\frac{Cov(F_t - s_t, e_{t+1})}{V(F_t - s_t)}$  is sufficiently large

and negative to drive the  $\hat{\beta}$  coefficient to become negative, creating the forward premium puzzle.<sup>9</sup>

In sum, the empirical evidence in Tables 3 through 6 is strongly consistent with the theoretical analysis relating the presence of a modest bias in the slope coefficient in the level specification to a substantial bias and sign reversal in the slope coefficient in the forward premium specification.

#### 4. Conclusion

This paper explores the econometrics behind the forward premium puzzle from a novel perspective. The perspective is to explain why any small deviation from unity in the coefficient of a regression of the future spot exchange rate on the current forward exchange rate (the level specification) becomes so magnified in the traditional forward premium specification to frequently yield a negative regression coefficient, i.e., the forward premium puzzle. This paper demonstrates, we believe, that the relationship between spot and forward exchange rates can be better understood by examining their link using both the level and forward premium specifications jointly rather than focusing solely on the traditional forward premium specification.

We decompose the OLS regression coefficients in the level and forward premium models, permitting both a risk premium and non-rationality. The theoretical decomposition and subsequent empirical analysis leads to two findings. First, for the forward premium model, the downward bias in the slope coefficient, with frequent sign reversal, can be explained by non-rationality but not a risk premium, as the bias stems

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<sup>9</sup> As noted above, non-rationality alone does not predict the sign of the bias in  $\hat{\beta}$ . As described in footnote 10, however, non-rationality stemming from recursive least squares learning does imply a negative bias since it implies a negative covariance between the forecast error and the forward premium.

from a negative covariance between the forecast error and the forward premium.

Second, with non-rationality, any modest deviation from unity in the level coefficient becomes greatly magnified in the traditional forward premium coefficient because of the stationary-nonstationary properties of the relevant variables.

In this paper, we make no conjecture about the source of the non-rationality that may generate the negative covariance between the forecast error and the forward premium.<sup>10</sup> Also, we do not explore whether or not marginal non-rationality in the level form is evidence of market inefficiency. It would seem that a key to understanding the implications for market efficiency lies in the nature of the non-rationality that can explain this negative covariance, and if the covariance is of such a magnitude as to yield a negative  $\hat{\beta}$  in a majority of cases. Nonetheless, our theory and evidence clearly suggests that only a modest deviation from rationality in the level specification is sufficient to cause a sign reversal in the forward premium regression, i.e., the forward premium puzzle.

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<sup>10</sup> See Chakraborty (2005) for a plausible explanation of this non-rationality and negative covariance in terms of recursive least squares learning. The key assumption is that risk neutral agents do not have perfect knowledge about the foreign exchange market, but attempt to learn the parameters of the stochastic process generating the exchange rate using constant-gain recursive least squares. Crucially, this approach predicts a negative covariance between the forecast error and the forward premium, which is necessary to explain the forward premium puzzle.

Table 1: Johansen's test for cointegration between the future spot exchange rate  $s_{t+1}$  and the current one-period ahead forward rate  $F_t$  for the US dollar price of the UK Pound-sterling, French Franc and Japanese Yen (monthly data)

The null hypothesis in Johansen's unrestricted cointegration rank test is that there exists no cointegration between the variables.

Exchange rate (US dollar price of foreign currency)	USD/UKP	USD/FRF	USD/JPY
No. of observations	230	230	230
<u>No. of cointegrating Relations</u>			
None			
Trace statistic	39.83**	28.23**	17.85*
5% Critical value	15.41	15.41	15.41
1% Critical value	20.04	20.04	20.04
At most 1			
Trace statistic	4.93*	2.66	0.15
5% Critical value	3.76	3.76	3.76
1% Critical value	6.65	6.65	6.65
Normalized coefficients			
$s_{t+1}$	1.00	1.00	1.00
$F_{t+1}$	-1.000097 (0.00294)	-1.000130 (0.00246)	-0.997777 (0.00405)

**Notes:** \* and \*\* denote statistical significance (two-tailed test) at 5% and 1% level, respectively. Numbers in parentheses are standard errors.

