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Currency Fluctuations in the Post-Bretton Woods Era

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The international monetary landscape that has emerged since the felling of Bretton Woods is characterized by a hybrid exchange rate system that lies somewhere between the textbook polar cases of a gold standard and a pure float. This system has relatively flexible exchange rates between major countries, active central bank intervention in the market for the major currencies, and predominantly fixed exchange rates (relative to the dollar or to some basket of currencies) for less developed countries and newly industrializing nations. The majority of research on currency markets since the early 1970s has focused on the characteristics of flexible exchange rates under this hybrid regime.

My thesis is that this research has been unsuccessful. The proportion of (monthly or quarterly) exchange rate changes that current models can explain is essentially zero. Even after-the-fact forecasts that use actual values (instead of forecasted values) of the explanatory variables cannot explain major currency movements over the post-Bretton Woods era. This result is quite surprising, since exchange rate changes would be entirely unpredictable only in very special cases of the theoretical models discussed. As the discussion below will argue, it is not a general implication of market efficiency that exchange rates follow a random walk process.[1]

[1]A random walk process (without drift or constant term) is represented by $y(t) = y(t-1) + u(t)$, where $u(t)$ is serially uncorrelated with constant variance. The process obeys the weaker martingale property that expected changes in the time series $y(t)$ are zero.

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What Variables Influence Exchange Rates?

The economics profession has not reached a consensus on the appropriate set of fundamental factors to include in an exchange rate equation. Some of the models of exchange rate determination discussed below suggest that exchange rates are jointly determined with macroeconomic variables such as domestic and foreign money supplies, real incomes, interest rates, price levels, and the balance of international payments. To understand why these factors have not been adequate to explain changes in exchange rates, it is useful to consider some descriptive statistics for an abbreviated set of American, Japanese and German macroeconomic variables that are given in Tables 1 and 2. The statistics include sample means, standard deviations, and a correlation matrix of both the level and first difference (one period change) of the two bilateral exchange rates (foreign currency per unit of U.S. currency), and American relative to Japanese and German interest rate differentials, relative money supplies, industrial productions and price levels. The sample period is January 1974 through July 1987.[2]

First, note that exchange rates are more variable (have larger standard deviation) than each fundamental variable included in Table 1 except for interest rate differentials, while changes in exchange rates are without exception more variable than changes in each fundamental. As we shall see, this empirical regularity is consistent with the current generation of exchange rate models. Second, the vast majority of Table 2 correlations of changes in either exchange rate with changes in their respective fundamentals are insignificant. Significance of any estimated correlation (rho) can be assessed in the same manner as the R-squared statistic from a simple regression: the ratio of rho-squared to one minus rho-squared, adjusted for degrees of freedom, is distributed as an F with one numerator and (163-2) denominator degrees of freedom. For 161 degrees of freedom, values of rho in excess of .15 are significant at a 5 percent level.

In addition, the signs of many of these correlations are difficult to explain. For example, consider the relation called purchasing power parity, between logarithms of exchange rates ($\log S$) and relative price levels ($\log P/P^*$), where * denotes a foreign variable. According to the theory, a higher relative price level should be associated with a weaker currency, and the correlation is indeed negative for both bilateral data series in Table 1. However, the relation between changes in exchange rates and relative inflation rates, called relative purchasing power parity, is positive. As shown

[2]Technically, it is better to examine the correlations of changes of exchange rates and changes in macroeconomics fundamentals, if one suspects nonstationary behavior in the level of these series (see the recent article by Stock and Watson (1988) in this journal). Think of nonstationary behavior as changes in the mean and/or variance of a series over time. For example, the mean value of a variable that exhibits trend growth over time should not be modeled as if it were constant, but the mean value of the growth rate (first difference of logarithms) of the series can be modeled this way. An additional advantage of Table 2 is that the simple correlations between changes in fundamental variables are quite small. Thus the important distinction between partial and simple correlation cannot be used to explain some of the anomalous pairwise relations noted in the text.

Table 1
Sample moments of the level of exchange rates and fundamentals January 1974 through July 1987

Variable	*Mean*	*Standard deviation*
1 log spot (yen/$)	5.460	.188
2 log spot (DM/$)	.839	.158
3 U.S.-Japanese interest differential	.094	.536
4 U.S.-German interest differential	.148	1.025
5 log U.S. to Japanese prices	−.094	.093
6 log U.S. to German prices	−.101	.130
7 log U.S. to Japanese M1	−5.041	.093
8 log U.S. to German M1	.586	.084
9 log U.S. to Japanese industrial production	−.078	.061
10 log U.S. to German industrial production	.032	.063

Correlation Matrix

variable no.

