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This paper contains preliminary findings from research work still in progress and should not be quoted without prior approval of the author.

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Some Irregular Regularities in the Canadian/U.S. Exchange Market

1. Introduction

There are a number of empirical regularities in foreign exchange markets which fit in neatly with the notion of "rational economic man" which theoreticians prefer to employ. Such regularities have been noted in an article by Mussa (1979). In the past few years, however, a substantial body of evidence has been developing which indicates that one of these regularities - that the forward rate is close to the best unbiased predictor of the future spot rate[1] - is false for almost every currency (Hansen & Hodrick (1980, 1981), Bilson (1981), Longworth (1981a, 1981b), Boothe (1982)). Furthermore, there has been little or no success in relating deviations of the future spot rate from the forward rate to the theoretical determinants of risk (Frankel (1979b, 1982)).

This paper notes some regularities in the Canadian/U.S. exchange market - regularities that are "irregular" in two senses: first, in the sense that they suggest that there are predictors which are better than the

1 Mussa (1979, p. 18) held that "The forward exchange rate is an unbiased predictor of the corresponding future spot rate, is close to the best available predictor of the corresponding spot exchange rate, but is not a very good predictor of the corresponding future spot exchange rate."

forward rate, and second in the sense that they suggest that the exchange market has overlooked fundamental economic variables, rather than just incorporating ex ante risk premia. We are aided in our study of these regularities by using results based on a whole term-structure of forward rates: 1, 2, 3, 6 and 12 month.[2]

We find it helpful in our study to distinguish two types of efficiency. The first, which we classify as "micro-efficiency" is the traditional definition, which relates to whether above normal profits are available to an individual investor. The second, which we classify as "macro-efficiency" relates to whether economic variables which are important in determining the "equilibrium" or "long-run" exchange rate are properly incorporated into the forward rate. Since we do not empirically examine theoretical determinants of a risk premium, we cannot conclude definitively whether or not the exchange market is efficient. However, we believe that the evidence points in the direction of inefficiency in both a "micro" and "macro" sense.

The paper proceeds as follows. In section 2 we examine the joint hypothesis of market efficiency and no time-varying risk premium in regression tests for the 1970-1981 period. Sub-period results are briefly considered

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2 The entire term structure of forward rates has only been used before in Longworth (1981b).

in section 3 before we proceed to tests of profitability based totally on ex ante information in section 4. In section 5 we draw together our results, relate them to other studies in the literature and derive conclusions. An appendix argues that some common assertions often heard at conferences to the effect that "if the exchange market appears to be inefficient, it is because of central bank intervention" are incorrect.

2. Statistical Tests Using Regression Equations for the Entire Period

a. The Tests

This section describes econometric tests of the joint null hypothesis of market efficiency and a constant risk premium. Since economic theory suggests that, in addition to other variables, contemporaneous interest rate differentials and relative price levels between two countries may influence the exchange rate, the tests performed examine whether information known about these variables[3] when forward contracts are entered into will aid

3 These variables were chosen because they are readily available. Balance of payments variables could have been used as well.

in exchange rate forecasting.[4] If there is any set of variables which can be combined to produce a forecast of the future spot rate which is better than that generated by the forward rate, then this means that we can reject the null hypothesis.

The strongly held covered-interest-parity relationship allows the forward premium to be used as the measure of the interest differential.[5] The relative prices are GNE deflators (the theoretically most appropriate series for a broad measure of PPP) which are revised only when new figures are released.

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4 The data used in this study have been carefully chosen such that the beginning of period spot and forward rates are at the same moment in time and such that the forward and future spot rates are matched as to value day. All price indices used would have been known to market participants, i.e., they are preliminary unrevised data with due regard to announcement lags. The data are described in detail in Appendix 2.

5 With this measure, it is not necessary to try to select the most comparable instrument from each country, since the market's choice is reflected in the forward premium. The study by Frenkel and Levich (1975) concluded that covered interest arbitrage held in Euro markets to within transactions costs.

Using this information, the null hypothesis is then tested with regressions of the following form:[6]

(1) $s_{t+k}-s_t = a + b(f_t^k-s_t) + u_t$

(2) $s_{t+k} = a + bf_t^k+cs_t + u_t$

(3) $s_{t+k} = a + bf_t^k+c(f_t-s_t) + u_t$

(4) $s_{t+k} = a + bf_t^k+c(s_t-ppp_t)+d(f_t^1-s_t) + u_t$

(5) $s_{t+k} = a + b(f_t^k-s_t)+cs_t+d(ppp_t) + u_t$

where s_t is the logarithm of the spot price of the U.S. dollar,

s_{t+k} is the logarithm of the spot exchange rate k months ahead,

f_t^k is the logarithm of the k-month forward exchange rate,

ppp_t is the logarithm of the ratio of the Canadian GNP deflator to the U.S. GNP deflator,

and

u_t is the error term.

If the null hypothesis of market efficiency and a constant risk premium holds, b=1 and c=d=0.[7]

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6 The reasons for selecting the particular forms of equations (1) to (5) are explained in the following section describing the results.

7 Except in equation (5), where, instead of c=0, the total coefficient on s, c-b, equals zero.

b. The Results

The first equation was specified in order to determine whether the forward premium ($f_t - s_t$) is an unbiased predictor of the future change in the spot rate $s_{t+k} - s_t$. In this regard, the results found in Table 1 indicate that unbiasedness can be rejected only for the 1-month forward premium, where its coefficient is actually less than zero. Although unbiasedness cannot be rejected statistically for the other maturities, for the 2-month and 3-month results the estimated coefficient on the forward premium, is numerically closer to zero (implying that the future spot rate is unrelated to the forward premium) than to its theoretically expected value of one. There is a monotonic increase in the coefficient of the forward premium as the maturity lengthens.

