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EVALUATING THE INFORMATION CONTENT AND MONEY MAKING ABILITY OF FORECASTS FROM EXCHANGE RATE EQUATIONS

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Evaluating the Information Content and Money Making Ability of Forecasts from Exchange Rate Equations

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Abstract

This paper evaluates a particular set of equations for the dollar/yen and dollar/mark exchange rates. The forecasts from the equations dominate both forecasts from the random walk model and forecasts using the forward rate. The results also suggest that money may be able to be made in the forward markets using the equations.

1 Introduction

It is clear from the current literature on exchange rates that there is no generally agreed-upon model of exchange rate determination.[1] The "asset" models, which were analyzed in an influential paper by Meese and Rogoff (1983a), have not done

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[1]See, for example, the recent surveys of Frankel and Rose (1995) and Taylor (1995). See also Levich (1998), Chapter 6.

well in empirical tests based on data beyond the late 1970s,[2] and no main alternative model has emerged.

This paper examines the type of exchange rate equations that are part of the multicountry econometric (MC) model in Fair (1994). Two methods are used to examine the equations. The first is the method in Fair and Shiller (1990)—denoted FS. In many cases this method is better at discriminating among alternative models than is the common method of comparing root mean squared errors of forecasts. The second method examines whether the exchange rate forecasts from the equations contain enough information to allow money to be made in the forward exchange markets. Two exchange rates are considered: the dollar/yen rate and the dollar/mark rate. The data are quarterly, and the basic estimation period is 1972:2-1997:2.

It will be seen that the equations do well in the FS tests and appear capable of being used to make money in the forward exchange markets. Although more tests and time are needed before any strong conclusions can be made, the evidence in favor of the equations so far is encouraging.

The next section presents the exchange rate equations. In order to carry out the FS and money making tests of the exchange rate equations, price and interest rate equations are needed, and these equations are presented in Section 3. The FS tests are then discussed in Section 4, and the money making tests are discussed in Section 5. Section 6 contains a discussion of some tests of alternative specifications.

The entire MC model is not used for the tests in this paper. The FS and money making tests are based on 65 sets of estimates, the first estimation period ending in

[2]There is, however, some evidence that the asset models do better for longer forecast horizons. See, for example, Meese and Rogoff (1983b) and Mark (1995).

1981:1, and sufficient data are not available for this to be done for the entire model. Some of the work in this paper is thus less "structural" than would be the case if the complete MC model were being analyzed. In particular, lagged values of some of the explanatory variables are used in the price and interest rate equations where contemporaneous values might otherwise have been used.

2 The Exchange Rate Equations

Notation

The following notation will be used. The United States is the domestic country, and the foreign country is either Japan or Germany. The nominal exchange rate at the end of quarter t is denoted e_t, and it is in units of foreign currency per dollar. (An increase in e_t is thus an appreciation of the dollar.) For each country, R_t denotes the three month interest rate at an annual rate, P_t denotes the GDP price index, and B_t denotes the ratio of the current account of the balance of payments to nominal GDP. When necessary, a superscript f will be used to denote that the variable is a foreign variable and a superscript u will be used to denote that the variable is a U.S. variable. Define: $r_t = [(1 + R_t^f)/(1 + R_t^u)]^{.25}$, $p_t = P_t^f/P_t^u$, and $b_t = (1 + B_t^f)/(1 + B_t^u)$. r_t is a relative interest rate measure, where the .25 is used to put it at a quarterly rate; p_t is the relative price level; and b_t is the relative current account position.[3]

[3]The relative interest rate and relative current account position are defined the way they are so that logs can be used in the specification below. This treatment relies on the fact that the log of $1 + x$ is approximately x for small values of x.

Specification

The following two equations are postulated:

$$e_t^* = \alpha p_t r_t^{\beta} b_{t-1}^{\gamma}, \quad \beta < 0, \quad \gamma < 0 \tag{1}$$

$$e_t/e_{t-1} = (e_t^*/e_{t-1})^{\lambda} \exp(\epsilon_t), \quad \lambda > 0 \tag{2}$$

Equation (1) states that the "long-run" nominal exchange rate, e_t^*, depends on the relative price level, the relative interest rate, and the lagged relative current account position. The current account position is lagged one quarter on the assumption that it is observed with this lag. The coefficient on the relative price level is constrained to be one, which means that in the long run the real exchange rate is assumed merely to fluctuate as the relative interest rate and relative current account position fluctuate. Equation (2) is a partial adjustment equation, which says that the actual exchange rate adjusts λ percent of the way to the long-run exchange rate each quarter. ϵ_t is an error term. Equations (1) and (2) imply

$$\log(e_t/e_{t-1}) = \lambda \log \alpha + \lambda(\log p_t - \log e_{t-1}) + \lambda\beta \log r_t + \lambda\gamma \log b_{t-1} + \epsilon_t \tag{3}$$

which can be estimated.

The latest discussion of the theory behind this exchange rate specification is in Section 2.2 in Fair (1994), where a two-country theoretical model is specified and then analyzed by simulation techniques. The appendix contains a brief discussion of this theory. There may, of course, be other theories than the one in the appendix that lead to an equation like (3) to estimate. The main aim of this paper is to test equation (3), not to argue strongly in favor of one theory over another. The theory in the appendix should be looked upon as only one possible justification of the specification in (3).

Data

The data used in this paper are part of the data for the MC model and are available from the website mentioned in the introductory footnote. The data on e are end of quarter data and were collected from the International Financial Statistics (IFS). The rest of the data are quarterly averages. The current account data are from the IFS. The interest rate data are also from the IFS and are data on three-month interest rates. The GDP data are from the U.S. Department of Commerce for the United States and from the OECD for Japan and Germany. The price indices used are GDP price indices. The GDP and current account data have been seasonally adjusted.

Estimates

Estimates of equation (3) are presented in Table 1 for two sample periods for each country. All the periods begin in 1972:2, roughly the beginning of floating exchange rates. The first sample period for each country ends in 1997:2, the latest quarter of data at the time of this writing. The second period ends in 1981:1, which is the first sample period used for the FS tests below. This sample period consists of only 36 observations.

Consider first the estimates of the equation for the longer sample period. The estimates of λ are fairly small (.049 and .067), which implies a slow adjustment process of the exchange rate to its "long run" value. The coefficient estimates of $\log r_t$ and $\log b_{t-1}$ are negative, as expected, and are fairly similar across the two countries. The equation standard errors, which are roughly in percent terms, are .0555 for Japan and .0615 for Germany.

