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On the Volatility of Exchange Rates*

A Test of Monetary and Portfolio Balance Models of Exchange Rate Determination

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Abstract

This paper tests whether the volatility in the fundamentals that ought to determine exchange rates is large enough to produce the observed volatility in exchange rates.

The results show that monetary and portfolio balance considerations cannot explain the observed variability in the exchange rate of the deutsche mark vis-a-vis the U.S. dollar, Japanese yen, and Swiss franc. However, monetary and portfolio balance considerations can explain the observed variability of the deutsche mark vis-a-vis other EMS currencies. This suggests that the EMS has been successful in reducing the exchange rate volatility to the minimum compatible with the volatility in the fundamentals.

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Summary

The highly erratic behavior of floating exchange rates since the breakdown of the system of fixed exchange rates has been largely unanticipated. Some claim that the volatility, or variability, of exchange rates is "excessive" and that it would be preferable to somehow limit the movements of exchange rates. Others claim that since exchange rates are driven by fundamentals, such as monetary and fiscal policies, the volatility of exchange rates only reflects the volatility of the underlying policies.

The purpose of this paper is to contribute to this discussion by testing whether the volatility in the fundamentals is large enough to produce the observed volatility in exchange rates. Exchange rates could be said to be "excessively" volatile if the volatility predicted by the fundamentals is smaller than the actual volatility of exchange rates.

These tests are applied to the major floating exchange rates including the deutsche mark, the Japanese yen, the British pound, the U.S. dollar, and the intra-European Monetary System (EMS) exchange rates. The results show that monetary and portfolio balance considerations cannot explain the observed variability in the exchange rate of the deutsche mark vis-a-vis the U.S. dollar, the Japanese yen, and the Swiss franc. However, monetary and portfolio balance considerations can explain the observed variability of the deutsche mark vis-a-vis the other EMS currencies; the French franc, the Italian lira, the Belgian franc, and the Dutch guilder. This suggests that the remaining variability in the intra-EMS exchange rates is determined by fundamentals; the much higher variance of the other, more freely floating, exchange rates cannot be explained by the models of exchange rate determination that are available today.

I. Introduction

The highly erratic behavior of floating exchange rates since the breakdown of the system of fixed exchange rates has been a puzzle for many observers. Some claim that the degree of volatility exhibited by exchange rates is excessive and thus undesirable; others claim that an efficient foreign exchange market is a better, or more efficient, outlet for many underlying disturbances than other markets that might not be able to react as swiftly. 1/ Another aspect of this problem is that there seem to be tranquil and turbulent periods in the foreign exchange market and that the degree of volatility of exchange rates varies over time. And it also seems that some currencies are more volatile than others. It is widely claimed that these differences in volatility are due to differences in the volatility of the underlying policies, however, this claim has not yet been substantiated.

The purpose of this paper is to contribute to the discussion about the volatility of exchange rates by analyzing a specific more narrowly focused question: is it possible to reject the joint hypothesis that (a) foreign exchange markets are efficient; and (b) that the exchange rate is determined by a particular model? This procedure is an application of the so-called variance bounds tests developed in the finance literature that examine the issue of excess volatility of stock prices. The basic idea behind this literature is that any asset price formed in an efficient market is a function of present and future fundamentals. The volatility of the asset price itself should thus not exceed the volatility of the fundamentals. Unfortunately, however, there is no general agreement about the fundamentals that ought to determine exchange rates. Therefore, a number of the most widely used exchange rate models are analyzed to determine whether the volatility of exchange rates is larger than the volatility of the fundamentals that ought to determine exchange rates. The purpose of this is not to find the model that performs best, but to find out whether these different models yield similar conclusions.

The most widely used exchange rate models in empirical work are all variants of the monetary approach. They can be subsumed in a general specification that implies that the exchange rate is a function of four variables: money supplies, national incomes, interest rate differentials, and inflation differentials. The monetary approach has also been integrated with portfolio balance considerations which place the emphasis on differences in asset supplies. Accordingly, the tests performed in this paper use two variants of the monetary approach and one representation of the portfolio balance approach.

1/ See Frenkel and Mussa (1980), and Frenkel and Levich (1977).

Assuming that the exchange rate is set in an efficient, forward-looking market, the fundamental determinants of exchange rates, according to these models are the expected discounted present values of future money supplies, incomes, and trade balances. The test consists in computing the variance of this present value and comparing it to the variance of the actual exchange rate. The procedure adopted here is quite different from the usual regression analysis because it asks whether there is enough variability in these fundamentals to justify the observed variability in exchange rates. 1/ In contrast, the usual regression analysis minimizes the variance of the difference between the estimated and the actual values. Thus, a good fit usually implies that the variance of the estimated exchange rate model is close to the variance of the actual exchange rate. But such a result per se does not answer the question whether exchange rates are too volatile to be compatible with efficient foreign exchange markets.

In answering this question, there is an examination of the experience of the EMS since the semi-fixed exchange rates in the EMS represent a useful contrast to more freely floating currencies like the U.S. dollar or the Japanese yen. For this purpose, it is useful to center the analysis on various deutsche mark (DM) exchange rates, thus analyzing the DM/U.S. dollar and DM/Japanese yen exchange rates as well as the exchange rates of the DM vis-a-vis other European currencies, including both EMS members, such as the French franc, the Belgian franc, the Dutch guilder, the Italian lira, and non-EMS members like the British pound, 2/ the Swiss franc, and the Swedish krona.

Throughout the discussion, volatility is defined as dispersion or second moment. 3/ Although other measures of volatility could be used, this measure seems to be the most widely accepted. This is also the most appropriate measure for variables following a normal distribution since a normal distribution is completely characterized by its mean and variance (i.e., the second moment around the mean). Moreover, if exchange rates follow a random walk, the variance (i.e., the second moment around the

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1/ On regression tests of the monetary and other models of exchange rate determination see Boughton (1986), Frankel (1979) and (1985a), Isard (1986), and Meese and Rogoff (1983) and (1985).

2/ The United Kingdom does participate in the wider EMS, but it does not participate in the exchange rate mechanism of the EMS.

3/ An important aspect of the methodology used in this paper is that it does not use the variance (i.e., the second movement around the mean) because the variance relies on the sample mean which leads to problems if the underlying stochastic process is nonstationary.

mean) of the percentage changes in exchange rates is an indicator of the predictability of exchange rates. A high variance implies that exchange rates are highly unpredictable.

Section II discusses the general methodology to be followed in dealing with the issue of excess volatility and presents the results of the application of this methodology to the flexible price monetary model. Section III applies the methodology developed in Section II to the sticky price Dornbusch model. Section IV analyzes the implications of the portfolio balance model and proposes three different ways to apply the volatility tests of the previous sections to this class of exchange rate model. Section V discusses some issues relevant to the determinants of the volatility of exchange rates and presents some data which contain suggestions about further research.