Equation 2 repeats the test of the joint hypothesis but relaxes the constraint on the beginning of period spot rate found in equation 1. The results found in Table 2 show that little additional information is gained in this way. As with equation (1) the null hypothesis is rejected at a 95% significance level only for the 1-month maturity, but note that for the 2- and 3-month maturities the forward rate adds little to the current spot rate in explaining the future spot rate. The coefficient on the forward rate increases, and that on the spot rate decreases, as the maturity lengthens.

Equation 3 includes the forward rate and the short-term interest rate differential proxied by the one-month forward premium, thereby testing the value of including information on the shortest (one month) interest differential in addition to the forward rate of the particular maturity. For the one month forward rate, this is mathematically equivalent to equation 2. For the other terms to maturity the findings are similar to those for equation 2, with rejection of the null hypothesis at a 90% level of significance at a 2 months and no rejection at longer maturities. The coefficient on the one-month forward premium is negative except for the 12 month maturity.[8]

Equation 4 adds the deviation of the spot exchange rate from purchasing-power parity[9] as an explanatory variable. In every case this variable is significantly different from a value of 0, its value under the null hypothesis. Moreover, the negative coefficient (which increases in absolute value as the maturity increases) indicates a tendency to return towards purchasing-power

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8 This finding, which could be paraphrased as: in the short run, the country with a high nominal short-term interest rate tends to have an appreciating currency relative to the country with a low nominal short-term interest rate and is strong contrast to Mussa's (1979, p. 25) assertion about the long run: "... countries with high nominal interest rates tend to have depreciating currencies relative to countries with low nominal interest rates." The finding parallels that of Bilson (1981) for a number of countries.

9 The test does not require us to specify an absolue value for ppp. Changes in the ratio of GNP deflators measure only relative movements in purchasing-power parity over given time periods. Monotonic transformations of the ratio (e.g. rebasing) would give results that differ only in the constant term.

parity which is not captured by the forward rate. The negative coefficient on the short-term interest rate (which also increases in absolute value as the maturity increases) is also significantly different from 0 in all but the 12 month forward rate equations and the coefficient on the forward rate is significantly different from 1 in all but the one-month equation. The results at all maturities strongly reject the null hypothesis.

Equation 5 employs the spot rate, the k-period forward premium and the relative price (ppp) term. In this case the null hypothesis is strongly rejected as the coefficient on the relative price term is significantly greater than zero for all maturities, and the coefficients on the other terms differ significantly from their values under the null hypothesis in all but the 12 month equation. In each equation the weights on the forward rate, spot rate and ppp term add up to approximately one. As the maturity increases the weight on the forward rate goes from a large negative value to near zero, the weight on the spot rate falls from .9 to .5 and the weight on ppp increases from .1 to .8. Once can readily determine from the equation results that the random walk model is not a good representation for the logarithm of the spot rate, as other explanatory variables are very significant. Thus for the Canadian dollar/U.S. dollar exchange rate we can reject the assertion by Mussa (1979), p. 10) and others that "The natural logarithm of the spot exchange rate follows approximately a random walk."

Table 1

Equation 1

$$s_{t+k}-s_t = a + b\,(f_t^k-s_t)$$

k	Period	a	b	S.E.E.
1	70M7 81M12	.0005 (.0009)	-.389** (.550)	.01067
2	70M8 81M11	.002 (.002)	.066 (.572)	.01556
3	70M9 81M10	.003 (.003)	.205 (.597)	.01812
6	70M12 81M7	.006 (.006)	1.010 (.717)	.02642
12	74M1 81M1	.020 (.011)	1.713 (.815)	.03723

In Tables 1-5 standard errors appear in brackets and:

* indicates that the coefficient is significantly different from its hypothesized value (b=1; c, d=0) at α=.10.

** indicates that the coefficient is significantly different from its hypothesized value at α=.05.

Table 2

Equation 2

$$s_{t+k} = a + b\ f_t^k + c\ s_t$$

k	Period	a	b	c	S.E.E.
1	70M7 81M12	.002 (.001)	-.431** (.547)	1.412** (.546)	.01061
2	70M8 81M11	.003 (.002)	.037* (.572)	.947 (.571)	.01557
3	70M9 81M10	.004 (.004)	.163 (.602)	.821 (.599)	.01815
6	70M12 81M7	.007 (.007)	1.008 (.784)	-.009 (.722)	.02653
12	74M1 81M1	.025 (.018)	1.491 (.965)	-.555 (.893)	.03723

Table 3

Equation 3

$$s_{t+k} = a + b \ f_t^k + c(f_t^1 - s_t)$$

k	Period	a	b	c	S.E.E.
1	see eq'n 2				
2	70M8 81M11	.003 (.002)	.985 (.023)	-1.909* (1.038)	.01552
3	70M9 81M10	.004 (.004)	.986 (.035)	-2.233 (1.523)	.01811
6	70M12 81M7	.007 (.007)	.998 (.076)	-.351 (2.951)	.02652
12	74M1 81M1	.029 (.018)	.905 (.166)	.172 (5.691)	.03770

Table 4

Equation 4

$$s_{t+k} = a + b\ f_t^k + c(s_t - ppp_t) + d(f_t^1 - s_t)$$

k	Period	a	b	c	d	S.E.E.
1	70M6 81M9	-.003 (.001)	1.021 (.014)	-.115** (.024)	-2.912** (.626)	.00973
2	70M6 81M9	-.005 (.002)	1.056** (.024)	-.203** (.042)	-4.737** (1.065)	.01393
3	70M6 81M9	-.006 (.003)	1.074** (.035)	-.253** (.058)	-5.753** (1.427)	.01594
6	70M6 81M7	-.009 (.006)	1.141** (.065)	-.421** (.101)	-6.632** (2.358)	.02193
12	74M1 81M1	-.019 (.019)	1.280* (.156)	-.725** (.199)	-7.691* (3.981)	.03108

Table 5

Equation

$$s_{t+k} = a + b(f_t^k - s_t) + cs_t + d\ ppp_t$$

k	Period	a	b	c	d	S.E.E.
1	70M6 81M9	-.003	-1.891**	.906**	.115**	.00973
		(.001)	(.621)	(.020)	(.025)	
2	70M6 81M9	-.005	-1.506**	.848**	.208**	.01398
		(.002)	(.583)	(.035)	(.043)	
3	70M6 81M9	-.007	-1.311**	.801**	.272**	.01579
		(.003)	(.557)	(.048)	(.059)	
6	70M6 81M7	-.011	-.656**	.674**	.466**	.02159
		(.006)	(.590)	(.089)	(.105)	
12	74M1 81M1	-.002	.045	.497	.802**	.03123
		(.020)	(.727)	(.160)	(.222)	

A ** in this column indicates that c-b, the total coefficient on s, is significantly different from zero at α=.05.

