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The Forward Exchange Rate Bias Puzzle: Evidence from Stochastic and Non Parametric Cointegration Tests

Abstract

An important puzzle in international finance is the failure of the forward exchange rate to be a rational forecast of the future spot rate. It has often been suggested that this puzzle may be resolved by using better statistical procedures that correct for both non-stationarity and non-normality in the data. We document that even after accounting for non-stationarity, non-normality, and heteroscedasticity using parametric and non-parametric tests on data for over a quarter century, US dollar forward rates for horizons ranging from one to twelve months for the major currencies, the British pound, Japanese yen, Swiss franc, and the German mark, are generally not rational forecasts of future spot rates. These findings of non-rationality in forward exchange rates for the major currencies continue to be puzzling especially as these foreign exchange markets are some of the most liquid asset markets with very low trading costs.

I. Introduction

The forward-spot relation in asset prices continues to be of great interest for investors, portfolio managers, and policy makers. While this relation is very important from an economic perspective, one reason why this relation continues to intrigue us is that, in spite of large trading volumes and low trading costs in currency markets, there continue to be seemingly large and persistent deviations from efficiency and rationality. There is consistent empirical evidence that forward rates are neither efficient nor rational forecasts of future spot rates. This is an important puzzle with important economic (e.g., for currency overlay policies in portfolio management) and public policy implications.

The efficient markets hypothesis (EMH) has played an important role in understanding asset markets especially in the past few decades. It states that if economic agents are risk neutral; all available information is used rationally; the market is competitive; and there are no taxes, transaction costs, or other frictions; then the foreign exchange market will be efficient in the sense that the expected rate of return to speculation in the forward exchange market will be zero (e.g., Gweke and Feige, 1979; and Hansen and Hodrick, 1980). The EMH implies that as forward exchange rates fully reflect available information about investors expectations of future spot rates, forward rates should be unbiased forecasts of future spot rates (see, e.g., Levich, 1979; Lin, 1999; and Lin et al., 2002, among others).

It is clear that tests of market efficiency are thus composed of joint tests of two null hypotheses: one is the market efficiency hypothesis (EMH) and the other is the unbiasedness or rational expectations hypothesis (UH or REH). While the theoretical foundations of the EMH and the REH seem sound, the vast amount of empirical work that has been undertaken to test the EMH[1] and the UH[2] in the foreign exchange markets has very rarely supported these theoretically elegant hypotheses. In a recent paper (Tauchen, 2001), it has been suggested that due to limitations in the statistical methodologies used in prior studies, the evidence against the hypothesis of unbiased forward rates is much stronger than previously believed. The forward rate puzzle in the foreign exchange markets persists and this study examines if improved statistical methodologies can help resolve this puzzle.

This study represents an improvement over the existing literature in a number of ways. Unlike prior literature on tests of the forward rate as a forecast of the future spot rate, we augment traditional models, using in addition the recently developed nonparametric model of Breitung (2002) and that of Aggarwal, Mohanty and Song (1995), to test the efficient markets hypothesis for foreign currency markets. This methodology features several innovations compared to the statistical procedures used in prior studies of the forward-spot relation.

Importantly, unlike the research designs used in prior literature, the cointegration methodology used here accounts for non-stationarity and non-normality in the data series - qualities widely documented in spot and forward exchange rate data.[3] Thus, as suggested by Sephton and Larsen (1991), our methodology meets the need for a more thorough analysis of cointegrating regressions and the error correction models used to describe equilibrium relations.

Finally, this paper uses a long sample period (of over a quarter century) from January 1973 (the start of the recent period of floating rates) to December 1998 (just prior to the consolidation of the European currencies into the Euro) that covers a wide range of major currencies with forward rates over various forecast horizons (one, three, six and twelve months). Thus, the statistical procedures used in this paper represent a significant improvement over prior

[1] See for example, Geweke and Feige, 1979; Hansen and Hodrick, 1980; Fama, 1984; Hodrick and Srivastava, 1986; Hsieh, 1984; Wolff, 1987; and Sephton and Larsen, 1991; Cavaglia, Verschoor, and Wolff, 1994.
[2] See, Levich, 1979; Kohlhagen, 1979; Bilson, 1981; Hsieh, 1984; Gregory and McCurdy, 1984; Cavaglia, Verschoor, and Wolff, 1993; Naka and Whitney, 1995; Bakshi and Naka, 1997; Lin, 1999; and Lin et al., 2002.
[3] See, Meese and Singleton, 1982; Hakkio and Rush, 1989; Barnhart and Szakmary, 1991; Liu and Maddala, 1992a; Liu and Maddala, 1992b; Naka and Whitney, 1995; Norrbin and Reffett, 1996.

studies of forward rates as forecasts of future spot exchange rates and the extended time span used should allow for robustness in the convergence of any parameters.

We document that even after accounting for non-stationarity, non-normality, and heteroscedasticity using parametric and non-parametric tests on data for over a quarter century, US dollar forward rates for horizons ranging from one to twelve months for the major currencies, the British pound, Japanese yen, Swiss franc, and the German mark, are generally not rational forecasts of future spot rates. These findings of non-rationality in forward exchange rates for the major currencies continue to be puzzling especially as these foreign exchange markets are some of the most liquid asset markets with very low trading costs.

