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THIS PAPER IS A STUDY OF THE IMPORTANCE of speculative bubbles in the bilateral exchange rate of the U.S. dollar with the currencies of Germany, France, and Japan. The maintained assumption of rational expectations allows us to differentiate between two types of deviations from the value dictated by the fundamentals: speculative bubbles and error terms. A rational speculative bubble specifies that its trend term is an exact function of the structural parameters of the asset demand equation.[1] An integral part of this paper is the estimation of a version of the portfolio-balance model of exchange rate determination. We suspect that the primary reason for the usual poor performance of bilateral portfolio models is the use of specifications that ignore the existence of speculative bubbles.

Section 1 of the paper reviews some aspects of the portfolio-balance approach, and derives the exchange rate equation. Section II subjects the bubble-

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[1]Flood and Garber (1980) use the same method in assessing the possibility of price bubbles during the German hyperinflation. Howver, as will be clear, the motivation for our bubble may differ from theirs—we test for uncertainty bubbles. Like them, we want to emphasize that this method cannot distinguish between bubbles and exchange rate movements caused by anticipations of events which were subsequently not realized. As far as we know, this weakness is true of every empirical paper on destabilizing speculation. In Section III, we offer qualitative evidence which indicates that the latter is unlikely in our case. A recent, excellent study by Meese (1986) finds evidence of exchange rate bubbles, conditional on a monetary model. His tests are more general than ours; they can detect both what we call here risk and uncertainty bubbles.

WING THYE WOO *is assistant professor of economics, University of California, Davis.*

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augmented portfolio model to the usual statistical tests and an out-of-sample dynamic forecasting exercise to match the model's forecasts with those from its unconstrained vector autoregression equivalent. Section III discusses the findings, and Section IV concludes the paper.

I. A PORTFOLIO BALANCE EQUATION

A frequently used bilateral portfolio equation takes the form

$$\frac{B}{S \cdot B^*} = \phi(r, r^* + \hat{e}) \tag{1}$$

where B = value of outside bonds denominated in country 1's currency held privately,
B^* = value of outside bonds denominated in country 2's currency held privately,
S = the exchange rate, number of units of country 1's currency to a unit of country 2's currency,
r = the interest rate on bonds denominated in country 1's currency,
r^* = the interest rate on bonds denominated in country 2's currency, and
$\hat{e}$ = the expected rate of change in S.

Interpretations of equation (1) depend on a number of assumptions. To minimize data requirements, the two most common interpretations are:

(1) *The two-sided scenario*: Agents in both countries hold both bonds in their portfolios. The imposition of the assumption that asset preferences are the same across countries removes the need to know the distribution of B and B^* between the two countries. This eliminates the preferred habitat effect on exchange rate determination. The identical preference assumption also ensures that inside bonds, whether held by residents or nonresidents, have no net portfolio effect. The additional assumption that governments issue only own-currency denominated bonds to finance deficits allows one to interpret B and B^* as the amount of the national debt held by the private sector.

(2) *The one-sided scenario*: While agents in country 1 hold B and B^* in their portfolios, agents in country 2 hold only B^*. So equation (1) represents the optimal portfolio for country 1 agents. The amount of B^* held by country 1 residents equals the cumulated current account adjusted by the change in foreign reserves of country 1's monetary authorities. B is the amount of national debt not held by the monetary authorities.

As far as we know, all studies that have successfully estimated exchange rate equations derived from portfolio-balance models fall within the one-sided scenario.[2] Rogoff (1983) attributes the success of these studies to the correlation between current account deficits and exchange rate depreciation, and argues that it should not be regarded "as solid evidence of a portfolio balance effect." He points out that (i) a current account-exchange rate link is also consistent with the elasticity approach which emphasizes trade flows and not portfolio factors, (ii) the effects of the current account on real wealth are small compared with other factors like interest rate changes, (iii) the current account-exchange rate link has weakened in recent years, and (iv) empirical studies have not established a correlation between the exchange rate risk premium and the relative supplies of assets denominated in different currencies.

We estimate the bubble-augmented portfolio model under the two-sided scenario because we find Rogoff's arguments persuasive. We assume that equation (1) takes the specific form of

$$(b-e-b^*)_t^{desired} = \alpha + \Psi r_t - \Psi^* [r_t^* + E(e_{t+1}|\Omega_t) - e_t] + \epsilon_t \qquad (2)$$

where x = ln X, except for interest rates which are in decimal fraction form,
e = ln S,
ϵ = portfolio or technological shock which is seen by economic agents but not the econometrician, and
Ω = information set containing all present and past values of $b, b^*, r, r^*, e, \epsilon$.

We assume $E(\epsilon_t|\Omega_{t-i}) = 0 \quad \text{for } i > 0$.