To summarize this section, the null hypothesis is rejected in the tests for at least the 1 month maturity in all equations. Although the simplest equation (1) does not allow the rejection of the hypothesis at other maturities, the additional information adds dramatically to the explanatory power of the equations. The information provided by known relative price levels (ppp) is particularly important in this regard; in all equations using ppp (equations 4 and 5), its coefficient is significantly greater than 0 and the null hypothesis is rejected. These rejections of the hypothesis lead us to conclude that the market is inefficient and/or there is an ex ante risk premium.

If one looks at a given equation across maturities there are striking monotonic increases in the absolute values of the coefficients on interest rate differentials and ppp as the maturity increases. In equation (4), for example, the deviations of all the coefficients from their values under the null hypothesis increase with the length of maturity.

3. Regressions for Sub-periods

Equations (1) through (5) have been estimated for selected two year sub-periods for each maturity. The results are summarized in appendix Tables A-1 through A-5 and in Table 6 below.

Table 6 tabulates how closely the estimated coefficients for the sub-periods correspond to the signs and/or size of the coefficients for the period as a whole. The conditions listed in the second column of the table are conditions which hold in the entire-period equations (Tables 1-5) for the maturities to the left of the solid line. To illustrate how to read the table, in 6 out of 6 sub-periods the point estimate of the coefficient b on the forward rate is negative in equations (1) or (2) for the one-month maturity just as it is in the entire-period equation,

Table 6

Summary of Sub-period Estimation of Equations (1) to (5)
Number of Sub-periods for which Given Condition Holds

Equation	Condition	Maturity: 1	2	3	6	12
(1)	negative coeff. on forward premium.	6/6	5/6*	5/6*	0/5	1/3
(2)	negative coeff. on forward rate.	6/6	6/6	6/6	4/5	1/3
(3)	coeff. on forward rate < 1.	6/6	6/6	6/6	5/5	3/3
	negative coeff. on 1 mo. forw. prem.	6/6	6/6	6/6	3/5	2/3
(4)	negative coeff. on (s-ppp).	3/6	3/6	4/6*	4/5	2/3
	negative coeff. on 1 mo. forw. prem.	6/6	6/6	4/6*	4/5	2/3
(5)	negative coeff. on forward premium.	6/6	5/6	4/6*	4/5	3/3
	0<c<1, where c is coeff. on spot rate.	6/6	6/6	6/6	2/5	1/3
	positive coeff. on ppp.	3/6	3/6	4/6*	4/5	2/3

* One of the exceptions is in the first sub-period, a sub-period of fewer than 24 observations.

\- Maturities to the right of the line are those for which the given condition in the second column did not hold in the entire-period equations (see Tables (1) to (5)). The given condition held in the total-sample-period equations for all entries to the left of the line.

whereas under the null hypothesis it is 1. The Table indicates that the violations of the null hypothesis which occurred in the entire sample period tend to be repeated in the majority of the sub-periods. In addition, to the right of the solid line, where the results in the sub-periods do not duplicate the results of the entire period, the sub-period results often deviate more from the null hypothesis (in a numerical sense) than the entire period results. Another regularity has been established, and an irregular one at that; numerical deviations from the coefficients under the null hypothesis are fairly systematic over time.

These results indicate that there may be enough systematic deviation of coefficients from those of the null hypothesis for one to make money based on one or more mechanical trading rules.[10] Such a rule is considered in the next section.

4. Profitability of a Simple Trading Rule

In this section, forecasts for each maturity are combined with a simple trading rule in order to test for the presence of unexploited speculative profits. Forecasts from all five equations estimated above are used in order to avoid preselection based on best fit over the total sample.

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10 Although it is not necessary for the coefficients of equations like (1) to (5) to be econometrically stable to show that profits can be made, it is interesting to note that with one-month data and division at the middle of the sample period, a Chow test does not reject the equality of coefficients in the two sample halves for equation (1) where the F statistics is 1.50 compared to a critical F of 3.07 at =.05. Other equations for the one-month forward rate are not stable, however.

In addition, three strategies suggested by the broad outline of the statistical results are used.

The five equations are first estimated using data for 1, 2, 3 and 6 month maturities to the end of 1973 in order to construct a forecast of the exchange rate beginning January 1974. These forecasts are based only on variables and coefficients that could easily be derived from data known at the time the contract was to have been made. Each period, the equations are re-estimated taking account of the most recent information available. Forecasts are constructed from January, 1974 until December 1981, with each maturity having a slightly different number of forecasts because of the initial information required. For the 12 month maturity the first forecast is made in January 1977 because of the information requirement.

