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An Investigation of the Empirical Performance of Several Exchange Rate Models

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Summary

This study analyzes several empirical models of exchange rate determination in order to determine whether these models provide useful information about the process by which the values of major currencies are determined. It presents a variety of statistical tests, including tests of whether the estimated relationships are stable within the sample period over which they were estimated and of whether they predict well beyond the end of that period. The paper concludes that portfolio balance models outperform monetary models and that in at least some cases they are sufficiently stable to do better than a random walk in explaining exchange rate movements beyond the end of the estimation period. By testing over a broader class of models and by incorporating a wider variety of specification and stability tests, this paper is thus able to draw more favorable conclusions about the performance of exchange rate models than have earlier studies. Nonetheless, it remains evident that none of these models explains more than a small portion of actual month-to-month changes in exchange rates.

I. Introduction

The empirical performance of exchange rate models has been widely criticized in recent years. The concerns derive partly from studies that have found certain models to fit poorly within the sample over which they were estimated or to predict poorly out of sample. In addition, there have been a number of periods during the early 1980s when the exchange rates of major industrial-country currencies have moved substantially in the opposite direction from what would appear to have been consistent

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with observed changes in other variables such as nominal and real interest rate differentials or current account balances. Nonetheless, such incidents do not necessarily invalidate the models; they may merely indicate the presence of important singular events. Furthermore, there are a number of models from which to choose in this context; the failure of some need not lead to a blanket condemnation.

This paper tests the properties of several empirical exchange rate models in order to determine whether they provide useful information about recent movements in exchange rates. It focuses on monthly data since 1973 for three key currencies: the U.S. dollar, the Japanese yen, and the deutsche mark. Section II describes the models, all of which are asset-market models but which vary in the restrictions that they impose on these markets. Section III presents a number of empirical tests, including both nested and non-nested tests of specification, tests of stability within the sample period, and tests of post-sample forecasting ability. The conclusions of the analysis are summarized in Section IV.

II. Model Specification

The first models to be considered in this paper are those that evolved from the monetarist model of Frenkel (1976). In Frenkel's model the expected rate of depreciation of the exchange rate equals the expected inflation differential, so that purchasing power parity (PPP) holds. Uncovered interest parity is also assumed, so that nominal interest rate differentials exactly equal the expected rate of depreciation. Hence real interest rate differentials do not arise, and the nominal interest rate differential is replaced in the reduced form by the expected inflation differential. However, in the extension of this model introduced by Dornbusch (1976), the provision for overshooting of exchange rates under conditions of price rigidity in product markets permits interest rate differentials to be introduced directly. In this extension, Dornbusch assumes that the expected rate of depreciation equals the expected inflation differential plus a portion of the difference between the current level of the real exchange rate and its PPP level. Thus there is an effect on the exchange rate from the real interest rate differential, with the coefficient depending solely on the speed of adjustment in the expectations function. The other determinants of the exchange rate are the same as in the monetarist model: relative stocks of money and relative flows of real income.

The Dornbusch model has been further extended by, among others, Hooper and Morton (1982) and Frankel (1983), through a relaxation of the assumption of uncovered interest parity. This parity condition in turn derives from the assumption that interest-bearing securities denominated in different currencies are perfect substitutes; dropping it implies that the ratio of the stock of securities denominated in the home currency to the stock denominated in other currencies should be an additional argument in the reduced-form equation for the exchange rate. Assuming that this ratio is determined primarily by the cumulated external private capital balance of the country in question, the latter may be added to the Dornbusch equation to yield a synthetic monetary-portfolio-balance (MPB) equation. 1/ This model may be represented by 2/

$$\log E = \alpha_{10} - \alpha_{11}\hat{i} + \alpha_{12}\hat{\pi} + \alpha_{13}k + \alpha_{14}\log \hat{M} - \alpha_{15}\log \hat{Y} \quad (1)$$

where E = the nominal exchange rate (defined as the domestic-currency price of foreign exchange).

$\hat{i}$ = the nominal interest rate differential (the domestic rate minus the foreign rate).

$\hat{\pi}$ = the expected inflation differential (the domestic rate minus the foreign rate).

k = the cumulated external private capital balance (defined so that a cumulated deficit in the home country's current account balance--an increase in its net foreign liabilities--gives a positive value).

$\hat{M}$ = the ratio of the domestic money stock to the money stock of the foreign country, each measured in local currency units.

and $\hat{Y}$ = the ratio of real income in the home country to foreign real income.

Equation (1) may be viewed as a general representation of a class of models in which the sticky-price monetary model and the monetarist model are nested as special cases. That is, if $\alpha_{13} = 0$, then the sticky-price monetary model holds. 3/ If, in addition, $\alpha_{11} = 0$, then the monetarist model holds. Both the general equation and its special cases have been subjected to extensive testing in recent years, and their failure to explain empirical exchange rate movements has provided the primary evidence against the stability of a relationship between exchange rate movements and interest rate differentials. 4/ These models are included here

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1/ For a more complete exposition of the derivation and specification of these models, see Frankel (1983).

2/ The first subscript on each coefficient refers to the equation number; the second indicates the coefficient number.

3/ In addition to these restrictions, all three monetary models imply that $\alpha_{14} = 1$, because if money is neutral the ratio of the two price levels will be proportional, ceteris paribus, to the ratio of the two money stocks. This restriction is not imposed in the tests presented here, because the unrestricted estimates are far from the assumed values.

4/ See, for example, Meese and Rogoff (1983a, 1983b), Frankel (1983), Boughton (1984), and Backus (1984).

primarily as a point of comparison with other, perhaps less well known, models rather than out of any conviction that they might turn out to work better than previous tests have indicated.

