THE FORWARD-BIAS PUZZLE: A SOLUTION BASED ON COVERED INTEREST PARITY*

John Pippenger
Department of Economics
University of California
Santa Barbara

The forward-bias puzzle is probably the most important puzzle in international macroeconomics. After more than 20 years, there is no accepted solution. My solution is based on covered interest parity (CIP). CIP implies: (1) Forward rates are not rational expectations of future spot rates. Those expectations depend on future spot rates and interest rate differentials. (2) The forward bias is the result of a specification error, replacing future forward exchange rates with current forward exchange rates. That misspecification is the direct result of (1). Implication (1) has the further implication that, in general, covered and uncovered interest parity are inconsistent.

JEL: E43, E44, F30, F31, G14, G15
Keywords: forward bias, covered interest parity, arbitrage

DRAFT VERSION AS OF 26 MARCH 2009. PLEASE DO NOT CITE WITHOUT PERMISSION OF THE AUTHOR.

Author: pipp@ix.netcom.com, 619-423-3618

* I want to thank Balke and Wohar for their data.

The forward-bias puzzle is probably the most important puzzle in international macroeconomics. The puzzle is important because it suggests that there are serious informational inefficiencies in foreign exchange markets.[1] I propose a solution based on covered interest parity. When covered interest parity holds, then: (1) Contrary to the usual interpretation, in general, current forward exchange rates are not rational expectations of future spot exchange rates. (2) Under certain special conditions, forward premiums will predict that exchange rates will move in one direction when it is likely that they will move in the opposite direction. (3) The econometric source of the forward bias is specification error due to (1), not an informational inefficiency.

Section I briefly reviews the forward-bias puzzle. Section II reviews the recent evidence regarding covered interest parity. Section III explains why covered interest parity implies items (1) through (3) above. Section IV provides some empirical evidence to support this solution to the forward puzzle. Section V summarizes the article and concludes that the forward premium is a reasonable (partial) predictor of the change in the exchange rate.

I. The Forward-Bias Puzzle

There is a large literature claiming that the forward premium is a biased predictor of the actual change in the exchange rate.[2] Let s_t be the logarithm of the current spot price for foreign exchange S_t, f_t be the logarithm of the current forward exchange rate F_t and s_{t+1} the logarithm of the future spot rate S_{t+1}. Using equations like (1), estimates of β are routinely closer to 0.0 than to 1.0 and are often negative.

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

Those negative estimates seem to imply an informational inefficiency. Exchange rates apparently fall when the forward premium predicts that they will rise and the reverse. That apparent predictive error is the forward-bias puzzle.

There have been many attempts to solve this puzzle. They include among others Goodhart, McMahon and Ngama (1992), Sarno, Valente and Leon (2006) and Sercu and Vinaimont (2006), Chakraboty and Haynes (2008) and Chakraborty and Evans (2008). But none

[1] For a discussion of the other puzzles see Obstfeld and Rogoff (2000).
[2] For a discussion of the puzzle and a review of the literature see Sarno (2005). More recent articles include Sarno, Valente and Leon (2006), Sercu and Vinaimont (2006), Kearns (2007), Chakraboty and Haynes (2008), Chakraborty and Evans (2008) and Wang and Wang (2009).

of these suggested solutions, or any other solutions, have been widely accepted. Most recently Wang and Wang (2009) argue that the "wrong signs and absurd sizes" are empirically irrelevant.

II. Covered Interest Parity

Covered interest parity is an equilibrium condition implied by effective arbitrage. Equation (2) describes covered interest parity as an equilibrium condition.

$$(f_t - s_t) - (i_t - i_t^*) = \pm e_t \qquad (2)$$

Where i is the domestic interest rate, i* is the foreign interest rate and $\pm e_t$ captures the errors within the thresholds caused by transaction costs.[3] These interest rates should be risk free and their maturities must match the maturity of the forward exchange rate.

After accounting for the transaction costs, covered interest parity appears to hold on a day-to-day basis. As Akram, Rime and Sarno (2008), point out "It seems generally accepted that financial markets do not offer risk-free arbitrage opportunities, at least when allowance is made for transaction costs." In the Conclusions to their article, Akram, Rime and Sarno explain in more detail how covered interest rate arbitrage works.

> This paper provides evidence that short-lived arbitrage opportunities arise in the major FX and capital markets in the form of violations of the CIP condition. The size of CIP arbitrage opportunities can be economically significant for the three exchange rates examined and across different maturities of the instruments involved in arbitrage. The duration of arbitrage opportunities is, on average, high enough to allow agents to exploit deviations from the CIP condition. However, duration is low enough to suggest that markets exploit arbitrage opportunities rapidly. These results, coupled with the unpredictability of the arbitrage opportunities, imply that a typical researcher in international macro-finance can safely assume arbitrage-free prices in the FX markets when working with daily or lower frequency data.

See Balke and Wohar (1998) for evidence of the thresholds created by transaction costs.

For simplicity of exposition, the next section ignores the thresholds created by transaction costs and assumes that $(f_t - s_t) = (i_t - i_t^*)$. Transaction costs re-enter the discussion in Section IV where they play an important role in explaining low Durbin-Watson statistics.