From the empirical literature on domestic asset demand functions estimated on quarterly data, we know that instantaneous adjustment of asset demand is seldom achieved. This should be especially true in our case as we are working with monthly data. We therefore assume partial adjustment in asset demand behavior:

$$(b-e-b^*)_t - (b-e-b^*)_{t-1} = \rho[(b-e-b^*)_t^{desired} - (b-e-b)_{t-1}] \qquad (3)$$

where $0 < \rho < 1$.

Combining equations (2) and (3) and rearranging terms we get[3]

$$E_t \left\{ (1 - \lambda_1 L)(e_t - \frac{1}{\lambda_2} e_{t+1}) = - \frac{\alpha}{\lambda_2 \Psi^*} + \frac{1}{\phi^* \lambda_2} \mathbf{R'Z}_t - \frac{\epsilon_t}{\Psi^* \lambda_2} \right\}$$

[2]Successful estimations of exchange rate equations under the one-sided scenario are: Branson, Halttunen, and Masson (1977, 1979), Dooley and Isard (1982) and Hooper and Morton (1982). Success is defined as getting significant coefficients with the right signs and with plausible magnitudes. In empirical implementations of both scenarios, all studies we know use the value of bonds evaluated at par rather than at existing market value. This procedure is dictated by data availability, and the resulting implicit assumption is that the bonds have short maturity.

[3]A detailed derivation is available from the author. We define $\mathbf{Z}_t$ to be a 12x1 vector because in empirical work we use four lags for each variable.

where

$$E_t\{X_{t+i}\} = E\{X_{t+i}|\Omega_t\} ,$$

$$\phi^* = \rho \cdot \Psi^* ,$$

$$\phi = \rho \cdot \Psi ,$$

$$\beta = (1 - \rho) ,$$

$$\mathbf{R}' = [1,\beta,0,0,-\phi,0,0,0,\phi^*,0,0,0] ,$$

$$\mathbf{Z}'_t = [b_t - b_t^*, b_{t-1} - b_{t-1}^*, b_{t-2} - b_{t-2}^*, b_{t-3} - b_{t-3}^*,$$

$$r_t, r_{t-1}, r_{t-2}, r_{t-3}, r_t^*, r_{t-1}^*, r_{t-2}^*, r_{t-3}^*] ,$$

$$\lambda_1 = \frac{1 + \phi^* - \sqrt{(1+\phi^*)^2 - 4\beta\phi^*}}{2\phi^*} < 1 \text{ , and}$$

$$\lambda_2 = \frac{1 - \phi^* + \sqrt{(1+\phi^*)^2 - 4\beta\phi^*}}{2\phi^*} > 1 .$$

A solution to equation (4) which we call the fundamental exchange rate, e_t^f, is given by

$$e_t^f = m + \lambda_1 e_{t-1} + \frac{1}{\phi^* \lambda_2} \mathbf{R}' \sum_{i=0}^{\infty} \left(\frac{1}{\lambda_2}\right)^i E_t(\mathbf{Z}_{t+i}) + s_t \qquad (5)$$

where

$$m = \frac{-\alpha}{\Psi^*(\lambda_2 - 1)}$$

$$s_t = \frac{-\epsilon_t}{\lambda_2 \Psi^*} \text{ , and}$$

$$(1 - \lambda_1 L)e_t^f = e_t^f - \lambda_1 e_{t-1} .$$

We define all the RHS terms of equation (5) as the fundamentals in exchange rate determination. Equation (4) has other solutions besides equation (5); it also has at least two speculative bubble solutions.[4]

The choice of bubble solution depends on whether we think agents are able to compute an objective probability on the incidence of bubbles. If agents are able

[4]As is well known, most rational expectations equations have an infinite number of solutions. We limit the analysis to solutions which are appropriate for our purpose.

to form a subjective probability which coincides with the conditional mathematical probability, then a bubble solution is[5]

$$e_t = e_t^f + c_t \tag{6}$$

where

$$c_t = \frac{\lambda_2}{\pi 2} c_{t-1} + \mu_t \quad \text{with probability } \pi ,$$

$$= \mu_t \quad \text{with probability } (1-\pi) ,$$

$$\pi = \text{probability that bubble will remain, and}$$

$$E_{t-1}(\mu_t) = 0 .$$

The above bubble solution, however, is not plausible for some situations. Lucas (1977) argues that unless a phenomenon is "a fairly well-defined recurrent event," rational agents would be unable to form a probability regarding its occurrence. The basis of Lucas' position is Knight's (1921) distinction between risk and uncertainty that the former is measurable and the latter is not.[6] By definition, the subjective probability of a rational agent can come only from either the observed frequencies of the event or the (widely known) true economic model. Hence, rational calculation of subjective probability is not possible when the event is infrequent and is caused by historically unique circumstances.