In order to speculate profitably in the forward exchange market, it is necessary to predict correctly the direction of forward rate error. This is done by comparing the forecasted value of the future spot rate to the forward rate. The trading rule is based on this comparison, and can be summarized as follows:

$$\text{if } S^{*k}_t > F^k_t \quad Z^k_t = 1.0 \text{ (buy foreign exchange forward)}$$

$$\text{if } S^{*k}_t < F^k_t \quad Z^k_t = -1.0 \text{ (sell foreign exchange forward)}$$

$$\Pi^k_t = Z^k_t \cdot (S_{t+k} - F^k_t).$$

The k-months-ahead forecast of the future spot rate is denoted by S^{*k}_t; profits from using the k-months-ahead forecast are denoted by Π^k_t. The strategy is simply to buy one dollar of foreign exchange forward if the predicted future spot rate is greater than the forward rate. Foreign exchange is sold forward if the future spot price is expected to be lower than the current forward rate. Profits are expressed in terms of return per dollar bet. Since very little, if any, capital is required to make forward purchases or sales of foreign exchange, and any capital that is required may bear the market rate of interest, it is difficult to express profits as a pure rate of return.

In the first five predictions, the S^{*k}_t correspond to the true ex ante predictions derived from equations (1) through (5) respectively. The sixth prediction is the current spot rate, based on the empirical observation that the change in the exchange rate is typically less than that predicted by the forward premium. Prediction (8) employs a strong version of purchasing power parity (ppp); the prediction is the current ppp exchange rate calculated with a constant term which is updated monthly. Strategy (7) involves no point prediction of the exchange rate. Rather it depends on the sign of the one-month interest rate differential:

$$Z_t^k = 1.0 \text{ if } S_t > F_t^1$$

$$Z_t^k = -1.0 \text{ if } S_t < F_t^1$$

Transaction costs are not specifically treated in these profit calculations. In practice transactions costs are embodied in the spread between bid and ask rates. If the treatment of transaction costs was thought to be a problem, the strategy could be modified to make bets only when the expected return was greater than the transaction costs involved.[11]

The means and standard deviations of returns per dollar bet for each equation and maturity are presented in Table 7. A number of patterns are noticeable. In general, bets made over the three shorter maturities are profitable, while the bets made over 6 and 12 months are not. Three

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11 Boothe (1981) has shown that taking transactions costs into account somewhat reduces the profitability of betting rules based on equations for the Canadian-U.S. exchange rate. However, the reduction in profits is generally less than the transactions costs and the profits remain positive. Bid-ask spreads for spot, 1, 2 and 3 month forward rates are typically in the order of 5 basis points, while spreads for the two longer maturities are usually around 10 and 15 points respectively. Since we use mid-point rates in our study, the transaction cost of a forward market bet would be equal to one half of spot spread plus one half the appropriate forward spread.

Table 7

Expected Returns to Forward Market Speculation

Equation	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	number of contracts
Maturity									
1 month	.00209	.00057	.00057	.00274	.00274	.00242	.00242	.00173	95
74M1-81M11*	(.01379)**	(.01394)	(.01394)	(.01367)	(.01367)	(.01369)	(.01369)	(.01383)	
2 month	.00199	.00195	.00213	.00285	.00260	.00135	.00264	.00177	94
74M1-81M10	(.01987)	(.01987)	(.01985)	(.01976)	(.01979)	(.01970)	(.01962)	(.01989)	
2 month	.00312	.00175	.00175	.00130	.00170	.00179	.00038	.00073	47
(first drawing)	(.01982)	(.01999)	(.01999)	(.02003)	(.02000)	(.01997)	(.01978)	(.02006)	
2 month	.00086	.00214	.00250	.00441	.00349	.00451	.00489	.00281	47
(second drawing)	(.02006)	(.01996)	(.01992)	(.01958)	(.01977)	(.01955)	(.01940)	(.01988)	
3 month	.00234	.00229	.00198	.00311	.00297	.00336	.00279	.00257	93
74M1-81M9	(.02284)	(.02285)	(.02288)	(.02275)	(.02277)	(.02243)	(.02273)	(.02281)	
3 month	.00061	.00088	.00228	.00433	.00433	.00058	-.00132	-.00117	31
(first drawing)	(.02577)	(.02576)	(.02567)	(.02539)	(.02539)	(.02571)	(.02574)	(.02575)	
3 month	.00202	.00253	.00315	.00307	.00172	.00355	.00595	.00320	31
(second drawing)	(.02153)	(.02186)	(.02201)	(.02140)	(.02156)	(.02044)	(.02077)	(.02138)	
3 month	.00439	.00253	.00031	.00191	.00286	.00595	.00376	.00570	31
(third drawing)	(.02156)	(.02186)	(.02201)	(.02193)	(.02182)	(.02114)	(.02150)	(.02124)	
6 month	-.00324	-.00008	-.00149	-.00679	-.00783	-.00205	-.00123	.00521	90
74M1-81M6	(.03241)	(.03257)	(.03254)	(.03184)	(.03160)	(.03250)	(.03210)	(.03209)	
12 month	.01942	-.01613	-.01524	-.00191	-.01867	-.00907	-.01151	-.00010	48
77M1-80M12	(.04170)	(.04311)	(.04344)	(.04184)	(.04204)	(.04516)	(.04451)	(.04608)	

* contracting period

** standard deviations are in parentheses months is the most profitable maturity. Focussing on the first three maturities, bets based on equations (4) and (5)[12] which include ppp, are more profitable than bets based on the equations (1), (2) and (3), which do not include it. This result confirms the findings of section 2, which showed efficiency is most often rejected by equations which include ppp among the explanatory variables; there is significant improvement in the explanatory power of the equations when ppp is added. Interestingly, the simplest forecasting procedures, (6), (7) and especially the strict ppp forecasting of (8), are just as profitable as the predictions based on equations (1) to (5) which are considerably more difficult to produce. Mean profits range from 6 to 34 basis points for the profitable maturities, but are most often in a small range around 20 points. The standard deviation of returns is generally about ten times the mean. Thus one cannot say with much confidence that any given bet will be profitable. However, one can make more convincing probability statements a series of bets.[13]

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12 For the 1 month maturity, the predictions of equations (2) and (3), equations (4) and (5) and forecasts (6) and (7) will be identical.