Table 1
Estimates of the Exchange Rate Equation (3)

$$\log(e_t/e_{t-1}) = \lambda \log \alpha + \lambda(\log p_t - \log e_{t-1}) + \lambda\beta \log r_t + \lambda\gamma \log b_{t-1} + \epsilon_t$$

	Japan		**Germany**	
	1972:2-1997:2	1972:2-1981:1	1972:2-1997:2	1972:2-1981:1
	Estimate (t-stat)	Estimate (t-stat)	Estimate (t-stat)	Estimate (t-stat)
$\lambda \log \alpha$	.252	-.119	.037	.059
	(1.94)	(-0.32)	(1.84)	(0.99)
λ	.049	-.022	.067	.125
	(1.93)	(-0.31)	(1.89)	(1.20)
$\lambda\beta$	-2.54	-1.96	-2.23	-.92
	(-2.95)	(-1.32)	(-2.24)	(-0.44)
$\lambda\gamma$	-.94	-1.32	-.43	-1.16
	(-3.94)	(-2.65)	(-1.93)	(-1.55)
SE	.0555	.0485	.0615	.0610
DW	1.92	1.71	1.85	2.05
# obs.	101	36	101	36

The estimates for the shorter sample period are not as good, especially for Japan. The estimate of λ for Japan is negative (although highly insignificant), which then calls into question the interpretation of the coefficient estimates of $\log r_t$ and $\log b_{t-1}$. Clearly this sample period for Japan is not long enough for meaningful results to be obtained. Although not shown in the table, the estimate of λ for Japan first turns positive for the sample period ending in 1987:2. The coefficient estimates for Germany for the shorter period are of the expected signs, although they have fairly low t-statistics.

No formal stability tests or other tests are performed here, since the emphasis in this paper is on the FS and money making tests below. Even though the estimates for

Japan for the early sample periods have negative estimates of λ, they have been used for the tests.

3 The Price and Interest Rate Equations

The FS and money making tests need forecasts from equation (3) based only on information through quarter $t-1$. Since P_t and R_t appear in equation (3)—through p_t and r_t— forecasts of these variables are needed. For present purposes an equation for P_t has been postulated that has no contemporaneous explanatory variables, and an equation for R_t has been postulated that has no contemporaneous explanatory variables except P_t. In this way the equations can be used to forecast quarter t using only information through quarter $t-1$.

The following equation is postulated for P_t for each country:

$$\log P_t = \alpha_1 + \alpha_2 t + \alpha_3 \log P_{t-1} + \alpha_4 \log PM_{t-1} + \alpha_5 \log Y_{t-1} + \mu_t \qquad (4)$$

where PM denotes the import price index and Y denotes real GDP. This type of price equation is discussed in Fair (1997a, 1997b), and this discussion will not be repeated here. The specification here uses lagged values of PM and Y, whereas in the complete MC model contemporaneous values are generally used. The data on PM are from the U.S. Department of Commerce for the United States and from the IFS for Japan and Germany.

Estimates of equation (4) are presented in Table 2 for two sample periods for each country. Again, the first sample period for each country ends in 1997:2 and the second ends in 1981:1. The beginning quarters are determined by data availability.

Table 2
Estimates of the Price Equation (4)

$$\log P_t = \alpha_1 + \alpha_2 t + \alpha_3 \log P_{t-1} + \alpha_4 \log PM_{t-1} + \alpha_5 \log Y_{t-1} + \mu_t$$

	Japan		**Germany**		**United States**	
	1967:3-1997:2	1967:3-1981:1	1969:1-1997:2	1969:1-1981:1	1954:1-1997:2	1954:1-1981:1
	Estimate (t-stat)	Estimate (t-stat)	Estimate (t-stat)	Estimate (t-stat)	Estimate (t-stat)	Estimate (t-stat)
α_1	-.974	-1.244	-.427	-.881	-.252	-.331
	(-2.73)	(-1.88)	(-7.54)	(-5.02)	(-3.91)	(-2.97)
α_2	-.000546	-.000419	-.000167	-.000965	.000082	-.000262
	(-2.01)	(-0.21)	(-1.83)	(-2.66)	(0.52)	(-1.09)
α_3	.937	.899	.945	.947	.936	.963
	(38.18)	(10.52)	(82.57)	(40.52)	(93.67)	(44.75)
α_4	.0146	.0340	.0165	.0257	.0330	.0266
	(1.85)	(1.86)	(4.29)	(3.23)	(8.50)	(3.13)
α_5	.0921	.114	.0710	.159	.0333	.0522
	(2.75)	(1.64)	(7.54)	(5.16)	(2.80)	(2.71)
ρ	.529	.590	–	–	.511	.465
	(6.34)	(3.75)			(7.67)	(5.20)
SE	.00740	.00966	.00339	.00357	.00270	.00312
DW	2.29	2.17	1.73	2.31	2.23	2.20
# obs.	120	55	114	49	174	109

ρ is the first order serial correlation coefficient of the error term.

Results for the two sample periods are presented to give an idea of how stable the coefficient estimates are across time. They are estimated under the assumption of first order serial correlation of the error terms except for Germany, where the estimates of the serial correlation coefficients were not significant. The coefficient estimates in Table 2 are of the expected signs and most are significant.

The postulated R_t equation for each country is:

$$R_t = \beta_1 + \beta_2 t + \beta_3 R_{t-1} + \beta_4 \Delta \log P_t + \beta_5 \log Y_{t-1} + \beta_6 R_t^u + \beta_7 \Delta R_{t-1} + \beta_8 \Delta R_{t-2} + \eta_t \quad (5)$$

As discussed in the appendix, this equation can be interpreted as an approximation to a feedback equation. It is similar to the interest rate equations in the MC model. Again, the specification here uses the lagged value of Y, whereas in the MC model the contemporaneous value is generally used. The use of P_t in the equation means that the monetary authority is assumed to know P_t when solving for the optimal value of R_t. The use of R_t^u, the U.S. rate, in this equation (for Japan and Germany) assumes that the Japanese and German monetary authorities are influenced by U.S. monetary policy. The two change in interest rate terms are meant to pick up dynamic effects not captured in the other variables. The time trend is included in the equation to in effect detrend output, under the assumption that the appropriate demand pressure variable is the deviation of output from its trend. As noted at the bottom of Table 3, the interest rate equation for the United States differs somewhat from the other two.

Estimates of equation (5) are presented in Table 3 for two sample periods for each country. The first sample period for each country ends in 1997:2 and the second ends in 1981:1. The beginning quarters are 1972:2 for Japan and Germany and 1954:1 for the United States.

The coefficient estimates for inflation ($\Delta \log P_t$) in Table 3 are positive, implying that the monetary authorities "lean against the wind" with respect to inflation in their setting of short term interest rates. For Japan and Germany the coefficient estimates for output ($\log Y_{t-1}$) are positive except for the shorter estimation period for Japan,

Table 3
Estimates of the Interest Rate Equation (5)

$$R_t = \beta_1 + \beta_2 t + \beta_3 R_{t-1} + \beta_4 \Delta \log P_t + \beta_5 \log Y_{t-1} + \beta_6 R_t^u + \beta_7 \Delta R_{t-1} + \beta_8 \Delta R_{t-2} + \eta_t$$