In contrast to the synthetic MPB model, a number of portfolio balance models employ expectations mechanisms that do not require the assumption that people believe that there is a systematic difference between the current value of the real exchange rate and its long-run equilibrium level. In these models, the relation between domestic and foreign money stocks does not necessarily play a direct role. An example of this class of models is the work of Artus (1976, 1981, 1984), which builds on the stock-flow models of Kouri and Porter (1974), among others. Artus uses the assumption of price rigidity that characterizes Dornbusch's model, and the assumption of imperfect substitutability among securities denominated in different currencies that characterizes the synthetic MPB model. However, instead of assuming that the exchange rate is expected to return to a PPP level at a fixed rate of adjustment, he formulates a short-run expectations function that incorporates PPP in the same equilibrium context in which it is used in Frenkel's monetarist model: ceteris paribus, the exchange rate is expected to move in line with the expected inflation differential. In addition, Artus assumes that short-run expectations are affected by the difference between the current external balance and its (fixed) long-run sustainable level, and by the difference between the current nominal interest rate differential and its (also fixed) long-run sustainable level. 1/ These assumptions yield an equation that may be written as

$$\Delta \log R = \alpha_{20} - \alpha_{21} \Delta \hat{i} + \alpha_{22} \Delta k + \alpha_{23} \Delta^2 k \qquad (2)$$

where

R = the real exchange rate

Δ is the first-difference operator

and the other variables are defined as for equation (1). It may be noted that Δk is the external capital balance, and $\Delta^2 k$ is the first difference of that flow. 2/

Another example of this class of portfolio balance models is developed in Boughton (1984). In this model, the expected rate of currency depreciation is equal to the expected inflation differential, as in the monetarist model. It is assumed that market participants lack sufficient information to enable them to base expectations on expected long-run sustainable values,

1/ This formulation is from Artus (1981); the specification is somewhat different in the other two papers.

2/ The role of Δk in equation (2) derives from the interest-differential coefficient in the net demand for foreign assets. The role of $\Delta^2 k$ derives from the effect of the expected change in the current account balance on the expected rate of change in the exchange rate. See Artus (1981), p. 528.

as in the two models described above. Actual changes in nominal exchange rates are determined by the state of effective excess demand in foreign exchange markets; because the external balance does not adjust quickly, and because the currency composition of existing financial assets may not adjust quickly to shifts in economic conditions, the momentary equilibrium in these markets need not be--and in general will not be--equivalent to the full long-run equilibrium. These assumptions, along with imperfect asset substitutability as in the models described above, lead to the following reduced-form equation:

$$\log R = \alpha_{30} - \alpha_{31} \hat{r} + \alpha_{32} k_{-1} + \alpha_{33} \log R_{-1} \qquad (3)$$

where $\hat{r}$ = the real interest rate differential $(i-\hat{\pi})$.

Shafer and Loopesko (1983) develop a much simpler model by assuming perfect asset substitutability and therefore uncovered interest parity. Shafer and Loopesko note that, with this assumption, the percentage difference between the current real exchange rate and its long-run equilibrium value (which is assumed to be fixed) must equal the compounded real interest differential over the length of time that the real exchange rate is expected to take to return to equilibrium. Taking the equilibrium value to be constant and assuming that long-run bond yields are proportional to the present value of the short-run yields that are expected during the life of the bond, Shafer and Loopesko derive the result that

$$\log R = \alpha_{40} - \alpha_{41} \hat{r} \qquad (4)$$

where for this model it is essential that $\hat{r}$ be based on long-term interest rates.

The first three models described above are non-nested, while the Shafer-Loopesko model is nested in that of Boughton (assuming that long-run interest rates are relevant for the latter). One could also develop a slightly more general version of Artus' expectations function by assuming that exchange rate expectations are affected by the difference between the current real interest differential and its sustainable level and by the difference between the current real exchange rate and its sustainable level, in addition to the variables suggested by Artus. With this generalization, treating the sustainable levels as constants, one could then extend equation (2) to obtain an equation in which the models of Artus, Boughton, and Shafer and Loopesko would all be nested:

$$\log R = \alpha_{50} - \alpha_{51} \hat{r} - \alpha_{52} \Delta i + \alpha_{53} k + \alpha_{54} k_{-1} + \alpha_{55} k_{-2} + \alpha_{56} \log R \qquad (5)$$

1/ In equation (5), the only restriction on the signs of the coefficients on the k's is that $\alpha_{53} + \alpha_{54} + \alpha_{55} \geq 0$. Strictly speaking, Artus' model also requires α_{53} and $\alpha_{55} > 0$ and $\alpha_{54} < 0$. However, the timing of these effects need not be that strictly interpreted, especially when monthly data are being used.

Starting from this compound model, if 53 - 54 + 55 = 0 and 56 = 1, then Artus' model results. 1/ If, instead, 52 = 53 = 55 = 0, then Boughton's model holds. If, in addition to these latter restrictions, 54 = 56 = 0, then one has the Shafer-Loopesko equation. Thus these various models may be evaluated by both nested and non-nested techniques. However, the MPB model and those nested within it are not nested with the others described here. 1/

III. Empirical Tests

The focus of this paper is on three major currencies: the U.S. dollar, the Japanese yen, and the deutsche mark. In order to develop detailed tests of the temporal stability of the various models during the period in which these exchange rates have been floating (i.e., the period beginning in April 1973), it is necessary to use monthly data. Quarterly data would provide just over 40 observations, which would suffice for simple parameter estimation but not for some of the tests to be conducted here. This requirement poses difficulties regarding the data on the external balance on private capital and on income flows. Although monthly data do not exist for many of the components of these series, they may be constructed through interpolation and benchmarking against closely related data. The construction of the monthly data base is described in the Appendix.