13 For maturities greater than 1 month, the overlapping nature of the contracts means that returns are not independent. Thus, each series of returns can be divided into a number (equal to the maturity) of independent drawings. Means and deviations for each independent drawing of 2 and 3 month bets are presented in Table 7. Probabilities associated with these independent drawings are presented in Table 8.

Table 8

Probability of Zero or Negative Mean Profits

Equation or Prediction	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	number of contracts
Maturity									
1 month	.069**	.343	.343	.025*	.025**	.042**	.042**	.113*	95
2 month	.166*	.171*	.149*	.082**	.102*	.060**	.096**	.194*	94
2 month (first drawing)	.064**	.200	.200	.270	.206	.194*	.428	.364	94
2 month (second drawing)	.340	.151*	.113*	.014**	.043**	.017**	.007**	.085**	94
2 month (first drawing)	.140*	.275	.275	.330	.281	.270	.448	.406	47
2 month (second drawing)	.385	.305	.194*	.061**	.113*	.057**	.042**	.169*	47
3 month	.161*	.167*	.202	.094**	.104*	.075**	.119*	.141*	93
3 month (first drawing)	.409	.375	.196*	.050**	.050**	.416	.687	.666	93
3 month (second drawing)	.182*	.059**	.065**	.083**	.220	.047**	.002**	.075**	93
3 month (third drawing)	.025**	.132*	.083**	.199*	.103*	.003**	.046**	.004**	93
3 month (first drawing)	.448	.424	.310	.171*	.171*	.453	.610	.598	31
3 month (second drawing)	.301	.182*	.191*	.212	.328	.169*	.056**	.204	31
3 month (third drawing)	.128*	.293	.212	.314	.232	.059**	.166*	.068**	31
6 month	.829	.509	.668	.978	.991	.722	.640	.060**	90
12 month	.001**	.995	.993	.999	.999	.917	.963	.504	48

* reject hypothesis at 80%
** reject hypothesis at 90%

In contrast to the three shorter maturities, the bets made over the 6 and 12 month horizons are, with only 2 exceptions, unprofitable. To be comparable, the 12 month bets using (6) to (8) were made over the same period as (1) to (5) even though they were not constrained by data availability in the same way. When the 12 month bets using (6) to (8) were begun in 1974 (the same starting point as the 1, 2 and 3 month maturities), bets (6) and (7) remained unprofitable, but bet (8) had a mean profit of .01051, almost three times as large as next largest mean profit at any maturity. Thus over the whole period 1974-81, procedure (8) is profitable for all maturities.

This result provides a clue to explaining why the bets made at the 6 and 12 month maturities are generally unprofitable, whereas the regressions presented in Section 2, especially for equations (4) and (5) would indicate the existence of profitable betting opportunities. First, although the regression coefficients presented in Section 2 indicate potential profits, these coefficients represent the average relationship over the whole period. The coefficients used in betting are updated each period, do not contain as much information as those of Section 2, and thus bets upon them cannot be expected necessarily to be profitable. It is possible that the coefficients used in forecasting drift considerably before arriving at their final, average value. Second, the period for the profitability tests omits the first three years that were used in section 2 regressions.

In order to make statements about the probability of mean profits or losses after a given number of bets, an assumption must be made about the distribution of returns. Returns are assumed to be normally distributed with population parameters given by their sample estimates. Each series of returns is tested using the Komolgorov-Smirnov test of normality. In no case can the hypothesis that the returns were drawn from a normal population be rejected at the 90% level.

Table 8 presents the probability, for each equation and maturity, that mean profits will be less than or equal to zero after a given number of bets. In each case, the number of bets is arbitrarily chosen to be the same as the number of bets tested above.[14] Thus, this is a calculation of the probability of earning zero or negative mean profits if one had bet over the periods described above, under the assumption that the population of returns generated by the betting rule is normally distributed with population parameters given by their sample estimates.

Related as they are to the results presented in Table 7, it is not surprising that in the case of the 1, 2, and 3 month maturities many equations reject the hypothesis of zero or negative profits at an 80% or higher level of confidence. Of the 21 combinations of predictions and maturity (3 are duplicated at the 1 month horizon) the hypothesis of negative or zero profits can be rejected in 8 cases with 90% confidence and in 19 cases with 80% confidence. This is equivalent to rejecting the joint hypothesis of market efficiency and no risk premium. Among the strategies based on equations, for the three shortest maturities, the probability of negative profits is lowest for equations (4) and (5) which were the regression equations in which it was easiest to reject the joint

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14 For the 2 and 3 month bets where independent drawings are considered, the number of bets used in the first calculation is the total number of bets tested above (e.g. 94 for the 2 month bets). In the second calculation, it is the number of bets in the particular drawing (e.g. 47 for the 2 month bets). The use of intervention variables in tests of efficiency is considered more extensively in Appendix 3.

hypothesis. For the 6 and 12 month maturities, the joint hypothesis can almost never be rejected at the 80% level. As discussed above, this contrasts with the strong rejection of the hypothesis in the regression equations for these maturities.

In summary, there is evidence of unexploited speculative profits using most equations for the 1, 2 and 3 month maturities. For these maturities, the addition of the ppp data to the information set increases the size of the mean profit. There is little evidence of unexploited speculative profits for the 6 and 12 month maturities except for the ppp-based procedure (8) used over the 1974-81 period. The rules for the shorter maturities strongly reject the joint null hypothesis of market efficiency and constant risk premium.

5. Conclusions

As we have gone through this paper we have noted a number of regularities in our empirical results. Some of the more important ones for our present purposes can be summarized as follows:

(1) In regression tests, the joint null hypothesis of market efficiency and no time-varying risk premium is decisively rejected for all maturities by equations which include both interest rate differentials and relative price levels.

(2) In results for sub-periods, qualitatively the deviations from the coefficients under the null hypothesis are fairly systematic over time.

(3) The country with a high nominal short-term interest rate tends to have an appreciating currency relative to the country with a low nominal short-term interest rate.

