IMF WORKING PAPER

WP/90/102

INTERNATIONAL MONETARY FUND

Research Department and Western Hemisphere Department

Structural Models of the Dollar *

Prepared by Charles Adams and Bankim Chadha

Authorized for Distribution by M.P. Dooley and Y. Horiguchi

November 1990

Abstract

This paper addresses several questions about the time series processes followed by dollar exchange rates. The stochastic process for exchange rates implied by structural models and the conditions under which they would be described by random walks are examined. Tests on the univariate time series for dollar exchange rates are undertaken to determine if there is evidence for departures from a random walk. Multivariate tests examine whether longer-run movements in the dollar are linked to those in other economic variables, and whether deviations from these long-run relationships contain information for predicting exchange rate movements.

JEL Classification Numbers:
210, 431

* We would like to thank Robert Corker, Michael Dooley, Morris Goldstein, Yusuke Horiguchi, Reva Krieger, Paul Masson, and Mark Stone for helpful comments.

Table of Contents

	Page
Summary	iii
I. Introduction	1
II. Structural Exchange Rate Models	2
III. Univariate Time Series Tests	12
IV. Multivariate Time Series Tests	23
V. Conclusion	32
References	33
Tables	
1. Flexible Price Monetary Model	5-6
2. Sticky-Price Monetary Model	8-9
3a. Summary Statistics for the log of U.S. Dollar Exchange Rates and Relative Price Levels	14
3b. Correlation of Changes in the log of U.S. Dollar Real and Nominal Exchange Rates	14
4. Test Statistics for the Null Hypothesis of a Unit Root	15
5. Q-Statistics for Sample Autocorrelations in First Differences	17
6. Estimates of $\hat{f}^N(0)$ and their Standard Errors $\hat{\sigma}$, Bilateral Dollar Nominal Exchange Rates	21
7. Estimates of $\hat{f}^N(0)$ and their Standard Errors $\hat{\varphi}$, Bilateral Dollar Real Exchange Rates	22
8. Estimated Order of Integration for Forcing Variables from Dickey-Fuller and Augmented-Dickey-Fuller Tests	26
9. Results for Bivariate Cointegration Tests for Exchange Rates and Other Economic Variables	28
10. Estimates of Error Correction Equation for Nominal Dollar Exchange Rates	31
Charts	
1. Estimates of $\hat{f}^N(0)$ For Bilateral Dollar Nominal Exchange Rates	20a
2. Estimates of $\hat{f}^N(0)$ For Bilateral Dollar Real Exchange Rates	20b
3. (Log of) Actual and Long-Run Value of Nominal Dollar-Japanese Yen Exchange Rate	30a
4. (Log of) Actual and Long-Run Value of Nominal Dollar-Deutsche Mark Exchange Rate	30b
5. (Log of) Actual and Long-Run Value of Nominal Dollar-Canadian Dollar Exchange Rate	30c
6. (Log of) Actual and Long-Run Value of Nominal Dollar-Pound Sterling Exchange Rate	30d

Summary

Despite a large amount of empirical work, the factors behind the substantial nominal and real appreciation of the dollar during the first half of the 1980s and its subsequent depreciation have been difficult to distinguish. Structural exchange rate models have had very limited success in explaining the dollar's movements and have typically exhibited periods of instability. In addition, the forecasts derived from these models, even when based on the actual realized value of the determining variables, have generally been inferior to those implied by a random walk (that is, the best predictor of tomorrow's value is simply today's value).

The stylized fact that has emerged is that the nominal and real exchange rates between the dollar and other major currencies are closely approximated by random walks, implying that exchange rate changes are unpredictable and are expected to be permanent. This approximation to a random walk is seen by some investigators as a natural outcome of efficient financial markets, in which prices reflect all available information. According to others, this finding has strong implications for identifying the kinds of shocks that have moved exchange rates, and the kinds of models that are appropriate for analyzing their behavior.

This paper addresses a number of questions about the time series processes followed by exchange rates over the recent floating-rate period so as to shed light on the factors behind longer-run movements in the dollar. The paper begins by examining the stochastic processes for exchange rates that are implied by several classes of structural exchange rate models and the conditions under which exchange rates would be expected to be described by random walks. Most structural exchange rate models are shown to generate departures from a random walk for exchange rates, suggesting that their close approximation to random walks is something of an anomaly. The univariate time-series properties for dollar exchange rates are then examined to determine if there is evidence suggesting departures from a random walk. While the data reveal some patterns in exchange rate changes, suggesting deviations from a random walk, the deviations are not found to be statistically significant.

Finally, tests are undertaken to determine whether the permanent or longer-run movements in the dollar are linked to long-run movements in the economic variables included in exchange rate models. While most of the forcing variables in structural exchange rate models are found to be characterized by a similar order of non-stationarity as exchange rates, and hence could potentially account for their long-run movements, only a small number of long-run relationships are found. Deviations from these long-run relationships play a small, but limited, role in predicting future exchange rate changes.

I. Introduction

The substantial nominal and real appreciation of the dollar during the first half of the 1980s and its subsequent depreciation after 1985 has been difficult to explain. 1/ According to one interpretation, the dollar's strength in the early 1980s reflected a substantial shift in the U.S. policy mix toward relatively tight monetary policy and large budget deficits that pushed up nominal and real interest rates causing large inflows of capital. Subsequently, as the monetary stance was loosened and the fiscal deficit narrowed, these pressures reversed themselves leading to declines in the dollar. According to another interpretation, changes in the incentives to invest in U.S. real assets in the early 1980s together with political uncertainties and financial deregulation abroad led to a massive but temporary increase in the demand for the dollar during the first half of the 1980s. With the unwinding of these factors in the latter part of the decade, the dollar then reversed its previous gains.

Notwithstanding a large amount of empirical work it has been very difficult to distinguish between these alternative interpretations of the dollar's movements during the 1980s. Most structural exchange rate models have explained only a small proportion of the dollar's movements, and have typically exhibited periods of instability. 2/ Moreover, the building blocks for many of these models including interest rate parity and purchasing power parity, have been shown to have been violated in the 1970s and 1980s.