The various equations to be estimated may be specified as linear in interest and inflation rates; and in the logarithms of exchange rates, money stocks, and income flows. However, the external balance must be scaled in some way. For example, Hooper and Morton (1982) scale it by the trend value of nominal GNP, while Artus (1981) uses the ratio of exports of goods and services to imports of goods and services (the import cover ratio). In order to compare model specifications rather than to evaluate specific measurement issues, it is desirable to use the same scaling procedure in all of the estimated equations. For this purpose, the external balance in these tests is divided by a measure of total financial wealth held by domestic nonbank private sectors. 2/

Interest rate differentials are based on long-term yields in order to provide a fair test of the assumption of uncovered interest parity that is incorporated in the monetary models and in the Shafer-Loopesko model. As Shafer and Loopesko note, it is necessary to use a long enough period to

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1/ A number of other exchange-rate models could be considered, but many of them require data that are not readily available. The models selected for this study thus should be regarded as representative rather than exhaustive.

2/ The rationale for this procedure is described in Boughton (1983, 1984).

maturity to allow for the restoration of long-run equilibrium of the real exchange rate within the period. For the portfolio-balance models, the choice of interest rate is somewhat arbitrary, so the use of long-run yields is at least not inconsistent with most of the models discussed here. 1/

For the U.S. dollar, the exchange rate is defined here as the effective rate against the other currencies that are included in the SDR basket: the Japanese yen, the deutsche mark, the pound sterling, and the French franc. For this purpose, the bilateral exchange rates--as well as the interest rate, money, and income differentials--between the dollar and the other four currencies are weighted by the weights established for the SDR in 1981. 2/ All of the tests presented in this paper are applied to this effective rate as well as to the bilateral dollar exchange rates for the yen and the mark.

In order to generate reasonably comparable estimates of the several reduced-form equations, it has been necessary to make certain assumptions that might not necessarily accord with all of the underlying structural models. First, expected inflation is measured here as a centered moving average of actual data. This procedure is the same as was used in Boughton (1984), and it is similar to the short-run measure employed in Artus (1981). 3/ Most estimates of the monetary models have assumed instead that expected inflation is proportional to the current rate of monetary growth. 4/ Second, it is assumed that the only endogenous variables in the equations are the nominal values of interest rates and exchange rates. All of the equations have been estimated with interest rates replaced by the values predicted by reduced-form money-market equations. 5/ It is interesting to note that estimates using actual interest rates are very similar to those reported here, except that the estimated coefficient variances are generally slightly larger. Either there is little simultaneity or the instrumental variables have failed to remove it.

Estimates of the various reduced-form equations described in Section II are presented in Table 1. In order to provide a consistent test of the

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1/ The possible exception is the Artus model, because equation (2) uses Artus' short-run expectations mechanism and therefore should properly use short-term interest rates.

2/ These weights are .328 for the mark and .224 for the other three currencies. For a further description, see the Appendix.

3/ Artus uses a moving average of current and past inflation, with weights estimated econometrically. His measure of long-run expectations does impose monetary neutrality, but that measure does not enter the exchange rate equation.

4/ The assumption that the growth rates of money and income follow random walks is necessary to ensure the rationality of an expectations mechanism based on current values; this assumption is made in most tests of the monetary models.

5/ Instruments for this purpose are domestic and foreign values of real income and inflation, and current and lagged values of the money stock.

goodness of fit for these equations, this table includes an F statistic. This statistic evaluates the hypothesis that the equation explains a statistically significant portion of the variance of month-to-month changes in nominal exchange rates against the null hypothesis that the explained portion is zero. 1/ Standard R^2 statistics are misleading in this context, because the dependent variable differs in the estimation of the different models. Standard errors of the estimate resolve this difficulty, but they do not take into account differences in the number of degrees of freedom. The F statistic is especially useful in the context of exchange rate equations, because all such equations explain, at best, only a small portion of actual period-to-period changes. The relevant question is whether this small portion is statistically different from zero. 2/

It is clear from Table 1 that the estimated monetary models (equations 1, 1a, and 1b) are of no value in explaining movements in any of these exchange rates. The F statistics uniformly indicate insignificance, most of the individual parameter estimates are insignificantly different from zero, and many of the signs of the coefficients are contrary to theoretical expectations. Similarly, the Shafer-Loopesko equation has mostly insignificant coefficient estimates, although the F statistic indicates overall significance when applied to the bilateral exchange rates. 3/ In contrast, all of the portfolio-balance models based on the assumption of imperfect asset substitutability provide a statistically significant explanation for one or more currencies; equation (3), from Boughton (1984), and equation (5), the compound model, have significant F statistics for all three currencies, while Artus' equation (2) is significant for the deutsche mark. Most of the coefficient signs in these equations are consistent with prior expectations, although they are not always signif-

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1/ The formula for this statistic is

$$F = [\text{variance } (\Delta \log E) \cdot (N-1) - S^2 \cdot (N-K-1)]/(S^2 \cdot K)$$

where N is the number of observations, K is the number of regressors excluding the constant, and S is the standard error of the estimate. This statistic gives commensurate information for all equations, regardless of whether the dependent variable is the nominal or the real exchange rate and whether the equation is estimated in level or first-difference form.

2/ For a discussion of why exchange rate equations cannot be expected to explain more than a small portion of actual changes, see Mussa (1979, 1984).

3/ All of the models that are estimated with a first-order autocorrelation correction show a coefficient (rho) that is approximately unity. Consequently, re-estimation of these models in first-difference form (i.e., imposing a value of unity and dropping the constant term) gives essentially the same results. Similarly, the addition of an autocorrelation correction to those equations that include a lagged dependent variable makes virtually no difference.