(4) There is a tendency, not captured in forward rates, for a currency to move towards its ppp value.

(5) For the short maturities (1, 2 and 3 months) of forward rates all eight trading strategies considered in this paper are profitable.

(6) At all maturities it is profitable to bet that the exchange rate will return towards ppp.

The rejection of the joint null hypothesis in regression tests is stronger than in earlier studies using data on the Canadian-U.S. exchange rate. This is due to the introduction of economic data in addition to past spot and forward rates.[15] Since interest rate differentials and

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15 To our knowledge, this is the first time this has been done in regression tests. Boothe (1982) uses such data in tests of profitability.

deviations from purchasing-power parity are not likely to be highly correlated with the determinants of risk premia, such as the relative stocks of outside assets and net foreign asset stocks that are suggested in the models of Frankel (1979a) and Stulz (1982), we are inclined to view these tests as rejection of a certain standard of market efficiency, rather than merely representing the finding of a risk premium. We are strengthened in this view by Frankel's (1982) failure to relate potential risk premia to their theoretical determinants and by Longworth's (1979) finding for the Canadian dollar/U.S. dollar exchange rate that in the presence of theoretical determinants of risk premia in regression equations, the coefficient on the forward rate remains significantly different from unity, its value under the joint null hypothesis.

We must view the tests as rejecting a certain <u>standard</u> of market efficiency because Grossman and Stiglitz (1976), assuming that information is costly, show that markets will never be fully efficient because not all information will be collected. In a similar vein, Figlewski (1978), in a model where market participants have different information, shows that the market is unlikely to be fully efficient. The key to interpreting these theoretical results is that information includes not only the data, but the elements of the model, however simple, of how the spot exchange rate evolves over time. We interpret our particular results, in which the market participants obviously have access to and are aware of the basic data, as a consistent failure by the market to understand the dynamic response of the exchange rate to interest rate differentials and relative price levels. With high enough costs of information, some may argue that this is still consistent with "efficient" processing of information, but it is not consistent with fully incorporating the small data set which we consider.

In viewing efficiency from the viewpoint of the private market participant, which we call "micro-efficiency", it is perhaps best to concentrate on the profitability tests which directly look at whether there are unexploited profit opportunities based on known information. As all eight trading strategies are profitable for the three shortest maturities, we are inclined to reject "micro-efficiency" given a standard of completely processing the data on the variables we have considered.

From a macro-policy viewpoint, an equally important question is whether over time the market fully incorporates important economic variables - what we call "macro-efficiency". In the short-run, "macro-inefficiency" may not necessarily present unexploited profit opportunities to the private market, so we prefer to examine our full-period regression tests to ask whether the market is efficient in this sense. Thus, we are inclined to reject "macro-efficiency" given a standard of completely processing the data on the variables we have considered.

But what of the oft-made assertion that central bank intervention causes inefficiency? In the absence of controls on international capital flows or forward contracts, private market participants are able to incorporate their information on past intervention and expected future intervention into the forward rate. Unpredictable intervention would be random and so would have the effect of any other unforeseen events as far as private market participants were concerned.[16]

The assertion of intervention causing inefficiency is rather incongruous in the Canadian case, where the Bank of Canada follows a leaning-against-the-wind policy (Longworth (1980)). Our regressions show a tendency for the spot rate to move in the direction opposite to that predicted by the forward premium; intervention of the leaning-aginst-the-wind type would only make this perverse movement less pronounced.

16 See the longer discussion of intervention and tests of efficiency in Appendix 3.

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Appendix 1: Sub-period Results

Table A-1

Summary of Sub-period Results for Equation 1

$$s_{t+k}-s_t=a+b(f_t^k-s_t)$$

Maturity	Sample	a	b
1	79M12-81M11	-.0014	-2.162
	77M12-79M11	.0005	-2.503
	75M12-77M11	.0060	-.768
	73M12-75M11	.0007	-.809
	71M12-73M11	-.0009	-.837
	70M7-71M11	-.0008	-.584
2	79M11-81M10	.0005	-1.100
	77M11-79M10	.0038	-2.659
	75M11-77M10	.0180	-1.982
	73M11-75M10	.0014	-1.238
	71M11-73M10	-.0013	-.945
	70M8-71M10	-.0016	.364
3	79M10-81M9	-.0010	-.627
	77M10-79M9	.0067	-2.913
	75M10-77M9	.0027	-2.236
	73M10-75M9	.0009	-2.044
	71M10-73M9	-.0011	-.295
	70M9-71M9	-.0016	1.029

6	78M12-80M11	.0047	.388
	76M12-78M11	.0224	2.218
	74M12-76M11	-.0014	.999
	72M12-74M11	.0068	1.354
	70M12-72M11	-.0013	1.691
12	78M1-79M12	.0107	1.040
	76M1-77M12	.0608	.740
	74M1-75M12	.0087	-2.359

Table A-2

Summary of Sub-period Results for Equation 2

$$s_{t+k}=a+bf_t^k+cs_t$$

Maturity	Sample	a	b	c
1	79M12-81M11	-.0504	-1.572	2.265
	77M12-79M11	.0366	-5.268	6.016
	75M12-77M11	.0293	-8.243	9.029
	73M12-75M11	.0003	-.043	.982
	71M12-73M11	-.0031	-1.846	2.520
	70M7-71M11	.0052	-2.177	2.685
2	79M11-81M10	.0843	-.371	.874
	77M11-79M10	.0718	-5.671	6.192
	75M11-77M10	.0880	-13.512	13.852
	73M11-75M10	.0007	-1.086	.976
	71M11-73M10	-.0049	-1.867	2.323
	70M8-71M10	.0061	-1.074	1.397
3	79M10-81M9	.0936	-.020	.460
	77M10-79M9	.0801	-5.999	6.473
	75M10-77M9	.0542	-5.419	6.134
	73M10-75M9	.0002	-.625	1.399
	71M10-73M9	-.0064	-1.274	1.484
	70M9-71M9	.0117	-.547	.407