**Sources:** Monthly data are taken for the period March 1973 to August 1992. The spot exchange rate, 1 month forward rate and 3 month forward rate data are taken from Harris Bank's Weekly Review. They are drawn from the Fridays occurring nearest to the end of the calendar month.

Table 2: Johansen's test for cointegration between the future spot exchange rate  $s_{t+1}$  and the current one-period ahead forward rate  $F_t$  for the US dollar price of the UK Pound-sterling, French Franc and Japanese Yen (quarterly data)

The null hypothesis in Johansen's unrestricted cointegration rank test is that there exists no cointegration between the variables.

Exchange rate (US dollar price of foreign currency)	USD/UKP	USD/FRF	USD/JPY
No. of observations	81	74	81
<u>No. of cointegrating Relations</u>			
None			
Trace statistic	15.74*	15.92*	24.43**
5% Critical value	15.41	15.41	15.41
1% Critical value	20.04	20.04	20.04
At most 1			
Trace statistic	4.98*	2.45	0.26
5% Critical value	3.76	3.76	3.76
1% Critical value	6.65	6.65	6.65
Normalized coefficients			
$s_{t+1}$	1.00	1.00	1.00
$F_{t+1}$	-1.013294 (0.01356)	-1.000748 (0.00785)	-1.005901 (0.00891)

**Notes:** \* and \*\* denote statistical significance (two-tailed test) at 5% and 1% level, respectively. Numbers in parentheses are standard errors.

**Sources:** Quarterly data are taken for the period 1973-quarter 1 to 1992-quarter 2 for French Franc and 1973-quarter 1 to 1994-quarter 1 for UK pound-sterling and Japanese Yen. The spot exchange rate, 1 month forward rate and 3 month forward rate data are taken from Harris Bank's Weekly Review. They are drawn from the Fridays occurring nearest to the end of the calendar quarter.

Table 3: Estimates from the "Level" regression equation  $s_{t+1} = \delta + \gamma F_t + \psi_{t+1}$  for USD price of UK Pound-sterling, French Franc and Japanese Yen (monthly and quarterly data)

The dependent variable is future spot rate  $s_{t+1}$ .

Exchange rate  
(US dollar price of  
foreign currency)

	USD/UKP	USD/FRF	USD/JPY
Monthly data			
No. of observations	233	233	233
$\hat{\gamma}$	0.9779 (0.0116)	0.988 (0.0094)	0.995 (0.0074)
$\bar{R}^2$	0.968	0.98	0.987
Quarterly data			
No. of observations	84	77	84
$\hat{\gamma}$	0.935 (0.0357)	0.957 (0.03)	0.992 (0.023)
$\bar{R}^2$	0.892	0.931	0.962

**Notes:** \* and \*\* denote statistical significance (two-tailed test) at 5% and 1% level, respectively, for  $H_0 : \gamma = 1$ . Numbers in parentheses are standard errors.

**Sources:** Monthly data are taken for the period March 1973 to August 1992 and the quarterly data span the period 1973-quarter 1 to 1992-quarter 2 for French Franc and 1973-quarter 1 to 1994-quarter 1 for UK pound-sterling and Japanese Yen. The spot exchange rate, 1 month forward rate and 3 month forward rate data are taken from Harris Bank's Weekly Review. They are drawn from the Fridays occurring nearest to the end of the calendar month for monthly data and calendar quarter for quarterly data.

Table 4: Estimates from the "Forward Premium" regression equation  $\Delta s_{t+1} = \alpha + \beta(F_t - s_t) + u_{t+1}$  for USD price of UK Pound-sterling, French Franc and Japanese Yen (monthly and quarterly data)

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The dependent variable is the change in the future spot rate  $\Delta s_{t+1}$ .