II. Literature Review

The empirical literature of tests on the validity of the market efficiency may be classified into two groups. One group consists of the tests on the UH and the other is constituted by the tests on the EMH. Well-known examples in the first group include the joint tests conducted by Geweke and Feige (1979) which have provided some indications of why foreign exchange markets are not efficient (due to market participants' risk averse behavior combined with the existence of transaction costs). While Hansen and Hodrick (1980) have rejected the EMH from the 1970s and the 1920s; the semi-strong-form tests undertaken by Longworth (1981) have rejected the joint null hypothesis of an efficient exchange market and no risk premium for the period ending in October 1976. Studies by Fama (1984), Boothe and Longworth (1986), and Hodrick and Srivastava (1986), Hakkio and Rush (1989), Sephton and Larsen (1991), Liu and Maddala (1992a, 1992b) have also failed to support the market efficiency hypothesis. Prior studies attributed the failure of market efficiency to several factors such as presence of risk premiums contained in forward rates, the (negative) correlation between the forward risk premiums and expected future spot rates, empirical irregularities in regression tests used, the mis-measurement of profit rules, and the lack of the use of appropriate econometric techniques.

A great number of studies have also been devoted to testing the UH. Lin and Chen (1998), Lin (1999), Lin and Lin (2000), and Lin et al. (2002) provide thorough reviews of this empirical literature. Many of the studies in this area have considered only one sample period, one time horizon (mostly one month), and one or more currencies, so that the rejection or acceptance of the UH may well depend on the sample periods, currencies, and time horizons under study (Lin, 1999). Some tests have been performed on the basis of the argument that functional forms are exploitable (e.g., Barnhart and Szakmary, 1991; Lin, 1999; and Lin et al., 2002). Still others believe that a number of well-cited tests of unbiasedness have suffered from specification error (misspecification), such as structural homogeneity bias arising from the assumption that the slope coefficient of the UH is invariant over time (see, e.g., Lin et al., 2002). Thus, to correct the bias created by the structural homogeneity assumption, Gregory and McCurdy (1984) have addressed the misspecification issue, Chiang (1988) has taken a stochastic coefficient approach, and Lin (1999) and Lin et al.(2002) have used a logarithmic change specification which is transformed into a variable mean response model estimated by a four-step generalized least squares procedure. More recently, Bhagli (2005) has employed a version of the breitug nonpametric cointegration approach used here in the investigation of the French Franc-Deutche Mark rate. The advantage of this approach is that it does not impose any parametric specifications on the relationship.

Nevertheless, in spite of a large body of literature, the empirical tests on the UH are inconclusive and conflicting. The UH is supported by a few early studies (e.g., Cornell, 1977; and Kohlhagen, 1979), but most of the more recent studies e.g., Levich (1979), Bilson (1981), Gregory and McCurdy (1984), Hsieh (1984), Bakshi and Naka (1997), Lin (1999), Lin et al. (2002), and Chernenko et al (2004), among others, have rejected the UH. Similarly, other studies (e.g., Edwards, 1982; Domowitz and Hakkio, 1985; Barnhardt and Szakmary, 1991; and Lin and Chen, 1998) have also provided mixed results for the UH. One reason that is often given for this uncertain state of affairs in this area is that the statistical procedures used in prior literature all have some limitations. It is often contended that better statistical procedures and longer time periods are necessary for better results in this area.

While some prior studies on the forward rate as a forecast of the future spot rate have accounted for non-stationarity in the data series, they have not corrected their statistical procedures for non-normality in the data. Thus, there is clearly a need to use improved methodology that is capable of testing the joint null hypothesis of efficiency and unbiasedness for the foreign exchange market. This is what we do in this paper. In addition to using data series that span over a quarter century, the statistical procedures we use account for non-stationarity and correct for non-normality, both important characteristics of exchange rate data series.

III. Data

The monthly spot and forward rates for five major currencies, expressed in terms of U.S. dollars, were collected from *The Wall Street Journal* and *Datastream*. They are the rates reported at the end of a month. The forward rate time horizons considered are m = 1, 3, 6, and 12 month. The data used cover the period from January 1973 to December 1998, yielding 312 monthly observations for each exchange rate series for a total of 7800 observations. The starting point is chosen to reflect the advent of floating rates and the ending point was dictated by the availability of data for all five currencies examined in this study[4]. These currencies are the Canadian dollar (CN), French frank (FR), German deutsche mark (DM), Japanese yen (JP), and United Kingdom pound sterling (UK).

IV. Model Specifications and Tests of Market Efficiency Hypothesis

Market efficiency hypothesis in forward exchange markets as defined in Hansen and Hodrick (1980) implies that market participants have rational expectations. The rational expectations hypothesis (REH) states that economic agents should make use of all available information in forming expectations and, thus, there should be no systematic patterns in forecast errors, and such errors should be a white noise. Thus, the rational expectations hypothesis asserts that the market's subjective probability distribution for any variable is identical to its objective probability distribution, conditional on all available information. Following Mishkin (1983) and Aggarwal, Mohanty and Song (1995), the appropriate model specification to test the REH is as follows:

$$E_m (S_{j,t+m}|\phi_t) = E (S_{j,t+m}|\phi_t), \qquad (1)$$

Where, ϕ_t = the set of information available including all present and past values of spot and forward rates at time t;

$S_{j,t+m}$ = the spot exchange rate for currency j in period t+m,

$E_m(..|\phi_t)$ = the subjective expectation assessed by the market;

$E(..|\phi_t)$ = the objective expectation conditional on ϕ_t.