	Japan		**Germany**		**United States**	
	1972:2-1997:2 Estimate (t-stat)	1972:2-1981:1 Estimate (t-stat)	1972:2-1997:2 Estimate (t-stat)	1972:2-1981:1 Estimate (t-stat)	1954.1-1997:2 Estimate (t-stat)	1954.1-1981:1 Estimate (t-stat)
β_1	-.674	.387	-.263	-.784	-.096	-.118
	(-3.16)	(0.28)	(-2.15)	(-0.83)	(-3.88)	(-3.77)
β_2	-.000661	-.000189	-.000246	-.001498	–	–
	(-3.33)	(-0.15)	(-1.61)	(-1.53)		
β_3	.800	.739	.748	.497	.862	.820
	(26.31)	(9.24)	(16.58)	(4.33)	(42.91)	(18.93)
β_4	.229	.166	.681*	1.033*	.307	.444
	(3.04)	(1.09)	(2.77)	(2.00)	(3.31)	(3.37)
β_5	.0675	-.0339	.0468	.1509	.0996[a]	.1219[a]
	(3.19)	(-0.25)	(2.08)	(0.89)	(3.97)	(3.83)
β_6	.090*	.325*	.138	.392	–	–
	(3.64)	(2.80)	(3.51)	(2.67)		
β_7	.308	.285	.223	.149	.272	.256
	(3.47)	(1.87)	(2.50)	(0.91)	(4.25)	(3.23)
β_8	.189	.208	.215	.286	-.345	-.444
	(2.15)	(1.24)	(2.36)	(1.61)	(-5.78)	(-5.21)
β_9	–	–	–	–	.176	.153
					(3.57)	(2.88)
β_{10}	–	–	–	–	.076	.124
					(2.54)	(3.19)
β_{11}	–	–	–	–	1.008	.883
					(9.24)	(6.68)
SE	.00576	.00786	.00782	.01099	.00550	.00525
DW	2.01	1.93	1.92	2.04	1.97	2.09
# obs.	101	36	101	36	174	109

*Variable is lagged one quarter.

[a]Variable is JJS_{t-1}, a measure of labor market tightness in Fair (1994).

β_9 is the coefficient of $\Delta \log Y_{t-1}$.

β_{10} is the coefficient of $\Delta \log M1_{t-1}$, where $M1$ is the money supply.

β_{11} is the coefficient of $D_t \Delta \log M1_{t-1}$, where D_t is 1 between 1979.4 and 1982.3 and 0 otherwise.

which also implies leaning against the wind behavior. The demand variables for the United States are JJS_{t-1} and $\Delta \log Y_{t-1}$. No time trend is included in the U.S. regression because JJS has no trend. Also used for the United States is the lagged growth of the money supply and the lagged growth of the money supply multiplied by a dummy variable that is 1 between 1979:4 and 1982:3 and 0 otherwise. The dummy variable is an attempt to capture the change in Fed behavior during the 1979:4-1982:3 period, where monetary aggregates were given much more weight than they were either before or after.

4 The FS Tests

A series of 65 one-quarter-ahead predictions of e_t was generated for each country (Japan and Germany). These predictions used the exchange rate equation for the country, the two relevant price equations, and the two relevant interest rate equations. The first prediction was for 1981:2 using coefficients estimated on data through 1981:1. These coefficient estimates are presented in Tables 1, 2, and 3. The second prediction was for 1981:3 using coefficients estimated on data through 1981:2, and so on. The 65th prediction was for 1997:2 using coefficients estimated on data through 1997:1.[4] No data on any variable for quarter t is used for the quarter t prediction. All the explanatory variables in the price equations (4) are lagged; the contemporaneous variables in the interest rate equations (5) are the price levels and the U.S. interest rate, which are determined by equations; and the contemporaneous variables

[4]Note that the estimates through 1997.2, which are presented in Tables 1, 2, and 3, are not used here. These estimates are the ones that would be used for a prediction for 1997:3. At the time of this writing data for 1997:3 are not available.

in the exchange rate equations (3) are the price levels and interest rates, which are determined by equations.

Let $\widehat{\log e_t}$ be the prediction of $\log e_t$ for quarter t. The FS test in the present context is to estimate:

$$\log e_t = \gamma_1 + \gamma_2 \widehat{\log e_t} + \gamma_3 \log e_{t-1} + \omega_t \tag{6}$$

over the 65 observations. The variable $\log e_{t-1}$ in this equation represents the random walk model, namely the model in which the forecast of $\log e_t$ is simply $\log e_{t-1}$. If neither the present model nor the random walk model contain any information useful for forecasting $\log e_t$, then the estimates of γ_2 and γ_3 should both be zero. In this case the estimate of γ_1 would be the average of $\log e_t$ over the period. If both models contain independent information, then γ_2 and γ_3 should both be nonzero. If both models contain information, but the information in, say, the random walk model is completely contained in the present model and the present model contains further relevant information as well, then γ_2 but not γ_3 should be nonzero.

The error term ω_t in equation (6) is likely to be heteroskedastic. If, for example, $\gamma_1 = 0$, $\gamma_2 = 1$, and $\gamma_3 = 0$, ω_t is simply the forecast error from the model, and in general forecast errors are heteroskedastic. The equation was thus estimated using White's (1980) correction for heteroskedasticity.

The results of estimating equation (6) are presented in Table 4. (Ignore for now the results in the table using $\log f_{t-1}$.) For both Japan and Germany the estimates of γ_2 but not γ_3 are significant. This suggests that the random walk model contains no useful information not contained in the present model. Given, however, the small sample size and the fact that the estimates of γ_3 are fairly large (.261 and .355),

Table 4
The FS Tests

$$\log e_t = \gamma_1 + \gamma_2 \widehat{\log e_t} + \gamma_3 \log e_{t-1} + \gamma_4 \log f_{t-1} + \omega_t$$

	Japan		Germany	
	Estimate (t-stat)	Estimate (t-stat)	Estimate (t-stat)	Estimate (t-stat)
γ_1	.032 (0.24)	.023 (0.17)	.034 (1.47)	.035 (1.50)
γ_2	.733 (2.54)	.824 (3.17)	.607 (2.08)	.732 (2.64)
γ_3	.261 (0.93)	–	.355 (1.25)	–
γ_4	–	.173 (0.68)	–	.233 (0.85)
SE	.0630	.0632	.0630	.0633
DW	2.10	2.09	1.89	1.89
# obs.	65	65	65	65

The sample period is 1981.2-1997.2.
The equations are estimated by OLS using White's correction for heteroskedasticity.

one may not want to completely rule out the possibility that the random walk model contains useful independent information. Nevertheless, it is clear that the present model does much better than the random walk model in the FS tests.

The FS results in Table 4 are the main results in this paper, and to some extent this paper could stop here. The FS test provides a straightforward way of seeing whether one model dominates another, and the results show that the random walk model is dominated. However, given the good FS results for the present model, it is of interest to see if the model can make money, which is the concern of the next section.

5 The Money Making Tests

Let f denote the three-month forward exchange rate, where f_t is the value for the end of quarter $t+1$. The value of f_t is known at the end of quarter t. Data on f are available from the IFS. The arbitrage condition that connects f, e, and r is:

$$\frac{f_t}{e_t} = r_t \tag{7}$$

where r_t is defined at the beginning of Section 2. Because of timing differences, namely that r_t is the average for the quarter and e_t and f_t are end of quarter, the data on f_t, e_t, and r_t do not exactly match equation (7), but the approximation is very close. In practice f_t is simply set to e_t times the correctly matching value of r_t.