	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
1	1.00									
2	.55	1.00								
3	−.50	−.55	1.00							
4	−.35	−.20	.73	1.00						
5	−.59	.15	.63	.24	1.00					
6	−.69	−.04	.44	.42	.94	1.00				
7	−.46	.31	−.08	−.12	.72	.52	1.00			
8	−.35	.37	−.10	−.25	.74	.50	.95	1.00		
9	.30	−.32	−.26	−.05	−.88	−.80	−.57	−.64	1.00	
10	−.68	.04	.62	.51	.75	.80	.55	.45	−.50	1.00

Data Sources: OECD and CITIBASE
Reading the entries of the correlation matrix: The entry −.50 in the third row and first column of Table 1 is the sample correlation coefficient between the logarithm of the yen/$ exchange rate (variable 1) and the U.S.-Japanese interest differential (variable 3).

by the correlation matrix in Table 2, dollar appreciation occurs on average when U.S. inflation is greater than foreign inflation. Even more damaging to the theory of purchasing power parity is the fact that deviations of exchange rates from values implied by relative price levels are so large and persistent that international economists have debated whether the real exchange rate (measured by log SP/P^*) follows a random walk process.[3]

[3]Many of the empirical regularities referred to in this article are documented in the survey paper by Richard Levich (1985). For the behavior of the real exchange rate see sections 2 and 3 of his paper, and the references cited therein.

Table 2
Sample moments of the first difference of exchange rates and fundamentals; February 1974 through July 1987

Variable	Mean × 100	Standard deviation × 100
1 log spot (yen/$)	−.423	2.80
2 log spot (DM/$)	−.260	2.69
3 U.S.-Japanese interest differential	.335	2.69
4 U.S.-German interest differential	.323	2.57
5 log U.S. to Japanese prices	.145	.74
6 log U.S. to German prices	.258	.36
7 log U.S. to Japanese M1	.068	1.18
8 log U.S. to German M1	.033	1.03
9 log U.S. to Japanese industrial production	.004	1.44
10 log U.S. to German industrial production	.001	2.17

Correlation Matrix

variable no.

	1	2	3	4	5	6	7	8	9	10
1	1.00									
2	.61	1.00								
3	.19	.28	1.00							
4	.14	.20	.78	1.00						
5	.10	.18	.03	.05	1.00					
6	−.04	.05	−.02	−.00	.29	1.00				
7	−.10	−.11	.02	−.08	−.02	−.08	1.00			
8	−.00	−.06	−.02	−.16	.13	−.04	.43	1.00		
9	−.05	.06	.33	.25	.05	.14	.18	.08	1.00	
10	−.04	.01	.13	.11	.09	.06	.13	.08	.25	1.00

Data Sources: OECD and CITIBASE
See the note below Table 1 on reading the correlation matrix.

The inquiring reader is sure to find other examples of correlations in these tables that are difficult to rationalize. While it is always dangerous to infer causal relations (or lack thereof) from simple correlations, Tables 1 and 2 suggest that it may be challenging to explain exchange rate fluctuations in the post-Bretton Woods era with macroeconomic fundamentals.

Alternative Methods of Modelling Exchange Rates

It is possible that puzzling pairwise correlations between fundamental factors and exchange rates in Tables 1 and 2 might be explained in the context of a well-specified model of exchange rate determination.[4] In general, models of the spot exchange rate contain both a set of fundamental factors, like those given above, and some conditional expectation of the spot exchange rate in the next time period, based on whatever information is available in the present. This general model can be written as:

$$S(t) = F[H(t), E(S(t + 1)|I(t))],$$

where the exchange rate $S(t)$ is a function of a set of explanatory variables denoted by $H(t)$ and the conditional expectation denoted by the symbol $E(S(t + 1)|I(t))$ of the next period spot rate given period t information, $I(t)$.

Most theoretical work on exchange rates in the 1970s assumed that exchange rates were primarily determined by equilibrium conditions in the markets for the stocks of domestic and foreign assets (money and government bonds), and was dubbed the "asset market approach." These models were not originally couched in terms of utility-maximizing behavior, but subsequent work has explored the consistency of their hypothesized behavioral relations with maximizing theory. The simplest versions of the asset market models, called monetary models, have proved useful in explaining currency movements during high inflation episodes, like the European interwar period and the more recent saga of Latin America.[5] Experience with floating rates between the industrialized countries in the moderate inflation environment of the post-Bretton Woods era suggests that monetary shocks alone are not enough to explain exchange rates; real shocks must play an important role as well.[6] The most recent models of exchange rate determination, couched in an explicit optimization framework, draw on the insights of the asset market approach while also allowing the exchange rate to play a role in accommodating commodity price, preference, or productivity shocks (which were not emphasized in the original asset market approach).