Table 1. Estimates of Exchange Rate Equations, May 1973-December 1983

Equation	Model	Dependent variable	$\hat{i}$	$\hat{i}_{-1}$	$\hat{\pi}$	k	k_{-1}	k_{-2}	$\hat{M}$	$\hat{Y}$	R_{-1} 1/	rho 1/	F 2/
			Coefficients and t-ratios on:										
						A: U.S. Dollar Effective Rate							
1	MPB	E	-1.52*		0.10	-0.37†			0.38	0.41†		0.99	1.40
			(2.24)		(0.25)	(0.89)			(0.87)	(0.19)		(0.90)	
1a	Monetary	E	-1.50*		0.11				0.42	0.04†		0.98	1.40
			(2.21)		(0.28)				(0.97)	(0.18)		(0.90)	
1b	Monetarist	E			0.05				0.24	-0.04†		0.99	0.24
					(0.13)				(0.56)	(0.16)		(0.86)	
2	Artus 3/	R	-1.45*	1.45*		-0.42	0.59	-0.17			1		1.93
			(2.19)	(2.19)		(0.58)	(0.56)	(0.40)					
3	Boughton	R	-0.60**				0.12				0.94**		6.70**
			(4.16)				(1.69)				(2.72)		
4	Shafer-Loopesko 3/	R	-0.51		0.51							0.98	2.74
			(1.44)		(1.44)							(0.99)	
5	Compound 3/	R	-1.57*	1.01	0.57**	-0.29	0.57	-0.18			0.94*		3.86**
			(2.47)	(1.57)	(3.89)	(0.72)	(0.99)	(0.46)			(2.46)		
						B: Deutsche Mark/Dollar Rate							
1	MPB	E	-1.32		0.38	-0.07†			0.02	0.13†		0.97	1.50
			(1.64)		(0.67)	(0.35)			(0.08)	(0.60)		(1.72)	
1a	Monetary	E	-1.29		0.38				0.01	0.15†		0.97	1.65
			(1.62)		(0.67)				(0.04)	(0.70)		(1.68)	
1b	Monetarist	E			0.32				-0.08†	0.20†		0.97	1.30
					(0.56)				(0.27)	(0.92)		(1.56)	
2	Artus 3/	R	-0.78	0.78		-0.25	0.84*	-0.59**			1		4.40**
			(1.02)	(1.02)		(0.98)	(2.18)	(3.18)					
3	Boughton	R	-0.31**				0.04				0.93*		3.33*
			(2.70)				(1.41)				(2.42)		
4	Shafer-Loopesko 3/	R	-0.87		0.87							0.98	3.79*
			(1.86)		(1.86)							(1.07)	
5	Compound 3/	R	-0.99	0.74	0.25	-0.32	0.79**	-0.44*			0.94		3.21**
			(1.28)	(0.97)	(1.92)	(1.65)	(2.71)	(2.19)			(1.86)		
						C: Yen/Dollar Rate							
1	MPB	E	0.81†		0.12	-0.06†			-0.20†	-0.04		0.96	1.66
			(1.03)		(0.69)	(0.13)			(0.31)	(0.30)		(1.57)	
1a	Monetary	E	0.82†		0.13				-0.21†	-0.05		0.96	0.87
			(1.05)		(0.73)				(0.33)	(0.31)		(1.58)	
1b	Monetarist	E			0.14				-0.06†	-0.04		0.97	0.84
					(0.84)				(0.10)	(0.25)		(1.41)	
2	Artus 3/	R	0.19†	-0.19†		-1.32	2.63	-1.31			1		1.44
			(0.24)	(0.24)		(1.52)	(1.79)	(1.92)					
3	Boughton	R	-0.32**				0.30**				0.89**		4.10**
			(3.01)				(2.66)				(3.34)		
4	Shafer-Loopesko 3/	R	-0.20		0.20							0.96	4.09*
			(1.15)		(1.15)							(1.71)	
5	Compound 3/	R	0.24†	-0.56†	0.32**	-1.21	2.38	-0.90			0.89**		2.66*
			(0.30)	(0.71)	(2.90)	(1.75)	(1.90)	(1.31)			(3.24)		

1/ t-ratio is for difference from unity.
2/ Significance of explanation of Δlog E; see footnote 1 on p. 8.
3/ Estimated subject to the restrictions described in the text.

* = significant at the .05 level.
** = significant at the .01 level.
† = sign inconsistent with model.

icantly different from zero. For example, most of the explanatory power in equation (3) comes from the real interest rate differential and relatively little from the cumulated external balance; only for the yen/dollar rate is the latter a significant determinant at the .05 level. 1/

A variety of more detailed tests of specification are presented in Table 2. The first section of this table reproduces the F tests from Table 1, along with comparable tests for a longer sample, ending in December 1984 instead of December 1983. The longer sample cannot at this time be generally applied to the monetary models, owing to the lack of current data on income and, in a few instances, on money stocks. Otherwise the F tests for this sample confirm the pattern observed above. Most of the F statistics are lower than their counterparts for the shorter sample, but only slightly so. On the basis of these results and the problems with the parameter estimates shown in Table 1, it is certainly warranted to conclude that the monetary models can be eliminated as explanations of movements in these currencies; the remaining tests in Table 2 therefore exclude equation (1) and its special cases. 2/

The second section of Table 2 contains F tests on the restrictions that equations (2, 3, and 4) impose on the more general compound model. As described above, equation (2) imposes two restrictions, while equation (3) imposes three and equation (4) imposes five; the F test shown here is a joint test of the validity of each set of restrictions. For the Artus and Shafer-Loopesko models, the restrictions are significant (i.e., the hypothesis that the restricted model is correct may be rejected) at the .01 level in two of the three cases. For the Boughton equation, the restrictions are significant at the .05 level in only one case. It would therefore appear that none of these models provides a generally valid explanation of the expectations and adjustment functions that are relevant for these currencies, but that each may be valid for at least one of the exchange rates under consideration. However, it is shown in the table that the two restrictions that the Shafer-Loopesko equation imposes on equation (3) are uniformly invalid. The Shafer-Loopesko model may thus be dropped from further consideration as being unnecessarily restrictive.