Most of the evidence in the literature suggests that f_{t-1} is not a great predictor of e_t. The FS results in Table 4 for f_{t-1} are consistent with this evidence. The estimates of the coefficients of $\log f_{t-1}$ are not significant and are smaller than even the respective coefficients for $\log e_{t-1}$. There is clearly little evidence in Table 4 that the forward rate contains information not in the present model.[5]

If the model can on average do better than the forward rate, there is possibly money to be made. Tables 5 and 6 show how this might be done. $\hat{e}_t$ in the second column is the predicted value of e_t from the set of 65 predictions [$\hat{e}_t = \exp(\widehat{\log e_t})$]. It is based only on information known at the beginning of quarter t. The next column presents f_{t-1}, which is also known at the beginning of quarter t. The next column

[5] In a recent paper Clarida and Taylor (1997), using weekly data, present a vector error correction model in which forward rates appear to contain useful forecast information, contrary to most other results. Whether this result will hold up under further tests is unclear, but the results in Table 4 are not supportive of it.

Table 5
Buying and Selling Results for Japan

Qtr.	$\hat{e}_t$	f_{t-1}	Predicted: $-100\times$ $\frac{\hat{e}_t}{f_{t-1}}-1$	d_t: buy(1) sell(-1)	e_t	Profit: $-100d_t\times$ $\frac{e_t}{f_{t-1}}-1$
1981.2	215.11	207.70	-3.6	-1	225.80	8.7
1981.3	231.96	219.95	-5.5	-1	232.70	5.8
1981.4	237.55	225.75	-5.2	-1	219.90	-2.6
1982.1	223.14	216.35	-3.1	-1	246.50	13.9
1982.2	252.80	243.05	-4.0	-1	254.00	4.5
1982.3	255.99	250.15	-2.3	-1	269.50	7.7
1982.4	268.30	266.50	-0.7	-1	235.00	-11.8
1983.1	232.16	233.90	0.7	1	239.40	-2.4
1983.2	237.36	237.45	0.0	1	239.70	-0.9
1983.3	231.14	237.85	2.8	1	236.10	0.7
1983.4	226.49	234.42	3.4	1	232.20	0.9
1984.1	223.17	230.05	3.0	1	224.70	2.3
1984.2	215.80	222.37	3.0	1	237.50	-6.8
1984.3	226.51	233.95	3.2	1	245.50	-4.9
1984.4	238.00	242.30	1.8	1	251.10	-3.6
1985.1	241.07	249.94	3.5	1	252.50	-1.0
1985.2	246.78	249.03	0.9	1	248.95	0.0
1985.3	238.88	247.98	3.7	1	217.00	12.5
1985.4	205.16	215.07	4.6	1	200.50	6.8
1986.1	185.82	200.04	7.1	1	179.60	10.2
1986.2	167.36	178.66	6.3	1	165.00	7.6
1986.3	151.34	163.02	7.2	1	153.60	5.8
1986.4	140.80	152.48	7.7	1	159.10	-4.3
1987.1	149.77	159.30	6.0	1	145.80	8.5
1987.2	136.78	144.68	5.5	1	147.00	-1.6
1987.3	140.61	145.57	3.4	1	146.35	-0.5
1987.4	141.03	145.04	2.8	1	123.50	14.9
1988.1	117.10	121.04	3.3	1	125.40	-3.6
1988.2	121.24	123.64	1.9	1	132.40	-7.1
1988.3	130.61	131.04	0.3	1	134.55	-2.7
1988.4	132.60	133.02	0.3	1	125.85	5.4
1989.1	123.32	124.47	0.9	1	132.05	-6.1
1989.2	131.60	130.64	-0.7	-1	144.10	10.3
1989.3	143.91	142.57	-0.9	-1	139.30	-2.3
1989.4	138.12	138.08	0.0	-1	143.45	3.9
1990.1	142.18	142.85	0.5	1	157.20	-10.0
1990.2	155.18	157.21	1.3	1	152.90	2.7
1990.3	151.99	152.61	0.4	1	137.80	9.7
1990.4	136.45	137.99	1.1	1	134.40	2.6

Table 5 (continued)

Qtr.	$\hat{e}_t$	f_{t-1}	Predicted: $-100\times \frac{\hat{e}_t}{f_{t-1}} - 1$	d_t: buy(1) sell(-1)	e_t	Profit: $-100d_t \times \frac{e_t}{f_{t-1}} - 1$
1991.1	132.41	135.57	2.3	1	141.00	-4.0
1991.2	140.45	141.04	0.4	1	137.90	2.2
1991.3	136.51	138.75	1.6	1	132.85	4.3
1991.4	131.01	133.25	1.7	1	125.20	6.0
1992.1	123.37	125.67	1.8	1	133.20	-6.0
1992.2	131.16	133.21	1.5	1	125.50	5.8
1992.3	124.01	125.75	1.4	1	119.20	5.2
1992.4	117.47	119.47	1.7	1	124.75	-4.4
1993.1	122.64	124.74	1.7	1	116.35	6.7
1993.2	114.05	115.37	1.1	1	106.75	7.5
1993.3	105.62	106.50	0.8	1	105.15	1.3
1993.4	103.98	104.86	0.8	1	111.85	-6.7
1994.1	110.98	111.52	0.5	1	103.15	7.5
1994.2	102.10	102.38	0.3	1	99.05	3.3
1994.3	98.85	98.29	-0.6	-1	98.45	0.2
1994.4	98.37	97.80	-0.6	-1	99.74	2.0
1995.1	99.65	98.82	-0.8	-1	89.35	-9.6
1995.2	89.37	87.40	-2.3	-1	84.60	-3.2
1995.3	85.22	83.75	-1.8	-1	98.30	17.4
1995.4	100.04	96.77	-3.4	-1	102.83	6.3
1996.1	105.09	101.58	-3.5	-1	106.28	4.6
1996.2	107.70	105.19	-2.4	-1	109.42	4.0
1996.3	111.79	108.48	-3.1	-1	110.97	2.3
1996.4	112.58	109.94	-2.4	-1	116.00	5.5
1997.1	117.50	114.52	-2.6	-1	124.05	8.3
1997.2	125.55	122.33	-2.6	-1	114.40	-6.5

Percentage of positive profit values	.63
Mean of positive profit values	6.00
Standard deviation of positive profit values	3.96
Mean of negative profit values	-4.70
Standard deviation of negative profit values	2.91
Overall mean	2.05
Overall standard deviation	6.30
Minimum value	-11.8
Maximum value	17.4