III. Some Implications of Covered Interest Parity

From this point on the discussion assumes that, ignoring transaction costs, covered interest parity holds. Given that assumption, the following statements hold: (1) Current forward

[3] Without logarithms, the equilibiurm condition is $[F_t/S_t]/[(1+i_t)/(1+i_t^*)] = (1 \pm e_t)$.

exchange rates are not, in general, rational expectations of future spot exchange rates. (2) Under certain special conditions, forward premiums will predict that exchange rates will move in one direction when it is likely that they will move in the opposite direction. (3) The primary source of the apparent forward bias is specification error. Item (1) is the "real" source of the apparent forward bias. Item (3) is the "econometric" source.

A. *Forward Exchange Rates Are not Rational Expectations of Future Spot Rates*

When covered interest parity holds, the current exchange rate equals the forward rate minus the interest rate differential.

$$s_t = f_t - (i_t - i_t^*) \tag{3}$$

But equation (3) also holds for s_{t+1}.

$$s_{t+1} = f_{t+1} - (i_{t+1} - i_{t+1}^*) \tag{4}$$

As a result, the rational expectation at time t of s_{t+1} denoted s_{t+1}^E is

$$s_{t+1}^E = f_{t+1}^E - (i_{t+1}^E - i_{t+1}^{*E}) \tag{5}$$

where x_{t+1}^E is the expectation at time t of x_{t+1}. In general, f_t will not equal $f_{t+1}^E - (i_{t+1}^E - i_{t+1}^{*E})$.

One special situation where that condition holds is in a steady state equilibrium where real interest rates are equal and there is no inflation. In that case, the expected future spot exchange rate will equal the expected future exchange rate and that rate will equal the current forward exchange rate.

As far as I am aware, all previous discussions, tests and explanations of the forward bias have assumed that the forward exchange rate represents the market's expectation of the future spot exchange rate. They have, in effect, assumed a steady state equilibrium. That assumption is the real error in the literature and the direct source of the econometric error.

The fact that f_t does not, in general, equal $f_{t+1}^E - (i_{t+1}^E - i_{t+1}^{*E})$ also implies that covered and uncovered interest parity are generally inconsistent.[4] That inconsistency may help explain why the evidence regarding uncovered interest parity is so mixed. For a recent discussion of that evidence and some new evidence on uncovered interest parity see Bekaert, Wei and Xing (2007).

B. *A Special Case*

When covered interest parity holds, the forward premium equals the nominal interest rate differential. That is, $f_t - s_t = (i_t - i_t^*)$ or $F_t/S_t = (1+i_t)/(1+i_t^*)$. Nominal interest rates contain both a

[4] One situation where the two are consistent is when the neutral ranges created by transaction costs overlap.

real and an inflationary component. In equilibrium, $(1 + i) = (1 + r)(1 + \dot{P}^E)$ where r is the real interest rate and $\dot{P}^E$ reflects the market's expected rate of inflation over the maturity of i.

Consider the case where $f_t - s_t$ and $i_t - i^*_t$ are both positive, but $\dot{P}^E_t - \dot{P}^{*E}_t$ is negative. The forward premium suggests that the exchange rate will rise because the positive real differential is larger than the negative inflation differential. But the inflation differential is likely to be associated with the domestic price of foreign exchange falling.

Although this special case may contribute to the estimated forward bias, it is almost certainly not the primary cause. The primary cause is the specification error due to assuming that the forward exchange rate is the market's expectation of the future spot exchange rate.

C. *Specification Errors*

When covered interest parity holds, equation (4) holds and equation (6) describes a correctly specified equation for the future change in the spot exchange rate Δs_{t+1}.

$$\Delta s_{t+1} = a + b(f_{t+1} - s_t) - c(i_{t+1} - i^*_{t+1}) \qquad (6)$$

Compared to equation (6), the standard test equation described by equation (1) contains two specification errors. The first is the result of replacing f_{t+1} with f_t. That replacement produces equation (7).

$$\Delta s_{t+1} = A + B(f_t - s_t) - C(i_{t+1} - i^*_{t+1}) \qquad (7)$$

The second specification error is to omit $(i_{t+1} - i^*_{t+1})$. That omission produces equation (1).

$$\Delta s_{t+1} = \alpha + \beta(f_t - s_t) \qquad (1)$$

As the next section shows, omitting the interest differential does not appear to cause serious problems. But replacing f_{t+1} with f_t reduces the estimates of β, often making them negative.

IV. Empirical Results

I assume that the residuals from all the regressions in this section are at least globally stationary is spite of occasionally small Durbin-Watson statistics. That assumption is based on the evidence that, after taking account of the transaction costs, covered interest parity holds day to day.