1/ Serial correlation tests are not shown in Table 1, but the estimates are all free of first-order serial correlation by standard tests: for the equations without lagged dependent variables, the Durbin-Watson statistic; and, for the others, Durbin's h.

2/ The tests presented here are not strictly tests of the models, but rather are joint tests of the models, the exogeneity of right-hand variables, and measurement of expected values. However, the conclusion with respect to the nonviability of the monetary models is consistent with other evidence cited above, in which exogeneity and measurement decisions have differed from those made here.

Table 2. Specification Tests

Model	U.S. Dollar		Deutsche mark		Japanese yen	
1. Overall F tests	To 1983	To 1984	To 1983	To 1984	To 1983	To 1984
MPB	1.40		1.50		1.66	
Artus	1.93	1.54	4.40**	4.09**	1.44	1.70
Boughton	6.70**	6.62**	3.33*	3.35*	4.10**	2.95*
Shafer-Loopesko	2.74	1.46	3.79*	1.86	4.09*	3.48
Compound	3.86**	3.64**	3.21**	3.08**	2.66*	2.41*
2. F tests on restrictions						
a. vs. compound model						
Artus	8.59**		2.94		5.81**	
Boughton	1.05		3.00*		1.23	
Shafer-Loopesko	4.19**		3.15**		2.43	
b. Shafer-Loopesko vs. Boughton	8.65**		3.09*		4.07*	
3. Davidson-McKinnon t-tests						
Artus	4.12**		2.41*		3.37**	
Boughton	1.77		2.90**		1.73	

* = significant at the .05 level.
** = significant at the .01 level.

Section 3 of Table 2 presents Davidson-MacKinnon tests for equations (2) and (3), which are non-nested. For this test, each equation is re-estimated with the predicted values from the other as an additional argument. The test is then repeated for the second equation. Davidson and MacKinnon (1981) show that a conventional test of the significance of the additional arguments may be used to compare the two equations. For example, if the predicted values from equation (2) are a significant determinant of the exchange rate when added to equation (3), while the predicted values from (3) are insignificant when added to (2), then one would reject equation (3) in favor of (2). This test may lead to the rejection of both equations (implying that a compound model would be preferred) or the acceptance of both (perhaps implying that a more restrictive model would be preferred).

For the dollar and the yen, the results from the Davidson-MacKinnon test are consistent with the F tests just described: Boughton's equation is preferred over Artus'. For the deutsche mark, the results are less clear. Both equations are rejected in the sense that each contributes something that is missing from the other. However, the significance level of the rejection is higher for Boughton's equation; thus in this case, as well as the other two, the two tests do appear to give consistent information about the relative merits of the two models.

The next step is to evaluate these equations for their ability to forecast outside the sample period. For this purpose, each equation has first been estimated through December 1980 and has then been used to generate a dynamic forecast of month-to-month changes in the nominal exchange rate during 1981, using actual data for the determining variables and predicted values for the lagged dependent variable. The test has then been repeated for each subsequent year (i.e., the equation is estimated through December 1981 and used to forecast 1982, and so on). The root mean squared errors (RMSEs) from these forecasts are then compared to the RMSEs calculated for a random walk in order to determine whether the models provide useful out-of-sample information about exchange rate movements. 1/

The results of this test are summarized in Table 3. The results show, for example, that in 1981 the Artus model does not do better than a random walk for any of the three exchange rates. The Boughton model, on the other hand, has an RMSE that is 22 percent lower than that of the random walk in predicting the deutsche mark/dollar rate and about 50 percent better for the other two exchange rates. The compound model falls between these two. Overall, the Artus model improves upon the random walk in four out of twelve cases, while the other two do better in nine out of twelve. The Boughton model does better than the compound model in six of the eight cases in which both do better than the random walk.

1/ For models that pass this test, it would also be interesting to know whether they perform better than an estimated univariate time-series model. However, tests by Meese and Rogoff (1983a) and by Backus (1984) indicated that the latter have generally done worse than a random walk; those tests have not been repeated here.

Table 3. Post-Sample Twelve-Month Dynamic Prediction Errors Relative to a Random Walk

(Percentage decrease in RMSE relative to the RMSE for a random walk) 1/

Model	U.S. dollar	Deutsche mark	Japanese yen
a. 1981			
Artus	--	--	--
Boughton	-54.3	-21.8	-51.0
compound	-48.2	--	-32.0
b. 1982			
Artus	--	-7.6	--
Boughton	-62.5	-55.4	-26.4
compound	-50.2	-33.6	-13.0
c. 1983			
Artus	-34.3	--	--
Boughton	-43.0	-18.8	--
compound	-58.1	-11.2	--
d. 1984			
Artus	-25.3	-9.6	--
Boughton	-16.2	--	--
compound	-25.6	-4.1	--

1/ Indicates a higher RMSE.

In general, the models predict better in 1981 and 1982 than in the two later years. The year 1984 was especially difficult for all exchange rate models. During the first nine months of the year, interest rate differentials generally moved in favor of the U.S. dollar, fostering an appreciation; however, the models all underpredict the appreciation. Then, during the last quarter, interest rate differentials moved in favor of both of the other currencies against the U.S. dollar, but the dollar continued to appreciate and even accelerated its rate of increase. Nonetheless, for the year as a whole, all three of the portfolio-balance models predict changes in the effective rate of the dollar better than a random walk. They do somewhat less well for the mark/dollar rate and not well at all for the yen/dollar rate.

For purposes of this test, the models take advantage of the information contained in contemporaneous movements in interest rate differentials and the external capital balance during the prediction periods. These results thus do not indicate the feasibility of forecasting exchange rates in practice; they only serve to illustrate the intertemporal stability of estimated relationships. The significance of the favorable results shown in Table 3 is that, as was previously shown by Meese and Rogoff (1983a) and by Backus (1984), other models in general have not been able to outperform a random walk forecast, even when using actual data from the forecast period.