Table 6
Buying and Selling Results for Germany

Qtr.	$\hat{e}_t$	f_{t-1}	Predicted: $-100\times \frac{\hat{e}_t}{f_{t-1}} - 1$	d_t: buy(1) sell(-1)	e_t	Profit: $-100d_t \times \frac{e_t}{f_{t-1}} - 1$
1981.2	2.139	2.090	-2.3	-1	2.391	14.4
1981.3	2.389	2.359	-1.3	-1	2.323	-1.5
1981.4	2.324	2.291	-1.5	-1	2.255	-1.6
1982.1	2.159	2.237	3.5	1	2.414	-7.9
1982.2	2.392	2.378	-0.6	-1	2.460	3.4
1982.3	2.423	2.418	-0.2	-1	2.528	4.5
1982.4	2.470	2.504	1.4	1	2.377	5.1
1983.1	2.293	2.357	2.7	1	2.427	-2.9
1983.2	2.391	2.400	0.4	1	2.542	-5.9
1983.3	2.523	2.514	-0.3	-1	2.639	5.0
1983.4	2.645	2.615	-1.1	-1	2.724	4.2
1984.1	2.699	2.697	-0.1	-1	2.590	-4.0
1984.2	2.551	2.559	0.3	1	2.784	-8.8
1984.3	2.782	2.740	-1.5	-1	3.025	10.4
1984.4	3.070	2.984	-2.9	-1	3.148	5.5
1985.1	3.136	3.125	-0.3	-1	3.093	-1.0
1985.2	3.128	3.070	-1.9	-1	3.061	-0.3
1985.3	3.026	3.044	0.6	1	2.670	12.3
1985.4	2.590	2.647	2.2	1	2.461	7.0
1986.1	2.343	2.443	4.1	1	2.318	5.1
1986.2	2.194	2.302	4.7	1	2.199	4.5
1986.3	2.053	2.187	6.1	1	2.021	7.6
1986.4	1.857	2.014	7.8	1	1.941	3.6
1987.1	1.814	1.935	6.2	1	1.805	6.7
1987.2	1.697	1.794	5.4	1	1.830	-2.0
1987.3	1.748	1.815	3.7	1	1.838	-1.3
1987.4	1.771	1.822	2.8	1	1.582	13.2
1988.1	1.500	1.567	4.3	1	1.659	-5.9
1988.2	1.624	1.645	1.3	1	1.821	-10.7
1988.3	1.771	1.806	1.9	1	1.880	-4.1
1988.4	1.828	1.864	1.9	1	1.780	4.5
1989.1	1.730	1.763	1.9	1	1.893	-7.4
1989.2	1.848	1.874	1.4	1	1.953	-4.2
1989.3	1.895	1.942	2.4	1	1.868	3.8
1989.4	1.798	1.862	3.4	1	1.698	8.8
1990.1	1.634	1.698	3.8	1	1.694	0.2
1990.2	1.630	1.693	3.7	1	1.672	1.3
1990.3	1.628	1.671	2.6	1	1.564	6.4
1990.4	1.503	1.565	4.0	1	1.494	4.5

Table 6 (continued)

Qtr.	$\hat{e}_t$	f_{t-1}	Predicted: $-100\times$ $\frac{\hat{e}_t}{f_{t-1}}-1$	d_t: buy(1) sell(-1)	e_t	Profit: $-100d_t\times$ $\frac{e_t}{f_{t-1}}-1$
1991.1	1.442	1.501	3.9	1	1.717	-14.4
1991.2	1.672	1.730	3.3	1	1.812	-4.7
1991.3	1.766	1.826	3.3	1	1.663	8.9
1991.4	1.613	1.679	3.9	1	1.516	9.7
1992.1	1.458	1.537	5.2	1	1.643	-6.9
1992.2	1.600	1.665	3.9	1	1.527	8.3
1992.3	1.478	1.550	4.7	1	1.409	9.1
1992.4	1.350	1.431	5.6	1	1.614	-12.8
1993.1	1.583	1.635	3.2	1	1.614	1.3
1993.2	1.579	1.634	3.4	1	1.688	-3.3
1993.3	1.654	1.707	3.1	1	1.620	5.1
1993.4	1.602	1.634	2.0	1	1.726	-5.6
1994.1	1.711	1.738	1.6	1	1.672	3.8
1994.2	1.658	1.680	1.3	1	1.595	5.0
1994.3	1.590	1.596	0.4	1	1.548	3.0
1994.4	1.553	1.547	-0.4	-1	1.549	0.1
1995.1	1.564	1.544	-1.3	-1	1.384	-10.4
1995.2	1.399	1.379	-1.4	-1	1.384	0.3
1995.3	1.393	1.379	-1.0	-1	1.419	2.9
1995.4	1.432	1.412	-1.4	-1	1.434	1.5
1996.1	1.460	1.427	-2.3	-1	1.476	3.4
1996.2	1.495	1.468	-1.8	-1	1.522	3.7
1996.3	1.544	1.514	-2.0	-1	1.527	0.8
1996.4	1.537	1.522	-1.0	-1	1.555	2.2
1997.1	1.569	1.546	-1.5	-1	1.678	8.5
1997.2	1.687	1.667	-1.2	-1	1.744	4.6

Percentage of positive profit values	.65
Mean of positive profit values	5.34
Standard deviation of positive profit values	3.44
Mean of negative profit values	-5.55
Standard deviation of negative profit values	3.80
Overall mean	1.49
Overall standard deviation	6.31
Minimum value	-14.4
Maximum value	14.4

presents the value of $-100(\frac{\hat{e}_t}{f_{t-1}} - 1)$, which is the percent by which the predicted value differs from the forward price. If this number is negative it means that the predicted value of e_t is greater than the forward price, which is a predicted depreciation of the yen from the forward price. In this case one should sell short the forward contract, which is represented by a minus 1 in the next column. A plus 1 means to buy the forward contract. The next column presents the actual value of e_t, the value that is known at the end of quarter t. The last column is the profit or loss in percent terms.

To take an example, consider the first row in Table 5. e_t is predicted to be 3.6 percent larger than f_{t-1}, which calls for selling the forward contract in yen short. So at the beginning of quarter t one could have sold yen for delivery at the end of the quarter for 207.70 per dollar. If the prediction turned out to be exact, one could have bought yen at the end the quarter for 215.11 per dollar, thus making a profit of 3.6 percent of the forward price. In fact, the actual value turned out to be 225.80, so the profit would have ended up being 8.7 percent of the forward price.

Summary statistics are presented at the ends of Tables 5 and 6. For Japan, 63 percent of the time there are profits, and the overall mean return is 2.05 percent (per quarter). For Germany, 65 percent of the time there are profits, and the overall mean return is 1.49 percent. The results thus say that on average one could have made money, although at considerable risk since a little over a third of the time losses are incurred. It is interesting to note that there are fewer losses near the end of the period. For example, for the 14 quarters beginning in 1994:1 there are only 3 losses for Japan and 1 loss for Germany. This improved recent performance is not necessarily surprising, since one might expect the results to improve as the estimation periods lengthen and thus more efficient coefficient estimates are obtained.

If one is willing to bear the risk, the mean returns in Tables 5 and 6 can be leveraged up. For example, it is currently possible for even a small investor to buy or sell a three-month futures yen contract worth about \$100,000 with about \$3,000 in margin, and the transactions costs are quite small. The mean annual return in Table 5 for a leverage ratio of 30 to 1 is $4 \times 2.05 \times 30 = 246$ percent!

Given the FS results in Table 4, it may not be surprising that the forecasts do well in Tables 5 and 6, since they clearly dominate the forward rate forecasts. Note, however, that the metric by which the forecasts are judged is different between Table 4 and Tables 5 and 6. A minus one/plus one decision is made in Tables 5 and 6 based on whether $\hat{e}_t$ is larger or smaller than f_{t-1}, and there is nothing comparable to this in Table 4.