The remainder of this section concentrates on two special cases of this general equation. The first is a model representative of the asset market approach, which typically presumes that asset supplies are set by government policy and the exchange rate is found by equating the predetermined asset supplies with their respective

[4]Additional references and more detailed discussion of the current state of theoretical exchange rate modeling can be found in volume two of the *Handbook of International Economics*. The chapters by Frenkel and Mussa (monetary models), Branson and Henderson (portfolio balance models), and Obstfeld and Stockman (exchange rate dynamics and optimizing models) are especially useful. Also, see Isard (1988) for a recent assessment of these alternative approaches to exchange rate modeling.

[5]However, DeGrauwe et al. (1985) find that the German hyperinflation of the early 1920s was also characterized by significant real exchange rate variation. Their results suggest that monetary models may be inadequate even in periods when monetary phenomena were clearly dominant.

[6]Flood (1981) provides an argument for the possible predominance of goods market shocks over financial shocks during the post Bretton Woods era. He notes that day-to-day movements in contemporaneous spot and forward exchange rates are very highly correlated. Contemporaneous spot and forward rates are linked to the interest rates of the two countries by an arbitrage relation known as covered interest parity (CIP); $F(t)/S(t) = (1 + i(t))/(1 + i^*(t))$, where F denotes the forward exchange rate corresponding to the same time horizon as the domestic and foreign interest rates i and i^*. When disturbances cause spot and forward rate to move in tandem, CIP can be maintained without a change in either interest rate. Thus money market equilibrium need not be initially disturbed.

demands. The second model is representative of the maximizing paradigm, where equilibrium exchange rates are derived from a consumer choice problem, where both domestic and foreign goods enter the utility function.

Asset Market Approach

In their survey article on monetary models, Frenkel and Mussa (1985) consider the following (linear) special case of the earlier general equation in which exchange rates can profitably be viewed as an asset price:

$$s(t) = H(t) + bE(s(t+1) - s(t)|I(t)), \tag{1}$$

where $s(t)$ is the logarithm of the exchange rate, $H(t)$ now represents a linear combination of both foreign and domestic, contemporaneous explanatory variables (for example, a coefficient times money supply plus a coefficient times real income, and so on, for both domestic and foreign variables), and b represents the elasticity of the current spot rate to its expected rate of change, $0 < b < 1$. The composition of $H(t)$ and the interpretation of the parameters vary by model. For example, in the simplest monetary models, b is minus the interest semi-elasticity of money demand, $H(t)$ is the log of relative (domestic to foreign) money supplies, and $E(s(t+1) - s(t)|I(t))$ is replaced by the interest rate differential.[7] Disequilibrium or "sticky-price" monetary models pioneered by Dornbusch (1976) that allow exchange rates to overshoot their long-run equilibrium values are also subsumed in equation (1) when $H(t)$ contains additional variables.

A nice feature of this general asset market specification is that by solving the equation forward in time, one will find that the current spot rate is the expected discounted sum of all future market fundamentals. To see how this works, rewrite equation (1) for period $t + 1$ and take the expectation relative to time t information. Plug this result in for $E(s(t+1)|I(t))$ on the right hand side of the equation, and continue the recursive process. You eventually derive:

$$s(t) = 1/(1+b) \sum_{i=0}^{\infty} (b/(1+b))^i E(H(t+i)|I(t)). \tag{2}$$

The idea that the current spot rate is the expected discounted sum of future market fundamentals is analogous to the notion that a stock price can be interpreted as the present value of the expectations about the future earnings of a company. Changes in the spot rate will result from "news" about future fundamentals: that is, any realization of future explanatory variables that is different than was expected.

[7]The substitution of the expected change in the exchange rate by the interest differential, called uncovered interest parity (UIP), is a building block of monetary exchange rate models. UIP is a combination of the unbiased forward rate (UFR) hypothesis and covered interest parity (defined in the previous footnote). While there is no controversy surrounding the arbitrage relation CIP, the same cannot be said about the UFR hypothesis. Levich (1985) and Hodrick (1987) provide reviews of the vast literature on unbiased forward rate tests and market efficiency. More complicated asset pricing models (like portfolio balance models) do not impose UIP a priori.

Thus, to the extent that changes in the economic fundamentals are predictable, changes in the spot exchange rate are predictable. However, in the unlikely event that the linear combination of the fundamentals $H(t)$ happens to follow a random walk process, then so will the spot rate.

In addition, it is worth noting that this specification allows exchange rates to be even more volatile than their component fundamental factors, if the covariances between fundamental factors used in $H(t)$ are such that their variances combine to push the variance of the spot rate still higher.[8] Thus, monetary models of exchange rate determination can rationalize the volatility of exchange rates relative to their determinants that was noted earlier in Tables 1 and 2. However, we will later return to this model to highlight some implications that are not in accord with the post-Bretton Woods experience.