II. Tests of Excess Volatility in the Foreign Exchange Market

It is now widely recognized that exchange rates represent asset prices which discount future events. The view that exchange rates are asset prices can be represented by a quite general model in which the (logarithm of the) exchange rate, s_t, is determined by:

$$(1)\quad s_t = X_t + \psi\,[E_t(s_{t+1}) - s_t]$$

Where $E_t(s_{t+1})$ denotes the expectation of the future exchange rate, s_{t+1}, formed and conditional upon information available at time t. X_t denotes the "fundamentals" that, according to the specific model, determine the exchange rate. The parameter ψ measures the sensitivity of the current exchange rate to its expected rate of change. Assuming that expectations are consistent with the application of equation (1) in all future periods 1/ does not use the variance (i.e., the second movement around the mean) for the current exchange rate in terms of present and future fundamentals: equation (1) can be solved by interating forward to yield an expression

$$(2)\quad s_t = (1-\alpha) \sum_{j=0}^{\infty} (\alpha)^j \; E_t(X_{t+j}),$$

where $\alpha \equiv \psi/(1+\psi) < 1$.

1/ That is, expectations are rational (and imposing a suitable boundary condition).

This relationship suggests that the variance of the exchange rate should not exceed the variance of the discounted sum of future fundamentals. One way to illustrate this is by defining the project foresight or ex-post rational exchange rate s_t^* by:

$$(3) \quad s_t^* = (1-\alpha) \sum_{j=0}^{\infty} (\alpha)^j X_{t+j}.$$

The difference between the actual exchange rate s_t, and the perfect foresight exchange rate, s_t^*, is due to an expectational error which is defined by: 1/

$$(4) \quad s_t^* = s_t + U_t$$

A rational forecast error, like U_t, must be uncorrelated with all information available at time t; and it must therefore also be uncorrelated with s_t (i.e., the covariance (s,U)=0). This implies that the variance of s_t^*, denoted by Var (s_t^*), must exceed the variance of s_t since:

$$(5) \quad \text{Var}(s_t^*) = \text{Var}(s_t) + \text{Var}(U_t)$$

and thus:

$$(6) \quad \text{Var}(s_t^*) > \text{Var}(s_t) \quad \text{2/}$$

In an efficient foreign exchange market, the variance of the perfect foresight exchange rate should exceed the variance of the actual exchange rate. However, there are two problems in using equation (6) for volatility tests. First, if exchange rates follow a random walk or another

1/ This error is related to the error in forecasting future fundamentals by:

$$U_t = (1-\alpha) \sum_{j=0}^{\infty} (\alpha)^j \, [E_t(X_{t+j})-X_{t+j}]$$

2/ Assuming the variances exist.

nonstationary process, the unconditional variances in equation (6) may not exist. This problem can be resolved by using the methodology proposed by Mankiw, et al. (1985). 1/ Second, there is no universally accepted model that specifies the fundamentals that determine the exchange rate. This problem cannot be solved; but, by using several different models, it should be possible to obtain conclusions that are robust. This is the method pursued in this section.

The tests in this section are based on the following technique (see Mankiw (1985), page 679), let s_t^o be a "naive forecast" exchange rate based on some naive forecast of future fundamentals $EN_t(X_{t+j})$:

$$(7) \quad s_t^o = (1-\alpha) \sum_{j=0}^{\infty} (\alpha)^j \; EN_t(X_{t+j})$$

The naive forecast $EN_t(X_{t+j})$ does not need to be rational, but it is assumed that rational agents have access to this naive forecast. The difference between the perfect forecast exchange rate, s_t^*, and the naive forecast exchange rate, s_t^o, can be written as:

$$(8) \quad s_t^* - s_t^o = (s^* - s_t) + (s_t - s_t^o)$$

Squaring both sides of equation (8) and taking expectations then implies:

$$(9) \quad E(s_t^* - s_t^o)^2 = E(s_t^* - s_t)^2 + E(s_t - s_t^o)^2$$

because the expectation of the cross product, $E(s_t^* - s_t)(s_t - s_t^o)$ is zero since $s_t^* - s_t = U_t$ is uncorrelated with any information available at time t or at the beginning of the sample period. The expectation in equation (9) is thus taken conditional upon information available at the beginning of the sample period. Equation (9) contains the two inequalities that are tested below:

$$(10) \quad E(s_t^* - s_t^o)^2 \; > \; E(s_t^* - s_t)^2$$

1/ This methodology was originally applied to U.S. stock market data. For the discussion in the finance literature about the excess volatility of stock prices, see De Bondt and Thaler (1985), Flavin (1983), LeRoy and Porter (1981), Singelton (1980), and Shiller (1981).

$$(11)\quad E(s_t^* - s_t^o)^2 > E(s_t - s_t^o)^2$$

The intuition behind equation (10) is that the mean square of the forecast errors is larger if the naive forecast is used than if the efficient market forecast is used. The intuition behind equation (11) is that the naive forecast is closer to the market forecast (in terms of average squared distances) than to the perfect forecast. The conditional expectations in equations (10) and (11) exist even if exchange rates follow a nonstationary process because they do not rely on a sample mean.

Previous volatility tests of exchange rates (see Huang (1981) and (1984), Bini-Smaghi (1985), and Wadhwani (1984)) used the variance as the measure of volatility. However, since it is widely accepted that exchange rates follow a nonstationary process, the use of the variance is clearly inappropriate and gives misleading results. Some authors have tried to circumvent this problem by using rates of change instead of levels. Since it seems that the rates of change of exchange rates follows a stationary process, it would be possible to use the variance, however, the tests that have used rates of changes have usually been inconclusive. The methodology used in this paper thus yields a more powerful test because the results show that it is possible to reject the joint null hypothesis for several currency pairs.

In actual tests, it is necessary to truncate the infinite series contained in equation (3) by using terminal values for the nominal exchange rate and the fundamentals. s_t^* can thus be redefined as:

$$(12)\quad s_t^* = (1-\alpha) \sum_{j=o}^{T-t} (\alpha)^j X_{t+j} + \alpha^{T-t+1} s_{T+1}$$

Since rationality implies $s_t = E_t(s_t^*)$ this does not affect the inequalities (10) and (11). Moreover, since equation (12) also includes the actual exchange rate at t, equation (12) and thus equations (10) and (11) would hold even in the presence of speculative bubbles. 1/

The most important problem in using the inequalities (10) and (11) for a volatility test on exchange rates is that there exist several different models that can be used to specify equation (1). The models differ not only regarding the fundamentals, X, but also regarding the discount factor ψ. However, by using several of the most "popular" models it should be possible to obtain results that are robust.

1/ A speculative bubble is defined here as a situation in which the weight of the short term in equation (12) does not go to zero as T goes to infinity, but all other relationships used so far continue to hold.