Keynes (1936) also makes this risk-uncertainty distinction, and he suggests that in situations where the "existing knowledge does not provide a sufficient basis for a calculated mathematical expectation," "rational economic men" would assume "that the existing state of affairs will continue indefinitely except in so far as [they] have specific reasons to expect a change."[7] Adopting Knight's terms and Keynes' martingale proposal, the uncertainty bubble solution to equation (4) is

$$e_t = e_t^f + A_t \lambda_2^t \tag{7}$$

where $E_{t-1}(A_t) = A_{t-1}$.[8]

[5]This solution is suggested by Blanchard and Watson (1982). Strictly speaking, since c_t contains the structural error term, a bubble occurs whenever μ_t is nonzero, and π denotes the probability that the bubble will cumulate. We will follow their usage: a bubble occurs when c_t cumulates.

[6]Lucas differs from Knight in that he interprets "the risk-uncertainty distinction as referring not to a classification of different types of individual decision problems but to the relationship between decision maker and observer." Lucas limits his analysis to cases where the subjective probability is the same across agents.

[7]The first and third quotes are from Keynes 1936 (p. 152), and the second is from Keynes 1937.

[8]The existence of bubbles is realistic in our model only because all bonds are assumed to be short term (see footnote 2). If we introduce consols into the model, the interest rate parity condition would yield the unrealistic result of infinite consol rate differential. This is true for both bubble solutions whenever a bubble is present, and true only for the risk bubble solution when a bubble is absent. One

It is important to note that equations (6) and (7) tell us only what the time profiles of risk and uncertainty bubbles look like when they occur; neither (6) nor (7) specifies the causes of bubbles. We only know that μ_t and A_t are stochastic, there is nothing so far which specifies what makes them nonzero. This point highlights that bizarre interpretations are possible. For example, the risk bubble solution of equation (6) assumes that agents know that some objective bubble generation mechanism exists and that it generates bubbles with the long-run frequency, π. If we cannot think of such a mechanism, then the only way for the probability to be rationally held is that agents intend to act in concert to create bubbles with that frequency!

We chose the uncertainty bubble solution over the risk bubble solution for two reasons. First, we believe that exchange rate bubbles are caused by events, outside of the economic model, that cannot be adequately described in probability terms.[9] Second, the uncertainty bubble solution is more consistent with the way we predicted future values of $\mathbf{Z}_t$ for use in estimation.[10] Note that this choice of bubble solution is not without statistical discipline. The time profiles of the uncertainty and risk bubbles are different (the latter being steeper), and hence the statistical tests will reject the uncertainty bubble hypothesis if it were not true.

The general form of our uncertainty bubble solution of the exchange rate derived from the portfolio model is given by

$$e_t = m + \lambda_1 e_{t-1} + \frac{1}{\phi^* \lambda_2} \mathbf{R}' \sum_{i=0}^{\infty} \left[\frac{1}{\lambda_2}\right]^i E_t[\mathbf{Z}_{t+i}] + A_t \cdot \lambda_2^t + s_t . \quad (8)$$

II. ESTIMATION AND PREDICTION

As equation (8) involves unobserved expectations of future $\mathbf{Z}_t$, we need to specify an expectations generator to enable estimation. The obvious rational way is to exploit our information set, Ω_t, to the fullest; in practice, this means projecting $\mathbf{Z}_t$ onto the information set to summarize its statistical characteristics. Part A of Table 1 shows that lagged exchange rates do not help to predict $\mathbf{Z}_t$ and, hence, ought to be dropped from the projection equation.[11] We want to emphasize that

way to avoid this result in the expanded model is to introduce also a risk premium which increases at the rate λ_2 for each additional year to maturity whenever an uncertainty bubble occurs. The risk premium specification is more complicated for risk bubbles given that μ_t is generally nonzero. (A referee had pointed out this unrealistic implication from the interest rate parity condition to us.)

[9]We expand on this point in Section III. Our choice is also influenced by the works of Aliber (1970) and Kindleberger (1978). The former, who concludes that destabilizing speculation did plague the French franc from late 1923 to 1926, is careful to stress "the unique circumstances of that postwar period."

[10]See equation (9). It is standard practice (e.g., Sargent 1978) to naively project $\mathbf{Z}_t$ forward on the basis of past characteristics rather than attempt to take possible switching of stochastic processes in the future into account.

[11]The data has been first differenced (see footnote 15). The chi-square statistics are adjusted by the factor $(T-k)/T$. T is the number of observations and k is the average number of regressors in each equation under the unconstrained case. This adjustment is due to Sims (1980) who shows that the likelihood ratio test "has a bias against the null hypothesis relative to the F test."