The remaining tests are concerned with the temporal stability of the regression relationships within the full sample period (1973-84). Section 1 of Table 4 shows the results of the cusum and cusum-of-squares tests for each of the three portfolio balance models. 1/ For these tests, each equation is estimated over a set of sample periods, beginning with the first or last K+1 observations (where K is the number of regressors) and then extended one observation at a time until the full sample is reached. The cumulated sum of the residuals (or the squared residuals) is then evaluated against a test statistic to determine whether the residuals are accumulating at a reasonably steady rate as the sample lengthens. If not, then the hypothesis that the parameter estimates are stable throughout the sample period is rejected at the specified confidence level.

These two recursive-regression tests give quite different impressions. Although most of the estimated equations appear to be stable when judged by the cusums test, they all show some temporal instability when subjected

1/ For a description of the cusum-of-squares test and its relationship to the Quandt log-likelihood ratio discussed below, see Brown, Durbin, and Evans (1975).

Table 4. Within-Sample Stability Tests

Model	U.S. dollar		Deutsche mark		Japanese yen	
1. Recursive residuals tests	cusum	cusums squared	cusum	cusums squared	cusum	cusums squared
Artus	.80	.142**	.88*	.138*	.50	.282***
Boughton	.74	.161**	.85*	.149**	.73	.231***
compound	.79	.175**	.76	.134*	.67	.251***
2. Time-trended coefficients	F	order	F	order	F	order
Artus	1.75	2	4.25***	1	0.72	1
Boughton	1.42	1	3.25***	1	2.98**	1
					2.37*	2
compound	1.40	2	4.05***	1	4.19***	1
3. Most likely shift date, from Quandt ratios						
Artus	Oct. 1978		Sept. 1979		Oct. 1978	
Boughton	May 1982		July 1975		Oct. 1978	
compound	May 1982		Sept. 1979		Oct. 1978	
4. F tests for shift	covar.	Gupta	covar.	Gupta	covar.	Gupta
Artus	2.46**	2.49**	6.62***	6.62***	2.24*	2.28*
Boughton	2.34*	3.09**	3.68***	2.75**	8.13***	8.01***
compound	1.74	2.31**	4.19***	4.23***	5.60***	5.50***
5. Goldfeld-Quandt tests for heteroskedasticity 1/	F	sign	F	sign	F	sign
Artus	1.55		1.24		2.94**	-
Boughton	5.93**	+	2.64**	-	2.16**	-
compound	6.37**	+	1.32		2.38**	-
6. t test on stability of interest rate coefficients	point shift	max. drift	point shift	max. drift	point shift	max. drift
Artus (nominal)	0.82	1.87*	1.06	2.46**	0.70	2.12**
Boughton (real)	1.85*	1.90*	1.23	6.94***	3.75***	6.64***
compound						
nominal	1.40	0.80	1.60	2.18**	1.10	2.13**
real	1.85*	1.78*	1.37	9.68***	3.69***	7.86***

* = significant at the .10 level.
** = significant at the .05 level.
*** = significant at the .01 level.

1/ The sign indicates whether the greater variance is in the first part of the sample (-) or in the second (+). The absence of a sign indicates that there is no significant difference between the two.

to the cusum-of-squares test. 1/ Only for the Artus and compound model equations for the deutsche mark/dollar rate is the null hypothesis (stability) not rejected at the .05 level. However, even in these two cases, the stability hypothesis would be rejected at the .1 level. 2/ These different results could be attributable to differences in the power of the two tests. It is important to note, however, that the two tests are designed to uncover different types of instability. The cusums test will only indicate systematic shifts in one direction that cause the errors to accumulate. The cusum-of-squares test, on the other hand, will also pick up haphazard instability that causes the sum of the squared errors to deviate from the hypothesized path. It therefore appears from this first pair of tests that these equations are subject to haphazard instability but probably not to systematic shifts.

Another test for systematic instability is provided in Section 2 of the table. For this test, the coefficients are specified as functions of time, rather than as constants. For each equation, the coefficients are first specified as first-order functions of time and then as second-order polynomials. An F statistic is computed for the hypothesis that each addition contributes significantly to the fit of the equation, against the null hypothesis that the contribution is zero. The result of this test is that all of the equations for the effective rate of the U.S. dollar appear to have untrended coefficients, while all but one of the equations for the bilateral rates display significant systematic change over time. Thus, for the bilateral rates, this test conflicts somewhat with the information obtained above, which suggested that whatever instability might be present was more likely to be haphazard than systematic.

Section 3 of Table 4 attempts to identify more precisely the timing of the instabilities suggested by the above tests. For this purpose, a time series of the Quandt log-likelihood ratio is computed for each equation on the basis of the recursive regressions. The minimum value of this time series occurs at the observation where the equation may be deemed to be most likely to shift, on the hypothesis that the equation undergoes a single shift at a specific point. Experience suggests that if the ratio jumps sharply from one observation to the next, that point may also indicate an instability in the function, even if the time series has a lower value elsewhere. For the present exercise, both procedures have been used

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1/ The cusum-of-squares statistic shown in the table is the largest value of the four statistics calculated for each equation. The four statistics refer to the cusum of squares being above or below the diagonal (i.e., testing for whether the residuals are accumulating unusually slowly or unusually rapidly), running forward from the first few observations or backward from the end of the sample period. Similarly, the cusum statistic is the larger of the two--forward and backward--estimates. This procedure may bias the tests against the null hypothesis. For a discussion of the power of the cusum and cusum-of-squares tests, see the comments by Quandt on page 183 of Brown, Durbin, and Evans (1975) and references therein.

2/ Stability tests frequently are evaluated against the relatively strict .1 criterion rather than .05 are higher.

judgmentally in order to determine the most likely date for a functional shift. Unfortunately, the probability distribution of the Quandt ratio under the null hypothesis is not known, so significance tests cannot be performed.