The Maximizing Paradigm

Our second model of exchange rate determination is based on the highly abstract model of Lucas (1982). In a two good, two country, general equilibrium model, where identical representative agents in each country maximize the expected discounted utility of current and future consumption subject to budget and cash in advance constraints,[9] the standard necessary condition for optimization obtains: the marginal rate of substitution (MRS) between domestic and foreign goods is equal to the relative price ratio. This result (coupled with the binding cash-in-advance constraints of the Lucas model) gives rise to an exchange rate equation of the form

$$S(t) = \text{MRS}(M(t)/M^*(t))(Y^*(t)/Y(t)),$$

where M and M^* are the exogenous domestic and foreign money supply and Y and Y^* are the domestic and foreign real income. Changes in monies, incomes or tastes for goods move the exchange rate, which depends in this model only on current information.

Richer theoretical models of this type can include forward-looking components. For example, a forward-looking component of the spot rate may come into play in models of this type when utility is not time separable, when the information structure

[8] Viewing the exchange rate as a present value relation allows us to draw upon the "variance bounds" literature of Leroy-Porter (1981) and Shiller (1981). Their work argues that the conditional variance of the spot rate can be bounded above by the conditional variance of $H(t)$, the linear combination of explanatory variables in the model. Depending on the structural parameters in the linear combination and the covariance between all the variables in $H(t)$, the variance of the spot rate can theoretically exceed the variance of any one of its fundamental factors. Only in the case where $H(t)$ contains one variable will the volatility of the spot rate be restricted to be less than that of that single fundamental variable.

[9] There is considerable debate in the profession as to the appropriate method of introducing money in optimizing models. The simplest solution is to put real money balances directly into the utility function. Those who find this solution unpalatable frequently use cash-in-advance constraints, which require agents to hold money before purchasing goods. Obstfeld and Stockman (1985) discuss both types of optimizing exchange rate models. Alternatively, money can be introduced in optimizing models using the paradigm of finitely lived overlapping generations. See Kareken and Wallace (1981) for discussion of this latter type of exchange rate model and its implications.

and the timing of goods and money transactions are altered, when a liquidity preference motive for holding money, or real investment opportunities, among other factors, are built into the structure. In these more complex models, it is not always possible to find closed form solutions for the exchange rate. Instead, the first order conditions for utility maximization place restrictions on co-movements of the model's endogenous variables (such as exchange rates and consumption), a result entirely analogous to the domestic asset pricing literature (for example, Hansen and Singleton, 1983).

Estimating the Models

It has become standard to test exchange rate models like the ones presented here using the techniques of rational expectations econometrics.[10] (The use of survey data on market participants' expectations of future exchange rates is another possibility that is pursued in the next section.) The remarkable empirical regularity that has emerged from tests of variants of asset market models is that forecasts of the future spot exchange rate using predicted or actual realized values of the explanatory variables are not significantly better than naive (no change) forecasts of a random walk model. Of course, there is nothing sacred about the random walk model as a benchmark for comparison. But because its prediction of no change (or of steady drift) is perhaps the most naive forecast that comes to mind, it is a natural choice.

While it is not surprising that currency movements are difficult to predict beforehand, since the fundamentals are hard to predict and the structural parameters need to be estimated, it is amazing that after the fact "forecasts" of exchange rates using the actual future values of the fundamentals still fail to dominate the simple random walk at forecasting horizons of 1 to 12 months. This result is documented in Table 3, and is based on the exchange rate equation:[11]

$$s = a_0 + a_1(m - m^*) + a_2(y - y^*) + a_3(i - i^*) + a_4(p - p^*) + a_5(tb - tb^*) + e, \tag{3}$$

where the fundamentals are relative money supplies, industrial productions, the interest differential, the inflation differential, and the difference in cumulated trade balances, respectively. The error term e is usually assumed to follow a first order

[10] The econometric terminology used in this article is standard; see Judge et al. (1985), or any other text that covers applied methods.

[11] The experimental design for post sample testing is described in Meese and Rogoff (1983a, b or 1988). The predictive comparisons are based on a "rolling regression" methodology where the parameters of models are updated with the addition of each new observation to the sample, and dynamic forecasts for 1 to 12 months ahead are constructed for each parameter update using actual (future) values of the fundamental variables. The ensuing set of forecast errors are then compared on the basis of root mean square error (RMSE) at each of the 12 forecasting horizons. Last, see Meese and Rogoff (1983a) for expected signs of the coefficients under alternative models.

Table 3

Root Mean Square Error (RMSE) out-of-sample forecast statistics November 1980 through June 1984 (44 months)

Exchange rate	*Horizon (months)*	*Random walk*	*Models*[a] *1*	*2*
log(DM/$)	1	3.1	3.1	3.2
	6	7.9	8.4	8.5
	12	8.7	11.1	11.4
log(yen/$)	1	3.5	3.3	3.5
	6	7.8	7.0	7.7
	12	9.0	7.5	8.7

Source: The working paper version of Meese-Rogoff (1988), Table 1, available from the authors.