TABLE 1

APPROPRIATENESS OF $\mathbf{Z}_t$ SPECIFICATION

Part A: To determine whether lagged exchange rates help to predict $\mathbf{Z}_t$.

	Germany	France	Japan
$\chi^2(6)$	5.11	10.04	10.28

Detail: Each component of $\mathbf{Z}_t$ enters with 4 lags, and the exchange rate with 2 lags. $\chi^2(6)95\% = 12.59$.

Part B: To test for stability of coefficients across equal subperiods.

Component equation	Germany F(13,94)	France F(13,88)	Japan F(13,63)
$b_t - b_t^*$	2.52	1.08	1.51
r_t	1.39	0.84	1.26
r_t^*	1.73	0.43	1.99

$F(13,60)95\% = 2.30$, $F(13,120)95\% = 2.25$
$F(13,60)97.5\% = 2.72$, $F(13,120)97.5\% = 2.66$

NOTES: The sample period is determined by availability of monthly data: Germany, 1973.4 to 1980.4; France, 1973.4 to 1982.9; and Japan, 1973.4 to 1980.4. Interest rates are expressed in decimal fraction form and at monthly rates. For source of data, see Appendix.

these Granger causality tests are not being used as tests of exogeneity specification but as "tests of 'incremental predictive content' " (Schwert 1979).

In light of the Lucas critique, we conduct tests for the stability of coefficients across equal subperiods to check for switches in stochastic processes during the sample period. Part B of Table 1 reports that it is reasonable to accept the null hypothesis of stability. The evidence against the stability of the German-U.S. bond equation is not conclusive for two reasons. First, stability just misses being accepted at the 5 percent significance level. Second, even when stability is true, there is only a 63 percent chance that all nine equations will pass the individual stability tests conducted at the 5 percent significance level. An overall Type I error of 5 percent requires the individual significance level to be 0.6 percent, a criterion which this equation easily passes.

On the basis of Table 1, our projection equation takes the form of[12]

$$\mathbf{Z}_t = \mathbf{J} + \mathbf{B}\mathbf{Z}_{t-1} + U_t \tag{9}$$

and we assume $E(U_t \mathbf{Z}_{t-i}) = E(U_t e_{t-i}) = 0$ for $i > 0$. We interpret U_t as the one-step-ahead forecast error of the projection equation (9).

It should be noted that by modeling the interest rate as a stationary stochastic process even in the presence of an exchange rate bubble, we are assuming that fiscal and monetary policies (especially, the official discount rate) have been varied to keep the interest rate within target zones which were not changed during periods of bubbles. This assumption is consistent with, but not proven by, both the findings in Table 1: that the exchange rate does not Granger-cause interest rates and that the interest rates are stable processes.

[12]$\mathbf{J}$ is a 12x1 vector and $\mathbf{B}$ is a 12x12 matrix.

Substituting (9) into (8) we get

$$e_t = n + \lambda_1 e_{t-1} + \frac{1}{\phi^* \lambda_2} \mathbf{R}' \left[I - \frac{1}{\lambda_2} \mathbf{B} \right]^{-1} \mathbf{B}\mathbf{Z}_{t-1}$$

$$+ A_t \cdot \lambda_2^t + v_t \tag{10}$$

where $n = f(m,J)$ and $v_t = g(s_t, U_t)$.

Given our assumptions of $\{\epsilon_t, U_t\}$, we know that

$$E(\mathbf{Z}_{t-i}\, v_t) = E(e_{t-i} v_t) = 0 \quad \text{for } i > 0\,. \tag{11}$$

Equations (9) and (10) are a particular constrained case of a more general VAR system represented by

$$\begin{bmatrix} \mathbf{Z}_t \\ e_t \end{bmatrix} = \begin{bmatrix} \mathbf{J} \\ d \end{bmatrix} + \begin{bmatrix} \mathbf{B} \\ D \end{bmatrix} Z_{t-1} + \begin{bmatrix} 0 \\ a \end{bmatrix} e_{t-1} + \begin{bmatrix} 0 \\ A_t k^t \end{bmatrix} + \begin{bmatrix} U_t \\ v_t \end{bmatrix} \tag{12}$$

where d, D, a and k are constant terms.

Equation system (12) shows very clearly the essence of estimation under rational expectations. The joint hypothesis of bubble-augmented portfolio model and rational expectations requires d, D, a and k to be exact nonlinear functions of the portfolio parameters and the process that generates $\mathbf{Z}_t$. We call equation system (12) the unconstrained VAR equivalent of the model embodied in equations (9) and (10). We use the full information maximum likelihood (FIML) method to (i) estimate equations (9) and (10) simultaneously with the cross-equation constraints imposed, and then (ii) estimate the unconstrained VAR system of (12). The first step gives us the parameter estimates, and the second allows us to use the likelihood ratio test to check if, overall, the cross-equation constraints are compatible with the data.