An interesting question regarding the results in Tables 5 and 6 is how the size of the profit in a particular quarter relates to the predicted size. Are large predicted deviations of e_t from f_{t-1} in absolute value associated with large profits? Figures 1 and 2 provide a visual answer to this question. The profit (or loss) is on the vertical axis, and the predicted deviation is on the horizontal axis. These values are from the fourth and seventh columns of Tables 5 and 6. As one moves right or left from zero on the horizontal axis, do the profit values move up? From the two figures it can be seen that there is only slight evidence that this is true. There does not appear to be much extra information in the *size* of the predicted deviation that is not already in the *sign* regarding the size of the expected profit.

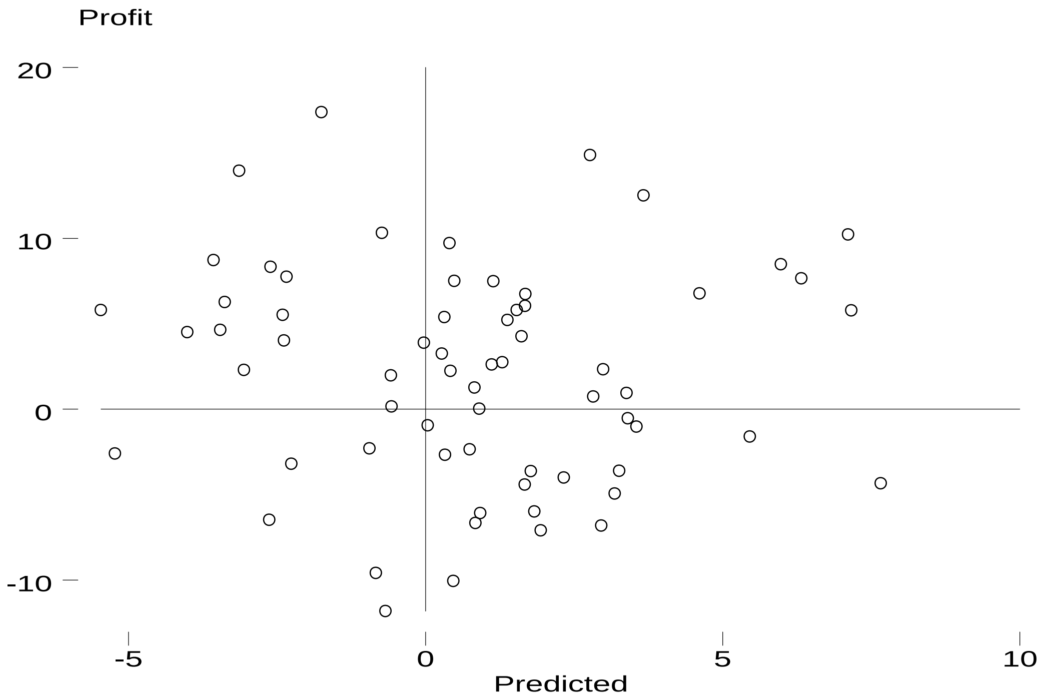

Figure 1 Japan: Values from Table 5

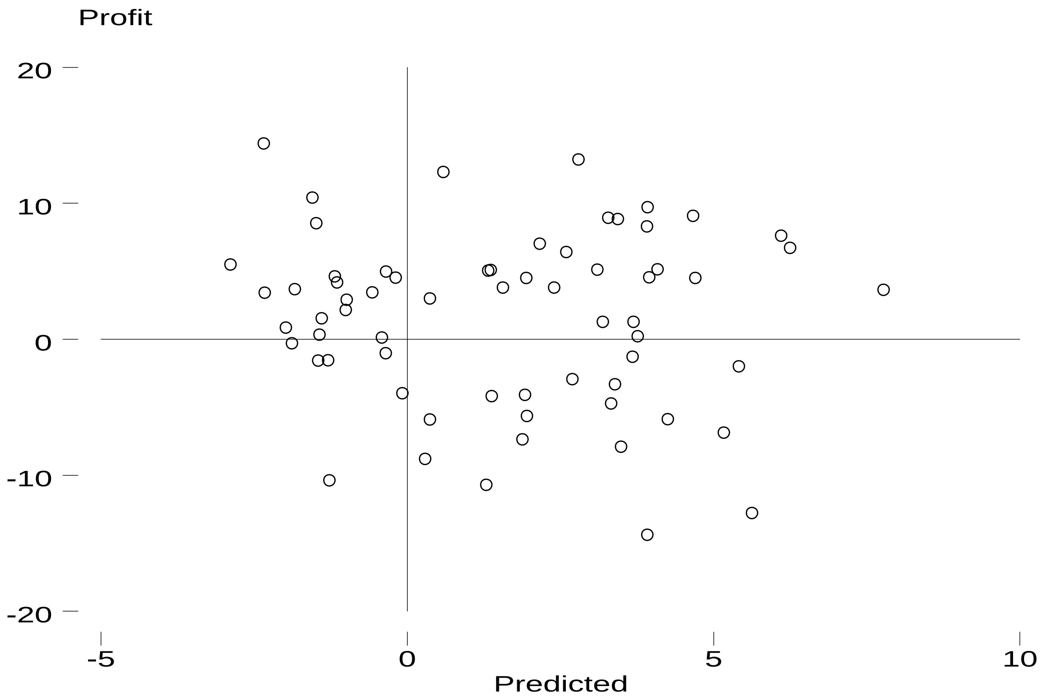

Figure 2 Germany: Values from Table 6

6 Tests of Alternative Specifications

The Monetary Model

An exchange rate equation that has been extensively examined in the literature is:

$$\log e_t = \alpha_1 + \alpha_2 \log m_t + \alpha_3 \log y_t + \alpha_4 \log r_t + \epsilon_t \tag{8}$$

where m_t is the ratio of the foreign to domestic money supply and y_t is the ratio of the foreign to domestic real GDP.[6] Under most theories α_2 is one. As noted in Section 1, this "asset" model of exchange rate determination has generally not done well in recent tests. For present purposes equation (8) was estimated for the 65 different sample periods and the FS test was performed. For this work the variables m_t, y_t, and r_t were taken to be exogenous (no estimated equations were used).[7] α_2 was not constrained to be one in the estimation.

The FS test results for equation (8) were very poor, even with the use of the actual values of m_t, y_t, and r_t in all the predictions. The estimate of the coefficient of $\widehat{\log e_t}$, which is γ_2 in equation (6), was -.015 for Japan and -.093 for Germany. The estimate of the coefficient of $\log e_{t-1}$ was .991 for Japan and 1.040 for Germany. The random walk model thus completely dominated equation (8). The results of the money making test were also poor. The overall mean return was -.62 for Japan (compared to 2.05 in Table 5) and -.55 for Germany (compared to 1.49 in Table 6). The present results

[6] In most studies the interest rate term is specified as $R_t^f - R_t^u$, where, as defined at the beginning of Section 2, R_t^f and R_t^u are the two interest rates. However, $R_t^f - R_t^u$ and $\log r_t$ are virtually the same, and it does not matter which is used—see footnote 3.