Thus, rational expectations, given in equation (1), imply the following condition:

$$E[S_{j,t+m} - E_m(S_{j,t+m} |\phi_t)|\phi_t] = 0. \qquad (2)$$

4 In essence, the replacement of the Deutche Mark by the Euro

Combining equations (1) and (2), the market equilibrium condition can be written as follows:

$$E(S_{j,t+m} - F_{j,t,m}|\phi_t) = 0, \quad (3)$$

where $F_{j,t,m}= E_m(S_{j,t+m}|\phi_t)$, the forward exchange rate for currency j in period t for delivery in m periods(months).

The orthogonally condition represented by equation (3) implies two key properties characterizing rational expectations. They are: (1) the forecast errors (the errors resulting from the use of forward rates for forecasting spot rates) conditional on the available information set (ϕ_t), have zero means i.e., the forecasts are unbiased; and (2) the forecast errors ($S_{j,t+m} - F_{j,t,m}$) should be uncorrelated with any information in ϕ_t, and, therefore, also with their own past values.

Unbiasedness Test

In this paper, we first focus on unbiasedness test, a necessary pretest before carrying out other tests of rational expectations or market efficiency. To test whether forward rates ($F_{j,t,m}$) are unbiased forecasts of future spot rates ($S_{j,t+m}$), we use the following model based on Muth (1961) :

$$S_{j,t+m} = ß_0 + ß_1 F_{j,t,m} + \varepsilon_{j,t+m}, \quad (4)$$

with $ß_0 = 0$ and $ß_1 = 1$; $E(\varepsilon_{j,t+m}) = 0$.

As in Muth (1961), $\varepsilon_{j,t+m}$ must be uncorrelated with $F_{j,t,m}$, the expected value. Moreover, the error series (ε_t) should be characterized by no significant serial correlation. If any of these conditions are not satisfied, then the hypothesis of unbiasedness is rejected.

Accommodating Non-Stationarity: It is well known that regressing one non-stationary series (random walk) against another such series can lead to spurious results in that conventional significance tests will indicate a relation between the variables when in fact none exists (e.g., Phillips, 1986). For example, the slope estimate in general, will be downwardly biased when we regress spot rates series having a unit root on a forward rates series having a unit root. In such case, a conventional significance test would lead toward the rejection of null hypothesis of unbiased forecasts. Prior research on the efficiency of the foreign exchange markets provides evidence that spot rates and forward rates are nonstationary and follow unit root processes[5]. In

[5] See for example, Meese and Singleton (1982), Baillie and Bollerslev (1989), Hakkio and Rush (1989), Barnhart and Szakmary (1991), Liu and Maddala (1992a &1992b), Naka and Whitney (1995), Norrbin and Reffett (1996),

this paper, we first test whether the spot rates and the forward rates used in this paper are all I (1) series (integrated of order 1). In such cases, a more appropriate approach is to estimate a cointegrating factor (e.g., Engle and Granger, 1987; Phillips and Perron, 1988), which is estimated from the cointegrated regression.

To examine the issue surrounding non-stationarity and unit roots associated with spot and forward rates, we use an *augmented Dickey-Fuller* (ADF) test which allows for serial correlation in error term ($\varepsilon_{j,t+m.}$). This is important since unit root tests of spot and forward rates series should take into account any seasonality in the generation of time-series data. The ADF test for unit roots is estimated by running the following OLS regression:[6]

$$S_{j,t+m} - S_{j,t-1+m} = \beta_0 + \beta_1 S_{j,t-1+m} + \beta_2 \Delta S_{j,t-1+m} + \beta_3 \Delta S_{j,t-2+m} \ldots + \beta_n \Delta S_{j,t-n+m} + \nu_{j,t+m} \quad (5)$$

If spot rates $S_{j,t+m}$ and forward rates $F_{j,t,m}$ are non-stationary and follow unit root process, a cointegration test has been suggested. Consistent with Engle and Granger (1987) and Hakkio and Rush (1989), spot rates $\{S_{j,t+m}\}$ and forward rates$\{F_{j,t,m}\}$] are said to be cointegrated if they satisfy the following three conditions. First, the spot rates $\{S_{j,t+m}\}$ and the forward rates $\{F_{j,t,m}\}$ are non-stationary in levels. Second, both spot and forward rate series ($S_{j,t+m}$ and $F_{j,t,m}$) are stationary in first difference. Third, there exists a linear combination of levels where, $u_{j,t+m} = S_{j,t+m} + \beta F_{j,t,m}$ is stationary.

As with the testing of rational expectations hypothesis (REH), the appropriate tests of the market efficiency hypothesis (EMH) in foreign exchange markets must meet the following three conditions: (i) spot rates ($S_{j,t+m}$) and the forward rates ($F_{j,t,m}$) must be cointegrated; (ii) the cointegrating factor must be 1; and (iii) forecast error must be a white noise process, a special case of a stationary series. In this paper, to test the EMH we use the above restricted cointegration tests along with the Q-statistics to test for serial correlation in the residuals.

Corrections for Non-Normality: The cointegrating factor can be estimated by simply running an OLS regression of spot rates ($S_{j,t+m}$) on forward rates ($F_{j,t,m}$). Stock (1987) shows that if ($S_{j,t+m}$) and ($F_{j,t,m}$) are cointegrated, then the estimate of β_1 (cointegrating factor) in the regression will possess a superconsistency property such that the estimated coefficient (cointegrating factor) should converge to its true value more quickly than under more general assumptions (e.g., Stock, 1987). However, one problem that exists in the above analysis is that

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Bakshi and Naka (1997), Lin and Chen (1998) and Lin et al. (2002).