The empirical regularity that has emerged is that the nominal and real exchange rates of the dollar in terms of other major currencies are closely approximated by random walks, and that forecasts from a random walk outperform those from most structural exchange rate models. 3/ Some investigators see the random walk property of exchange rates as a natural outcome of efficient financial markets in which prices fully reflect all available information. 4/ According to others, the random walk carries strong implications for identifying the kinds of shocks that have driven exchange rates, with the presumption that most of these shocks have been expected to be permanent, and the models that are appropriate for analyzing their behavior. 5/

1/ For a discussion of the dollar's movements during the 1980s, see Obstfeld (1985), and Campbell and Clarida (1987).

2/ See Meese and Rogoff (1983a, b).

3/ See Meese and Rogoff (1983a, b).

4/ Under this interpretation, the condition for market efficiency is taken to imply that exchange rates change unpredictably and hence are described by a random walk.

5/ Under the random walk a given shock permanently changes the level of the exchange rate; it is then expected to remain at this level until another, unanticipated, shock occurs.

This paper addresses a number of questions about the time series processes followed by exchange rates with a view to shedding light on the factors behind the permanent or longer-run movements in the dollar. Rather than estimate a particular structural model, the paper focuses on the stochastic processes for exchange rates implied by wide classes of structural models, and whether the data are consistent with these processes. In addition, using cointegration techniques, the paper examines whether the long-run variance of exchange rates can be accounted for by the economic variables identified in structural exchange rate models.

The paper is organized as follows. Section II discusses the stochastic processes for exchange rates implied by structural exchange rate models and identifies two sources of systematic movement in exchange rates and hence departures from a random walk--those related to predictable movements in forcing variables (extrinsic dynamics) and those related to the internal dynamics of models (intrinsic dynamics). Section III examines the actual time series processes followed by nominal and real exchange rates of the dollar to see if there is evidence of mean reversion and departures from a random walk. Section IV identifies the time series properties of the forcing variables appearing in structural exchange rate models and tests for long-run cointegrating relationships between these variables and dollar exchange rates. Section V provides some concluding remarks.

II. Structural Exchange Rate Models

This section reviews several classes of exchange rate models with a view to identifying the time series processes they predict for exchange rates. The section begins by considering the solutions for exchange rates implied by flexible and fixed price monetary models, and then discusses the dynamic process contained in portfolio models. 1/ Two sources of systematic exchange rate movements are identified: those caused by predictability in the forcing variables included in exchange rate models (extrinsic dynamics) and those due to dynamic adjustment to shocks (intrinsic dynamics).

Monetary models. The monetary models are based on parity conditions linking interest rates on assets denominated in different currencies (equations (1) and (2)); a parity condition linking domestic and foreign prices, with the long-run real exchange rate constant under purchasing power parity (equation (3)); and equilibrium in financial markets, as represented by equality between the stock demands and supplies of domestic

---

1/ For a comprehensive review of exchange rate models, see Obstfeld and Stockman (1985).

and foreign money (equations (4) and (5)). 1/ The monetary models assume residents of each country hold only their own money.

$$R_t = R_t^* + [f_t^{t+1} - s_t] \tag{1}$$

$$R_t = R_t^* + [E_t s_{t+1} - s_t] \tag{2}$$

$$q_t = s_t + p_t^* - p_t \tag{3}$$

$$m_t = p_t + \beta y_t - \alpha R_t \tag{4}$$

$$m_t^* = p_t^* + \beta^* y_t^* - \alpha^* R_t^* \tag{5}$$

Monetary models have been applied in different ways over the recent floating rate period. 2/ In 'flexible-price' applications, the models determine nominal exchange rates on the basis of given values for real variables such as relative outputs and the real exchange rate. 3/ In "sticky-price" applications, equations (1)-(5) describe the long-run behavior of nominal exchange rates, with departures from these relationships in the short run. 4/

Under the assumption of flexible prices, the solution to equations (1)-(5) has a familiar form in which the nominal exchange rate depends on the current and expected future values of its determinants: here, relative money supplies, relative outputs, and the real exchange rate 5/

1/ In equations (1)-(5) all variables with the exception of interest rates are measured in logarithms. Foreign variables are distinguished from domestic variables by an asterisk. m_t, p_t, y_t, and q_t refer to the money stock, prices, output, and the real exchange rate. R_t denotes the interest rate on one period bonds. s_t is the spot exchange rate, measured as the domestic currency price of a unit of the foreign currency; f_t^{t+1} is the one period forward exchange rate. E_t denotes the expectations operator conditional on information in period t.

2/ For an application of these models to floating exchange rates during the 1920s, see Frenkel (1980).

3/ See, for example, Bilson (1978).

4/ For examples, see Dornbusch (1976), Driskill (1981), and Frankel (1979).

5/ Equation (6) can be derived by repeatedly substituting for the expected future spot exchange rate in equations (1)-(5) and using the law of iterated projections. Domestic and foreign money demand parameters are assumed to be equal and current values of variables are in information sets. As is well known, the resulting solution also contains an explosive term which has been set to zero in equation (6). The explosive term is sometimes associated with speculative bubbles in which self-fulfilling expectations rather than fundamentals determine exchange rates. For a justification for setting this term to zero, see Mussa (1976).

$$s_t = \frac{1}{(1+\alpha)} \sum_{i=0}^{\infty} E_t \left[\frac{\alpha}{(1+\alpha)}\right]^i \cdot \left[(m_{t+i} - m^*_{t+i}) - \beta(y_{t+i} - y^*_{t+i}) + q_{t+i} \right] . \qquad (6)$$

The significance of events in the future in equation (6) is determined by the size of the discount factor $\alpha/(1 + \alpha)$, which depends on the (semi-interest) elasticity of money demand. If the elasticity of money demand is very high, events expected far into the future have almost the same weight as those in the present.

The forward-looking nature of equation (6) does not mean that exchange rates should be entirely unpredictable and follow driftless random walks (or martingales), conditions that are sometimes regarded as an implication of market efficiency. 1/ The only efficiency conditions in the monetary model relate to the forward exchange market and imply that forward exchange rates should be unbiased predictors of expected future spot exchange rates. Given the assumption that residents in each country only hold their own money, there is no efficiency condition for the spot exchange market and exchange rates can be characterized by systematic movements in the monetary model.