Equation (11) is the assumption which permits consistent estimation of the parameters, and is the condition which FIML enforces on the data. Consistent estimation does not require that $\mathbf{Z}_t$ be econometrically exogenous, i.e., $E(\mathbf{Z}_t v_{t+i}) = 0$ for all values of i. The predeterminedness assumption, given by (11), is the common assumption in macroeconomics to justify instrumental variable estimation. Consistent estimation does not depend on the contemporaneous disturbance terms of the component equations being uncorrelated.

To prevent the nonzero A_ts from playing the opportunistic dummy variable role of assuming a different value each period and hence assuring our equation a good fit, we assume that A_t is a constant over the period when it is nonzero.[13] A

[13]This assumption makes our bubbles have the same time profile as Flood and Garber's bubbles. Like us, they allow bubbles to start within the period of their sample—but they should not be implicated as our coreligionists in uncertainty bubbles.

pre-estimation look at the data is unavoidable as we need to impose ex ante the periods that A_t is nonzero. To minimize the discretionary element involved, we do not revise our bubble choices after the estimation has begun. Our criteria for a bubble are: (i) a noticeable spike in the exchange rate series, (ii) a (near) continuous acceleration or deceleration of the exchange rate before the spike,[14] and (iii) the mood of the foreign exchange markets as can be gleaned from the Treasury and the Federal Reserve reports on their foreign exchange market interventions in various issues of the *Federal Reserve Bulletin*, and from the financial pages of the *New York Times* and *Washington Post* of the period.

Each of the destabilizing speculation periods we identified satisfied at least two of the stated criteria; these periods are

1. the German–United States exchange rate from June to October 1978 and again from December 1979 to March 1980.
2. the French–United States exchange rate from June to October 1978 and again from January to March 1980.
3. the Japanese–United States exchange rate in October 1978 and from August to November 1979.

In our estimations, we denote the coefficients of the first and second bubbles, $A1$ and $A2$ respectively.[15]

We find that the estimation cannot converge when β is unconstrained. We set the value of β to be 0.5. This addition of seemingly arbitrary restrictions, however, is not without an external discipline. The likelihood ratio test is an overall assessment of the statistical veracity of all these hypotheses combined. Any one restriction that strongly contradicts the data should lead to the rejection of all the joint hypotheses by the likelihood test statistic.

Table 2 reports the results of the estimation. The model seems to fit the German and French exchange rates quite well. For these two countries, at least three of the four exchange rate equation parameters (ϕ, ϕ^*, $A1$, $A2$) are statistically significant.

We do two sets of constrained estimation for the Japanese model. In the first set, ϕ has the wrong sign and both ϕ and ϕ^* are statistically insignificant. The negative value of ϕ suggests to us that the true value of ϕ is smaller than that of ϕ^*. In the second set of constrained estimation we set $\phi = 0.5\phi^*$.[16] This additional constraint renders ϕ^* statistically significant and reduces the possibility of

[14]Blanchard and Watson (1982) propose formal "run" and "tail" tests to check for bubbles. They suspect, however, that the power of these tests may be quite low. An ingenious specification test for the existence of bubbles by West (1985) was recently brought to my attention.

[15]The model is estimated in first-differenced form to avoid the spurious regression pitfall discussed in Granger and Newbold (1974). Differencing the data also ensures stationarity, a feature which makes use of the usual statistical tests legitimate (see Meese and Singleton 1982). Estimation in first-differenced form means that the coefficient constraints in the first period of, and the period after, a bubble must be adjusted accordingly. To be consistent, we now assume that the error term in equation (2) is a random walk instead of a white noise process.

[16]We also tried $\phi = 0.75\phi^*$ and $\phi = 0.25\phi^*$, but these estimations could not achieve convergence.