[6] Lag lengths are chosen based on Schwarz (1978) Information Criterion.

the estimator may be biased and its distribution may not be asymptotically normal (e.g., Phillips and Ouliaris, 1990). Thus, usual inference procedures do not work (e.g., Campbell and Perron, 1991).[7] Therefore, we need to correct the estimator of the cointegrating regression using the following three-step error correction model (e.g., Engle and Yoo, 1987; and Aggarwal, Mohanty and Song, 1995).

Step I. The cointegration regression coefficient is estimated from the equation (4):

$S_{j,t+m} = \beta_0 + \beta_1 F_{j,t,m} + \varepsilon_{j,t+m}$.

Step II. Estimate γ from the following regression equation:

$$\Delta S_{j,t+m} = \gamma (S_{j,t+m} - \hat{\beta}_0 - \hat{\beta}_1 F_{j,t,m}) + \beta_1 \Delta F_{j,t,m} + \beta_2 \Delta S_{j,t-1+m} + \beta_3 \Delta F_{j,t-1,m} + \omega_{j,t+m} \qquad 6(a)$$

$$\text{with } \omega_{j,t+m} = \delta_0 + \delta_1(-\gamma * F_{j,t-1,m}) + \mu_{j,t+m} \qquad 6(b)$$

Step III. The correct estimate of cointegration regression coefficient (β_1) is given as:

$$\beta_1 = \hat{\beta}_1 + \hat{\delta}_1 \qquad 6(c)$$

where the studentized coefficient is given by: $t = \beta_1 / std.(\delta_1)$

One alternative method is also deployed, the method of Breitung (2002) who has suggested an alternative, non-parametric procedure. Let y_t be a process

$$y_t = \delta' d_t + x_t , \qquad (7)$$

where d_t is deterministic part, and x_t stochastic. The d_t may include constant, time trend or dummy variables. The stochastic element, x_t, is decomposed as a random walk and a transitory component that represents a short-run dynamics of the process. Breitung first suggests a variance ratio test statistic for a unit root, similar to the one of Kwiatkowski et al. (1992). Breitung's variance ratio test statistic is employed for testing the null hypothesis that y_t ~ I(1) against the alternative y_t ~ I(0). The test statistic constructed as

$$\hat{\rho}_T = \frac{T^{-1}\sum_{t=1}^{T}\hat{U}_t^2}{\sum_{t=1}^{T}\hat{u}_t^2} , \qquad (8)$$

[7] For additional details on the advantages and limitations of using cointegration and analysis to assess time series data, see for example, Phillips and Perron (1988), Campbell and Perron (1991), Banerjee and Hendry (1992), and Engle and Granger (1992).

where $\hat{u}_t = y_t - \hat{\delta}' d_t$ and $\hat{U}_t = \sum_{i=1}^{t} \hat{u}_i$. The limiting distribution of the test statistic is

$$T^{-1}\hat{\rho}_T = \frac{T^{-4}\sum_{t=1}^{T}\hat{U}_t^2}{T^{-2}\sum_{t=1}^{T}\hat{u}_t^2} \Rightarrow \frac{\int_0^1 [\int_0^a \widetilde{W}_j(s)ds]^2}{\int_0^1 \widetilde{W}_j(a)^2 da} . \tag{9}$$

Breitung provides simulated critical values of the asymptotic distribution under the null hypothesis. Breitung next generalises the variance ratio statistic for a nonparametric unit root to test hypotheses on cointegrating rank. The alternative hypothesis here is of stationarity. It is assumed that the process can be decomposed into a *q*-dimensional vector of stochastic components ξ_t and *(n-q)*-dimensional vector of transitory components υ_t. The dimension of the stochastic component is related to the cointegration rank of the linear system by $q=n-r$, where r is the rank of the matrix Π in the vector-error correction representation of the process $\Delta y_t = \Pi y_{t-1} + e_t$.The test statistic for cointegration rank is based on the eigenvalues λ_j ($j = 1,...,n$) of the problem

$$\left|\lambda_j B_T - A_T\right| = 0 , \tag{10}$$

where $A_T = \sum_{t=1}^{T}\hat{u}_t\hat{u}_t'$, $B_T = \sum_{t=1}^{T}\hat{U}_t\hat{U}_t'$ and $\hat{U}_t = \sum_{i=1}^{t}\hat{u}_i$. The eigenvalues of (11) can be found by finding the eigenvalues of the matrix $R_T = A_T B_T^{-1}$. The eigenvalues of (11) can be written as

$$\lambda_j = \frac{(\eta_j' A_T \eta_j)}{(\eta_j' B_T \eta_j)}, \tag{11}$$

where η_j is the eigenvector associated with the eigenvalue λ_j. The test statistic for the hypothesis that $r=r_0$ is given by

$$\Lambda_q = T^2 \sum_{j=1}^{q} \lambda_j , \tag{12}$$

where $\lambda_i \le \lambda_2 \le \lambda_3 \le \ldots \le \lambda_n$, is the series of ordered eigenvalues of the matrix R_T.

The advantage of this testing procedure is that it is independent of the Engle-Granger and Dickey-fuller family of cointegration analyses and provides a degree of methodological triangulation to the research. In particular, it corrects for the issues surrounding non-normality and potential sources of nonstationarity from heteroskedasticity.