The amount of systematic exchange rate movement in the flexible-price model is determined by the size of the (semi) interest elasticity of money demand and the systematic movement in the forcing variables. Table 1 shows the solutions for the nominal exchange in the flexible-price model under alternative assumptions about the stochastic processes for relative money supplies, including those with inter-temporally correlated components. 2/ Interpretation of the solutions is facilitated by decomposing the change in the nominal exchange rate between any two periods into a component that is unpredictable as of period t-1 (unsystematic component) and a component that is predictable (systematic component) 3/

$$s_t - s_{t-1} = (s_t - E_{t-1}s_t) + (E_{t-1}s_t - s_{t-1}) . \qquad (7)$$

Given that there are no intrinsic dynamics in the flexible-price monetary models, systematic exchange rate movements only occur when there are predictable elements in the forcing variables. The most obvious

---

1/ For further elaboration, see Levich (1979).

2/ The solutions are based on Adams and Boyer (1987), and are derived by substituting given stochastic processes for money supplies into equation (6) and taking expectations conditional on information available at time t.

3/ The systematic component--the expected change in the exchange rate--is, of course, equal to the nominal interest rate differential. Several empirical studies have used equations like (7) to model the exchange rate in "news" form. See, for example, Isard (1980). Of course, given that the exchange rate is viewed as close to a random walk, most exchange rate changes are unpredictable.

Table 1. Flexible Price Monetary Model

General Solution

$$s_t = \frac{1}{(1+\alpha)} \sum_{i=0}^{\infty} E_t \left[\frac{\alpha}{(1+\alpha)}\right]^i \cdot \left[(m_{t+i} - m^*_{t+i}) - \beta(y_{t+i} - y^*_{t+i}) + q_{t+i} \right]$$

In what follows it is assumed that

$$y_{t+i} - y^*_{t+i} = q_{t+i} = 0 \text{ for all } i.$$

Case I: Money supplies follow random walks around random trends. (Money Supplies are I(2) processes.)

$$m_t = m_{t-1} + g_t + d_t \qquad m^*_t = m^*_{t-1} + g^*_t + d^*_t$$

$$g_t = g_{t-1} + k_t \qquad g^*_t = g^*_{t-1} + k^*_t$$

where d_t, d^*_t, k_t, k^*_t are white noise errors.

$$s_t = (m_{t-1} - m^*_{t-1}) + (d_t - d^*_t) + (1 + \alpha)(g_{t-1} - g^*_{t-1}) + (1 + \alpha)(k_t - k^*_t)$$

$$E_t s_{t+i} = (m_{t-1} - m^*_{t-1}) + (d_t - d^*_t) + (i+1+\alpha)(g_{t-1} - g^*_{t-1}) + (i+1+\alpha)(k_t - k^*_t)$$

$$E_t s_{t+1} - s_t = (g_{t-1} - g^*_{t-1}) + (k_t - k^*_t)$$

Case II: Money supplies are subject to temporary and permanent shocks. (Money supplies are I(1) processes.)

$$m_t = \bar{m}_t + v_t \qquad m^*_t = \bar{m}^*_t + v^*_t$$

$$\bar{m}_t = \bar{m}_{t-1} + \mu_t \qquad \bar{m}^*_t = \bar{m}^*_{t-1} + \mu^*_t$$

where v_t, v^*_t, μ_t, μ^*_t are white noise errors.

$$s_t = (\bar{m}_{t-1} - \bar{m}^*_{t-1}) + (\mu_t - \mu^*_t) + (1 + \alpha)^{-1}(v_t - v^*_t)$$

$$E_t s_{t+i} = (\bar{m}_{t-1} - \bar{m}^*_{t-1}) + (\mu_t - \mu^*_t)$$

$$E_t s_{t+1} - s_t = - (1 + \alpha)^{-1}(v_t - v^*_t)$$

Table 1. Flexible Price Monetary Model (Concluded)

Case III: Money supplies are subject to intertemporally correlated shocks. (Money supplies are I(0) processes.)

$m_t = \bar{m} + v_t$ $\qquad$ $m_t^* = \bar{m}^* + v_t^*$

$v_t = \rho v_{t-1} + \Sigma_t$ $\qquad$ $v_t^* = \rho v_{t-1}^* + \Sigma_t^*$

$\rho \in (0,1)$ $\qquad$ $\rho \in (0,1)$

where v_t, v_t^*, Σ_t, Σ_t^* are white noise errors.

$$s_t = (\bar{m} - \bar{m}^*) + \lambda(v_t - v_t^*)$$

$$E_t s_{t+i} = (\bar{m} - \bar{m}^*) + \lambda\rho^i(v_t - v_t^*)$$

where $\lambda = [1 + \alpha(1 - \rho)]^{-1}$

$$E_t s_{t+1} - s_t = \lambda(\rho - 1)(v_t - v_t^*)$$

Note:

For each money supply process the systematic (or predictable) change in the exchange rate over the next period is given by

$$(E_t s_{t+1} - s_t)$$

source of systematic movements arises from differences in monetary growth rates across countries: countries with faster monetary growth rates will tend to have continuously depreciating currencies (Table 1). 1/ But systematic movement can also be the result of temporary or intertemporally correlated shocks to money supplies. 2/ For example, a temporary increase in the domestic money supply will lead to a temporary depreciation of the domestic currency, followed by expectations of appreciation. The only case in which the nominal exchange rate follows a driftless random walk in the flexible-price model is when the forcing variables are described by driftless random walks. 3/

The solutions in Table 1 also imply that any nonstationarity in nominal exchange rates derives from nonstationarity in the forcing variables. In each solution, the order of integration of the exchange rate matches that of the money supply process. 4/ If, for example, relative money supplies are integrated of order two, exchange rates have the same order of integration. The real exchange rate is exogenous in this version of the flexible-price monetary model. If purchasing power parity holds in the long run, the real exchange rate will be a stationary variable. However, if there are permanent real shocks, such as changes in tastes or productivity, it will be nonstationary.