The models to be used in this section, all variants of the monetary approach, are those that have been tested most frequently in the literature. The general results of the tests performed so far are summarized in Meese and Rogoff (1983, 1985), Boughton (1986), and Isard (1986). Meese and Rogoff, in particular, indicate that the in-sample fit of these models varies widely, depending on the currency and the period of observation. However, the out-of-sample fit or predictive ability of these models is generally poor. 1/

The starting point for all the models is a conventional money demand function of the form:

$$(13) \quad m_t^d = k + \phi y_t + p_t - \eta\, i_t$$

where m_t^d, y_t, and p_t represent (the natural logarithum) of the quantity of money demanded, income, and the general price level. ϕ and η represent the income elasticity and interest semi-elasticity of money demand respectively; i_t represents the nominal interest rate. Assuming purchasing power parity (PPP), interest parity, and equilibrium on the domestic money market (these three assumptions imply: $p_t = s_t + p_t^*$, $i_t - i_t^* = E_t(s_{t+1}) - s_t$ 2/ and $m_t^d = m_t^s = m_t$); equation (13) can be rewritten as:

$$(14) \quad m_t = k + \phi y_t + s_t + p_t^* - \eta\, [i_t^* + E_t(s_{t+1}) - s_t]$$

where p_t^* and i_t^* represent the foreign price level and interest rate, respectively. The three assumptions embedded in equation (14) will be relaxed subsequently. The assumption of continuous PPP is relaxed in the next section that considers the role of sticky prices in a Dornbusch model. The version of the model that assumes continuous PPP is referred to as the flexible price version of the monetary model. The assumption that desired money balances are always equal to actual balances is relaxed in the tests that use quarterly data since the form of the adjustment assumed to govern the money market depends on the time horizon considered. For yearly data, it is assumed that the money market adjusts fully, for quarterly data it is assumed that actual balances adjust gradually to desired balances. The assumption of uncovered interest parity (including

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1/ This result does not imply per se that these models are not able to account for the observed variability of exchange rates. The poor performance of these models might be due to econometric problems which would not affect the results of this paper.

2/ The existence of a constant risk premium would not affect the analysis in any way as it would only lead to another constant in the exchange rate equation and would have no effect on the variability measures.

a constant risk premium) will be relaxed in the section that considers portfolio balance models where it is assumed instead that the risk premium is a function of asset stocks.

Equation (14) can be rewritten as the general form of equation (1):

$$(15)\quad s_t = [m_t - k - \phi y_t - p_t^* + \eta i_t^*] + \eta\,[E_t(s_{t+1}) - s_t]$$

According to this model, the "fundamentals" that determine exchange rates are thus given by $X_t \equiv m_t - k - \phi y_t - p_t^* + \eta i_t^*$ the current perfect foresight exchange rate, s_t^*, can thus be written as:

$$(16)\quad s_t^* = \left(\frac{1}{1+\eta}\right)\left(\sum_{j=0}^{T-t}\left(\frac{\eta}{1+\eta}\right)^j X_{t+j}\right) + \left(\frac{\eta}{1+\eta}\right)^{T-t+1} s_{T+1}$$

The naive forecast used in this analysis is based on the assumption that the fundamentals are expected to remain constant forever. This forecast is not as naive as it seems, since for a number of countries money supplies seem to follow a process that is close to a random walk. The naive forecast thus implies:

$$(17)\quad s_t^o = \frac{1}{1+\eta}\sum_{j=0}^{\infty}\left(\frac{\eta}{1+\eta}\right)^j X_t = X_t = m_t - k - \phi y_t - p_t^* + \eta i_t^*$$

A first test of the inequities (10) and (11) thus requires only calculation of s_t^o and s_t^* which can then be used to calculate the sample variances of $(s_t^* - s_t)$ and $(s_t^* - s_t^o)$.

The figures in Table 1 (a) report the results of a first such test on yearly data for various DM exchange rates for the 1973-84 period. 1/ In this test, the parameters of a previously estimated money demand function for Germany were used to obtain estimates for ϕ and η. The regression results of the money demand estimate are reported in Appendix II; these results show that variations in income (GNP at 1980 prices) and interest rates (interbank rates) can explain 94 percent of the variance of real

1/ T is equal to 1984 so that the exchange rate at the end of 1985 represents s_{T+1}. In this, as in other tests, the "equilibrium" PPP level was set equal to the average of the sample period.

Table 1. Test for Excess Volatility of Selected Deutsche Mark Exchange Rates 1/

(a) The Flexible Price Monetary Model

Yearly Data 1973-84

Country 2/	(1) $\frac{1}{T}[\Sigma(s_t^* - s_t^o)^2]^{.5}$	(2) $\frac{1}{T}[\Sigma(s_t^* - s_t)^2]^{.5}$	(3) $\frac{1}{T}[\Sigma(s_t - s_t^o)^2]^{.5}$	(4) $\frac{\text{Max}[(2),(3)]}{(1)}$
Belgium	4.04	4.16	6.00	1.49
Canada	4.63	19.81	22.89	4.94
Denmark	6.06	3.38	7.75	1.28
France	6.58	5.37	8.24	1.25
Italy	11.21	9.63	17.03	1.52
Japan	7.92	13.55	20.05	2.53
Netherlands	2.68	2.60	4.05	1.51
Sweden	6.81	8.15	11.39	1.67
Switzerland	3.58	9.92	10.94	3.06
United Kingdom	8.86	14.22	19.04	2.15
United States	5.55	17.89	23.10	4.16

1/ The numbers are equivalent to percentage changes since they represent the standard deviations of logarithms.

2/ Indicates the currency of the exchange rate vis-a-vis the deutsche mark.

money (M1 divided by the consumer price index) in Germany. The point estimate for ϕ is equal to 1.18, and the point estimate for η is equal to 1.32. 1/

It is apparent that for all of the bilateral DM exchange rates analyzed, at least one of the inequalities (10) and (11) is always violated. Since violation of only one inequality is sufficient to reject the efficient market hypothesis, this table implies that the joint hypothesis of an efficient foreign exchange market and the flexible price monetary model is inadequate to explain the observed variability of exchange rates. 2/ This table also seems to suggest that the rejection of the monetary model is strongest for the Canadian and U.S. dollar and in general is stronger for the non-EMS currencies like the Swiss franc or the British pound than for the EMS currencies. 3/

Table 1 (b) contains the results of another test of the flexible price version of the monetary model. This test is based on quarterly data from Q1 1974 to Q3 1984. The basis for this test is a money demand function

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1/ Preliminary sensitivity analysis indicates that changes in the income elasticity of money demand do not influence the results to any appreciable extent. The results are, however, affected by changes in the η, the interest semi-elasticity of money demand because $\eta/(1+\eta)$ determines the discount factor used to discount future monetary factor. The point estimate of η=1.32 gives a discount factor equal to 0.56.

2/ Indeed, for all currencies considered here, the sample mean square of the difference between the perfect forecast and the naive forecast exchange rate $(s_t^*-s_t^o)$ is much smaller than the sample mean square of the difference between the naive forecast and the actual exchange rate $(s_t^o-s_t)$. However, the sample variance of the difference between the perfect forecast and actual exchange rate $(s_t^*-s_t)$ is also always much smaller than the variance of the difference between the actual and the naive forecast exchange rate $(s_t^o-s_t)$. This tends to give some support to the monetary model since it indicates that the market takes future monetary factors into account. Graphs of s_t, s_t^o, and s_t^* for the DM exchange rates used in Table 1 (a) from 1961 to 1983 show that the fundamentals that determine s_t^o and s_y^* move very smoothly and that the naive forecast, s_t^o is always very close to the perfect forecast, s_t^*. This reflects the fact that money supplies are much more forecastable than exchange rates. The graphs also show that the monetary model is quite successful in tracking the movements of the exchange rates of the EMS members: France, Belgium, Italy, and Denmark. The failure of the model in these cases is thus not due to an inability of the model to predict the trend in exchange rates. The graphs are available upon request from the author.