A. *Estimates of Equations (6), (7) and (1).*

Table 1 reports estimates of equations (6), (7) and (1) over two intervals between the United States and Canada and over two intervals between the United States and the United Kingdom. For US-Canada, the weekly interest rates are 13 week Treasury bills. Those interest rates are from various issues of the *Federal Reserve Bulletin* starting in the issue of October 1964. Spot and forward exchange rates are for noon and were supplied by the Bank of Canada. As the *Bulletin* makes clear, the Treasury bill rates are only approximations of the rates needed for arbitrage.[5] The data run from January 1961 to June 1973.[6] The first interval for Canada in Table 1 covers the era of pegged exchange rates that started *de facto* in December 1960 and ended in May 1970. The second interval covers a period of flexible exchange rates from June 1970 to June 1973.[7]

For the United Kingdom and the United States, the data are from Balke and Wohar (1998). Their interest rates are one month euro rates. See Balke and Wohar (1998) for more details.[8] Their daily data start in January 1974 and end in September 1993. To account for any effects of the switch to flexible rates in the early 1970s, the interval is divided into roughly two equal parts. The first begins in January 1974 and runs through early November 1983. The second begins the next day and ends in early September 1993.[9]

For the Canadian data, where the interest rates are for 91 days, the future spot and future forward exchange rates are t plus 13 weeks. For the UK data, where the interest rates are for 30 days, the future spot and future forward exchange rates are t plus 22 observations.[10]

The data are not ideal. Interest rates, future spot exchange rates and forward rates are not always matched exactly. Particularly for the US-Canadian data, the timing of the observations is not ideal. Future research should correct those shortcomings. However it seems unlikely that correcting those shortcomings will change the basic message. The forward-bias puzzle is the

---

[5] For a detailed description of the interest rates, see the issue of October 1964.

[6] The data start in January 1959 when rates were flexible. I start in January 1961 because the rates were pegged *de* facto in December of 1960. The data end in August 1973, but 13 weeks are lost due to the difference between spot and forward exchange rates.

[7] For both US-Canada and US-UK, missing observations are replaced with the previous observation. If two observations in a row are missing, the first is replaced with the previous observation and the second with the following observation.

[8] The data in Balke and Wohar (1998) are bid and ask. Like them, I use the geometric mean of the bid and ask.

[9] Twenty two observations are lost because the interest rates are 30 day. With five business days per week, 22 observations correspond to 30 calendar days.

[10] For the 13 week Canadian data, future rates always fall on the same day of the week as the spot rate. For the 30 day data, future rates can fall on a weekend. In that case, the next business day is used.

result of equation (1) containing specification errors implied by covered interest parity. The most important error is replacing f_{t+1} with f_t. That substitution is the direct result of the assumption that the forward exchange rate is the market's expectation of the future spot exchange rate.

In addition to reporting the estimated coefficients for equations (6), (7) and (1), Table 1 also reports the adjusted R^2 or $\bar{R}^2$ and the Durbin-Watson statistic or DW. The $\bar{R}^2$ provides an indication of the effect of the specification errors as we move through the three equations. The DW statistic indicates how the serial correlation in the residuals increases as we move through the three equations. Table 1 also reports the averages for the $\bar{R}^2$, the DW statistic, the coefficients and their standard errors.[11]

Estimates of equation (6) in Table 1 support covered interest parity. All the estimated *b*s or $\hat{b}$s are close to 1.0 with small standard errors. The average $\hat{b}$ is 0.994. All $\hat{c}$s are negative and 3 of the four estimates are close to -1.0. The average $\hat{c}$ is -0.991. The average $\bar{R}^2$ is 0.992. The average DW statistic is 0.909, which is respectable considering the thresholds created by transaction costs.

Moving from equation (6) to (7) by replacing f_{t+1} with f_t changes the results substantially.[12] The average $\hat{B}$ is -1.236 and estimates vary widely. The average $\hat{C}$ remains negative, -0.584, but estimates also vary widely with one estimate positive. In addition, both the average $\bar{R}^2$ and DW drop drastically. The average $\bar{R}^2$ falls from 0.992 to 0.112. The average DW falls from 0.909 to 0.136.

Moving from equation (7) to (1) by dropping the future interest rate differential affects the estimated coefficient for $(f_t - s_t)$ only slightly, -1.236 versus -1.221. The major effect of dropping the future interest rate differential is to reduce the average $\bar{R}^2$ from 0.112 to 0.015 and to reduce the average DW from 0.136 to 0.103.

To summarize the results in Table 1, the major cause of the forward-bias puzzle appears to be replacing f_{t+1} with f_t. Omitting the future interest rate differential has little effect.

[11] All the estimates use RATS with "Robusterrors".

[12] Omitting the future interest rate differential has only a small effect on the coefficient for $(f_{t+1} - s_t)$.

B. *Levels*

Negative estimates of β from equation 1 are not the only puzzle associated with estimates of that equation. Another puzzle that needs to be explained by a valid solution to the forward-bias puzzle is the drastic difference between the results of the early research and the later research. Early research used a version of equation (1) in levels like equation 8.

$$s_{t+1} = \boldsymbol{\alpha} + \boldsymbol{\beta} f_t \tag{8}$$

With equation 8, estimates of $\boldsymbol{\beta}$ were usually close to one and were never negative.[13] Equation 1 replaced equation 8 because of the possibility of spurious results caused by unit roots.