An important extension of the monetary model allows for short-run price rigidities. In an early paper Dornbusch(1976) modified the flexible-price monetary model to allow for price stickiness and attempted to rationalize the high degree of volatility in nominal exchange rates over the floating rate period. The major features of Dornbusch's sticky-price model are illustrated in Table 2 using a simple stochastic model that includes a Phillip's curve and an aggregate demand equation. 5/ Solutions to the model are shown for the case in which the domestic money supply follows a first-order auto-regressive process and all other forcing

---

1/ Predictable differences in monetary growth rates show up as a nonzero drift in the stochastic process for the nominal exchange rate. Essentially the drift in the relative money supply process is translated into a drift in the exchange rate process.

2/ In these cases, the predictable components in the processes for relative money supplies lead to serial correlation in the stochastic process for the nominal exchange rate.

3/ In this case, not only are exchange rate changes unpredictable from their own history (the characteristic of a random walk) they also cannot be predicted from the history of other variables in agents information sets.

4/ In general a variable is said to be integrated of order n, denoted ~ I(n), if it needs to be differenced n times to obtain a stationary variable.

5/ Problems with the particular price adjustment rule employed in the Dornbusch model are discussed by Obstfeld and Rogoff(1984). For a discrete-time rational staggered prices model in the Dornbusch tradition see Chadha(1987).

Table 2. Sticky-Price Monetary Model

$$m_t - p_t = \beta\bar{y}_t - \alpha R_t$$

$$R_t = R_t^* + E_t s_{t+1} - s_t$$

$$p_{t+1} = p_t + \pi(y_t - \bar{y}_t)$$

$$y_t = \theta(s_t - p_t) \qquad p_t^* = 0$$

General solution

$$(s_t - p_t) = \frac{(\lambda_1 - 1)}{\pi\theta} p_t + \frac{(\lambda_1 - \lambda_2)}{\pi\theta} \sum_{i=0}^{\infty} \lambda_2^{-(i+1)} \Omega E_t(z_{t-1+i})$$

$$p_t = \lambda_1 p_{t-1} - \pi\bar{y}_{t-1} + (\lambda_1 - \lambda_2) \sum_{i=0}^{\infty} \lambda_2^{-(i+1)} \Omega E_t(z_{t-1+i})$$

Here, λ_1 and λ_2 are the eigenvalues given by

$$\lambda_1 = 1 - \frac{\pi\theta}{2} - \frac{1}{2}\left[(\pi\theta)^2 + 4\theta\pi\alpha^{-1}\right]^{1/2}$$

$$\lambda_2 = 1 - \frac{\pi\theta}{2} + \frac{1}{2}\left[(\pi\theta)^2 + 4\theta\pi\alpha^{-1}\right]^{1/2}$$

so that $\lambda_2 > \lambda_1$. It is assumed that λ_1 lies inside the unit circle and that λ_2 lies outside it. z_t is the vector given by

$$z_t = [m_t, R_t^*, \bar{y}_t]$$

and Ω is a coefficient vector given by

$$\Omega = \left[\frac{-\pi\theta\alpha^{-1}}{\lambda_2 - \lambda_1}, \frac{\pi\theta}{\lambda_2 - \lambda_1}, \frac{\pi[\theta(\alpha^{-1}\beta + \pi) - (1 - \lambda_1)}{\lambda_2 - \lambda_1}\right]$$

Table 2. Sticky-Price Monetary Model (Concluded)

The particular solution when the money supply follows an AR1 process is given below:

$$m_t = \rho m_{t-1} + \mu_t \qquad \text{where } \mu_t \text{ is white noise.}$$

$$R^*_t = 0$$

$$\bar{y}_t = 0$$

When $\rho \in (0,1)$, m_t follow a stationary stochastic process. When $\rho = 1$, m_t follows a random walk.

$$(s_t - p_t) = \frac{(\lambda_1 - 1)}{\pi\theta} p_t + \frac{\alpha^{-1}}{\lambda_2 - \rho} m_t$$

$$p_t = \lambda_1 p_{t-1} + \frac{\pi\theta\alpha^{-1}}{\lambda_2 - \rho} m_{t-1}$$

$$s_t = \frac{(\lambda_1 - 1)}{\pi\theta} p_t + \lambda_1 p_{t-1} + \alpha^{-1} \frac{(\rho + \pi\theta)}{\lambda_2 - \rho} m_{t-1} + \frac{\alpha^{-1}}{\lambda_2 - \rho} \mu_t$$

variables are constant. 1/ In contrast to the flexible-price model, the Dornbusch model includes intrinsic dynamics associated with slowly adjusting commodity prices.

The solutions to the sticky-price model presented in Table 2 have two important implications for short-run exchange rate behavior. The first is that nominal and real exchange rates may overshoot in response to innovations in the money supply. A sufficient condition for nominal exchange rate overshooting in the model presented in Table 2 is that the money supply follows a random walk so that all changes in the money supply are expected to be permanent. 2/ The second implication is that there can be predictable nominal and real exchange rate movements associated with the slow adjustment of commodity prices. These can arise with the money supply itself following a random walk (with $\rho = 1$ in Table 2), implying that deviations of the exchange rate from a random walk occur even if forcing variables are entirely unpredictable, and reflect the intrinsic dynamics of the model.

If purchasing power parity is assumed to hold in the long run, the real exchange rate is a stationary variable in the sticky-price model. It will, however, be closely correlated with the nominal exchange rate in the short run and display predictable movements. If there are permanent real shocks, changing for example the level of potential output, the real exchange rate will be nonstationary in this model.

Given the potential importance of real shocks for exchange rates, the flexible-price monetary model has been adapted to allow a more explicit role for real factors, giving rise to inter-temporal equilibrium models in which nominal and real exchange rates are simultaneously determined. 3/ These applications continue to assume price flexibility but allow for shocks such as productivity improvements or increases in real government spending to explicitly influence nominal and real exchange rates. In addition, the models include intrinsic dynamics associated with factors such as slow adjustment of investment spending and inter-temporal labor substitution.