TABLE 2

ESTIMATION OF THE BUBBLE-AUGMENTED PORTFOLIO BALANCE MODEL

Country	χ^2	ϕ	ϕ^*	Bubble coefficients $A1$	$A2$	Roots of equation λ_1	λ_2	Durbin h-statistic
Germany	21.89	13.184	1.585[a]	−0.023	0.021[a]	0.224[a]	1.41[a]	0.50
		(1.08)	(3.38)	(1.85)	(2.09)	(5.17)	(9.85)	
France	20.68	496.62[a]	1.844[a]	−0.026[a]	0.018	0.202[a]	1.34[a]	0.58
		(1.79)	(2.59)	(1.71)	(1.62)	(3.69)	(8.66)	
Japan I	12.78	−2.763	9.269	−0.88[a]	0.023	0.051	1.057[a]	2.13
		(0.80)	(1.50)	(5.22)	(1.54)	(1.59)	(26.47)	
Japan II	18.39	3.048	6.096[a]	−0.086[a]	0.024	0.075[a]	1.089[a]	1.54
			(2.02)	(5.05)	(1.62)	(2.21)	(23.08)	

NOTES Japan II is where $\phi = 0.5\ \phi^*$

Degrees of freedom of chi-square for Germany, France, and Japan I is 12, and for Japan II 13.

$\chi^2(12)_{95\%} = 21.0$, $\chi^2(12)_{97.5\%} = 23.3$, $\chi^2(13)_{95\%} = 22.4$, $\chi^2(13)_{97.5\%} = 24.7$

Figures in brackets are absolute values of t-statistics

[a] = t-statistic is significant at 5 percent level, one-tail test.

autocorrelation. The latter is important because autocorrelation may indicate omission of relevant variables.

The one unanimous finding from Table 2 is that the roots of the equation, λ_1 and λ_2, are always of the correct theoretical magnitude, i.e., $0 < \lambda_1 < 1$, $\lambda_2 > 1$. Our estimations do not constrain λ_1 and λ_2 in any way; their values are solely determined by the estimated value of ϕ^*. The statistical significance of λ_1 and λ_2 in every estimation of Germany and France supports our previous statement that the model fits these two countries particularly well. The improved statistical performance of λ_1 in the Japanese model after addition of the restrictions on ϕ lends further support to the imposed restriction.

To assess our hypothesis that the usual poor performance of the portfolio-balance approach is due to the failure to model destabilizing speculation, we propose two tests. The first test is to exclude the possibility of speculative bubbles. We reestimate the model without the bubble terms; see Part A of Table 3. The fact that none of the coefficients are anywhere near statistical significance suggests that the exclusion of destabilizing speculation is a misspecification error.

The second test is to draw a sharp distinction between our stochastic bubble approach and the dummy variable approach. Our theoretical formulation posits that it is the constrained time path of the bubble that makes the empirical specification of the portfolio model correct. The constrained time path performs more than the dummy variable function of accounting for outliers. An estimation of the portfolio model which puts a different dummy variable for the duration of each bubble is a misspecification of the economic process. Our theoretical priors are that this dummy variable approach will give wrong estimates of the structural parameters, ϕ, and ϕ^*. Part B of Table 3 reports the reestimation of the model with dummy variables in place of the constrained bubbles. The estimates of ϕ and ϕ^* are invariably insignificant. This finding supports the position that our speculative bubbles are not ad hoc dummy variables which perform the spurious

TABLE 3

ALTERNATIVE SPECIFICATIONS OF THE PORTFOLIO MODEL

Part A: No Speculative Bubbles

	ϕ	ϕ^*
Germany	2481.55	505.385
	(0.0141)	(0.0141)
France	−376.8	142.331
	(0.103)	(0.108)
Japan: Model I	−13.911	33.492
	(0.362)	(0.391)
Model II	7.902	15.803
		(0.764)

Part B: Use of Dummy Variables instead of Theoretically Constrained Bubbles.

	ϕ	ϕ^*	Dummy for 1978 speculation	Dummy for 1979–80 speculation
Germany	55.933	9.552	−0.058	0.025
	(0.692)	(0.662)	(2.558)	(1.062)
France	−62.323	43.185	−0.061	0.023
	(0.190)	(0.345)	(2.953)	(1.087)
Japan: Model I	−13.651	34.111	−0.093	0.026
	(0.400)	(0.433)	(5.159)	(1.414)
Model II	7.756	15.511	−0.094	0.025
		(0.877)	(4.922)	(1.319)

NOTES: Japan Model II refers to the case where we set $\phi = 0.5\phi^*$

The same priors as in Table 2 are imposed because the same estimation problems were encountered

Figures in brackets are absolute values of t-statistics.

function of improving the fit of the model. The two sets of results in Table 3 together reinforce our view that sustained destabilizing speculations in foreign exchange markets do occur, and that neglect of them in estimation constitutes a serious specification error.