[7] Data on the money supplies were taken from the Federal Reserve for the United States and from the IFS for Japan and Germany. The data are data on M1. Again, these data are on the website mentioned in the introductory footnote.

thus add support to the view that equations like (8) are not good approximations.

Real versus Nominal Relative Interest Rates

Some exchange rate equations are estimated using a measure of the *real* relative interest rate in place of the nominal relative interest rate. (Remember that r_t in equation (3) is the nominal relative interest rate.) Theory, however, suggests that the nominal relative interest rate should be used. If, say, I am a Japanese investor deciding whether to invest in U.S. securities versus Japanese securities, I should compare the Japanese and U.S. nominal interest rates, not the real rates. If the goods that I eventually buy are priced in yen, the expected U.S. inflation rate is not of direct concern to me. The expected rate of inflation I care about is the Japanese inflation rate. Tobin (1993, p. 586) has made this point very clearly: "The real rate that concerns Japanese investors is the difference between the yen yield of holding dollar assets and the *Japanese* inflation rate. The U.S. inflation rate is irrelevant to them except as a possible indicator of likely changes in the nominal exchange rate."

It thus does not seem appropriate to replace r_t in equation (3) with a measure of real relative interest rates, and so no specifications of this type have been tested here.

Alternative Dynamics

Boughton (1987) specifies and tests the following equation:

$$\log(e_t/p_t) = \alpha_1 + \alpha_2 r_t^* + \alpha_3 k_{t-1} + \alpha_4 \log(e_{t-1}/p_{t-1}) + \epsilon_t \qquad (9)$$

where r^* is a real interest rate differential and k is the cumulated deficit in the home country's current account balance as a percent of a measure of the country's total financial wealth. He finds that this equation does well relative to equations like (8) above. The variable k is not relative to the cumulated deficit of another country, and so equation (9) is not relevant for bilateral exchange rates. Boughton (1987) took the exchange rate to be against a SDR basket of other currencies, which was meant to approximate the rest of the world. Because of this, no attempt was made here to test equation (9) directly. In addition, the equation uses the real interest rate differential, which does not seem sensible.

Equation (9) does, however, provide an alternative dynamic specification to be tested. Consider replacing equations (1) and (2) with:

$$e_t^*/p_t = \alpha r_t^\beta b_{t-1}^\gamma, \quad \beta < 0, \quad \gamma < 0 \tag{10}$$

$$(e_t/p_t)/(e_{t-1}/p_{t-1}) = [(e_t^*/p_t)/(e_{t-1}/p_{t-1})]^\lambda \exp(\epsilon_t), \quad \lambda > 0 \tag{11}$$

These two equation imply:

$$\log(e_t/p_t) = \lambda \log\alpha + (1-\lambda)(\log(e_{t-1}/p_{t-1}) + \lambda\beta \log r_t + \lambda\gamma \log b_{t-1} + \epsilon_t \tag{12}$$

Like equation (9), equation (12) has the real exchange rate on the left hand side and the lagged real exchange rate on the right hand side. The specification (10)-(12) differs from (1)-(3) in that the partial adjustment pertains to the real exchange rate rather than the nominal exchange rate. Boughton's equation can thus be looked upon as one in which the partial adjustment is with respect to the real exchange rate.

Equation (12) was estimated for the 65 different sample periods and tested in the same way equation (3) was (using the estimated price and interest rate equations). The results were close between the two specifications. The estimate of the coefficient of $\widehat{\log e_t}$ was .792 (t-statistic 2.49) for Japan and .524 (t-statistic 1.91) for Germany. These compare to .733 (t-statistic 2.54) and .607 (t-statistic 2.08) in Table 4. The estimate of the coefficient of $\log e_{t-1}$ was .211 (t-statistic of 0.69) for Japan and .445 (t-statistic of 1.69) for Germany. These compare to .261 (t-statistic of 0.93) and .355 (t-statistic of 1.25) in Table 4. For the money making tests, both equations gave the same results for Japan (overall mean return of 2.05), and equation (3) did better than (12) for Germany (overall mean return of 1.49 versus 1.09). There is thus slight, but only slight, evidence in favor of equation (3) over (12), namely that the partial adjustment is in nominal terms rather than in real terms.

Using e_{t-1} and f_{t-1} as Forecasts of e_t

Two possible forecasts of e_t are e_{t-1} and f_{t-1}. How do these compare? It turns out that e_{t-1} and f_{t-1} are too collinear for the FS test to be useful. However, it can be seen from Table 4 that when each by itself is compared to the forecast from equation (3), e_{t-1} does better than f_{t-1}, which is at least slight evidence that e_{t-1} is the better of the two. If this is so, then it may be possible to make money in the forward exchange market using e_{t-1} as the forecast of e_t. To test this, the Table 5 and 6 calculations were done with $\hat{e}_t = e_{t-1}$. The average profit was 0.79 percent for the yen and 0.60 percent for the mark, which compare to 2.05 percent and 1.49 percent respectively in Tables 5 and 6. It thus appears that one might be able to make money using the random walk model, but the average percents are much smaller than those for the present model.

A Fourth Order Autoregressive Equation

A fourth order autoregressive equation was specified for the exchange rate, where $\log e_t$ was taken to be a function of its first four lagged values and a constant term. This equation was estimated 65 times and a set of 65 predictions were generated. The autoregressive model did not do well. The random walk model completely dominated it in the FS tests, and when the Table 5 and 6 calculations were done, the average percents were low (0.15 and 0.48, respectively). These results suggest that there is no useful forecasting information in the values of the exchange rate lagged two or more periods.

Combining Forecasts

It may be that a better forecast for Tables 5 and 6 would be a weighted average of the forecast from equation (3) and e_{t-1}. The FS results in Table 4, for example, suggest weights of around .7 and .3. Some experimentation along these lines was done, but the results were not robust to small changes in the weights. Also, when there was an improvement for a particular set of weights, the gain was small. This is thus further evidence that e_{t-1} appears to contain little useful information not already in the forecast from equation (3).

Testing for Future Information Bias

It may be that future information has been used in the exchange rate forecasts, which would bias the results in their favor. For example, all the values for quarter $t-1$ have been assumed to be known for the forecast for quarter t. In practice the data on some of the variables are not available until some time after the end of the quarter. This means that the outside sample forecast computed for, say, 1981:2 is not exactly the forecast that could have been made in 1981:1.

To examine the sensitivity of the results to the assumption that the quarter $t-1$ values are known, the above exercise was repeated assuming that for all variables except the exchange rates and the interest rates, which are available daily, only quarter $t-2$ values are known for the quarter t forecast. The details are as follows. Consider the forecast for t. Equation (3) for each country was estimated through quarter $t-1$ using p_{t-2} as the value for p_{t-1} in the regression. Equations (4) and (5) for each country were estimated only through $t-2$. The values of b, PM, Y, $M1$, and JJS for $t-1$, which are needed for the quarter t forecast, were taken to be the $t-2$ values. The price equations (4) were then solved for $t-1$ to get the predicted value of P for $t-1$ for each country, and then all the equations were solved for t to get the predicted values of e_t for Japan and Germany. This exercise results in a set of 65 predicted values of e_t for each country that are based only on information through quarter $t-2$ except for the values of r_{t-1} and e_{t-1}, which are readily available at the end of $t-1$.