Portfolio models. The key assumptions of the portfolio models are that (interest-earning) assets denominated in different currencies are imperfect substitutes and residents of each country have a preference at

---

1/ To make the model in Table 2 consistent with Dornbusch's original model, it is assumed in addition that the demand for money depends on capacity rather than current output. This assumption simplifies the solutions presented in Table 2 but does not qualitatively change the conclusions.

2/ For generalized money supply processes, overshooting of nominal exchange rates need not occur. For further discussion, see Obstfeld and Stockman (1985).

3/ For example, see Stockman (1980), and Stockman (1983).

the margin for assets denominated in their own currencies. 1/ An important source of systematic movement in nominal and real exchange rates in these models derives from intrinsic dynamics associated with current account imbalances. When residents of a country have a preference at the margin for their own commodities and assets, countries with current account surpluses may have continually appreciating real and nominal exchange rates due to the need to offset incipient excess demands for domestic assets and goods. 2/ More generally, these models suggest that nominal exchange rates will depend on the accumulation of outside domestic assets (money and bonds) and (net) foreign bonds. Given that outside domestic assets are created through the fiscal balance while (net) foreign assets are acquired by running current account surpluses, the models imply that the evolution of the exchange rate may be associated with fiscal and current account balances. The stochastic processes nominal and real exchange rates follow then depend on the stochastic processes describing asset supplies--money, public interest-bearing debt, and foreign assets, as well as the intrinsic dynamics of the models. 3/

Neither the monetary nor portfolio models reviewed in this section implies that nominal or real exchange rates should be characterized by random walks. Predictable movements in exchange rates can arise either from extrinsic dynamics in the forcing variables or from intrinsic dynamics that spread the adjustment to shocks over time. If purchasing power parity is assumed to hold in the long run, real exchange rates will display predictable fluctuations around a fixed mean. But if allowance is made for permanent real shocks, such as changes in tastes or technology, real exchange rates will be nonstationary. The stochastic process for nominal exchange rates also displays predictable movements in these models which can either be around a fixed or a varying mean, depending on the processes followed by forcing variables. Differences in monetary policy across countries are one reason why nominal exchange rates might be nonstationary. Divergences in fiscal policy as well as current account imbalances are another potential source of nonstationarity. Both nominal

---

1/ For a review of these models, see Frenkel and Mussa (1985), and Branson and Henderson (1985). See also Branson (1977), and Branson, Halttunen and Masson (1977), and Frankel (1984).

2/ For further discussion of these mechanisms which do not imply that there will in general be an unambiguous relationship between current account imbalances and exchange rates, see Kouri (1976), and Dornbusch and Fischer (1980).

3/ The portfolio models have been extended in numerous directions in the exchange rate literature. Major extensions include: the incorporation of additional assets into the models including claims on physical capital, and the differentiation of assets not just by currency of denomination but also by country of issuer. See Dooley and Isard (1983), and Dooley and Isard (1986).

and real exchange rates are expected therefore to deviate from random walks on the basis of standard exchange rate models. 1/

The only models that predict a (driftless) random walk for nominal or real exchange rates, regardless of the stochastic process describing forcing variables, are the currency substitution and financial arbitrage models. Neither of these models, however, appears to have found its way into the mainstream of structural exchange rate models. In currency substitution models, the requirement that the expected pecuniary returns from holding domestic and foreign monies be equal when monies are perfect substitutes implies that the change in the nominal exchange rate should be unpredictable. 2/ In financial arbitrage models, the equalization of expected real interest rates on domestic and foreign bonds is interpreted as requiring that the expected change in the real exchange rate be unpredictable. 3/ It is unclear, however, why real interest rates measured in terms of different consumption baskets should be equalized, suggesting that the financial arbitrage models may not provide a firm basis for expecting real exchange rate changes to be entirely unpredictable.

III. Univariate Time Series Tests

This section presents evidence on the time series processes followed by nominal and real exchange rates of the dollar in terms of other major currencies. 4/ After briefly examining measures of the variability of dollar exchange rates over the recent floating rate period, the section presents standard tests for the stationarity of exchange rates and departures from a random walk. This is then followed by the application of new and more powerful tests intended to detect evidence of mean reversion in exchange rates over long periods. 5/

An examination of the time series processes followed by exchange rates is useful for a number of reasons. First, in the absence of speculative bubbles, any nonstationarity in exchange rates must ultimately be determined by nonstationarity in the forcing variables appearing in structural exchange rate models. Explaining the long-run behavior of exchange rates then requires identifying other economic variables with similar orders of nonstationarity. Second, particular processes such as

---

1/ Mussa (1984), has argued that standard estimates of the interest elasticity of money demand imply that the predictable component of exchange rates should be small (but not zero). The relative size of this component, however, depends also on the relative magnitude of unanticipated, shocks which is an empirical question.

2/ See Adams and Boyer (1987).

3/ See Adler and Lehman (1983). See also Roll (1979).

4/ For background material on the empirical regularities under floating exchange rates see Mussa (1979, 1986).

5/ Some of these recent techniques have been applied to real exchange rates. See Huizinga (1987), and Kaminsky (1987).

the random walk are frequently regarded as carrying strong implications for the shocks that have driven exchange rates, and the economic models that are appropriate for analyzing their behavior. If one is to view the exchange rate as an equilibrium exchange rate, then the random walk property implies that all shocks driving them must be permanent. 1/ Further, for the real exchange rate such a finding argues for the prevalence of real rather than nominal shocks, since the latter would be expected to have only transitory effects. As noted earlier, moreover, the random walk finding argues against the applicability of models--such as the sticky-price monetary model of Dornbusch(1976)--that ascribe a major role to short-run disequilibrium dynamics, since such dynamics induce systematic movements in exchange rates. Third, specific hypotheses such as purchasing power parity can be tested by looking for evidence of mean reversion in real exchange rates. 2/

The data series for the study comprise the four bilateral spot exchange rates between the U.S. dollar and the deutsche mark, Japanese yen, pound sterling, and Canadian dollar. In order to ensure comparability with other studies, real exchange rates are measured using consumer prices. The data are sampled quarterly over the period 1974:1 through 1989:4 and are taken from International Financial Statistics.