The dates determined in this manner all turn out to have been periods of major policy shifts or of trend reversals in economic variables. July 1975 marked the trough of a major recession in the Federal Republic of Germany, the implementation of a policy of active monetary easing, and the beginning of a period of sustained growth. This date appears to have altered at least one of the relationships for the deutsche mark/dollar exchange rate. September 1979, also indicated for the deutsche mark/dollar rate, was the date of the first realignment in the European Monetary System, when the central rate of the deutsche mark was revalued upward by 2 percent just six months after the implementation of the system of fixed parities within the group of eight European currencies.

At the beginning of November 1978, the U.S. government implemented a package of measures intended to tighten monetary policy and support the exchange rate. This date is indicated as a likely shift date for the U.S. dollar effective rate and for the yen/dollar rate equations. Finally, for two of the U.S. dollar equations, May 1982 is found to be a possible point of instability. This finding could be related to the abandonment at that time of the three-year experiment under which the U.S. Federal Reserve had allowed short-term interest rates to float freely while controlling bank reserves more closely as the principal policy instrument.

That the policy shift in the United States after October 1978 appears to have had a more destabilizing effect on the dollar's exchange rate against the yen than on its rate against the deutsche mark is evident also in examining the exchange rate data for that period. From October 1978 through November 1979, when the Federal Reserve dramatically shifted its domestic monetary operating procedures away from close control of short-term interest rates, there was virtually no change in the dollar/mark rate. During that same period, the yen depreciated by more than 40 percent against the dollar. The reasons for this difference are difficult to summarize, but there may have been a shift in expectations regarding the sustainable value of the yen, associated with the sudden turnaround in the Japanese balance of payments in the third quarter of 1978. Apparently because of the lagged effects of the earlier appreciation of the yen, the large surplus in the Japanese current account balance began to decline quite sharply at that time, and the balance became negative by the second quarter of 1979.

It should be noted that these various episodes would not in general have been expected to lead to instability of exchange rate equations. There have been a number of other major policy shifts or trend reversals in important economic variables that have not been associated in any way with such instability. What is likely is that the more general context in which these particular episodes occurred gave rise to shifts in expectations that induced greater movements in exchange rates than the econometrically estimated relationships would indicate.

Section 4 of Table 4 lists the results of tests of whether the various equations undergo a significant shift at the dates indicated above. These tests should be viewed not so much as alternatives to the recursive-regressions tests for general instability in the functional relationship, but rather as a more specific test for a shift in the function at a particular date. Two such tests are presented in the table. 1/ The first is the standard analysis of covariance test, in which the residual variance for the full sample is compared with the residual variances obtained from the two subsamples, allowing the coefficients to vary between the subsamples. A finding of significance by this test (or by the cusum-of-squares test) could mean that one or more coefficients shift significantly or that that the residuals are heteroskedastic. The second test, devised by Gupta (1978), asks more specifically whether the coefficient vector has shifted. Both of these tests suggest that most of the estimated equations do shift significantly at the indicated dates. The only possible exception is the Artus model for the yen/dollar rate, where the shift is significant only at the .1 level. The Boughton and compound models for the U.S. dollar also are relatively stable when subjected to the covariance test, but not to the Gupta test. In all other cases, both tests suggest a significant shift.

Section 5 of Table 4 presents a test for heteroskedasticity between the two subsamples for each equation. For this exercise, which is a variant of the Goldfeld-Quandt test, the sample period is split at the dates described above and the two residual variances are compared directly. As it happens, this test reveals very little about the relative performance of the various models; the differences in significance that are reported in the table are attributable to the different dates at which the sample is split rather than to differences in the specification of the equations. The result of this test is that there is a significant decrease in the residual variance after May 1982 for the U.S. dollar equations, a significant increase after July 1975 for the deutsche mark, and a significant increase after October 1978 for the yen.

The final section of Table 4 presents tests of the stability of the interest rate coefficients in each of these equations. The other tests in this table examined the overall stability of the estimated models, whereas the stability of the key relationship between interest rate differentials and exchange rates is also of interest. For the first test in this section,

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1/ In addition, Chow tests were performed; although Chow (1960) suggested that the covariance test is more appropriate whenever the second subsample has positive degrees of freedom, subsequent tests by Wilson (1978) indicated that the Chow test might still be more powerful in such circumstances. In the present case, however, the Chow tests uniformly showed less instability than the covariance test. Both statistics are described in Chow (1960).

each equation is estimated over the full sample period with the addition of a dummy variable that has the value zero during the period up to the shift date indicated by the Quandt ratio; after that date, it has the value of the real interest differential (in the Boughton model) or the change in the nominal interest differential (in the Artus model). For the compound model, both dummies are included. The t-statistics on these dummy variables generally do not allow one to reject the hypothesis that the interest rate coefficients are stable between the two sample periods. The notable exception is the coefficient on the real interest differential in the equations for the yen/dollar rate, which becomes a much larger negative number in the second part of the sample.

The other test in this final section is more general but somewhat less formal. Rather than testing for whether the interest rate coefficients have shifted at a predetermined point, it is also useful to determine whether the maximum difference between the full-sample estimate and any of the sub-sample estimates is in some sense large. In order to be able to examine the full range of estimates while retaining sufficient degrees of freedom, this test has been conducted using the second half of the forward-recursive and of the backward-recursive estimates. From this series, a maximum difference relative to the full-sample estimate has been obtained; this figure may be regarded as an estimate of the maximum drift in the interest rate coefficient as the sample period is lengthened. Then, in order to have a consistent and relatively strict criterion for comparing the various equations, these maximum values are compared to the smallest full-sample standard error obtained from the different models. The ratio of the maximum drift to the minimum standard error may be treated as a conventional t-statistic, although its probability distribution obviously cannot be determined precisely and the test is probably biased against the null hypothesis. This test indicates relatively little drift in the coefficients in the U.S. dollar equations but quite a bit of drift in the equations for the bilateral rates; it thus tends to confirm the results described earlier for the time-trended regressions.