RMSE out-of-sample forecast statistics
November 1976 through June 1981 (56 months)

Exchange rate	*Horizon (months)*	*Random Walk*	*Forward Rate*	*Models*[a] *1*	*2*
log(DM/$)	1	3.22	3.20	3.65	3.50
	6	8.71	9.03	12.03	9.95
	12	12.98	12.60	18.87	15.69
log(yen/$)	1	3.68	3.72	4.11	4.20
	6	11.58	11.93	13.94	11.94
	12	18.31	18.95	20.41	19.20

Source: Meese–Rogoff (1983a), Table 1.
[a]Table Notes: Model 1: Equation (3) with $a5 = 0$. Model 2: Equation (3) with all parameters freely estimated. Both models are sequentially estimated by either Generalized Least Squares or Instrumental Variables with a correction for serial correlation. RMSE is just the average of squared forecast errors for each of the three predictive horizons.

autoregression, or the equation is fit in first difference form, or with an error correction mechanism. The failure of empirical models with these factors to explain currency movements has been shown to be quite robust, as numerous authors have either replicated the results given in Table 3 or confirmed them using different sample periods, additional models, and different data sources.[12]

A few empirical researchers have estimated structural models that can predict currency movements better than a random walk over particular subsamples of the

[12]See Frankel (1984), Wolff (1985), Somanath (1986), and Boughton (1987), among others, for both in- and out-of-sample evidence that is damaging to asset market models of exchange rate determination. Explicit optimizing models of the spot rate have not yet been subjected to as much out-of-sample testing, but the first order conditions of these models have been extensively investigated in the related risk premium literature. My view is that optimizing models have shown some success in explaining risk premia (expected currency return), but they have had little to say about the determinants of the level of the spot rate.

modern floating rate period. But on the whole, forecasting success with empirical exchange rate models has proved to be ephemeral. The explanatory power of these models diminishes as the estimation period or forecast horizon is extended. Continued forecasting success typically requires regular updates of model specification and parameter estimates (which is to say that forecasting doesn't seem to work very well). A perusal of published empirical work reveals that the set of explanatory variables most correlated with exchange rate movements depends on the sample period analyzed. For example, most recently researchers have shifted focus from real interest differentials (the focus of the early 1980s) to U.S. budget and current account deficits (the focus from the mid-1980s to the present). The current account was also an important explanatory variable in the late 1970s.

One explanation for the lack of a stable exchange rate equation is the Lucas (1976) critique; the parameters of current exchange rate models are not structural, since they change with different policy regimes. Empirical proxies for the expectations of future fundamentals should be especially subject to this limitation. If the parameters of utility functions are stable over time, then models based on a representative agent's explicit optimization problem, such as the second exchange rate model, should be robust to the Lucas critique. However, even these models are typically rejected in-sample using data from the recent floating rate period.

Many hypotheses have been advanced to explain the dismal explanatory power of current exchange rate models, and I will group these suggestions into two possibilities. The first is that current models are basically correct, but are plagued by estimation problems, and the second is that current models are misspecified.

Estimation Problems

Potential estimation problems include simultaneity, the reliance on limited information estimation techniques, imposition of inappropriate constraints or misspecified dynamics, and small sample bias.

In the exchange rate literature, researchers have tried to deal with simultaneity issues in a variety of ways. They have fit vector autoregressions (VARs) which do not impose a priori exogeneity assumptions; they have imposed theoretical priors on the structural coefficients to avoid estimation entirely; they have been careful in the use of instrumental variables estimators. The hackneyed seminar comment about the obvious need to deal with simultaneity bias is not warranted at this point.

Since the majority of empirical exchange rate research has focused on single equation methods, it is important to weigh the potential gains (and losses) associated with a system approach to currency modeling. An important benefit of multi-equation estimation is the potential for increased precision of parameter estimates. Drawbacks of the system approach include the danger that misspecification of any single equation can contaminate the estimates of parameters in every equation, and the empirical observation that forecasts of large macroeconomic models are not necessarily more accurate than those of single equation models or a VAR.

Another problem with large equation systems is that the univariate time series model of an exchange rate that is implied by the structural equation system is generally quite complex, even when the dynamics of the multi-equation system are relatively simple (Rose, 1986). This implication would appear to be inconsistent with the widely accepted empirical regularity that the best linear time series model of (monthly or quarterly) spot exchange rates is a simple random walk. In sum, I feel there is little reason to believe that additional emphasis on system approaches will enhance the explanatory power of current exchange rate models.

The imposition of inappropriate constraints and misspecified dynamics comes next in this litany of estimation problems. Most exchange rate models are formulated in relative (domestic to foreign) terms to simplify exposition, and posit a contemporaneous (and forward-looking) relation between the exchange rate and fundamental variables. In estimation, there is no need to impose the constraints that structural parameters are the same in both countries or that all adjustment is contemporaneous. However, relaxation of these constraints does little to resuscitate the current generation of asset market models.