Before applying the statistical tests, it is useful to consider some summary statistics for the data series. Confirming the view that exchange rates behave like asset prices, Tables 3a and 3b show that the variance of quarterly changes in nominal exchange rates has been considerably larger than that in relative consumer prices. 3/ For some bilateral rates, it is almost 75 times the variance of changes in commodity prices. As a result, the variance of changes in the real exchange rate is dominated by that of changes in the nominal exchange rate. In fact, the variance of changes in real and nominal exchange rates are essentially equal, and there is almost perfect contemporaneous correlation between them. 4/ The table also shows that while there is some evidence of drift in exchange rates, in no case is it statistically significant.

The first set of tests we apply are for unit-root nonstationarity in the time series processes for nominal and real exchange rates and relative prices (Table 4). 5/ As was noted earlier, none of the structural

---

1/ See Stockman (1983), Campbell and Clarida (1987), and Kaminsky (1987).
2/ For tests on individual goods prices, see Isard (1987).
3/ For a discussion of the variability of exchange rates relative to other asset prices, see Frenkel and Mussa (1980).
4/ This finding has been emphasized by Mussa (1979).
5/ The Dickey-Fuller tests reported in the table are based on regressing the first difference of each series on its own lagged value, and testing whether the coefficient on the lagged value is statistically different from zero. In the case of the augmented Dickey-Fuller tests, lagged first differences of the variable are also included in the regression. The reported test statistics have non-standard distributions, requiring critical values tabulated by Dickey and Fuller (1979, 1981).

Table 3a. Summary Statistics for the Log of U.S. Dollar Exchange Rates and Relative Price Levels
Quarterly, 1974:1 to 1989:4

	Levels	First Differences		
	Standard deviation	Mean	t-statistic for mean	Standard deviation
Spot rate, s^X				
X = UK	0.186	-0.00634	-0.91	0.0556
GR	0.173	0.00629	0.81	0.0618
CA	0.107	-0.00277	-0.99	0.0222
JA	0.268	0.01039	1.35	0.0609
Relative Price level, $p^X - p^{US}$				
X = UK	0.137	0.00867	4.68	0.0147
GR	0.143	-0.00740	-7.79	0.0075
CA	0.045	0.00213	2.84	0.0060
JA	0.128	-0.00480	-3.74	0.0102
Real exchange rate, q^X				
X = UK	0.143	0.00232	0.33	0.0552
GR	0.189	-0.00111	-0.14	0.0618
CA	0.080	-0.00064	-0.23	0.0219
JA	0.192	0.00559	0.71	0.0628

Table 3b. Correlation of Changes in U.S. Dollar Real and Nominal Exchange Rates
Quarterly, 1974:1 to 1989:4

Lag length 1/	0	1	2	3	4	5	6
UK	0.97	0.21	-0.11	0.16	0.16	-0.19	0.04
GR	0.99	0.17	-0.10	0.11	0.18	0.06	-0.13
CA	0.96	0.09	-0.06	0.17	0.00	0.01	0.23
JA	0.99	0.18	0.06	0.03	0.00	-0.19	-0.15

1/ The reported correlations are between contemporaneous values of the first difference of real exchange rate and 0 to 8 lags of the first difference of nominal exchange rates.

Table 4. Test Statistics for the Null Hypothesis of a Unit Root 1/
Quarterly, 1974:1 to 1989:4

	Dickey-Fuller Statistic	Augmented Dickey-Fuller Statistic 2/	Durbin-Watson 3/
Spot rate, s^X			
X = UK	-1.58	-1.75	1.94
GR	-1.04	-1.43	1.95
CA	-1.81	-1.76	1.97
JA	-0.52	-1.13	2.02
Relative price levels, $p^X - p^{US}$			
X = UK	-5.50***	-4.60***	2.09
GR	-2.24	-0.96	2.07
CA	-0.78	-1.33	2.04
JA	1.51	-0.36	2.18
Real exchange rates, q^X			
X = UK	-1.48	-1.60	1.91
GR	-1.25	-1.37	1.94
CA	-1.36	-1.39	2.00
JA	-1.18	-1.79	2.03
Critical values 4/			
1%***	-4.07	-3.77	
5%**	-3.37	-3.17	
10%*	-3.03	-2.84	

1/ All regressions include a constant and three seasonals.
2/ Regression includes two lags.
3/ For residuals from the augmented Dickey-Fuller regression.
4/ See Hall and Henry (1988).

exchange rate models carries strong predictions as to whether we would expect to find stationarity in nominal exchange rates, with the issue an empirical one. Differences in monetary growth rates across countries as well as current account imbalances, however, suggest that it is quite likely nominal exchange rates will be nonstationary. Whether real exchange rates would be expected to be stationary is also an empirical question. Only in the case of models built on purchasing power parity is there a presumption that real exchange rates will be stationary.

Based on the test statistics recorded in Table 4, the null hypothesis of a unit root cannot be rejected for any nominal or real exchange rate. Given that movements of the real exchange rate are dominated by those of the nominal exchange rate, we also examined whether the nonstationarity in real exchange rates reflected a single source of nonstationarity in nominal exchange rates. Accordingly, we performed unit root tests on the relative price series separately. These tests were unable to reject the null hypothesis of nonstationarity in relative prices with the exception of those for the United Kingdom. Overall, the results are consistent with non-stationarity in the bilateral nominal and real exchange rates of the dollar with the yen, deutsche mark, and Canadian dollar. Only in the case of the real exchange rate with the United Kingdom is there some ambiguity, with tests on the price component of the real exchange rate suggesting that nonstationarity in the real rate derives only from nonstationarity in the nominal exchange rate.

An inability to reject unit root nonstationarity in real and nominal exchange rates does not imply that exchange rates have no predictable components. Even when these series have unit roots, the changes in these series could be serially correlated implying that the history of each series would contain information for predicting its future. 1/ In addition, the series could be described by drift. The next set of tests are for the null hypothesis that exchange rates follow random walks. 2/ As indicated earlier, most exchange rate models do not predict that exchange rates will follow random walks except under very special conditions. Essentially all the forcing variables must follow random walks and there must be no intrinsic dynamics associated with factors such as sticky prices and asset accumulation.