Covered interest parity can shed light on the drastic difference in the estimates of equations (1) and (8).[14] According to covered interest parity, equation (9) describes the appropriate relation between the forward rate and the future spot rate.

$$s_{t+1} = \mathbf{a} + \mathbf{b} f_{t+1} - \mathbf{c}(i_{t+1} - i^*_{t+1}) \tag{9}$$

Replacing f_{t+1} with f_t produces equation 10.

$$s_{t+1} = \mathbf{A} + \mathbf{B} f_t - \mathbf{c}(i_{t+1} - i^*_{t+1}) \tag{10}$$

Dropping the interest rate differential produces equation 8 above.

Table 2 reports the results of estimating these three equations using the same data as in Table 1. As in Table 1, the estimates of equation (9) in Table 2 are consistent with covered interest parity given the existence of thresholds. The fit is very good. The average $\hat{\mathbf{b}}$ is essentially 1.0. The average $\hat{\mathbf{c}}$ is -0.8. The average $\bar{R}^2$ is 0.996. The average DW is 0.667.

But the changes from equation (9) to (10) in Table 2 are quite different from the changes from (6) to (7) in Table 1. In Table 1, the average $\hat{b}$ is very close to 1.0 and the average $\hat{B}$ is close to -1. In Table 2, the $\hat{\mathbf{b}}$ remain close to 1.0, but all the $\hat{\mathbf{B}}$ are positive, highly significant and closer to 1.0 than to 0.0.

In both tables, omitting the interest rate differential has little effect. In Table 1 the average $\hat{B}$ is -1.236 and the average $\hat{\beta}$ is -1.221. In Table 2 the average $\hat{\mathbf{B}}$ is 0.850 and the average $\hat{\boldsymbol{\beta}}$ is 0.816.

---

[13] For an example of such estimates, see Chakraborty and Haynes (2008).

[14] For an alternative explanation, see Chakraborty and Haynes (2008).

As Table 3 illustrates, the reason for the drastic difference between the estimates of equations (8) and (1) is that f_t is a good proxy for f_{t+1}, but $f_t - s_t$ is a poor proxy for $f_{t+1} - s_t$. Table 3 reports the cross-correlations between f_t and f_{t+1} and between $f_t - s_t$ and $f_{t+!} - s_t$. Moving from left to right, the four intervals in Table 3 are re-arraigned so that the $\hat{\beta}$s decline from left to right. This arraignment highlights the role of the cross-correlation between $f_t - s_t$ and $f_{t+!} - s_t$ in producing negative estimates of β.

Estimates of B in Table 2 are positive because f_t is a reasonable proxy for f_{t+1}. The average cross-correlation between f_t and f_{t+1} in Table 3 is 0.89. Estimates of β in Table 1 are small and often negative because $f_t - s_t$ is a poor proxy for $f_{t+1} - s_t$. Cross-correlations between $f_t - s_t$ and $f_{t+1} - s_t$ in Table 3 are much smaller than between f_{t+1} and f_t and often negative. The largest cross correlation between $f_t - s_t$ and $f_{t+1} - s_t$ is only 0.14. The smallest cross correlation between f_t and f_{t+1} is 0.74.

Using covered interest parity as the benchmark, Subsection C below examines the effects of the linear restriction in equation 1 and the cross-correlations between the relevant variables.[15] The linear restriction does not appear to be important. It is the cross-correlations between the relevant variables that cause the apparent forward bias.

C. *Linear Restrictions and Cross-Correlations*

This section ignores interest rate differentials and concentrates on the effects of the linear restriction and replacing f_{t+1} with f_t.

Estimates of equations (11) and (12) are used to evaluate the effects of the linear restriction. Equation 11 is equation (6) without an interest rate differential or linear restriction.

$$\Delta s_{t+1} = a_0 + b_1 ft_{+1} - b_2 s_t \qquad (11)$$

Equation (12) is equation (1) without a linear restriction.

$$\Delta s_{t+1} = \alpha_0 + \beta_1 f_t - \beta_2 s_t \qquad (12)$$

Table 4 reports the estimates for equations (11) and (12). The order of the estimates from top to bottom is the same as the order in Table 3 from left to right. With f_{t+1} in equation (11), all $\hat{\mathbf{b}}_1$ have the right sign and three of the four are close to 1.0. All $\hat{\mathbf{b}}_2$ also have the right sign and three of the four are close to -1.0. Except for Canada from 1970 to 1973, the linear restriction

[15] See Haynes and Stone (1982) for a discussion of the potential effects of inappropriate linear restrictions in situations like this one.

that $\hat{\mathbf{b}}_1$ equals $\hat{\mathbf{b}}_2$ appears reasonable when using f_{t+1}. Even the potential problem with the linear restriction for Canada from 1970 to 1973 does not cause a problem in Table 2 where the estimate of b is close to 1.0.