An additional problem with the testing of asset market theories of exchange rate determination is that researchers have focused on different empirical implications of the same theory, sometimes with conflicting results. For example, when testing monetary exchange rate theories it is best to rely on the more general asset demand equation (1) rather than the present value form (2), because the latter form requires more auxiliary hypotheses to hold true. Estimation of the present value relation requires the imposition of a boundary condition or "no bubbles" constraint. The problem is that the recursive process that led to the present value relation does not provide a unique solution for the exchange rate unless an initial or terminal condition is available.[13] It also requires an assumption about the stochastic process generating the variables in $H(t)$, so that the conditional expectation of future fundamental variables can be replaced by an appropriate prediction formula.[14]

If models with the fewest number of auxiliary assumptions are rejected by the data, there is little point in pursuing more complicated tests of the same structure. At worst, empirical tests of the present value relation with its additional constraints might spuriously indicate a reasonable structural model because the deterioration in the fit of the constrained model (2) is small relative to the large amount of unexplained

[13]This issue is explored in the symposium on asset market bubbles that will appear in the Spring 1990 issue of this journal. Bubbles arise when an exchange rate differs from the value implied by its fundamental determinants, which is to say that the definition of a bubble is model specific. Without a boundary condition on equation (2), there is no guarantee that future exchange rates will equal their fundamental value. The possibility of currency market bubbles is pursued further in that issue.

[14]Once a specification for $H(t)$ is selected, such as a vector autoregression, it is then customary to estimate the present value form jointly with the equations describing the fundamentals $H(t)$. Constraints across the equation system arise because the $H(t)$ specification is used to replace the expected values of future fundamentals in (2) by an appropriate prediction formula given current information. Imposing and testing these (nonlinear) cross equation constraints is the hallmark of rational expectations econometrics.

variation in a less constrained model such as (1). Recall that the results in Table 3 are based on a variant of the less constrained model (1), thus precluding exchange market bubbles as an explanation for the empirical failure of monetary models.[15]

The last estimation problem to be discussed is that of small sample bias. Under this rubric we will consider "peso problems" and statistical inference in environments characterized by changes in policy regime or financial innovation. Peso problems result when agents incorporate a small probability of an unusual event (like a large devaluation of a currency or a change in a country's exchange rate policy) in their expectations, but the unusual event does not occur or occurs infrequently during the sample period analyzed by the econometrician. The potential for peso problems to distort statistical inference will remain until data samples contain enough of these expectational episodes that we can comfortably invoke the large sample distribution theory needed to interpret our findings.

Exchange markets are unlike most other asset markets because central banks routinely engage in exchange market intervention. This activity can be thought of as either an open market operation (unsterilized intervention) or as a swap of domestic and foreign debt in official portfolios that has no effect on domestic or foreign money supplies (sterilized intervention). It is difficult to obtain information on the currency denomination and size of official intervention, but the available evidence suggests that the size of this activity is small relative to total supply of outstanding government obligations, and to daily trading volume.[16] In theory, sterilized intervention will affect exchange rates by altering the mix of domestic and foreign bonds in private portfolios, provided these assets are perceived as imperfect substitutes. Exchange rate models that allow for a risk premium, such as portfolio balance models, already incorporate this effect. Unsterilized intervention is incorporated into all types of asset market models that include domestic and foreign money supplies.

Central bank reaction functions (possible feedback from the exchange rate to intervention policy through the fundamental $H(t)$) also cannot explain the dismal performance of monetary models in Table 3. Researchers have been careful about simultaneity problems when estimating equation (1), as noted earlier.

Intervention might signal a change in expectations of future central bank policy, and an expectations effect on exchange rates is potentially quite large (as was explained earlier in the discussion of equation 2). However, as noted above, this is essentially a problem with small sample inference. It will take many like episodes before we can reliably estimate the expectation effect on the level of the current spot rate.

[15]This point is made forcefully by Flood (1987). Intuitively, bubbles may be ruled out as an explanation of the empirical failure of the models embedded in (3) because the exchange rate enters both sides of this equation, albeit indirectly through the interest differential.
[16]For example, it is thought that current daily volume on exchange markets exceeds $400 billion, while the total reserves of central banks are around $250 billion.

Finally, the failure of asset market exchange rate equations coincides with the demise of conventional money demand equations.[17] Since the simplest monetary models are derived from domestic and foreign transactions demand equations, it is not surprising that models emphasizing monetary phenomena work poorly over a period characterized by money demand instability. Financial innovation and the mitigation of international capital controls over the post-Bretton Woods era complicates inference just as peso problems do. Econometric modeling of financial markets will never be easy in an environment where the rules of the game keep changing.