3/ The test statistics used in this table (and the following tables well) are random variables. A precise statistical statement about the "significance" of the results could be made only by taking into account the distribution of the test statistics.

Table 1. Test for Excess Volatility of Selected Deutsche Mark Exchange Rates 1/

(b) The Flexible Price Monetary Model

Quarterly Data 1974-83

Country 2/	(1) $\frac{1}{T}[\Sigma(s_t^* - s_t^o)^2]^{.5}$	(2) $\frac{1}{T}[\Sigma(s_t^* - s_t)^2]^{.5}$	(3) $\frac{1}{T}[\Sigma(s_t - s_t^o)^2]^{.5}$	(4) $\frac{\text{Max}[(2),(3)]}{(1)}$
Belgium	8.63	3.81	9.68	1.12
Canada	9.22	18.66	23.70	2.57
Denmark	13.18	3.04	14.19	1.08
France	12.61	5.26	12.31	0.98
Italy	21.27	7.74	25.53	1.20
Japan	13.83	9.70	21.46	1.55
Netherlands	6.72	2.69	7.42	1.10
Sweden	13.15	7.47	16.15	1.23
Switzerland	6.75	9.55	12.95	1.92
United Kingdom	15.23	12.16	21.31	1.40
United States	8.51	16.23	23.20	2.73

1/ The numbers are equivalent to percentage changes since they represent the standard deviations of logarithms.
2/ Indicates the currency of the exchange rate vis-a-vis the deutsche mark.

for Germany that was estimated for the same period. 1/ In contrast to the test using yearly data, however, in this case it is assumed that within each quarter actual money balances adjust gradually towards desired balances according to the partial adjustment process:

$$(18) \quad m_t - m_{t-1} = \lambda[m_t^d - m_{t-1}]$$

where m_t^d are desired money balances which depend on income and interest rates as specified in equation (13). The only consequence of this specification of the money market equilibrium is that the monetary factor for quarterly data contains a weighted average of past and current money instead of just current money. Solving equation (18) for m_t^d implies that the exogenous forcing variable becomes:

$$x_t \equiv [m_t + m_{t-1}(\lambda-1)]/\lambda - k - p_t^* - \phi y_t + \eta i_t^*.$$

The formulae for s_t^o and s_t^* remain the same.

The results using quarterly data are presented in Table 1 (b). The simple monetary model is still rejected in 10 out of the 11 cases considered, since, except for France, at least one of the two inequalities (20) and (11) is always violated. It is also apparent from this table that the rejection of the simple monetary model is only marginal for the EMS countries (Belgium, Denmark, and the Netherlands) which operate within the narrow bank of the EMS and were members of the snake before the inception of the EMS. However, the strong rejection of the simple monetary model for the deutsche mark exchange rate vis-á-vis the Canadian and U.S. dollars, the Japanese yen, the British pound, and the Swiss franc seems to imply that monetary factors alone are not sufficient to explain the variability of these exchange rates.

III. The Role of Sticky Prices

This section uses a model with sticky prices to check whether the inability of the simple monetary model to explain exchange rate varability that was found in the preceding section is due to stickiness in nominal prices. The specific model used here is taken from Mussa (1985), but it is very similar in spirit to the so-called Dornbusch model.

1/ See Appendix II for the results.

The only difference between the simple monetary model of the preceding section and the model used in this section is that it is no longer assumed that PPP holds instantaneously. Instead, it is assumed that prices adjust slowly to deviations from PPP according to:

$$(19)\quad E_t(p_{t+1}) - p_t = \beta\,(s_t+p_t^*-p_t) + [E_t(s_{t+1}+p_{t+1}^*) - (s_t+p_t^*)]$$

The second term in equation (19) allows the price level to rise in line with its equilibrium level if the real exchange rate is at its equilibrium level. (The equilibrium level of the real exchange rate has been normalized to zero in equation (19).) The parameter β indicates how much prices react to the current disequilibrium of the real exchange rate.

The price adjustment rule (19) implies that the real exchange rate $(s_t+p_t^*-p_t)$ moves towards its equilibrium value at a rate equal to $(1-\beta)$:

$$(20)\quad E_t\,(s_t+p_t^*-p_t) = (1-\beta)(s_t+p_t^*-p_t)$$

The model also contains a money demand function identical to equation (13). This money demand function can be transformed to give an expression containing the real exchange rate; after using the interest parity condition (see equation (14)) this yields:

$$(21)\quad s_t\,(1+\eta) = \eta E_t\,(s_{t+1}) + [m_t - k - \phi y_t - p_t^* + \eta i_t^*] + q_t$$

The expression in the square brackets represents the same, exogenous, 1/ monetary factor as in the previous section; i.e.,

$$X_t \equiv m_t - k - \phi y_t - p_t^* + \eta i_t^*.$$

By using equation (20), equation (21) can be iterated forward to yield an expression for the perfect foresight exchange rate: 1/

$$(22)\quad s_t^* = \frac{1+\beta\eta}{\beta\eta(1+\eta)}\,[\sum_{j=0}^{\infty}(\frac{\eta}{1+\eta})^j\,X_{t+j}] + (\frac{1}{\beta\eta})\,(p_t^* - p_t)$$

1/ At this stage, income is still taken as exogenous.

This equation shows that the exchange rate depends on an initial condition given by the domestic and the foreign price level and a discounted sum of present and future fundamentals. The discount factor is the same as in the simple monetary model, however, the discounted sum is multiplied by a factor that is greater than in the simple monetary model. Since the variability of national price levels is very small, equation (22) still suggests that most of the observed variability in prices is due to the variability in the exogenous monetary factor X_t.

Comparing equation (22) to equation (16) shows that for a given variance of the discounted sum of the monetary factors, the variance of the perfect foresight exchange rate with sticky prices is greater than the variance of the perfect foresight exchange rate with flexible prices. This is, of course, the result of the overshooting phenomenon. Neglecting the variance of $(P_t^* - P_t)$, the ratio of the variances of the sticky price exchange rate, denoted Var (s_{sp}^*) to the variance of the flexible price exchange rate, denoted Var (s_{Fp}^*), is equal to:

$$(23) \quad \frac{Var(s_{SP}^*)}{Var(s_{FP})} = \left(\frac{1 + \beta\eta}{\beta\eta}\right)^2 > 1$$

However, for the volatility tests, it is again necessary to truncate the infinite sum contained in equation (22). The perfect foresight exchange rate can thus be written as a finite sum similar to equation (16): 2/

$$(24) \quad s_t^* = \left[\frac{1 + \eta\beta}{\eta\beta + \left(\frac{(1-\beta)\eta}{1+\eta}\right)^{T-t+1}}\right] \left\{\left(\frac{1}{1+\eta}\right)\left[\sum_{j=0}^{T-t}\left(\frac{\eta}{1+\eta}\right)^j X_{t+j}\right] + \left(\frac{\eta}{1+\eta}\right)^{T-t+1} s_{T+1}\right.$$

$$\left. + (p_t^* - p_t)\frac{\left(1-\left(\frac{(1-\beta)\eta}{1+\eta}\right)^{T-t+1}\right)}{1+\eta\beta}\right\}$$

The naive forecast, s_t^o is again based on the assumption that the forcing variable is expected to remain constant forever. Using this assumption in equation (22) implies that the naive forecast in this model is given by:

1/ See Appendix I.
2/ See Appendix I, equation (A.6).

$$(25)\ s_t^o = \frac{(1+\beta\eta)}{\beta\eta} X_t + \frac{1}{\beta\eta}(p_t^* - p_t)$$

The tests are again based on the relative variances of $(s_t^*-s^o)$, $(s_t^*-s_t)$, and $(s_t-s_t^o)$. If markets are efficient and if the sticky price model is an accurate reflection of the way exchange rates and prices are set, the variance of $(s_t^*-s_t^o)$ should exceed the variance of $(s_t^*-s_t)$ and $(s_t-s_t^o)$.