The results for $\hat{\boldsymbol{\beta}}_1$ and $\hat{\boldsymbol{\beta}}_2$ where f_t replaces f_{t+1} are very different. All the $\hat{\boldsymbol{\beta}}_1$ are negative and vary over a wide range. Only one $\hat{\boldsymbol{\beta}}_2$ is negative and that estimate is not significant. The $\hat{\boldsymbol{\beta}}_2$ also vary over a wide range. The linear restriction in equation (1) does not seem to be the problem behind the apparent forward bias. That apparent bias appears to be the result of sign reversals between $\hat{\mathbf{b}}_1$ and $\hat{\boldsymbol{\beta}}_1$ and between $\hat{\mathbf{b}}_2$ and $\hat{\boldsymbol{\beta}}_2$.

Table 5 uses four cross-correlations to explain that sign reversal: (1) between f_t and s_t or f_{t+1} and s_{t+1}, (2) between f_t and f_{t+1}, (3) between f_t and s_{t+1}, and (4) between s_t and s_{t+1}. The order of the intervals in Table 5 is the same as in Table 4. $\hat{\mathbf{b}}_1$ and $\hat{\mathbf{b}}_2$ in Table 4 have the right signs because f_{t+1} is highly correlated with s_{t+1}. The average cross-correlation between the future forward and future spot exchange rates is 0.994. That cross-correlation is larger than the average between s_t and s_{t+1}, which is 0.888.

The forward bias reflects the fact that $\hat{\boldsymbol{\beta}}_1$ and $\hat{\boldsymbol{\beta}}_2$ in Table 4 have the wrong sign or are insignificant. That sign reversal is primarily the result of two cross correlations: (1) f_t is more closely correlated with s_t than with s_{t+1}, and (2) cross correlations between s_t and s_{t+1} are about the same as the cross correlation between than f_t and s_t. The average correlation between f_t and s_t is 0.994, but the average correlation between f_t and s_{t+1} is only 0.878. Correlations between s_t and s_{t+1} and between f_t and s_{t+1} are both fairly large and similar: on average 0.888 between s_t and s_{t+1} and 0.878 between f_t and s_{t+1}.

The one case in Table 1 where $\hat{\boldsymbol{\beta}}$ is positive, but not significantly different from 0.0, is Canada from 1970 to 1973. That small positive $\hat{\boldsymbol{\beta}}$ appears to be the result of the correlations between f_t and s_{t+1} and between s_t and s_{t+1} both being relatively low. In Table 5, Canada from 1970 to 1973 has the smallest correlations between f_t and s_{t+1} and between s_t and s_{t+1}, 0.687 and 0.721 respectively.

Of course additional research is needed, but these results suggest that the puzzle of the forward bias is the result of $f_t - s_t$ being a very poor proxy for $f_{t+1} - s_t$. The forward premium appears to be a poor proxy for f_{t+1} - s_t because f_t is more highly correlated with s_t than with s_{t+1} and s_t is about as closely correlated with s_{t+1} as f_t.

D. *Relative Variances*

There is another puzzle that a valid solution to the forward-bias puzzle needs to explain. That puzzle is the drastic difference between the variance of the spot exchange rate and the variance of the forward premium. Wang and Wang (2009, p. 186) document this difference. "The figures in the last column further demonstrate that the variance of spot rate changes is in the range of 100-200 times the variance of the forward premium."

Covered interest parity explains why this is the case. The variance in the forward premium is small because the variance in the interest rate differential is small. The variance in Δs_{t+1} is much larger because the variance in Δf_{t+1} is much larger.

If covered interest parity holds, then equation 6 describes a test equation that is correctly specified.

$$\Delta s_{t+1} = a + b(f_{t+1} - s_t) - c(i_{t+1} - i^*_{t+1}) \qquad (6)$$

If one adds the current forward rate and also subtracts it from equation 6, that reformulation produces a correctly specified equation that includes the forward premium.

$$\Delta s_{t+1} = \lambda_0 + \lambda_1(f_t - s_t) + \lambda_2\Delta f_{t+1} - \lambda_3(i_{t+1} - i^*_{t+1}) \qquad (13)$$

As implied by covered interest parity and as Table 6 shows, the variance of the forward premium is small because the variance of the interest rate differential is small. The variance of the spot exchange rate is much larger because the variance of the change in the forward exchange rate is much larger.[16]

Equation 13 suggests one final test of the forward bias. The main advantage of this final test is that it is consistent with covered interest parity and includes the forward premium

D. *Estimating Equation 13*

Table 7 reports the results of estimating equation 13 for the same country pairs and intervals used earlier. The order of the intervals and countries is the same as in Table 6. All the relevant parameters in Table 7 have the correct sign and are highly significant. They are all closer to their predicted values than to 0.0. All the $\bar{R}^2$ are at least 0.98 and two are 0.999. The Durbin-Watson statistics for US-Canada are relatively low, suggesting that the neutral range

[16] This observation does not imply causation. The presumption here is that spot and forward exchange rates are mutually determined.

created transaction costs is relatively important for US-Canada. That is probably because the variance of the change in the exchange rate reported in Table 6 is relatively small. The Durbin-Watson statistics for the US-UK are reasonable.