The tests presented in Table 5 are for the null hypothesis that each series (with the exception of relative prices with the United Kingdom 3/)

1/ A random walk is a special case of a unit root process in which the error term is white noise. Unfortunately, the use of the term unit root to describe first-difference stationarity has lead to some confusion.

2/ Prior to these tests, we checked to see whether drift terms were significantly different to zero (see also Table 3). In no case could we reject the null hypothesis of zero drift.

3/ These were found to be stationary (see Table 3).

Table 5. Q - Statistic for Sample Autocorrelations in First Differences 1/ 2/
Quarterly, 1974:1 to 1989:4

	20 lags	40 lags
Spot rate, s^X		
X = UK	45.96**	73.61**
GR	23.68	46.44
CA	23.67	41.17
JA	27.13	52.28
Relative Price levels, $p^X - p^{US}$		
X = GR	137.96**	145.61**
CA	92.67**	104.82**
JA	175.45**	201.16**
Real exchange rates, q^X		
X = UK	40.38**	65.60**
GR	21.31	42.96
CA	22.21	46.97
JA	27.67	54.51
Critical value 5% **	31.41	55.75

1/ The Ljung-Box Q-statistic is constructed as

$$Q(N) = T(T+2) \sum_{j=1}^{N} \frac{1}{N-j} \hat{\rho}_j^2$$

where T is the number of observations, N the number of lags employed and $\hat{\rho}_j$ is the estimated autocorrelation coefficient at lag j. Q(N) is distributed approximately as a chi-square with N degrees of freedom.

2/ All first differences were first regressed on a constant and three seasonals, and the Q-statistic was then computed for the residuals.

is a random walk, under the maintained hypothesis that each series has a unit root. 1/ They are based on the autocorrelations of the first difference of each series and testing whether these sample autocorrelations are statistically different from zero. 2/ When these autocorrelations are significantly different from zero, changes in the variable are judged to have systematic components, and the null hypothesis of a random walk is rejected. 3/ According to these tests, the null hypothesis of a random walk cannot be rejected for any bilateral exchange rate, with the exception of that with the pound sterling. In all reported cases, however, there is strong and statistically significant evidence against a random walk in relative price levels. Although relative prices are nonstationary, they appear to have strong systematic components that are easily detected by the statistical tests. 4/

The results from these tests suggest that in all cases other than the bilateral rates with the United Kingdom, nominal and real exchange rates are indistinguishable from a random walk. This is the case even though there is evidence suggesting systematic movements in relative prices. The failure to reject the hypothesis that the real exchange rate follows a random walk reflects the fact that the time series properties of relative prices are swamped by those of nominal exchange rates.

Given the potential importance of a random walk in nominal and real exchange rates, the next set of tests attempt to determine whether there is any evidence of departures from a random walk in the long run. The central advantage of the tests is that--by focusing on the longer-run components of the data--they should be able to detect small and slowly evolving deviations from a random walk. The tests thus address the problem that while exchange rates may not be exactly described by random walks they may be sufficiently close to be indistinguishable in the short run. The use of long-run data has to be weighed, of course, against the small number of observations at long lags. Nevertheless, the tests have been applied with some success in measuring the size of the unit root component in real GNP and in stock prices, and some investigators have applied the tests to measuring the permanent component of real exchange rates. 5/

1/ See Table 4.

2/ The test statistic is the Q-statistic described in Table 5.

3/ In addition to having a white-noise error term, a random walk has a fixed distribution over time. In practice there is evidence consistent with the variance of exchange rate changes changing over time (heteroskedasticity). For further details, see Hodrick (1987).

4/ Since the random walk hypothesis is decisively rejected for relative price levels we fitted low order ARMAs to relative price changes. Most satisfactory estimate were obtained for an AR(1) process with a constant.

5/ See Cochrane (1986), and Fama and French (1986). Huizinga (1987) and Kaminsky (1987) have applied them to real exchange rates.

The tests are based on estimating the ratio of 2π times the spectral density of the first differences of a series at frequency zero, to the variance of its first differences. This ratio or 'normalized' density can be written in terms of the autocorrelations of the series as

$$f(0) = 1 + 2 \sum_{i=1}^{\infty} \rho_i \ , \qquad (8)$$

where ρ_i is the autocorrelation at lag i of the first difference of the series. The spectral density cannot become negative by construction, and can assume any positive value or zero. When the spectral density exceeds one in value there is a preponderance of positive correlations, and conversely when it is below one negative correlations dominate.

There are two values of the spectral density function that are of particular interest. One arises when a series follows a random walk, and all the autocorrelations of the first differences are zero. In this case the spectral density will equal unity, suggesting that departures from a value of unity can be used to detect deviations from a random walk. 1/ The other arises when the level of a series follows any stationary stochastic process. The spectral density in this case will be zero, implying that the statistic can also be used to detect mean reversion and stationarity. 2/

Estimation of the spectral density requires estimates of the autocorrelation parameters at different numbers of lags. Ideally, the number of lags should be large enough to pick up mean reversion over very long periods, but this has to be weighed against the small number of observations at long lags. In what follows we work with a maximum lag length of 44 quarters, that is 11 years. Given a finite number of autocorrelations, the estimates are based on constructing the statistic

$$f(0) = 1 + 2 \sum_{j=1}^{n} w(n,j) \cdot \hat{\rho}_j ,$$

where n denotes the number of autocorrelations and w(n,j) represent a set of weights given by

$$w(n,j) = (n+1-j)/(n+1).$$

1/ For further details, see Huizinga (1987).

2/ For example consider a white noise process. Then its first difference will be a moving average process of order one, so that $\rho_1 = -0.5$ in equation (8), while all other ρ_is are zero, and therefore $f(0) = 0$.

Use of these weight has the effect of giving smaller weight to autocorrelations at long lags. For further details, see Huizinga (1987).