Table 2 (a) contains the results of a first test of excess volatility using the sticky price model. It is again based on yearly data for 1973-84. In this test β was set equal to 0.5 1/ and all other parameters and variables are the same as in the test of the flexible price model. By comparing the first columns of Tables 1 (a) and 1 (b), it is apparent that the sticky price model predicts a much higher variability of exchange rates in that the variance of (s^*-s^o) is much higher in the sticky price model. 2/ This test clearly rejects the sticky price version of the monetary model for the non-EMS currencies. However, the rejection is less strong than in the flexible price case since the values in the last columns of Table 2 (a) are lower than the values in the last column of Table 1 (a); nevertheless, it is apparent that the inequality (11) is rejected for all countries (whereas the inequality (10) is rejected only in three out of eleven cases). 3/

Table 2 (b) contains the results of another test of the sticky price model; this test is based on quarterly data and uses the same money demand estimates used in Table 1 (b). In this test, β was set equal to 0.16, this implies that in one quarter prices adjust to eliminate 16 percent of the initial difference between the existing price level and the price level (i.e., PPP) that would obtain if all prices were flexible. The value of β=0.16 was chosen to make Table 2 (b) comparable to Table 2 (a) because

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1/ β=0.5 implies that in one year prices adjust by one half of the initial difference between the existing price level and the price level of that which would be obtained if all prices were flexible (i.e., the PPP level).

2/ With β=0.5 and η=1.3, the magnification factor (see equation (26)) is about 5.8.

3/ Since this represents work *in progress, I would like to add that* the results appear to be sensitive to the value of β and the time horizon, further tests are therefore necessary to check the robustness of these results. It seems that the degree to which the inequalities (10) and (11) can be rejected grows with β, thus it might be possible to accept equations (10) and (11) for values of β much closer to zero. But for values of β below 0.5, the perfect foresight and the naive forecast exchange rates sometimes have unrealistically extreme values.

Table 2. Test for Excess Volatility of Selected Deutsche Mark Exchange Rates 1/

(a) The Sticky Price Monetary Model

Yearly Data 1973-84

Country 2/	(1) $\frac{1}{T}[\Sigma(s_t^* - s_t^o)^2]^{.5}$	(2) $\frac{1}{T}[\Sigma(s_t^* - s_t)^2]^{.5}$	(3) $\frac{1}{T}[\Sigma(s_t - s_t^o)^2]^{.5}$	(4) $\frac{Max[(2),(3)]}{(1)}$
Belgium	10.11	5.64	11.71	1.16
Canada	11.76	21.64	29.77	2.53
Denmark	15.40	7.86	19.63	1.27
France	16.88	6.92	17.96	1.06
Italy	28.86	12.91	34.92	1.21
Japan	18.13	12.22	25.89	1.43
Netherlands	6.82	6.01	10.11	1.48
Sweden	17.36	10.68	22.72	1.31
Switzerland	8.98	12.34	17.19	1.91
United Kingdom	22.33	13.19	24.88	1.11
United States	12.38	14.37	25.12	2.03

1/ The numbers are equivalent to percentage changes since they represent the standard deviations of logarithms.

2/ Indicates the currency of the exchange rate vis-a-vis the deutsche mark.

Table 2. Test for Excess Volatility of Selected Deutsche Mark Exchange Rates 1/

(b) The Sticky Price Monetary Model

Quarterly Data 1973-84

Country 2/	(1) $\frac{1}{T}[\Sigma(s_t^* - s_t^o)^2]^{.5}$	(2) $\frac{1}{T}[\Sigma(s_t^* - s_t)^2]^{.5}$	(3) $\frac{1}{T}[\Sigma(s_t - s_t^o)^2]^{.5}$	(4) $\frac{Max[(2),(3)]}{(1)}$
Belgium	13.60	4.30	13.83	1.02
Canada	14.15	19.41	29.92	2.12
Denmark	22.68	4.81	24.18	1.07
France	21.34	6.99	19.51	0.91
Italy	35.87	10.18	41.60	1.16
Japan	15.57	8.99	21.21	1.36
Netherlands	11.48	4.82	12.42	1.08
Sweden	20.02	9.05	24.07	1.20
Switzerland	7.13	11.03	14.55	2.04
United Kingdom	25.81	11.74	28.67	1.11
United States	10.68	13.85	21.82	2.04

1/ The numbers are equivalent to percentage changes since they represent the standard deviations of logarithms.
2/ Indicates the currency of the exchange rate vis-a-vis the deutsche mark.

it implies that within four quarters (one year) about 50 percent of the disequilibrium is eliminated. 1/ Comparing Table 2 (b) to Table 1 (b), it seems that the results are very similar; the sticky price version of the monetary model is rejected for all countries, except for France. The rejection is again only marginal for the EMS countries and much stronger for the non-EMS countries. Overall, however, the numbers in the last column of Table 2 (b) are only a little lower than the corresponding numbers in Table 1 (b). This result and the comparison of Table 2 (a) with Table 1 (a) indicate that the introduction of sticky prices does not improve the performance as the monetary model in terms of its ability to predict the actual degree of exchange rate volatility.

IV. Portfolio Balance Models

The two versions of the monetary model used so far both incorporated the interest parity condition which implies that the interest rate differential is equal to the expected rate of change of the nominal exchange rate. The preceding analysis and tests are also valid if there exists a constant risk premium, indeed a constant risk premium would just add a constant to the various exchange rate equation and would thus leave the variability measures unaffected. The interest parity condition is usually obtained under the assumption that domestic and foreign bonds are perfect substitutes. In this section, this assumption is relaxed, instead it is assumed that domestic and foreign bonds are imperfect substitutes because of exchange risk. The precise form of the risk aversion is not analyzed here; it is simply assumed that investors adjust the proportion of their bond portfolio that go to domestic and foreign bonds respectively as a function of the expected return differential. 2/ In logarithmic form, this is written as:

$$(26) \quad b_t - s_t - f_t = \gamma[i_t - i_t^* - E_t(s_{t+1} - s_t)]$$

where b_t represents the logarithm of the stock of domestic denominated bonds and f_t the logarithm of the stock of foreign denominated bonds. The parameter γ is related to the risk aversion of investors and determines the relationship between the excess return on domestic bonds and the proportion of domestic bonds investors wish held in their portfolios. It is also assumed that the home country, in this case Germany, is small in relation to the rest of the world and that domestic residents are the only investors to hold domestic denominated bonds, thus b_t is equal to

1/ Since for quarterly data $\eta = 2.5$, this implies that the magnification factor (see equation (23)) is given by about 12.