V. Empirical Results

Prior to estimating equation (4), it is necessary to know whether the spot rates and forward rates follow a random walk. We use Augmented Dickey-Fuller (ADF) tests to evaluate the stationarity of spot and forward rates ($S_{j,t+m}$ and $F_{j,t,m}$) for five currencies considered during the full sample period, January 1973 through December 1998. These tests are estimated based on equation (5). The coefficient estimates on the lagged value of the level of spot rates as well as forward rates and their studentized coefficients are reported in Table 1 for one-month, three-month, six-month and twelve-month ahead forecast horizons The 5% and 1% critical values are -2.93 and -3.58 respectively (see tables in Dickey and Fuller, 1979). As can be seen from Table 1, the unit root hypothesis for each of these currencies can not be rejected at the 5% level. Consistent with previous findings, the general conclusion that emerges from these results is that while spot and forward exchange rates are non-stationary, they are stationary in first differences.

(Please insert Table 1 about here)

We next turn to the cointegration regression tests. Table 2 presents the results of the cointegration tests for all forecast horizons (m=1, 3, 6, and 12). Tests of co-integration are simply tests to examine whether the residuals based on regressing $S_{j,t+m}$ on $F_{j,t,m}$ with a constant in equation (4) have unit roots. As can be seen from Table 2, the null hypothesis of no-cointegration can be rejected at the 5% level of significance for all exchange rates with the exception of six-month and twelve-month-ahead forecasts for the Swiss Franc (SF). We find that for all forecast horizons (m=1, 3, 6 and 12) forward rates and spot rates are cointegrated in the case of British Pound (BP), German Mark (DM), Japanese Yen (YEN), and the Canadian Dollar (CD). By contrast, in the case of the Swiss Franc (SF), spot and forward rates are cointegrated only for one-month and three-month-ahead forecast horizons (m=1 and 3). With the exception of 6-, and 12- month-ahead forecasts for Swiss Franc, our results suggest that there exists a long-run or equilibrium relation between the forward rates and the corresponding future spot rates. Thus, the spot rate ($S_{j,t+m}$) and the forward rate ($F_{j,t,m}$) series for these cases do not drift too far apart from each other over time, i.e., ($S_{j,t+m}$) and ($F_{j,t,m}$) and are long-term convergent (e.g., Engle and Granger, 1992).

(Please insert Table 2 about here)

The approach above however is a parametric approach. Shown in Table 3 are the results of the Breitung estimations. In all cases, the application of a non-parametric approach indicates cointegration, in all but a few cases this being at the 5% level.

(Please insert Table 3 about here)

However, EMH also require that the cointegrating factor be unity. The cointegrating factor is estimated by running an OLS regression of spot rates ($S_{j,t+m}$) on forward rates ($F_{j,t,m}$). As mentioned earlier, the OLS estimation method might suffer from mis-specification error because the distribution of the OLS estimator of the cointegrating regression (cointegrating factor) is not asymptotically normal so that the cointegrating factor estimated from the OLS regression is likely to be biased. Therefore, the null hypothesis of unbiasedness of the forward rate as a predictor of the future spot rate is likely to be rejected. We correct the bias in the cointegrating factor following the error correction model suggested by Engle and Yoo (1987) and Aggarwal, Mohanty and Song (1995).

Table 4 presents cointegration regression results for all forecast horizons (m=1, 3, 6, and 12) using the OLS estimator (column 2) and the corrected estimator (column 3) based on the three-step error correction model. Results reported in Table 4A (column 3) for 1-month-ahead forecast horizon show that the null hypothesis of the cointegrating factor being unity is rejected at the 5% significance level for British, German and Switzerland foreign exchange rates. In contrast, the corrected estimators for 3-month-ahead forecast horizon suggest that the null hypothesis of unbiasedness (i.e. cointegrated factor equal to 1) is rejected at the 5% significance level for British, German and Japanese exchange markets. Examining the corrected estimates of the cointegrating factors for both 6-, and 12-month-ahead forecast horizons, we notice that the cointegrating factor is significantly different from unity at the 5% significance level for both British and Japanese foreign exchange markets. Please note that the estimated cointegrating factors for 6- and 12- month ahead forecast horizon for the Swiss frank are not estimated as the spot and forward rates have been found to be not cointegrated. Our test results show that only the corrected cointegrating factor for all forecast horizons for Canadian Dollars is not significantly different from unity, providing support for UH hypothesis for the forward exchange rate for the Canadian dollar. Test results for all other currencies provide mixed results. For each of the 1-, 3-, 6- and 12-month-ahead forward exchange rates for British pound indicate that forward rate is a biased indicator of the future spot rate. While the UH for 6- and 12- month-ahead forward rates can not be rejected, the UH for the 1- and 3-month-ahead forward rates is rejected for the German mark. With the exception of the 1-month ahead forward rate, the UH is rejected for all other horizons for the Japanese yen. Similarly, while the UH for 3- month-ahead forward rate can not be rejected, the results for 1-month-ahead forward rate do not provide support for UH for the Swiss frank. In general, except for the Canadian dollar, there is little support for the UH among the other major currencies.