The overall results using these sets of predictions were slightly weaker, but the general conclusions hold. For the first FS test for Japan the estimate of γ_2 was .616 with a t-statistic of 2.10 and the estimate of γ_3 was .372 with a t-statistic of 1.30. The overall mean return for the Table 5 calculations was 1.63 percent, and 60 percent of the profit values were positive. For Germany the estimate of γ_2 was .496 with a t-statistic of 1.64 and the estimate of γ_3 was .463 with a t-statistic of 1.58. The overall mean return was 1.43 percent, and 63 percent of the profit values were positive. In practice one is likely to have somewhat more information than simply the $t-2$ values, and it is encouraging that the results generally hold even if only knowledge of the $t-2$ values is assumed.

7 Conclusion

Equation (3) does well in the tests in this paper, and it appears to explain exchange rates better than does the random walk model. The main results are the FS tests in Table 4, where the random walk model is dominated. In addition, the forecasts from the equation suggest that there may be money to be made in the forward exchange market (at least until enough people are using the equation to eliminate the excess profits?).

The main caveat is that some future information may have been used in the forecasts, thus biasing the results in their favor. There are three possible reasons for this. 1) The specification of equations (3), (4), and (5) was not made as early as 1981:1, and information about what happened between 1981:1 and the present may have been used in the specification. 2) All the data that have been used are the currently revised data, not necessarily the first-released data. 3) All the values for quarter $t-1$ have been assumed to be known for the forecast for quarter t. Regarding the third possible bias, the results reported at the end of the previous section suggest that the bias from assuming that quarter $t-1$ values are known is not large. Whether the other two possible biases are large is unclear, and a true test of the money making ability of the equations will have to be done in real time.

Appendix

This appendix reviews the two-country theoretical model in Section 2.2 in Fair (1994), which is used to justify the specification of equation (3).

In the model each country's monetary authority can influence its interest rate through buying and selling government securities. If, as is done in the paper, an interest rate equation is postulated for a country, this equation is interpreted as an "interest rate reaction function" of the monetary authority. The monetary authority is assumed to buy or sell government securities each period to achieve the interest-rate value implied by the equation. The amount of government securities outstanding is thus endogenous when an interest rate equation is postulated. Similarly, if a money supply reaction function were postulated, the amount of government securities outstanding would be endogenous.

The monetary authorities of the two countries can influence the exchange rate by buying and selling international reserves. Country 1's international reserve holdings is denoted Q and country 2's holdings is denoted q, where $\Delta Q + \Delta q = 0$. If Q is taken to be exogenous, then the exchange rate e is implicitly determined in the model. If, on the other hand, an equation is postulated for e, as above, then Q becomes endogenous. Its value each period is whatever is needed to achieve the exchange-rate value implied by the equation. Postulating an exchange rate equation thus implicitly assumes that monetary authorities intervene in the foreign exchange markets, just as it is implicitly assumed that they intervene in the bond markets when interest rate equations are postulated.

Consider the monetary authority of country 1 and assume that it solves a multi-period optimal control problem each period, where the short term interest rate R and the exchange rate e are the control variables. If the model of the economy that it uses were linear and the objective function quadratic, analytic feedback equations for R and e could be derived, where the variables in the equations are the predetermined variables in the model and the coefficients multiplying the variables are functions of the structural coefficients in the model and the coefficients in the objective function.[8] For a nonlinear model and/or a non-quadratic objective function, the feedback equations are only implicit since no analytic expressions are in general available. In this optimal control context equation (3) above can be thought of as an approximation of a feedback equation for the exchange rate. The aim in specifying the equation is then to choose explanatory variables that are likely to have large effects on the exchange rate in the feedback equation.

Monetary authorities are fairly small players in foreign exchange markets, and it may take large changes in Q relative to the size of Q to change the exchange rate very much from what market forces alone imply. If, say, the monetary authority of country 1 does not want there to be large changes in Q, this means in the optimal control context that there are penalties in the objective function for changes in Q. If the penalties are large, then the optimal response of the monetary authority will be not to intervene much, which means that the coefficients in the feedback equation will depend mostly on the structural coefficients in the model.

The simulation experiments with the theoretical model were used to guide the

[8] See, for example, Chow (1981).

choice of the explanatory variables in the exchange rate equation. The results of the following three experiments are relevant for present purposes.[9] They were all run with Q taken to be exogenous, which means no intervention in the foreign exchange market by the monetary authorities. The amount of government securities outstanding is endogenous for both countries since either the interest rates or the money supplies were taken to be exogenous in the experiments. 1) With country 2's interest rate exogenous, a decrease in country 1's interest rate results in a depreciation of country 1's currency. The use of r in equation (1) is an attempt to account for these kinds of interest rate effects. 2) With either both countries' interest rates exogenous or both countries' money supplies exogenous, a positive price shock in country 1 results in a depreciation of country 1's currency. The use of p in (1) is an attempt to account for these kinds of price effects. 3) With both countries' money supplies exogenous, a positive import demand shock in country 1 results in a depreciation of country 1's currency and a worsening of its current account. The variable b is an attempt to account for shocks of this kind.

To summarize, these experiments suggest that r, p, and b are likely to be important variables in the feedback equation for the exchange rate. They reflect market forces operating on the exchange rate. Intervention by the monetary authorities (i.e., changes in Q) are in part meant to be modeled by the specification of the adjustment process in equation (2), under the assumption that monetary authorities may try to dampen changes in e in the short run.

This completes the transition from the theoretical model to the specification of

[9] See Section 2.2 in Fair (1994) for a detailed explanation of these results.

equation (3). This procedure is, of course, crude. The transition from theory to empirical specifications in macroeconomics is never very precise, and the present case is no exception. If one does not like the transition, an alternative way to think about this paper is that it simply examines whether an exchange rate equation with the relative interest rate, the relative price level, and the relative current account position as explanatory variables outperforms the random walk model.

A final point about timing should be mentioned. If equation (3) is interpreted as an approximation of a feedback equation, it should not have any variables on the right hand side that are unknown to the monetary authority at the time the optimal control problem is solved. It thus must be assumed that the monetary authority knows p_t and r_t when solving for the optimal value of e_t. The data are in part consistent with this, since e_t is the exchange rate at the end of quarter t, whereas all the other variables are averages within the quarter. Since the domestic interest rate R is part of r, if r_t is assumed known when the optimal value of e_t is determined, R_t must also be assumed known. Therefore, if R is also a control variable of the monetary authority, it must be assumed that the optimal value of R_{t+1} (not R_t) is determined at the same time as the optimal value of e_t is. In other words, it must be assumed that the monetary authority knows R_t near the end of period t and chooses at that time the optimal paths of $e_t, e_{t+1}, \ldots$ and $R_{t+1}, R_{t+2}, \ldots$.

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