2/ The microeconomic foundations of this relationship are derived in Frankel (1983, 1985b).

the stock of domestic bonds. Since investors are only concerned with their net position outside, i.e., government bonds, enter b_t. The only way in which domestic residents can acquire foreign bonds is via a current account surplus, f_t is thus equal to the stock of cumulated past current account deficits.

There are two ways to subject the portfolio balance models to a volatility test. The simplest way to obtain an expression for the exchange rate would be to solve equation (26) for the exchange rate and iterate forward. This implies:

$$(27)\quad s_t = \left(\frac{1}{1+\gamma}\right)[b_t - f_t - \gamma(i_t - i_t^*)] + \frac{\gamma}{1+\gamma} E_t(s_{t+1})$$

In this equation, the fundamentals are given by relative bond supplies and interest rate differentials. Further, forward iteration yields:

$$(28)\quad s_t = \left(\frac{1}{1+\gamma}\right) \sum_{j=0}^{\infty} E_t[b_{t+j} - f_{t+j} - \gamma(i_{t+j} - i_{t+j}^*)]\left(\frac{\gamma}{1+\gamma}\right)^j$$

This equation provides a test of the pure portfolio balance model since it uses only the variables that are most important to the portfolio balance approach: interest rate differentials and relative bond supplies. 1/

For the actual tests, it is again assumed that the naive forecast is based on the expectation that current fundamentals will not change, this implies that the naive forecast exchange rate is given by:

$$(29)\quad s_t^o = b_t - f_t - \gamma(i_t - i_t^*)$$

The perfect forecast exchange rate is again given by a truncated version of the equation that determines the market exchange rate:

$$(30)\quad s_t^* = \frac{1}{1+\gamma} \sum_{j=0}^{T-t} [b_{t+1} - f_{t+j} - \gamma(i_{t+j} - i_{t+j}^*)]\left(\frac{\gamma}{1+\gamma}\right)^j + \left(\frac{\gamma}{1+\gamma}\right)^{T-t+1} s_{T+1}$$

1/ Equation (33) is not a complete exchange rate equation in the sense that it does not specify what anchors expectations about present and future interest rates.

In contrast to the monetary model, this pure portfolio balance approach implies that the forcing variable contains only relative asset supplies and interest rates. The pure portfolio balance framework can then be tested by selecting values of γ and the precise definition of the asset supplies b and f.

For the actual tests, it proved difficult to select values for γ because regression estimates of γ often yield negative values and have almost always large standard errors. However, it is also possible to obtain an estimate of γ by using an assumed value for the coefficient of risk aversion and the observed variances of exchange rates in the mean variance optimization approach. In the tests developed in this paper, γ was arbitrarily set equal to 30 for all countries since this value represents a mean value found by Frankel (1985b), using the mean variance approach for several different currency pairs. The data on asset supplies was taken from International Financial Statistics and Government Finance Statistics. It was assumed that the assets that enter equation (26) refer to the total, privately held, government debt. 1/ Thus, b_t refers to the debt of the German government held by the private sector (German and foreign residents). 2/

Table 3 presents the results of this test of the pure portfolio balance model for the eight currencies for which data on asset supplies were available using yearly data from 1973 to 1983. Recall that the first column of the table shows the root mean squared difference between the naive and the perfect forecast. The values in the first column of Table 3 are very large, indeed more than ten times the numbers in the first column of the preceding tables. This sugggests that the methodology applied here is only of limited usefulness in this case, because the naive forecast is too far from the perfect forecast. The reason for this is not that relative bond supplies are extremely volatile, instead the large discrepancies between the naive and the perfect forecast are a consequence of the large value of γ. With $\gamma = 30$, a change in the interest rate differential of e.g., 3 percent (at unchanged relative bond supplies) leads to a jump in the naive forecast exchange rate of more than 100 percent. (The natural logarithm of the exchange rate would jump by 0.9, this corresponds to a jump of 145 percent.) The perfect forecast exchange rate, however, does move only very little because the discount rate used to discount the end-of-the observation period exchange rate is very close to

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1/ The data used were taken from Government Finance Satistics, Table 7, which gives outstanding debt by type of debt holder (consolidated central government). Privately held debt was defined as total debt minus debt held by the monetary authorities or other levels of government.

2/ One way to motivate this choice is to assume that all government debt is issued in national currency and that the private sector regards government debt as net wealth. In this case, the bond stocks used here represent the net wealth of the private sector invested in securities with different currency denominations.

Table 3. Test for Excess Volatility of Selected Deutsche Mark Exchange Rates 1/

The Pure Portfolio Balance Model

Yearly Data 1973-84

Country 2/	(1) $\frac{1}{T}[\Sigma(s_t^* - s_t^o)^2]^{.5}$	(2) $\frac{1}{T}[\Sigma(s_t^* - s_t)^2]^{.5}$	(3) $\frac{1}{T}[\Sigma(s_t - s_t^o)^2]^{.5}$	(4) $\frac{Max[(2),(3)]}{(1)}$
Belgium	98.26	4.02	96.49	0.98
Canada	98.84	35.34	118.87	1.20
Japan	124.96	19.18	120.37	0.96
Netherlands	67.37	2.50	68.76	1.02
Sweden	144.61	10.04	152.79	1.06
Switzerland	122.40	13.93	131.41	1.07
United Kingdom	160.91	19.91	176.76	1.10
United States	92.08	32.06	89.01	0.97

1/ The numbers are equivalent to percentage changes since they represent the standard deviations of logarithms.
2/ Indicates the currency of the exchange rate vis-a-vis the deutsche mark.

one (0.9677=γ/(1+γ)), and the observation period is rather short (11 years). The combination of these two factors implies that even at the beginning of the observation period, the calculation of the perfect foresight exchange rate (see equation (30)) is denominated by the influence of the discounted end-of-period exchange rate, since the discount factor applied to the end of period exchange rate is still close to one, about 0.7 (i.e., 0.9677 raised to the power eleven). In the preceding tests of the monetary model, the discount factor was much lower so that the end of period exchange rate did not influence the calculation of the perfect foresight exchange rate strongly even up to two years before the end of the observation period.

The large value of γ used here, which corresponds to the general finding that assets denominated in different currencies are highly substitutable, thus leads to a very low power of the test. This is borne out in the last column of Table 3, the values around one indicate that this test is not able to reject the portfolio balance model.

Another test of the portfolio balance model can be obtained by using equation (26) to solve out for the domestic interest rate and combining the result with the monetary approach, to obtain a synthesis of the monetary approach and the portfolio balance models. This can be done for both versions of the monetary approach (flexible price and sticky price) considered here.