(Please insert Table 4 about here)

The acceptance of REH not only requires that the spot rates ($S_{j,t+m}$) and the forward rates ($F_{j,t,m}$) are cointegrated and the cointegrating factor must be 1, but also that the forecast errors in the forward rate forecasts of the future spot rate must be a white noise. We analyze each of the five currencies and four forecast horizons for which the cointegration analysis for testing REH is appropriate. In Table 5 we report Q-statistics that test for serial correlation in the forecast errors. The critical values for the $Q_{(1)}$, $Q_{(2)}$, $Q_{(3)}$, $Q_{(4)}$, $Q_{(6)}$ and $Q_{(12)}$ statistics are 3.84, 5.99, 7.81, 9.49, 12.59, and 21.03, respectively at the 5 percent significance level. Our results indicate that Q-statistics are significant for most cases and that there is significant serial correlation in the residuals. Although evidence from the cointegration tests suggests that the unbiasedness hypothesis for the forward exchange rates is not rejected for most cases, the significant Q-statistics associated with forecast errors suggest the rejection of the Rational Expectations Hypothesis.

(Please insert Table 5 about here)

VI. Discussion

Unlike prior literature on the forward rate as a forecast of future exchange rates, our methodology accounts and corrects for both non-stationarity and non-normality in the data series. Our results show that there is little empirical support for rational expectations in the forward rates as a forecast of the future spot rate and suggest that the seeming failure of market efficiency is probably attributable to either expectation errors or risk premia or both. A number of studies since Fama (1984) have suggested that risk premia in the foreign exchange markets may be time-varying accounting for the failure of the tests for EMH and the REH.[8] A second explanation for these failures has centered on expectation errors. For example, Frenkel and Froot (1987) provide evidence that investors in foreign exchange market may not have rational expectations. Prior studies also suggest (e.g., Frenkel, 1981; and Ott and Veugelers, 1986) that forward exchange rates which predict future spot exchange rates are influenced by changes in interest and inflation rates differentials and monetary policy changes between countries. These studies imply that the changes in expectations between the time that forward rate prediction is made and the spot rate is observed explain partly the forecast errors. For example, unanticipated changes in interest rate differentials between time t and t+m could lead to expectational errors. While the reasons for deviations from the EMH and the REH remain a topic for future research, using an improved statistical methodology, this study shows clearly that both hypotheses are violated in most foreign exchange markets – the puzzle continues!

However, our results do provide a small hint about the possible direction for future research on this topic. Given the similarity in economic and monetary policies between Canada and the US and that we cannot reject efficiency and rationality for the US dollar forward rate for the Canadian dollar, indicates that future research on this topic may usefully examine international differences related to distance and to differences in monetary and economic policies as possible sources of these deviations from efficiency and rationality.

VI. Conclusions

In spite of high liquidity and low trading costs, forward exchange rates are not efficient or rational forecasts of future spot rates. These results have been a puzzle for many years in spite of numerous empirical studies. It has been suggested that these puzzling results in prior studies may be due to the use of inadequate statistical methodologies. This study uses a new and improved statistical methodology to examine the rationality of forward exchange rates as forecasts of future spot rates. Our study uses data over a long period (1973-1998) and for forecast horizons ranging from one to twelve months for the major industrialized nations' currencies. Unlike prior literature on the forward rate as a forecast of future exchange rates, our methodology accounts and corrects for non-stationarity, non-normality, and heteroskedasticity in the data series. This

[8] Unlike other asset markets, the concept of risk premia in foreign exchange markets is particularly difficult to apply consistently as a currency value is denominated in terms of another currency so that what would be a risk premium for the holder of one currency would be a risk "discount" for the holder of the other currency in a foreign exchange.

improved statistical methodology still documents significant deviations from efficiency and rationality for the US dollar forward rate as a forecast of the future spot rate for the British pound, Japanese yen, Swiss franc, and the German mark. Thus, the forward exchange rate puzzle generally seems robust to improved statistical procedures.

However, our results do provide a small hint about the possible direction for future research on this topic. Given the similarity in economic and monetary policies between Canada and the US and that we cannot reject efficiency and rationality for the US dollar forward rate for the Canadian dollar, indicates that future research on this topic may usefully examine international differences related to distance and to differences in monetary and economic policies as possible sources of these deviations from efficiency and rationality.

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Table 1: UNIT ROOT TESTS: SPOT AND FORWARD EXCHANGE RATES

This table provides unit root test results for spot rates as well as forward exchange rates for five major currencies using sample period January 1973- December 1998. The Augmented Dickey-Fuller (ADF) test is based on the following regression:

$$S_{j,t+m} - S_{j,t-1+m} = ß_0 + ß_1\, S_{j,t-1+m} + ß_2\, \Delta\, S_{j,t-1+m} + ß_3\, \Delta\, S_{j,t-2+m} \ldots + ß_n\, \Delta\, S_{j,t-n+m} + \nu_{j,t+m}$$

The variable Sj,t+m = Time series exchange data. Value of t-ratio is reported in parentheses. The 5% and 1% critical values for the Dickey-Fuller (1976) tests are –2.89 and –3.14, respectively.