IV. Conclusions

This paper has investigated the performance of a number of models of exchange rate determination in order to see whether stable relationships exist between exchange rates and variables such as interest rate differentials and, if so, how those relationships should be specified. It has been shown for three major currencies that estimates of a variety of models using monthly data from May 1973 to December 1984 do display a relationship in which an increase in interest rate differentials favoring assets denominated in a specified currency is associated with an appreciation of that currency. The statistical significance of this relationship is generally greater for the model developed by Boughton than for the other models examined here. For the bilateral rate between the U.S. dollar and the Japanese yen, the other models indicate an insignificant or a perverse relationship. Overall, when account is taken of the expected signs of the coefficients on the other variables included in each model, only the Boughton model consistently displays coefficient estimates that conform to prior expectations.

Models that hypothesize that exchange rate expectations are predicated on the belief that the real exchange rate will tend to return to a level of purchasing power parity determined by the demand for and supply of money in each country do not appear to provide a useful explanation of exchange rate behavior. Neither do models that assume perfect substitutability among interest-bearing securities denominated in different currencies. Portfolio balance models that assume imperfect substitutability and that incorporate an eclectic expectations function (as in the Artus model) or a stock-adjustment process in foreign exchange markets (as in the Boughton model) tend to perform better empirically, at least in terms of the formal tests presented in this paper.

By any criterion, interest rate differentials and the other determining variables included in these various models explain only a small portion of actual month-to-month exchange rate changes. This conclusion is consistent with the widely held view that most exchange rate movements are responses to specific unforeseen disturbances. Nonetheless, the portfolio balance models do generally explain a statistically significant proportion of these changes. Furthermore, although there is strong evidence of instability or shifts in the reduced-form estimating equations during the sample period for each of these models, the Boughton model and the compound model generally perform better than a simple random walk in explaining changes beyond the sample period.

Sources and Definitions of Data

The source for the data used in this paper is the IMF data fund, except where otherwise noted.

I. Exchange rates

A. Nominal exchange rates

1. The basic data are end-period exchange rates between the U.S. dollar and the four other SDR currencies. These data are indexed so that the average value for the first decade of floating exchange rates (April 1973 through March 1983) is equal to 100.

2. For the effective dollar rate, a log-linear weighted average of the bilateral indexes is constructed, using the weights established in 1981 for the SDR. These weights are based on the average exchange rates that prevailed during the fourth quarter of 1980.

B. Real exchange rates

1. The basic price index is the deflator for private domestic expenditure, seasonally adjusted. This deflator is interpolated to a monthly series by benchmarking on monthly data for the consumer price index, also seasonally adjusted.

2. For the bilateral exchange rates, the real rate (R) is the product of (a) the nominal rate and (b) the ratio of the domestic price index to the U.S. index. The effective real dollar rate is a log-linear weighted average of the reciprocal of these products.

II. Interest rates

A. The interest rates are monthly averages of yields on government bonds with maturities ranging from 10 to 20 years.

B. The specific series used are

1. United States: 20-year constant maturity
2. Japan: 10 years and longer
3. Germany: public authority bonds, including bonds issued by the federal and Länder governments, municipalities, the railways, the postal system, and public associations
4. France: National Equipment Bonds of 1965, 1966, and 1967
5. United Kingdom: 20-year maturities

C. For Germany and Japan, the nominal interest differential is the difference between the domestic rate and the U.S. rate. For the United States, the differential is between the domestic rate and a weighted average of the other four, using the same weights as for exchange rates.

D. The expected inflation rate is the unweighted nine-month centered moving average of the annualized rate of change in the price index described above at I.B.1.

E. Real interest rates are computed as the difference between nominal rates and the expected inflation rate; real interest rate differentials are computed analogously to the nominal differentials.

III. Money stocks

A. Data are for broadly defined money stocks, seasonally adjusted, measured in local currency units.

B. Specific data series are M2 for the United States and Japan, M3 for Germany, sterling M3 for the United Kingdom, and resident M2 for France.

C. Data for France and the United Kingdom are from national sources.

D. The foreign money stock used in the equations for the dollar effective rate is a log-linear weighted average of the figures for the four other countries.

IV. Real income

A. Basic data are quarterly values of real private domestic expenditure, seasonally adjusted, measured in local currency units.

B. Monthly data are constructed by benchmarking against seasonally adjusted industrial production data.

C. Foreign income is computed analogously to foreign money stocks.

V. External balance as ratio to financial wealth

A. Balance on private capital account

1. Monthly coverage for balance of payments data varies among these countries; the basic procedure is to benchmark quarterly data wherever necessary on closely related available monthly series.

2. Because the focus of this analysis is on financial assets, direct investment is excluded from the private capital balance and put above the line. The current account is seasonally adjusted, but official capital flows are not; this procedure implies that seasonal changes in the current account balance are not systematically offset through official intervention.

3. The cumulated balance is estimated by first cumulating annual flows from 1965 (the earliest date for which a complete set of data is available for all countries) through 1969 and then adding cumulated monthly flows to that stock from the beginning of 1970. For all countries, these flows are cumulated in U.S. dollars.

B. Financial wealth

1. The cumulated balance is scaled by an estimate of total financial wealth held by domestic private nonbank sectors. This stock of wealth is measured as the outstanding stock of government debt held outside the central bank, plus the nonborrowed domestic components of the monetary base, minus government deposits in commercial banks, minus the cumulated external balance on private capital. The rationale for this measure is described in Boughton (1983) and in the Appendix to Boughton (1984).

2. All of the additional data required for this estimate of wealth are available monthly. Debt and deposit data are not seasonally adjusted.

3. Data on government debt in Japan and some of the debt data for Germany are from national sources.

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