Exchange rate  
(US dollar price of  
foreign currency)

	USD/UKP	USD/FRF	USD/JPY
<b>Monthly data</b>			
No. of observations	233	233	233
$\hat{\beta}$	-0.73** (0.606)	-0.961** (0.659)	-0.153** (0.397)
$\bar{R}^2$	0.002	0.005	0.004
<b>Quarterly data</b>			
No. of observations	84	77	84
$\hat{\beta}$	-1.323** (0.791)	-0.006 (0.874)	-0.352** (0.417)
$\bar{R}^2$	0.021	0.013	0.003

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**Notes:** \* and \*\* denote statistical significance (two-tailed test) at 5% and 1% level, respectively, for  $H_0 : \beta = 1$ . Numbers in parentheses are standard errors.

**Sources:** Monthly data are taken for the period March 1973 to August 1992 and the quarterly data span the period 1973-quarter 1 to 1992-quarter 2 for French Franc and 1973-quarter 1 to 1994-quarter 1 for UK pound-sterling and Japanese Yen. The spot exchange rate, 1 month forward rate and 3 month forward rate data are taken from Harris Bank's Weekly Review. They are drawn from the Fridays occurring nearest to the end of the calendar month for monthly data and calendar quarter for quarterly data.

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Table 5: "Level" Specification: Variance and covariance terms for the forward rate and forecast error for USD price of UK Pound-sterling, French Franc and Japanese Yen (monthly and quarterly data)

Exchange rate (US dollar price of foreign currency)	USD/UKP	USD/FRF	USD/JPY
Monthly data:			
No. of observations	233	233	233
$Cov(F_t, e_{t+1})$	-0.000736	-0.000634	-0.000412
$V(F_t)$	0.033301	0.053236	0.086846
$\frac{Cov(F_t, e_{t+1})}{V(F_t)}$	-0.0221	-0.0119	-0.00475
Quarterly data			
No. of observations	84	77	84
$Cov(F_t, e_{t+1})$	-0.002119	-0.002377	-0.000787
$V(F_t)$	0.032407	0.055036	0.102807
$\frac{Cov(F_t, e_{t+1})}{V(F_t)}$	-0.0654	-0.0432	-0.00760

**Sources:** Monthly data are taken for the period March 1973 to August 1992 and the quarterly data span the period 1973-quarter 1 to 1992-quarter 2 for French Franc and 1973-quarter 1 to 1994-quarter 1 for UK pound-sterling and Japanese Yen. The spot exchange rate, 1 month forward rate and 3 month forward rate data are taken from Harris Bank's Weekly Review. They are drawn from the Fridays occurring nearest to the end of the calendar month for monthly data and calendar quarter for quarterly data.

Table 6: "Forward Premium" Specification: Variance and covariance terms for the forward premium and the forecast error for USD price of UK Pound-sterling, French Franc and Japanese Yen (monthly and quarterly data)

Exchange rate (US dollar price of foreign currency)	USD/UKP	USD/FRF	USD/JPY
Monthly data:			
No. of observations	233	233	233
$Cov(F_t - s_t, e_{t+1})$	-0.000145	-0.000065	-0.000333
$V(F_t - s_t)$	0.000062	0.0000649	0.000246
$\frac{Cov(F_t - s_t, e_{t+1})}{V(F_t - s_t)}$	-2.339	-1.002	-1.354
Quarterly data			
No. of observations	84	77	84
$Cov(F_t - s_t, e_{t+1})$	-0.00002	-0.00002	-0.000034
$V(F_t - s_t)$	0.000012	0.00001	0.000029
$\frac{Cov(F_t - s_t, e_{t+1})}{V(F_t - s_t)}$	-1.667	-2.000	-1.172

**Sources:** Monthly data are taken for the period March 1973 to August 1992 and the quarterly data span the period 1973-quarter 1 to 1992-quarter 2 for French Franc and 1973-quarter 1 to 1994-quarter 1 for UK pound-sterling and Japanese Yen. The spot exchange rate, 1 month forward rate and 3 month forward rate data are taken from Harris Bank's Weekly Review. They are drawn from the Fridays occurring nearest to the end of the calendar month for monthly data and calendar quarter for quarterly data.

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