The next criteria we apply to the model is the prediction test. If the estimated model is indeed true, it should outforecast its unconstrained vector autoregression equivalent for all time horizons. The intent here is also to indicate whether the asymptotic theory implicit in the earlier use of test statistics applies. If the model predicts poorly, the preceding hypothesis testing may be invalid. We use the last twenty-four observations in our sample for this purpose. To ensure that the predictions are untainted by future information, we compare the out-of-sample dynamic forecasts of the model with those from its unconstrained VAR equivalent. For robustness of conclusion, we compare the one-, two-, three-, four-, and five-step-ahead forecasts. Table 4 reports the root-mean-squared error (RMSE) and the mean absolute error (MAE) of the simulation exercise.[17] We find that the imposition of the constraints results in lower RMSE and MAE for Germany, France, and Japan.

[17]The statistics refer to errors made in forecasting the level of the exchange rate. The forecast of the level at each date is obtained by summing cumulatively the first-differenced forecasts of the model (or the VAR), and then adding the sum to the exchange rate level of the last period used in the rolling regression that generated these first-differenced forecasts.

TABLE 4.

OUT-OF-SAMPLE DYNAMIC SIMULATION, ROOT-MEAN-SQUARED ERROR (RMSE) AND MEAN ABSOLUTE ERROR (MAE)

	1-month		2-month		3-month		4-month		5-month	
	RMSE	MAE	RMSE	MAE	RMSE	MAE	RMSE	MAE	RMSE	MAE
Germany										
Model	0.03060	0.02628	0.05151	0.04254	0.06106	0.05065	0.06855	0.05568	0.06778	0.05882
Unconstrained VAR	0.03652	0.02758	0.06270	0.04683	0.07779	0.05822	0.08860	0.06559	0.08704	0.06755
France										
Model	0.04002	0.03244	0.06512	0.05487	0.08417	0.07240	0.1070	0.09387	0.1226	0.1039
Unconstrained VAR	0.04279	0.03465	0.06619	0.05694	0.08991	0.08020	0.1129	0.1036	0.1293	0.1161
Japan										
Model I	0.04174	0.03447	0.05801	0.04705	0.06974	0.05908	0.08530	0.07524	0.09847	0.09204
Model II	0.04351	0.03589	0.06161	0.05062	0.07196	0.05891	0.08702	0.07674	0.09941	0.09218
Unconstrained VAR	0.04390	0.03542	0.08654	0.06321	0.11090	0.08803	0.13130	0.1070	0.1412	0.1250

NOTES: Japan: Model I refers to when ϕ, ϕ^* are free parameters; Model II refers to when $\phi = 0.5\,\phi^*$. For Japan, eight estimates did not converge on our first attempt. We did not put any more effort into getting convergence because of the costs involved. So the number of observations for Japan is less than that of Germany and France.

III. DISCUSSION

Table 5 shows the duration and magnitude of the bubbles we found. The longest bubble lasted for five months—June to October 1978—in the German and French bilateral exchange rates with the United States. In October 1978, the German mark was overvalued with respect to its fundamental value by 12 percent, the French franc by 11 percent, and the Japanese yen by 9 percent.

With the benefit of hindsight, we would hazard the thesis that speculative bubbles occur only when there is a change in the fundamentals during a period of great uncertainty in the foreign exchange markets about some political or economic outcomes. This prerequisite atmosphere of uncertainty can be generated by a fortuitous culmination of minor political and economic shocks as well as by a single big shock. The June 1978 bubble was preceded by concern about the short-term economic outlook of the U.S. economy after a prolonged coal strike

TABLE 5

IMPACT OF SPECULATIVE BUBBLES

Part A: The 1978 bubble

	June	July	August	September	October
Germany, DM/$					
Counterfactual, S_F	2.1440	2.1370	2.1188	2.1227	1.9732
Actual, S_A	2.0753	2.0413	1.9865	1.9386	1.7367
$(S_A/S_F)\cdot 100$	96.80	95.52	93.76	91.33	88.02
France, FF/$					
Counterfactual, S_F	4.6596	4.5801	4.6318	4.7070	4.4586
Actual, S_A	4.5015	4.3730	4.3530	4.3310	3.9875
$(S_A/S_F)\cdot 100$	96.61	95.48	93.98	92.01	89.43
Japan, Yen/$					
Counterfactual, S_F					193.387
Actual, S_A					176.000
$(S_A/S_F)\cdot 100$					91.01

Part B: The 1979–80 bubble

	December 1979	January 1980	February	March
Germany, DM/$				
Counterfactual, S_F	1.6820	1.6699	1.6735	1.7913
Actual, S_A	1.7315	1.7394	1.7723	1.9419
$(S_A/S_F)\cdot 100$	102.94	104.16	105.91	108.41
France, FF/$				
Counterfactual, S_F		3.9764	4.0244	4.2931
Actual, S_A		4.0710	4.1533	4.4785
$(S_A/S_F)\cdot 100$		102.38	103.20	104.32