6	78M12-80M11	.1721	-.180	.111
	76M12-78M11	.0692	-.746	1.352
	74M12-76M11	.0277	-2.066	1.120
	72M12-74M11	-.0168	-.918	.594
	70M12-72M11	-.0015	.530	-.134
12	78M1-79M12	.190	-1.593	1.351
	76M1-77M12	.077	.083	.759
	74M1-75M12	-.002	.260	-.988

Table A-3

Summary of Sub-period Results for Equation 3

$$s_{t+k}=a+bf_t^k+c(f_t^1-s_t)$$

Maturity	Sample	a	b	d
2	79M11-81M10	.0809	.5244	-1.962
	77M11-79M10	.0742	.5087	-11.136
	75M11-77M10	.0881	.3569	-26.800
	73M11-75M10	.0007	.8549	-1.278
	71M11-73M10	-.0047	.4666	-4.154
	70M8-71M10	.0063	.3082	-2.901
3	79M10-81M9	.0914	.4563	-1.541
	77M10-79M9	.0797	.4801	-12.398
	75M10-77M9	.0498	.7726	-15.441
	73M10-75M9	.0002	.6902	-.023
	71M10-73M9	-.0058	.2352	-3.612
	70M9-71M9	.0116	-.1443	-1.794
6	78M12-80M11	.1745	-.0842	.143
	76M12-78M11	.0886	.4634	-12.834
	74M12-76M11	.0290	-.9041	-5.735
	72M12-74M11	-.0137	-.2776	.069
	70M12-72M11	-.0015	.3660	-1.475

12	78M1-79M12	.1840	-.1916	-5.027
	76M1-77M12	.1019	.6313	-12.626
	74M1-75M12	-.0015	-.7167	4.685

Table A-4

Summary of Sub-period Results for Equation 4

$$s_{t+k}=a+bf_t^k+c(f_t^1-s_t)+d(f_t^k-s_t)$$

Maturity					
1	79M12-81M11	.034	.820	-.248	-3.13
	77M12-79M11	.074	.478	.205	-7.68
	75M12-77M11	-.020	1.118	-.321	-4.61
	73M12-75M11	-.006	1.005	-.122	-1.42
	71M12-73M11	-.003	.651	.026	-2.61
	70M7-71M11	.018	.511	.013	-2.59
2	79M11-81M10	.070	.625	-2.770	-2.58
	77M11-79M10	.126	.125	.288	-13.28
	75M11-77M10	-.006	.991	-.590	-18.28
	73M11-75M10	-.007	.925	-.166	-.93
	71M11-73M10	-.004	.431	.035	-4.27
	70M8-71M10	.004	.401	.115	-1.99
3	79M10-81M9	.081	.563	-.363	-2.80
	77M10-79M9	.114	.229	.193	-14.49
	75M10-77M9	-.049	1.413	-.728	-10.32
	73M10-75M9	-.012	.812	-.271	.60
	71M10-73M9	-.006	.260	-.211	-3.55
	70M9-71M9	.004	.074	.288	.16

6	78M12-80M11	.157	.055	-.128	.07
	76M12-78M11	.021	.938	-.428	-10.45
	74M12-76M11	-.010	.145	-.686	-17.64
	72M12-74M11	-.023	.130	-.337	-2.78
	70M12-72M11	-.002	.316	.036	-1.29
12	78M1-79M12	.229	-.516	.236	-5.65
	76M1-77M12	.015	1.180	-.644	-11.80
	74M1-75M12	-.019	-.516	-.344	1.76

Table A-5

Summary of Sub-period Results for Equation 4

$$s_t = a + b(f_t^k - s_t) + cs_t + dppp_t$$

Maturity					
1	79M12-81M11	.034	-2.31	.573	.248
	77M12-79M11	.074	-7.20	.683	-.205
	75M12-77M11	-.020	-3.49	.798	.321
	73M12-75M11	-.006	-.42	.884	.122
	71M12-73M11	-.003	-1.96	.677	-.026
	70M7-71M11	.018	-2.08	.524	-.013
2	79M11-81M10	.072	-.63	.338	.270
	77M11-79M10	.119	-6.88	.440	-.260
	75M11-77M10	-.007	-8.78	.367	.610
	73M11-75M10	-.007	.32	.764	.162
	71M11-73M10	-.005	-1.99	.454	-.042
	70M8-71M10	.003	-.35	.586	-.146
3	79M10-81M9	.078	-.54	.207	.363
	77M10-79M9	.108	-6.82	.428	-.161
	75M10-77M9	-.036	-4.09	.543	.742
	73M10-75M9	-.011	.22	.601	.257
	71M10-73M9	-.064	-1.24	.212	.013
	70M9-71M9	.004	.48	.426	-.313

6	78M12-80M11	.152	-.09	-.053	.135
	76M12-78M11	-.004	-.33	.586	.530
	74M12-76M11	-.018	-3.77	-.656	.768
	72M12-74M11	-.024	-.86	-.246	.329
	70M12-72M11	-.002	.52	.357	-.102
12	78M1-79M12	.217	-1.68	-.289	-.150
	76M1-77M12	.003	-.51	.461	.797
	74M1-75M12	-.018	-.03	-.872	.315

Appendix 2: The Data

In this section we describe the data used in our study. Two sets of exchange rate data are used, as well Canadian and U.S. GNE deflators which are combined to calculate the measure of purchasing-power-parity (PPP). All exchange rates are expressed as the price of foreign exchange, that is, the Canadian value of one U.S. dollar.