** Evidence of rejection of a unit root at the 5% level.
*** Evidence of rejection of a unit root at the 1% level.

Currency		**Augmented Dickey-Fuller tests**	
		Levels	**Differences**
Spot	British Pound	-0.02954 (-2.4841)	-1.03334 (-18.1292) ***
	German Mark	-0.01711 (-1.8035)	-0.96064 (-16.6538) ***
	Japanese Yen	-0.00641 (-.9214)	-0.01803 (-17.6395) ***
	Canadian Dollar	-0.00539 (-.8354)	-1.07284 (-18.7198) ***
	Swiss Franc	-0.01662 (-1.8993)	-0.92786 (-16.1593) ***
1 Mo Frwd	British Pound	-0.02583 (-2.5310)	-0.90869 (-15.9065) ***
	German Mark	-0.01714 (-1.7887)	-0.98061 (-16.9993) ***
	Japanese Yen	-0.00659 (-.9604)	-0.94991 (-16.4412) ***
	Canadian Dollar	-0.00632 (-.9396)	-1.10563 (-19.2845) ***
	Swiss Franc	-0.01665 (-1.9052)	-0.93656 (-16.3096) ***

(to be continued)

Table 1 (continued): UNIT ROOT TESTS: SPOT AND FORWARD EXCHANGE RATES

Currency		**Augmented Dickey-Fuller tests**	
		Levels	**Differences**
3 Mo Frwd	British Pound	-0.02635	-0.92938 **
		(-2.5477)	(-16.2707) ***
	German Mark	-0.01728	-0.98763
		(-1.7877)	(-17.1256) ***
	Japanese Yen	-0.00659	-0.9519
		(-.9537)	(-16.4648) ***
	Canadian Dollar	-0.0077	-1.13576
		(-1.1099)	(-19.8481) ***
	Swiss Franc	-0.01683	-0.93391
		(-1.9172)	(-16,2613) ***
6 Mo Frwd	British Pound	-0.02661	-0.90607
		(-2.5869)	(-15.8704) ***
	German Mark	-0.01813	-1.04213
		(-1.7448)	(-18.0934) ***
	Japanese Yen	-0.00679	-1.07012
		(-.9139)	(-18.6153) ***
	Canadian Dollar	-0.00801	-1.14297
		(-1.1229)	(-19.9424) **
	Swiss Franc	-0.01727	-0.95986
		(-1.9303)	(-16.7137) **
12 Mo Frwd	British Pound	-0.0302	-1.03124
		(-2.4929)	(-18.1157) ***
	German Mark	-0.01899-1.05419	
		(-1.7940)	(-18.3058) ***
	Japanese Yen	-0.00636-0.98964	
		(-.9135)	(-17.1413) ***
	Canadian Dollar	-0.00907-1.12936	
		(-1.2405)	(-19.7194) ***
	Swiss Franc	0.01772	-0.99773
		(-1.9357)	(-17.3793) ***

Table 2: COINTEGRATION TESTS

This table presents cointegration regression test results for all forecast horizons. The Augmented Dickey-Fuller Tests are based on the following regression:

$$\Delta U_t = \Phi_0 + \Phi_1 u_{t-1} + \Phi_2 \Delta u_{t-1} + \Phi_3 \Delta_{t-2} + v_t$$

Value of t- ratio is reported in parentheses. The 5% and 1% critical values for the Dickey-Fuller tests are -2.90 and -3.58 respectively. $S_{j,t+m}$ = Spot exchange rates and $F_{j,t,m}$ = Forward exchange rates. U_t is the residual from regression $S_{j,t+m}$ on $F_{j,t,m}$.

** Rejection of null hypothesis of no cointegration at the 5% level.
*** Rejection of null hypothesis of no cointegration at the 1% level.

Currency/Horizon	Month = 1	Month = 3	Month = 6	Month = 12
British Pound	-0.97456*** (-9.9671)	-0.62952*** (-7.6822)	-0.33127*** (-5.4994)	-0.05892** (-3.1042)
German Mark	-0.85124*** (-9.1026)	-0.70688*** (-8.123)	-0.49119*** (-6.5775)	-0.26907*** (-4.7662)
Japanese Yen	-0.66252*** (-8.3331)	-0.51616*** (-7.2082)	-0.46189*** (-6.632)	-0.20936*** (-4.3925)
Canadian dollar	-0.89584*** (-9.8799)	-0.68552*** (-8.2782)	-0.4013*** (-6.1001)	-0.20459*** (-4.3071)
Swiss Franc	-0.43537*** (-6.2032)	-0.10839** (-3.1161)	-0.05497 (-2.4032)	-0.04171 (-2.3132)

Table 3 BREITUNG NONPARAMETRIC COINTEGRATION ESTIMATION

Table shows the calculated test statistic for Breitungs nonparametric cointegration test. This tests Ho: r=0 against Ha:r>0, where *r* is the rank of the matrix Π in the vector-error correction representation of the process $\Delta y_t = \Pi y_{t-1} + e_t$. The test statistic for cointegration rank is based on the eigenvalues λ_j ($j = 1,...,n$)of the matrix $R_T = A_T B_T^{-1}$. The test statistic for the hypothesis that $r=r_0$ is given by $\Lambda_q = T^2 \sum_{j=1}^{q} \lambda_j$,where $\lambda_i \leq \lambda_2 \leq \lambda_3 \leq \ldots \leq \lambda_n$, is the series of ordered eigenvalues of the matrix R_T. ** indicates rejection of the null at 5%, * at 10%

	Japanese		UK		Swiss		Germany		Canada	
	No Drift	Drift	No Drift	Drift	No Drift	Drift	No Drift	Drift	No Drift	Drift
1	2563.73**	2337.2**	5306.04**	5543.51**	4134.49**	4272.42**	2654.4**	2730.49**	2441.87**	2487.94**
3	938.27**	1001.5**	1842.06**	2150.35**	1636.36**	1873.96**	1190.7**	1283.1**	605.36**	638.8**
6	505.69**	584.52**	1061.69**	1278.39**	918.07**	1164.75**	689.68**	798.8**	340.05**	387.11**
12	251.28*	314.99*	555.28**	722.56**	467.37**	702.99**	369.39**	477.62**	217.57*	262.91*

Table 4: TESTS FOR COINTEGRATING FACTOR ($H_0 : \beta_1 = 1$)

The rational expectations hypothesis (REH) suggests that the cointegrating factor must be 1. This table provides the results for cointegrating factor before and after the correction.