The critical parameter in Table 7 is λ_1, the parameter for the forward premium. With a correctly specified test and no forward bias, estimates of λ_1 should be positive, significant and closer to 1.0 than 0.0. (The neutral range created by transaction costs will tend to bias estimates toward 0.0.) Those conditions for no forward bias are met for all the estimates of λ_1 in Table 7. In addition, both estimates of λ_1 for US-UK are within one standard deviation of 1.0.

When one includes the forward premium in a test equation that is correctly specified, there is no evidence of a forward bias. If additional research confirms these results, as I expect that it will, then the puzzle of the apparent forward bias is solved.

The apparent puzzle has two sources, one real and one statistical. The real one is the assumption that the forward exchange rate is the expected future spot exchange rate. When covered interest parity holds, that equality holds only under certain special conditions. The statistical one is a miss-specified test equation that omits the interest rate differential and changes in the forward exchange rate implied by covered interest parity.

V. Summary and Conclusion

My solution to the forward-bias puzzle is based on covered interest parity, for which there is substantial empirical support. According to covered interest parity, and contrary to an almost universal assumption, in general, the forward premium does not represent the market's rational expectation of the future spot exchange rate. When covered interest parity holds, the rational expectation of the future spot exchange rate depends on the expected future forward exchange rate and the expected future interest rate differential. These variables will equal the forward exchange rate only under special conditions.

Section I discuss the literature concerning the forward bias. Section II discusses covered interest parity. Section III points out that covered interest parity is, in general, inconsistent with the standard assumption that the forward exchange rate represents the market's expectation of the future spot exchange rate. That inconsistency implies that, in general, covered and uncovered interest parity are inconsistent. Section III also discusses how the assumption that the forward rate is the market's expectation of the future spot rate produces the misspecifications that lead to the forward-bias puzzle.

Section IV presents the empirical evidence regarding the effects of those misspecifications. That section shows how those misspecifications produce the forward-bias puzzle, but reasonable estimates in levels. There is no evidence of any informational inefficiency.

Section IV ends with estimates of an appropriately specified equation that contains the forward premium. That equation produces coefficients for the forward premium that are positive, highly significant and closer to 1.0 than 0.0. Two of the four estimates are within one standard deviation of 1.0. Given the fact that transaction costs can introduce a neutral range bordered by thresholds, these estimates provide strong support for the forward premium as a reasonably accurate (partial) predictor of the change in the exchange rate. If future research supports my results, then the puzzle of the apparent forward bias is solved.

References

Akram, Q. Farooq, Dagfinn Rime, and Lucio Sarno. 2008. "Arbitrage in the Foreign Exchange Market: Turning on the Microscope." *Journal of International Economics*, Vol. 76(2), pp. 237-253.

Balke, Nathan S., and Mark E. Wohar. 1998. "Nonlinear Dynamics and Covered Interest Rate Parity." *Empirical Economics*, Vol. 23(4), pp. 535-559.

Bekaert, Geert, Min Wei and Yuhang Xing. 2007. "Uncovered Interest Parity and the Term Structure." *Journal of International Money and Finance*, Vol. 26(6), pp. 1038-1069.

Chakraborty, Avik, and George W. Evans. 2008. "Can Perpetual Learning Explain the Forward-Premium Puzzle?" *Journal of Monetary Economics*, Vol. 55(3), pp. 477-490.

Ch**akraborty, Avik, and Stephen E. Haynes.** 2008. "Econometrics of the Forward Premium Puzzle." *Economics Bulletin*, Vol. 6(4), pp. 1-17.

Goodhart, Charles A., Patrick C. McMahon and Yerima Lawan Ngama. 1992. "Does the Forward Premium/Discount Help to Predict the Future Change in the Exchange Rate?" *Scottish Journal of Political Economy*, Vol. 39(2), pp. 129-140.

Haynes, Stephen E., and Joe Stone. 1982. "Spurious Tests and Sign Reversals in International Economics." *Southern Economic Journal*, Vol. 48(4), pp. 868-876.

Kearns, Jonathon. 2007. "Commodity Currencies: Why Are Exchange Rate Futures Biased if Commodity Futures Are Not?" *The Economic Record*, Vol. 83(260), pp. 60-73.

Obstfeld, Maurice, and Kenneth Rogoff. 2000. "The Six Major Puzzles in International Macroeconomics: Is There a Common Cause?" *NBER Macroeconomics Annual*, Vol. 15, pp. 339-390.

Sarno, Lucio. 2005. "Viewpoint: Towards a Solution to the Puzzles in Exchange Rate Economics: Where Do We Stand?" *Canadian Journal of Economics*, Vol. 38(3), pp. 673-708.

Sarno, Lucio, Giorgio Valente and Hyginus Leon. 2006. "Nonlinearity in Deviations from Uncovered Interest Parity: An Explanation of the Forward Bias Puzzle." *Review of Finance*, Vol. 10(3), 443-482.

Sercu, Piet, and Tom Vinaimont. 2006. "The Forward Bias in the ECU: Peso Risks vs. Fads and Fashions." *Journal of Banking and Finance*, Vol. 30(8), pp. 2409-2432.