We have called our main data set the "contract" data. In this case closing forward rates were selected from the last Wednesday of each month for value the next business day. The Wednesday rates were chosen to minimize the effects of the U.S. dual payments system which was in operation until October 1981 (see M. Levi (1978)). The closing spot rate corresponding to the contract value date of each forward rate was also selected, in order to correctly calculate the value of any contracts bought or sold at the aforementioned forward rates. The value dates were chosen according to the following rules:

1. If the next business day following the last Wednesday of month 't' is a given date, the value date of an 'n' month forward contract is the same date in month 't+n', except

2. if the value date in month 't+n' falls on a weekend or holiday, in which case the value date becomes the next business day, except

3. when the next business day is outside month 't+n', in which case the value date becomes the last business day of month 't+n', except

4. when the next business day following last Wednesday of month 't' is the last business day of that month, in which case the value date becomes the last business day of month 't+n'.

Thus spot rates are chosen which correspond exactly to the rates at which forward contracts made the last Wednesday of each month would close. These are actual prices faced by market participants.

The data set includes spot, one, two, three and six month forward rates which begin in June 1970, when the most recent Canadian flexible regime began, and end in December 1981. A twelve month forward rate series beginning in January 1974 and ending in December 1981 is also included. With the contract data, it is necessary to have a spot rate series which corresponds to each forward rate series, as is obvious when the spot rates are chosen using the criteria discussed above. Second, spot rate series corresponding to each forward maturity will be of different length since a one month forward contract is concluded the next period, while a twelve month contract needs twelve periods. Thus, the longer the forward contract, the shorter the corresponding spot rate series.

The PPP measure was constructed using Canadian and U.S. GNE deflators based to 1971=1.0. The data used are the first announcements of these figures. To convert the series from quarterly to monthly frequency, each announcement is recorded in the month it was made, and then repeated until the next announcement was made. These data series begin in June 1970 and end in September 1981.

Appendix 3: Intervention Variables and Tests of Efficiency

To review the definition of efficiency, a market is said to be efficient if prices set in that market reflect all information available to the private sector. Therefore, if the exchange market is efficient, spot and forward exchange rates must reflect, among other things, known past intervention and rationally forecasted future intervention. Thus intervention cannot by itself render a market inefficient. Intervention can, however, affect the interpretation of statistical tests in a number of ways.

The first, and most obvious, way is that past intervention affects the relative asset stocks held by the private sector and therefore, in the presence of risk aversion, may affect the expected risk premium at the beginning of a period. This does not affect rejection of the "joint hypothesis" ("speculative efficiency"), but may affect the interpretation of why the "joint hypothesis" is rejected.

The second way in which intervention can affect the interpretation of tests is when a large intervention, which is both unexpected ex ante and unexplainable by previous policy rules as a reaction to the size of the contemporaneous exchange rate change, causes a large shift away from unity in the coefficient of the forward rate in equations such as (1) through (5). In such a case one should not interpret this bias as a rejection of efficiency, because there would be no way ex ante or ex post to take advantage of the information. The results from mechanical trading rules, such as those in section 4 of this paper, would show this clearly.

It appears that the problem treated in the above paragraph cannot be dealt with by including contemporaneous intervention in the regression equation since contemporaneous intervention will nearly always be correlated with some information that the market did not have when it made its forecasts. However, observations associated with periods of large interventions unexplained by previous policy rules could be dropped in performing regression tests for bias of the forward rate.

The econometric problems encountered when attempting to include contemporaneous intervention can be illustrated by the following simple model:

$$\Delta s_t = b p_t + c X_t + u_t$$

$$X_t = k \Delta s_t + v_t$$

where $\Delta s_t = s_t - s_{t-1}$;

$p_t = f^1_{t-1} - s_{t-1}$, the beginning of period forward premium;

X_t is intervention from time t+1 to time t;

and u_t and v_t are white noise error terms.

The reduced form of the system is

$$X = \left[\frac{k}{1-kc}\right] p + \left[\frac{k}{1-kc}\right] u + \left[\frac{v}{1-kc}\right]$$

$$s = \left[b + \frac{ck}{1-ck}\right] p + \left[\frac{u}{1-kc}\right] + \left[\frac{v}{1-kc}\right]$$

If Δs is regressed on p and X, the ordinary least squares estimates of b and c are:

$$\hat{b}_{ols} = \frac{(X'X)(\Delta s'p) - (X'p)(\Delta s'X)}{(p'p)(X'X) - (X'p)^2}$$

$$\hat{c}_{ols} = \frac{(p'p)(\Delta s'X) - (X'p)(\Delta s'p)}{(p'p)(X'X) - (X'p)^2}$$

It can be shown that if $\frac{p'p}{n} \longrightarrow$ a matrix, say Q, and if u and v are uncorrelated in the limit, then

$$\text{plim } \hat{b}_{ols} = b + \frac{ck}{1-ck} - \frac{k}{1-ck}\left[\frac{k^2\sigma_u^2 + c\sigma_v^2}{k^2\sigma_u^2 + \sigma_v^2}\right]$$

and

$$\text{plim } \hat{c}_{ols} = \frac{k\sigma_u^2 + c\sigma_v^2}{k^2\sigma_u^2 + \sigma_v^2}$$

In general, these are not equal to b and c, so the OLS estimates are not consistent. (The case k=0, which give consistency, is the case where intervention does not respond to the current change in the exchange rate). When intervention in truth has no effect on the exchange rate, c=0, and

$$\text{plim } \hat{b}_{ols} = b - k\left[\frac{1+\sigma_v^2}{k^2\sigma_u^2}\right]$$

$$\text{plim } \hat{c}_{ols} = \frac{1}{k+\frac{\sigma_v^2}{k\sigma_u^2}}$$

which, if X_t is measured in sales of foreign reserves and if s_t is the log of the price of foreign exchange rate implying that k is positive for a leaning-against-the-wind rule, means that $\hat{b}_{ols}$ is downward biased and that $\hat{c}_{ols}$ will tend to be positive. In the example given, there is only one exogenous variable. The system is therefore under-identified, so no consistent estimator can be found.

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