Cointegration regression: $S_{j,t+m} = \beta_0 + \beta_t F_{j,t,m} + E_{j,t+m}$

Estimated coefficient is based on the cointegration regression. Corrected coefficient is based on the three – step error correction model suggested by Engle and Yoo (1987).

** Cointegrating factor significantly different from unity at 5% level.
*** Cointegrating factor significantly different from unity at 1% level

Currency	Estimated Coefficient (β_1)	Corrected Coefficient (β_1)
	Month = 1	
British Pound	1.01084 *** (0.00420)	1.01037 *** (0.00304)
German Mark	0.99672 (0.00722)	0.98674 *** (0.00349)
Japanese Yen	0.99912 (0.00366)	0.99703 (0.00277)
Canadian Dollar	1.00556 (0.00429)	1.00463 (0.00367)
Swiss Franc	1.00301 *** (0.00113)	1.00260 ** (0.00124)
	Month = 3	
British Pound	1.01803 *** (0.00503)	1.01730 *** (0.00455)
German Mark	(1.00298) (0.00762)	0.99155 ** (0.00429)
Japanese Yen	0.99335 (0.00392)	0.99063 *** (0.00337)
Canadian Dollar	1.00761 (0.00468)	1.00703 (0.00458)
Swiss Franc	1.00349 (0.00224)	1.00004 (0.00526)

Table 4 (continued): TEST FOR COINTEGRATING FACTOR ($H_0 : \beta_1 = 1$)

Cointegration regression: $S_{j,t+m} = \beta_0 + \beta_t F_{j,t,m} + E_{j,t+m}$

Currency	Estimated Coefficient (β_1)	Corrected Coefficient (β_1)
	Month = 6	
British Pound	1.02584*** (0.00638)	1.02309 *** (0.00834)
German Mark	1.01184 (0.00898)	0.99485 (0.00684)
Japanese Yen	0.98431 *** (0.00463)	0.98004 *** (0.00419)
Canadian Dollar	1.00753 (0.00566)	1.00628 (0.00798)
Swiss Franc *	….. …..	….. …..
	Month = 12	
British Pound	1.00822 (0.00702)	0.97305 *** (0.00886)
German Mark	1.01158 (0.01110)	0.98591 (0.01266)
Japanese Yen	0.96686 *** (0.00548)	0.96018 *** (0.00736)
Canadian Dollar	1.00471 (0.00774)	1.00125 (0.01652)
Swiss Franc *	….. …..	….. …..

Table 5: Q-STATISTICS FOR FORECAST ERRORS

This table presents results for Q-statistics which indicates whether the forecast errors follow white noise processes (a special case of stationary series).

The 5 percent significant levels for Q_statistics: Q(1), Q(2), Q(3), and Q(4) are 3.84, 5.89, 7.81, and 9.49. # Month 1 estimates go upto 12 lags while the others go upto 4 lags. In the case of monthly forecast, we chose longer lag length (upto 12 lags) due to largest number of observation available for this horizon.

** Indicates rejection of no serial correlation in forecast errors at the 5% level.

#A: Month = 1

Currency	**Q(1)**	**Q(3)**	**Q(6)**	**Q(12)**
British Pound	0.8765	1.0197	2.4716	2.8942
German Mark	0.0039	1.1882	4.3432	19.1753
Japanese Yen	0.0165	4.7527	14.8477**	58.6184**
Canadian Dollar	0.6519	6.9985	7.4554	27.0107**
Swiss Franc	24.7154**	28.7623**	34.1136**	44.1489**

B: Month = 3

Currency	**Q(1)**	**Q(2)**	**Q(3)**	**Q(4)**
British Pound	10.45919**	11.62315**	12.55241**	15.93822**
German Mark	0.1150	2.1839	5.6828	5.7359
Japanese Yen	0.4422	0.8157	9.6078**	10.2183**
Canadian Dollar	5.90116**	16.74288**	16.86078**	18.56702**
Swiss Franc	46.87251**	47.537**	47.54166**	47.60085**

C: Month = 6

Currency	**Q(1)**	**Q(2)**	**Q(3)**	**Q(4)**
British Pound	26.3072**	26.597**	26.6825**	30.4424**
German Mark	3.0998	7.6871	15.7218**	16.7679**
Japanese Yen	6.8532**	6.9166**	12.4265**	12.7039**
Canadian Dollar	21.3207**	36.835**	36.8755**	41.2689**

D: Month = 12

Currency	**Q(1)**	**Q(2)**	**Q(3)**	**Q(4)**
British Pound	0.0049	0.4351	6.2347	6.3171
German Mark	16.6479**	19.1331**	27.2829**	28.2802**
Japanese Yen	18.8925**	24.5567**	31.7304**	31.7304**
Canadian Dollar	44.9948	59.6053	60.5638	64.3174

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