Equation (26) implies that the domestic interest rate is given by:

$$(31) \quad i_t = (\frac{1}{\gamma})[b_t - f_t + \gamma i^*_t + \gamma E_t(s_{t+1}) - (1+\gamma)s_t]$$

This equation can be combined with the basic money demand equation if the monetary approach, equation (13), to yield:

$$(32) \quad m^d_t = k + \phi y_t + p_t - \frac{\eta}{\gamma}[b_t - f_t + \gamma i^*_t - E_t(s_{t+1}) + (1+\gamma)s_t]$$

For the flexible price version of the monetary model, it is assumed that purchasing power parity holds at all times, this implies $p_t = s_t + p^*_t$, using this condition in equation (31), assuming money market equilibrium, i.e., $m^d_t = m^s_t = m_t$ and iterating forward, one obtains an expression exchange rate:

$$(39)\quad s_t = \frac{\gamma}{\gamma+\eta(1+\gamma)} \sum_{j=0}^{\infty} E_t[x_{t+j} + \frac{\eta}{\gamma}(b_{t+j} - f_{t+j})][\frac{\gamma\eta}{\gamma+\eta(1+\gamma)}]^j$$

To save on notation, the exogenous monetary forcing variable as in the preceding sections, i.e., $X_t \equiv m_t - k - \phi y_t - p_t^* + \eta i_t^*$. This equation shows that the incorporation of the portfolio balance approach in the monetary approach leads to two modifications: (i) the fundamentals that determine the exchange rate include relative bond supplies besides money supplies and the factor determining money demand; and (ii) the factor used to discount future fundamentals is also a function of the parameter γ, which is related to the risk aversion of investors. In general, with γ positive, the discount factor is smaller in this combined model than in the flexible price, pure monetary approach model. This implies that in this combined model, future fundamentals are discounted more than in the flexible price, pure monetary approach model.

The flexible price version of the combined portfolio-balance-monetary approach model leads to the following expression for the naive forecast exchange rate:

$$(34)\quad s_t^o = \frac{\gamma}{\gamma+\eta}(X_t + \frac{\eta}{\gamma}(b_t - f_t))$$

And the truncated form of the perfect forecast exchange rate is given by:

$$(35)\quad s_t^* = \frac{\gamma}{\gamma+\eta(1+\gamma)} \sum_{j=0}^{T-t} (\frac{\eta\gamma}{\gamma+\eta(1+\gamma)})^j (X_{t+j} + \frac{\eta}{\gamma}(b_{t+j} - f_{t-j})) + (\frac{\eta\gamma}{\gamma+\eta(1+\gamma)})^{T-t+1} s_{T+1}$$

Table 4 contains the results of the test of the combination of the portfolio balance approach with the flexible price version of the monetary model. These results are very similar to the ones obtained for the monetary model alone. (This test uses the same values for η and ϕ as Table 1 (a).) The reason for this outcome lies again in the magnitude of γ. With γ=30, the elasticity of the naive forecast exchange rate with respect to changes in relative bond supplies is equal to 0.08 ($=\eta/\gamma$). The last column of Table 4 thus suggests, as Table 1 (a), that the flexible price version of the monetary model, even in conjunction with the portfolio balance approach is not able to account for the variability of the exchange rates analyzed here. The rejection is again weaker for the EMS currencies (the Belgian franc and the Dutch guilder) than for the non-EMS currencies.

Table 4. Test for Excess Volatility of Selected Deutsche Mark Exchange Rates 1/

Yearly Data 1973-83

The Combined Portfolio Balance/Flexible Price Monetary Model

Country 2/	(1) $\frac{1}{T}[\Sigma(s_t^* - s_t^o)^2]^{.5}$	(2) $\frac{1}{T}[\Sigma(s_t^* - s_t)^2]^{.5}$	(3) $\frac{1}{T}[\Sigma(s_t - s_t^o)^2]^{.5}$	(4) $\frac{\text{Max}[(2),(3)]}{(1)}$
Belgium	4.09	4.19	6.12	1.50
Canada	7.47	15.96	19.99	2.68
Japan	8.69	10.51	16.86	1.94
Netherlands	2.58	2.56	3.93	1.52
Sweden	5.86	9.38	12.12	2.07
Switzerland	4.44	9.97	12.01	2.71
United Kingdom	8.55	13.78	18.44	2.16
United States	10.51	11.61	19.01	1.81

1/ The numbers are equivalent to percentage changes since they represent the standar deviations of logarithms.

2/ Indicates the currency of the exchange rate vis-a-vis the deutsche mark.

The sticky price version of the monetary model can also be combined with the portfolio balance approach. The only difference to the flexible price model is that in the sticky price version, PPP is no longer assumed to hold; instead the real exchange rate is $(s_t + p^*_t - p_t)$ is assumed to follow $E_t(s_{t+1} + p^*_{t+1} - p_{t+1}) = (1-\beta)(s_t + p^*_t)$ (see equation (20)). Using this adjustment rule of the real exchange rate in equations (32) and (33) yields:

$$(36)\quad s_t = \frac{\gamma}{\gamma + \eta(1+\gamma)} \sum_{j=0}^{\infty} E_t[X_{t+j} + \frac{\eta}{\gamma}(b_{t+j} - f_{t+j})][\frac{\gamma\eta}{\gamma + \eta(1+\gamma)}]^j$$

$$+ q_t[\frac{\gamma}{\gamma + \eta(1+\beta\gamma)}]$$

The naive forecast exchange rate is thus equal to:

$$(37)\quad s^o_t = \frac{[\gamma+\eta(1+\beta)]\gamma}{\eta(1+\beta\gamma)(\gamma+\eta)}[x_t + \frac{\eta}{\gamma}(b_t - f_t)] + (p^*_t - p_t)(\frac{\gamma}{\gamma+\eta(1+\beta\gamma)})$$

And the perfect forecast exchange rate is equal to:

$$(38)\quad s^o_t = [\frac{1-D}{D-D^{T-t+1}}][(\frac{D}{(1-\beta)\eta}) \sum_{j=0}^{T-t}[x_{t+j} + \frac{\eta}{\gamma}(b_t - f_t)](\frac{D}{(1-\beta)})^j$$

$$+ (p^*_t - p_t)(\frac{1-DT-t+1}{1-D}) + S_{T+1}(\frac{D}{1-\beta})^{T-t+1}]$$

Table 5 contains the results of a test of the model that combines the sticky price version of the monetary model with the portfolio balance approach. This test uses the same data (yearly, 1973-83) and parameters as Table 4. Furthermore, to make this Table comparable to Table 2 (b), which contains the results of the sticky price version of the monetary model, the price adjustment parameter, β, was again set equal to 0.5. The last column in Table 5 indicates that it is still possible to reject this combined model in all of the eight cases for which data is available. It also appears that for most currencies the values of the last columns of Table 2 (a) and of Table 5 are quite similar. Thus, the introduction

Table 5. Test for Excess Volatility of Selected Deutsche Mark Exchange Rates 1/

Yearly Data 1973-83

The Combined Portfolio Balance/Sticky Price Monetary Model

Country 2/	(1) $\frac{1}{T}[\Sigma(s_t^* - s_t^o)^2]^{.5}$	(2) $\frac{1}{T}[\Sigma(s_t^* - s_t)^2]^{.5}$	(3) $\frac{1}{T}[\Sigma(s_t - s_t^o)^2]^{.5}$	(4) $\frac{Max[(2),(3)]}{(1)}$
Belgium	9.69	5.09	10.76	1.11
Canada	14.53	20.72	25.90	1.78
Japan	18.67	11.23	21.53	1.15
Netherlands	6.34	5.46	8.95	1.41
Sweden	14.60	12.84	22.25	1.52
Switzerland	10.73	12.29	19.14	1.78
United Kingdom	20.71	12.86	23.14	1.12
United States	21.09	15.00	23.86	1.13

1/ The numbers are equivalent to percentage changes since they represent the standard deviations of logarithms.