	August 1979	September	October	November
Japan, Yen/$				
Counterfactual, S_F	214.172	217.122	230.8325	241.293
Actual, S_A	220.0	223.3	237.7	248.8
$(S_A/S_F)\cdot 100$	102.72	102.85	102.98	103.11

NOTE: The figures for Japan are computed for the case where $\phi = 0.5\phi^*$.

and the fierce winter weather, the economic program that would emerge after the Bonn summit in July, and the reaction of the Arab countries in OPEC to the Israeli invasion of southern Lebanon. The 1979–80 bubble had as its background the announced OPEC price increases, the reduction in oil supplies caused by the revolution in Iran, rumors of a change in OPEC investment strategy, the unknown effects of the Federal Reserve change in operating procedures, and the forthcoming American response to the Iranian hostage crisis and to the Soviet invasion of Afghanistan.[18]

It must be stressed that while a change in the fundamentals under such uncertain conditions can touch off destabilizing speculation, the subsequent exchange rate movements are not related to the (actual and expected) evolution of these fundamentals. A speculative bubble is a self-fulfilling phenomenon with individual agents expecting to be able to exit before it bursts. Two excerpts from official sources suggest that this may be the case in the 1978 bubble:

> Market participants continued to shift out of dollars, despite an apparent consensus that the dollar was undervalued from a long-run point of view. Almost all market participants commenting in the press or in discussions during the fall of 1978 expected an eventual turnaround of the dollar. Only the timing and duration of the expected recovery were uncertain . . . the continued decline of the dollar had become disorderly and was not justified by fundamental economic conditions.
>
> *Economic Report of the President*, 1979, p. 154.

> By the end of October, . . . the decline of the dollar had clearly been excessive against a number of major currencies . . . and, in view of the prevailing mood and trading conditions in the exchange markets, few expected the dollar's slide to stop on its own. . . .
>
> *Federal Reserve Bulletin*, December 1978, p. 940.

These two quotations also constitute independent evidence in favor of our statistical tests. Since it is reasonable to believe that official observers are at least as well-informed as private participants, these quotations indicate that the slide of the dollar was not caused by wrong expectations of the future values of fundamentals.[19]

IV. CONCLUSION

We have provided what we deem to be reasonable evidence in support of the bubble-augmented portfolio model. The model passes the usual statistical tests, and yields insignificant coefficients whenever the bubble term is misspecified. The model also passes the positive methodology test: the imposition of the model structure on a VAR improves the VAR's predictive performance. As we found only two bubbles after a decade of floating exchange rates, we agree with Fried-

[18]It is events like these which made us choose uncertainty bubbles over risk bubbles. We may form subjective probabilities on the events, but it will not be possible to show that they are rational in the sense that they correspond to objective probabilities either calculated from observed frequencies or generated by the economic model.

[19]See footnote 1.

man's (1953) argument that destabilizing speculation does not constitute the behavioral norm in foreign exchange markets.

We urge a cautious interpretation of our results. Even though the bubble-augmented portfolio model makes the cut empirically, we are wary of appealing to Occam's razor to defend its austere simplicity. Bubbly acceptance of our results is justified only upon confirmation with more sophisticated portfolio specifications which relax some of the two-sided scenario assumptions, explicitly test for different bubble solutions (both rational and 'non-rational'), and use better bond stock data.

APPENDIX: DESCRIPTION OF DATA

Unless otherwise indicated, data is from the July 1983 IFS tape.

All interest rates were divided by 100 to express them in decimal fraction form, and then by 12 to get the monthly rate.

B_{USA}	Total debt (series 88) minus debt held by monetary authorities (series 88aa). Billions of U.S. dollars; end of period. Missing values in series 88 were proxied by simple interpolation.
$B_{Germany}$	Total debt (series 88) minus Federal Bank claims on government (series 12a). Billions of deutsche marks; end of period.
B_{France}	Total debt (series 88) minus Bank of France claims on government (series 12a). Billions of francs; end of period. Missing values in series 88 were proxied by simple interpolation.
B_{Japan}	Total debt denominated in yen (series 88b) minus monetary authorities claims on government (series 12a). Billions of yen; end of period.
r_{USA}	Treasury Bill Rate (series 60c), period average.
$r_{Germany}$	Interbank Deposit Rate (series 60bs), period average.
r_{France}	Interbank Monetary Rate (series 60bs), period average.
r_{Japan}	3-month repurchase agreements, bond-equivalent yield, at or near end of month. Source: various issues of *World Financial Markets*.
$S_{Germany}$	Exchange Rate, deutsche marks per U.S. dollar, end of period (series ae).
S_{France}	Exchange Rate, francs per U.S. dollar, end of period (series ae).
S_{Japan}	Exchange Rate, yen per U.S. dollar, end of period (series ae).

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