Wang, Peijie, and Ping Wang. 2009. "Does a 'Correct' Parameter Estimate Tell a Better Story about Foreign Exchange Market Efficiency?" *Journal of International Money and Finance*, Vol. 28(2), pp. 183-197.

Table 1

Estimates of Equations 6, 7 and 1

	$\Delta s_{t+1} = a + b(f_{t+1} - s_t) - c(i_{t+1} - i^*_{t+1})$				$\Delta s_{t+1} = A + B(f_t - s_t) - C(i_{t+1} - i^*_{t+1})$				$\Delta s_{t+1} = \alpha + \beta(f_t - s_t)$		
	$\hat{a}$	$\hat{b}$	$\hat{c}$	$\bar{R}^2$/DW	$\hat{A}$	$\hat{B}$	$\hat{C}$	$\bar{R}^2$/DW	$\hat{\alpha}$	$\hat{\beta}$	$\bar{R}^2$/DW
US-Canada											
5 Jan 1961 to	0.002	1.005	-0.786	0.984	0.194	-0.673	0.825	0.012	0.251	-0.425	0.003
31 Dec 1969	(0.006)	(0.003)	(0.031)	0.136	(0.049)	(0.259)	(0.518)	0.103	(0.046)	(0.175)	0.100
US-Canada											
5 Jun 1970 to	-0.137	0.972	-1.151	0.983	-0.941	0.702	-3.674	0.364	-0.238	0.268	-0.003
29 Jun 1973	(0.022)	(0.012)	(0.071)	0.252	(0.109)	(0.297)	(0.376)	0.273	(0.093)	(0.372)	0.151
US-UK											
2 Jan 1974 to	0.007	1.000	-1.018	1.000	0.716	0.010	-1.749	0.045	0.657	-1.425	0.033
1 Nov 1983	(0.001)	(0.000)	(0.004)	1.474	(0.068)	(0.325)	(0.374)	0.088	(0.069)	(0.166)	0.087
US-UK											
2 Nov 1983 to	0.003	0.999	-1.009	1.000	0.826	-4.984	-2.261	0.027	0.930	-3.034	0.025
30 Sep 1993	(0.002)	(0.000)	(0.010)	1.776	(0.115)	(1.819)	(1.765)	0.080	(0.129)	(0.406)	0.075
Averages	-0.031	0.994	-0.991	0.992	0.199	-1.236	-0.584	0.112	0.400	-1.221	0.015
	(0.008)	(0.004)	(0.028)	0.909	(0.085)	(1.675)	(0.758)	0.136	(0.084)	(0.280)	0.103

Standard errors in parentheses.

Table 2

Estimates of Equations 9, 10 and 8

	$s_{t+1} = \mathbf{a} + \mathbf{b}f_{t+1} - c(i_{t+1} - i^*_{t+1})$				$s_{t+1} = \mathbf{A} + \mathbf{B}f_t - \mathbf{C}(i_{t+1} - i^*_{t+1})$				$s_{t+1} = \boldsymbol{\alpha} + \boldsymbol{\beta}f_t$		
	$\hat{\mathbf{a}}$	$\hat{\mathbf{b}}$	$\hat{\mathbf{c}}$	$\bar{R}^2$/DW	$\hat{\mathbf{A}}$	$\hat{\mathbf{B}}$	$\hat{\mathbf{C}}$	$\bar{R}^2$/DW	$\hat{\alpha}$	$\hat{\beta}$	$\bar{R}^2$/DW
US-Canada											
5 Jan 1961 to	0.010	0.990	-0.883	0.994	0.319	0.703	0.090	0.792	0.319	0.703	0.792
31 Dec 1969	(0.002)	(0.002)	(0.032)	0.134	(0.042)	(0.039)	(0.424)	0.121	(0.042)	(0.039)	0.121
US-Canada											
5 Jun 1970 to	-0.057	1.055	-1.140	0.990	0.224	0.770	-2.891	0.598	0.394	0.606	0.469
29 Jun 1973	(0.008)	(0.008)	(0.063)	0.312	(0.056)	(0.055)	(0.466)	0.235	(0.040)	(0.040)	0.133
US-UK											
2 Jan 1974 to	0.001	0.998	-0.529	1.000	0.006	0.996	-1.262	0.965	0.002	0.998	0.962
1 Nov 1983	(0.000)	(0.000)	(0.004)	0.669	(0.002)	(0.004)	(0.105)	0.092	(0.002)	(0.004)	0.084
US-UK											
2 Nov 1983 to	0.002	0.997	-0.653	1.000	0.053	0.931	-3.456	0.917	0.025	0.957	0.912
30 Sep 1993	(0.000)	(0.000)	(0.004)	1.372	(0.007)	(0.011)	(0.278)	0.071	(0.006)	(0.010)	0.067
Averages	-0.004	1.010	-0.801	0.996	0.150	0.850	-1.880	0.818	0.185	0.816	0.784
	(0.002)	(0.002)	(0.026)	0.667	(0.027)	(0.027)	(0.318)	0.130	(0.022)	(0.023)	0.101

Standard errors in parentheses.