2/ Indicates the currency of the exchange rate vis-a-vis the deutsche mark.

of portfolio balance considerations does not seem to dramatically improve the power of the monetary model to explain the observed degree of exchange rate volatility.

V. Conclusions

This paper has examined the question whether it is possible to explain the observed variability of exchange rates in terms of the so-called fundamentals. If money supplies, prices, interest rates, and relative asset supplies are taken to be the fundamentals that ought to determine exchange rates, the results of this paper suggest that the freely floating exchange rates are considerably more volatile than one could justify from the behavior of the fundamentals.

But the results also suggest that there is a marked difference in this respect between the major freely floating exchange rates, such as the exchange rate of the DM vis-a-vis the U.S. dollar, the Japanese yen, the Swiss franc, and the intra-EMS exchange rates. The much lower variability of the intra-EMS exchange rates can be explained in terms of the fundamentals, whereas this is not the case for the major freely floating exchange rate. This difference in behavior suggests that the EMS has been successful in reducing the variability of intra-EMS exchange rates to the minimum that is attainable given the differences in policies between the member states. In contrast, the variability of the major freely floating exchange rates cannot be explained in terms of the fundamentals. This does not necessarily imply that markets always overreact, but it does suggest that the models of exchange rate determination that are available today cannot explain the observed variability of exchange rates.

Derivation of the Expression for s_t^* and s_t^o for the Sticky Price Monetary Model

Equation (21) in the text can be iterated one step forward to yield:

$$\text{(A.1)}\quad s_t = \frac{1}{1+\eta}\left[X_t + q_t + \frac{\eta}{1+\eta} E_t\,(X_{t+1} + q_{t+1}) + \frac{\eta^2}{1+\eta} E_t(s_{t+2})\right]$$

It is apparent that further forward iteration of equation (A.1) will lead to two infinite sums; the stable solution then implies that the current exchange rate is given by:

$$\text{(A.2)}\quad s_t = \frac{1}{1+\eta}\left[\sum_{j=0}^{\infty}\left(\frac{\eta}{1+\eta}\right)^j E_t(X_{t+j})\right] + \frac{1}{1+\eta}\left[\sum_{j=0}^{\infty}\left(\frac{\eta}{1+\eta}\right)^j E_t(q_{t+j})\right]$$

However, using equation (20) in the text, the second infinite sum in this equation can be simplified, which yields an expression for the current nominal exchange rate as function of the discounted sum of future monetary factors and the current real exchange rate: 1/

$$\text{(A.3)}\quad s_t = \frac{1}{1+\eta}\left[\sum_{j=0}^{\infty}\left(\frac{\eta}{1+\eta}\right)^j E_t(X_{t+j})\right] + \left(\frac{1}{1+\eta}\right)\frac{q_t}{1-\frac{(1-\beta)\eta}{1+\eta}}$$

Using the definition of the real exchange rate and taking the realized values of the monetary forcing variables yields an expression for the perfect foresight exchange rate:

$$\text{(A.4)}\quad s_t^* = \frac{1+\beta\eta}{\beta\eta(1+\eta)}\left[\sum_{j=0}^{\infty}\left(\frac{\eta}{1+\eta}\right)^j X_{t+j}\right] + \left(\frac{1}{\beta\eta}\right)(p_t^* - p_t)$$

1/ At this stage, income, which is one of the variables determining money demand, is still taken exogenous.

$$(A.5)\quad s_t^* = \frac{1}{1+\eta}\left[\sum_{j=0}^{T-t}(X_{t+j} + q_{t+j})\left(\frac{\eta}{1+\eta}\right)^j\right] + \left(\frac{\eta}{1+\eta}\right)^{T-t+1} s_{T+1}$$

This can be transformed into:

$$(A.6)\quad s_t^* = \frac{1}{1+\eta}\left[\sum_{j=0}^{T-t}\left(X_{t+j}\left(\frac{\eta}{1+\eta}\right)^j\right)\right] + q_t\left(\frac{1 - \left[\frac{(1-\beta)\eta}{1+\eta}\right]^{T-t+1}}{1+\eta\beta}\right) + \frac{\eta}{1+\eta}^{T-t+1} s_{T+1}$$

Using the definition of the real exchange rate, this yields an equation that is the finite horizon equivalent to equation (16) in the text.

$$(A.7)\quad s_t^* = \left[\frac{1+\eta\beta}{\eta\beta + \left(\frac{(1-\beta)\eta}{1+\eta}\right)^{T-t+1}}\right]\left\{\left(\frac{1}{1+\eta}\right)\left[\sum_{j=0}^{T-t}\left(\frac{\eta}{1+\eta}\right)^j Xt+j\right] + \left(\frac{\eta}{1+\eta}\right)^{T-t+1} s_{T+1}\right.$$

$$\left. + (p_t^* - p_t)\left(\frac{1-\left(\frac{(1-\beta)\eta}{1+\eta}\right)^{T-t+1}}{1+\eta\beta}\right)\right\}$$

Money Demand Estimates for Germany

The two money demand estimates for Germany used in the tests of the paper are based on data from International Financial Statistics. Line 34, i.e., M1 was used for money; line 99a.r., GNP at 1980 prices, was used for income; line 60b.s., interbank rate, was used for the interest rate; and line 64, consumer price index, was used for prices. The dependent variable was real M1, i.e., the natural logarithm of M1 divided by the CPI and the two explanatory variables were the natural logarithm of income and the interest rate.

Using yearly data from 1970 to 1984, the result was (standard errors in parentheses):

$$\text{real M1} = \underset{(0.61)}{-7.62} + \underset{(0.08)}{1.18}\ \text{income} - \underset{(0.29)}{1.32} * \text{interest rate}$$

$$\bar{R}^2 = 0.94, \quad \text{SEE} = 0.03 \quad \text{D.W.} = 1.5$$

In the estimation using quarterly data from Q1 1973 to Q4 1984, the explanatory variables also included a lagged dependent variable to capture the lagged adjustment. The point estimates were little affected by the choice of the correction for seasonality. The results reported here are based on nonseasonal adjusted data for M1 but include three seasonal dummies:

$$\text{real M1} = \underset{(0.8)}{-1.6} - \underset{(0.07)}{0.11} + \text{Dummy Q1} - \underset{(0.006)}{0.028} + \text{Dummy Q2} - \underset{(0.006)}{0.063} + \text{Dummy Q3}$$

$$+ \underset{(0.089)}{0.227} + \text{income} - \underset{(0.087)}{0.521} + \text{interest rate}$$

$$+ \underset{(0.064)}{0.800} + \text{lagged real M1}$$

$$\bar{R}^2 = 0.9774, \quad \text{SEE } 0.015, \quad \text{DWH} = 0.695$$

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