Misspecification in Current Models

Current models may be misspecified because of nonlinearities in the data generation mechanism for exchange rates, omitted variables, or the inappropriate modeling of expectation formation.

Nonlinear models are the focus of much current research, and it is too early to assess all the fruits of this labor.[18] Recent work exploring possible nonlinearities in how exchange rates are generated is grounded on the empirical regularity that the distribution of (high frequency) exchange rate changes has "fatter tails" than a normal distribution. Documentation of this fact is widespread; for two early references, see Dooley and Shafer (1976) or Westerfield (1977). When the data generation process for the spot rate and fundamentals is non-normal, lack of correlation between these variables doesn't necessarily imply lack of a nonlinear relationship.

Three nonlinear modeling strategies that can potentially account for the fat–tailed distribution of exchange returns (logarithmic change in rates) include Stock's (1987) model that allows economic events to occur on a time scale that differs from observable time (time deformation), Hamilton's (1988) procedure for analyzing rational expectations models subject to regime changes, and the line of research derivative to Engle's (1982) autoregressive conditional heteroskedasticity (ARCH) model. The ARCH procedure is widely used to model persistence in the (conditional) variance of asset returns. For example it is common for exchange markets to cycle through periods of turbulence (high return variance) and then quiescence (low return variance).

The appeal of the Stock and Hamilton procedures derives from their explanations of the apparent nonstationarity that appears to characterize linear time series

[17]This is subject upon which reasonable economists will disagree. See footnote 9 for the various ways economists have modeled money, and older issues of *Brookings Papers on Economic Activity* for empirical evidence on money demand equations.

[18]There are at least two distinct channels for nonlinearities to arise in exchange rate models. First, an intrinsically linear data generating model may be poorly modeled by linear techniques because of misspecification of the functional form of an economic relation, improper account of regime shifts, or mismeasurement of the time scale on which economic events take place (see below for examples). Alternatively, the data generating model may be intrinsically nonlinear. Examples of this latter manifestation of nonlinear behavior include theoretical models with hysteresis effects, and models of exchange rates subject to target zones that are credibly enforced by policy makers. See Baldwin and Lyons (1988) or Krugman (1988) for examples of these models and additional references.

models of macroeconomic data (recall footnote 2 for a definition of nonstationarity). Both procedures can also explain the fat-tailed distribution of currency returns and the serial correlation in return volatility.

In Stock's model of time deformation, exchange rates could exhibit a stationary linear relation to fundamentals when viewed in the appropriate time frame. For example, the theoretically appropriate time scale for the currency market might "speed-up" in calendar time in periods when an unusually large amount of economic news must be processed by the market (see also Clark, 1973). Hamilton's procedure relies on a latent variable that signals the probability of a regime shift. If econometricians observed the indicator variable along with the fundamentals, then the specification for the exchange rate would be linear in this complete set of variables, but linear forecasts based on an information set that excludes the regime indicator variable could be misleading and result in spurious inference.

In sum, innovations in nonlinear theoretical models and estimation technology are promising directions for new research. However, I remain skeptical of the proposition that appropriate account of nonlinearities will resurrect current exchange rate theory for several reasons. First, two recent papers by Diebold and Nason (forthcoming) and Meese and Rose (1989) examine potential nonlinearities in how exchange rates are generated using a variety of nonparametric statistical procedures, and are unable to improve on the forecasts of a simple random walk model. Second, it is my view that nonlinearities resulting from the current representative agent models seem of second order importance when compared with the modeling problems associated with heterogeneous agents and aggregation.[19]

Omitted variables is another possible explanation for the lack of explanatory power of asset market models. However, empirical researchers have shown considerable imagination in their specification searches, so it is not easy to think of variables that have escaped consideration in an exchange rate equation. In fact, at this point, exchange rate modelers can be justly accused of in-sample data mining. This review has emphasized out-of-sample explanatory power as one method to control for the myriad specification searches conducted by empirical exchange rate modelers on post–Bretton Woods data. Scientific method has always emphasized predictive ability as a model selection device. Given that economists most frequently rely on nonexperimental data to test their theories, the importance of out-of-sample explanatory power cannot be overstated.

[19]Adler and Dumas (1983) make the point that heterogeneity must be seriously considered in international finance models. They argue that the random walk behavior or real exchange rates necessitate a multi-agent paradigm (except in the special case of logarithmic preferences), since agents in each country measure their real returns using national price indexes that never conform with any version of purchasing power parity over any horizon. Also, Geweke (1985) considers the consequences of using aggregate data to estimate representative agent models. He constructs an example where ignoring the sensitivity of aggregator functions to policy change is just as bad as ignoring the dependence of expectations on the policy regime (the Lucas critique.)