Table 3

Cross Correlation Estimates and $\hat{\beta}$s

	$(f_{t+1}-s_t)$ vs (f_t-s_t) f_{t+1} vs f_t $\hat{\beta}$		$(f_{t+1}-s_t)$ vs (f_t-s_t) f_{t+1} vs f_t $\hat{\beta}$		$(f_{t+1}-s_t)$ vs (f_t-s_t) f_{t+1} vs f_t $\hat{\beta}$		$(f_{t+1}-s_t)$ vs (f_t-s_t) f_{t+1} vs f_t $\hat{\beta}$
US-Canada	0.142	US-Canada	0.026	US-UK	-0.076	US-UK	-0.114
5 Jun 1970 to	0.742	5 Jan 1961 to	0.894	2 Jan 1974 to	0.981	2 Nov 1983 to	0.956
29 Jun 1973	0.268	31 Dec 1969	-0.425	1 Nov 1983	-1.425	30 Sep 1993	-3.034

Table 4

Estimates of Equations 11 and 12

$\Delta s_{t+1} = a_0 + b_1 f_{t+1} - b_2 s_t$ $\qquad$ $\Delta s_{t+1} = \alpha_0 + \beta_1 f_t - \beta_2 s_t$

	$\hat{a}_0$	$\hat{b}_1$	$\hat{b}_2$	$\bar{R}^2$/DW	$\hat{\alpha}_0$	$\hat{\beta}_1$	$\hat{\beta}_2$	$\bar{R}^2$/DW
US-Canada								
5 Jun 1970 to	0.102	0.638	-3.850	0.019	0.048	-81.274	72.359	0.346
29 Jun 1973	(0.027)	(1.311)	(1.281)	0.088	(0.018)	(13.678)	(12.378)	0.175
U.S-Canada								
5 Jan 1961 to	0.000	0.965	-0.980	0.973	0.022	-0.267	-0.023	0.405
31 Dec 1969	(0.000)	(0.011)	(0.008)	0.068	(0.003)	(0.121)	(0.134)	0.127
US-UK								
2 Jan 1974 to	-0.127	1.012	-1.010	0.984	0.126	-1.454	1.446	0.034
1 Nov 1983	(0.033)	(0.003)	(0.003)	0.043	(0.238)	(0.170)	(0.169)	0.087
US-UK								
2 Nov. 1983 to	-0.053	1.007	-1.001	0.998	-1.951	-4.918	4.843	0.079
30 Sep 1993	(0.016)	(0.001)	(0.001)	0.151	(0.348)	(0.162)	(0.459)	0.080

Standard errors in parentheses.

Table 5
Relevant Cross-Correlations

	f_t versus s_t (f_{t+1} versus s_{t+1})	f_t versus f_{t+1}	f_t versus s_{t+1}	s_t versus s_{t+1}
US-Canada 5 Jun 1970 to 29 Jun 1973	0.982	0.742	0.687	0.721
U.S-Canada 5 Jan 1961 to 31 Dec 1969	0.995	0.894	0.891	0.896
US-UK 2 Jan 1974 to 1 Nov 1983	0.9997	0.981	0.980	0.981
US-UK 2 Nov. 1983 to 30 Sep 1993	0.9999	0.955	0.954	0.955
Averages	0.994	0.893	0.878	0.888

Table 6
Relevant Variances

	Δs_{t+1}	$f_t - s_t$	Δf_{t+1}	$i_{t+1} - i^*_{t+1}$
US-Canada 5 Jun 1970 to 29 Jun 1973	1.067	0.050	0.883	0.030
U.S-Canada 5 Jan 1961 to 31 Dec 1969	0.960	0.027	0.980	0.018
US-UK 2 Jan 1974 to 1 Nov 1983	4.266	0.122	4.265	0.115
US-UK 2 Nov. 1983 to 30 Sep 1993	8.781	0.042	8.830	0.038

Table 7
Estimates of Equation 13

$$\Delta s_{t+1} = \lambda_0 + \lambda_1(f_t - s_t) + \lambda_2 \Delta f_{t+1} - \lambda_3(i_{t+1} - i^*_{t+1})$$

	$\hat{\lambda}_0$	$\hat{\lambda}_1$	$\hat{\lambda}_2$	$\hat{\lambda}_3$	$\bar{R}^2$/DW
US-Canada					
5 Jun 1970 to	-0.138	0.789	0.984	-1.083	0.984
29 Jun 1973	(0.021)	(0.049)	(0.013)	(0.074)	0.266
U.S-Canada					
5 Jan 1961 to	0.014	0.605	1.002	-0.611	0.988
31 Dec 1969	(0.006)	(0.037)	(0.004)	(0.043)	0.173
US-UK					
2 Jan 1974 to	0.007	0.996	0.999	-1.012	0.999
1 Nov 1983	(0.001)	(0.011)	(0.000)	(0.011)	1.460
US-UK					
2 Nov. 1983 to	0.003	0.995	0.999	-1.005	0.999
30 Sep 1993	(0.002)	(0.012)	(0.000)	(0.016)	1.778

Standard errors in parentheses.