The last misspecification issue to be pursued is the modeling of expectations. A number of recent papers have made use of survey data on exchange rate expectations. The survey data are taken from American Express Banking Corporation, the Economist Financial Report, and Money Market Services. These studies (Dominguez, 1986; Frankel and Froot, 1987) find evidence against rational expectations, as survey forecast errors are correlated with information that would have been available to market participants. Typically, survey participants could improve their forecast accuracy by putting more weight on the current spot rate and less on fundamental factors when predicting future spot rates.

The survey data also suggest heterogeneous expectations. The survey responses vary considerably (the studies mentioned above use the median response) and the model of expectation formation appears to differ by forecast horizon. Frankel and Froot (1987) argue that expectations data for short horizons (inside a month) seem to exhibit "bandwagon" effects, while expectations data for long horizons (six months and beyond) appear to be regressive.[20]

The forward exchange rate is also a biased predictor of the future spot rate, and it too produces less accurate forecasts of future spot rates than the current spot rate (recall the RMSE statistics of Table 3). It would appear that rational agents should base their expectations of future spot rates entirely on current spot rates and not on some estimate of market fundamentals. Dornbusch and Frankel (1987) have argued that if expected currency depreciation is a variable that is best forecast as zero, then it is hard to imagine how expected depreciation could have a stabilizing effect on investor behavior. One of their explanations for the lack of a relation between macroeconomic fundamentals and the exchange rate is thus based on an absence of short-run stabilizing speculation. They support this conjecture by citing the literature on stochastic bubbles, and evidence from experimental psychology.

Theoretically, speculative bubbles can explain how speculators with destabilizing expectations might not be driven from the market. More important, models where an exchange rate occasionally deviates from its fundamental value need not imply that there are easily exploitable profit opportunities (Arrow, 1982; Frankel and Froot, 1986; De Long et al., 1987, among others). The evidence from experimental psychology (Tversky and Kahneman, 1981) suggests that agents overreact to current information relative to past experience. In the present context, Dornbusch and Frankel (1988) interpret this evidence as agents placing too much weight on the current spot rate and not enough weight on fundamentals when forecasting future spot rates.

While the modeling of expectation formation deserves considerable attention, it is important to realize that the empirical evidence in Table 3 on the failure of monetary models cannot be attributed to problems with the modeling of expectations. No stand

[20]Bandwagon or destabilizing expectations occur when market participants extrapolate the most recent trend in the exchange rate. Investors sell the currency that they expect to depreciate. Regressive expectations occur when agents expect a currency to return to some equilibrium level (however defined). Both types of expectations could be rational depending on the underlying theoretical model of the spot rate.

on expectation formation was explicitly taken, as actual future values of fundamentals were used in the out-of-sample predictive experiments.

Conclusion

Economists do not yet understand the determinants of short- to medium-run movements in exchange rates. Neither models of exchange rates based on macroeconomic fundamentals nor the forecasts of market participants as embodied in the forward rate or survey data can explain exchange rate movements in the post-Bretton Woods era significantly better than a naive alternative such as a random walk model. Worse yet, exchange rate changes are hard to explain after the fact, even with the knowledge of actual future values of fundamental variables. It remains an enigma why the current exchange rate regime has engendered a time series data base where macroeconomic variables and exchange rates appear to be independent of one another.

One possible explanation is that economists have not yet discovered the appropriate set of fundamentals. Models emphasizing real shocks, such as shifts in tastes or technology, have increased in popularity because of this possibility. Thus far these models have not provided an improved ability to explain currency fluctuations; it has proven difficult to identify which real factors (typically unobservable) buffeted exchange rates over what periods of the post-Bretton Woods regime.

Another explanation is that insufficient speculation based on directly observable macroeconomic fundamentals—like money supplies, real incomes, inflation rates, interest differentials and current accounts—provides a solution to the puzzle. Proponents of this view cite a wealth of anecdotal evidence on the transactions volume of currency markets and the myopic behavior of its major players. The transactions volume of exchange market is a great deal larger than international trade in goods and services and long term capital. (See Schulmeister (1987) or the Federal Reserve Bank of New York (1986) for additional information.) Goodhart (1987) has surveyed banks that specialize in the foreign exchange market and he reports that their speculation takes place mainly in the spot market over very short time horizons. An open position overnight is unusual. The business periodical *Euromoney* reports that more foreign exchange forecasting services use technical analysis than use models based on fundamentals.

The picture that emerges from this abbreviated description of trading activity on currency markets presents a challenge to traditional economic modeling of exchange rates, and to the modeling of asset prices in general. The major players perceive the market to be too risky to take open positions for very long, and few report taking long run positions based on economic fundamentals. Only recently have academic economists started to study the behavior of exchange rates using high frequency data. It is premature to assess the value-added of this research, but any new theories of exchange rate determination will need to reckon with the dismal predictive ability of current generation models as well as the stylized facts that have emerged from the study of the short run behavior of major exchange market participants.

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