The estimates of the spectral density function are presented in Charts 1 and 2. There are a number of rather interesting features of the estimates. First, reflecting the high correlation between nominal and real exchange rates, the estimates of the spectral density functions are essentially the same for nominal and real exchange rates. Second, all exchange rates with the exception of those with the Canadian dollar show a distinct hump-shaped pattern, with the spectral density first rising above unity and then falling below it. This pattern implies a preponderance of positive correlations at short lags and negative correlations at long lags, and suggests that exchange rate changes in the short run tend to be reinforced, while in the long run they tend to be reversed.

The possibility of positive autocorrelation in short-run exchange rate changes was noted by Mussa (1979) in his characterization of empirical regularities under floating exchange rates. Mussa suggested that such correlations were consistent with bandwagon effects in exchange markets, whereby once a rate started moving in a certain direction speculators would move it further. More recently, it has been suggested that the correlations may reflect very short-term bubbles in exchange markets. 1/ The preponderance of negative correlations at long lags, on the other hand, suggests mean reversion in nominal and real exchange rates over very long periods. 2/ The exceptions are the Canadian dollar exchange rates where the finding of values for the spectral density above unity at short and long lags suggests a dominance of positive autocorrelations and no evidence of mean reversion.

Given the spectral density function declines below one, the results suggest that there is evidence for mean reversion over the long run for three of the four exchange rates examined. As such there may be grounds for believing that the apparent random walk in nominal and real exchange rates is masking a rather slow adjustment process, and that the use of observations at long lags allows the random walk to be rejected. Somewhat interestingly, the results suggest that there is mean reversion in both nominal and real rates. As far as we know, the possibility of nominal rates being stationary has not been noted in the literature. Taken literally, stationarity in nominal rates implies the absence of any permanent differences in nominal shocks across countries.

There is, however, a rather basic difficulty in establishing the statistical significance of the deviations of f(0) from unity as is evident from Tables 6-7 which present (two) standard errors for the

---

1/ See Kaminsky (1987).

2/ These findings are also consistent with the evidence from survey studies of exchange market expectations. For a recent survey of this evidence, see Takagi (1990).

Chart 1. Estimates of f(0) for bilateral dollar nominal exchange rates with the United Kingdom, Germany, Canada, and Japan.

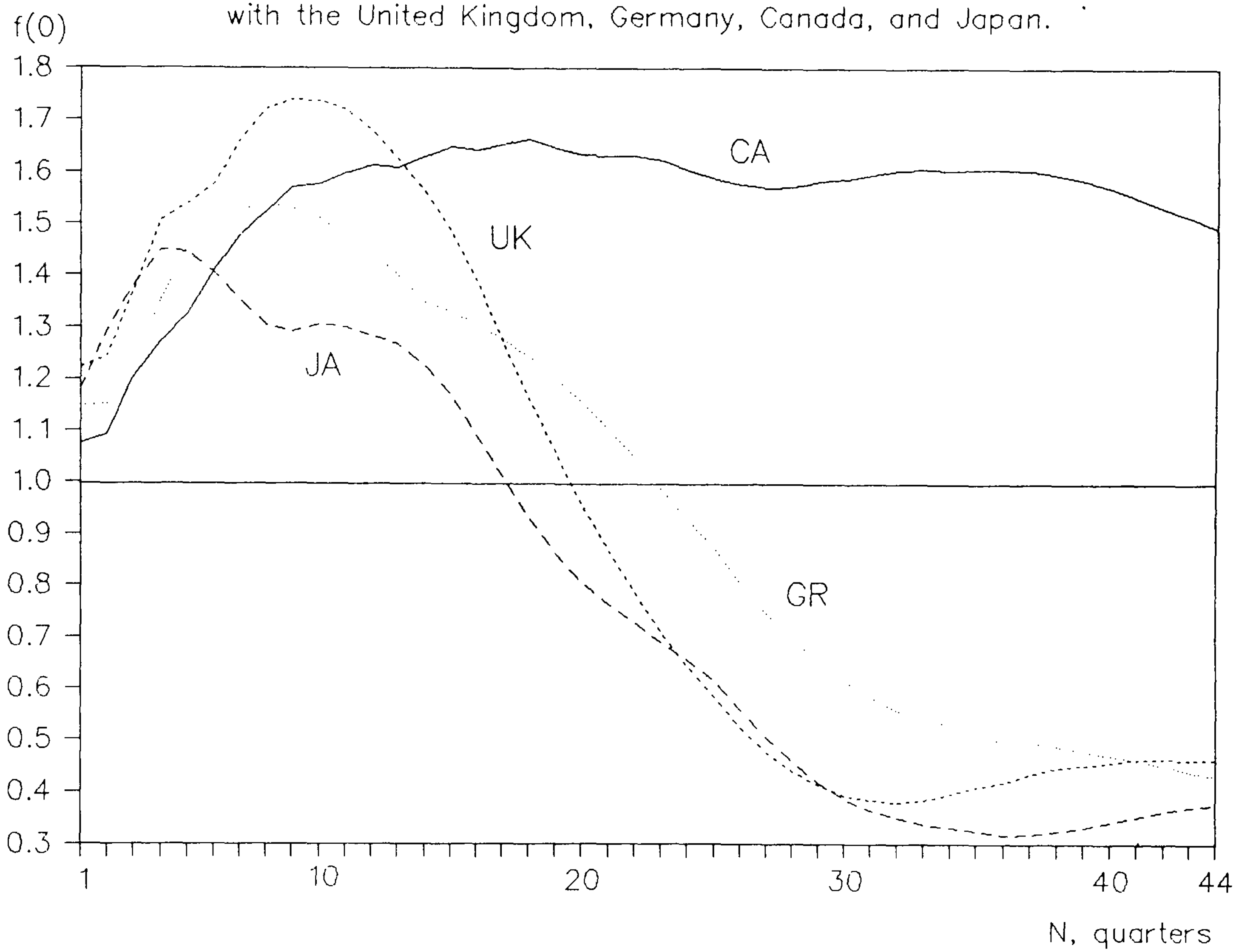

Chart 2. Estimates of f(0) for bilateral dollar real exchange rates with the United Kingdom, Germany, Canada, and Japan.

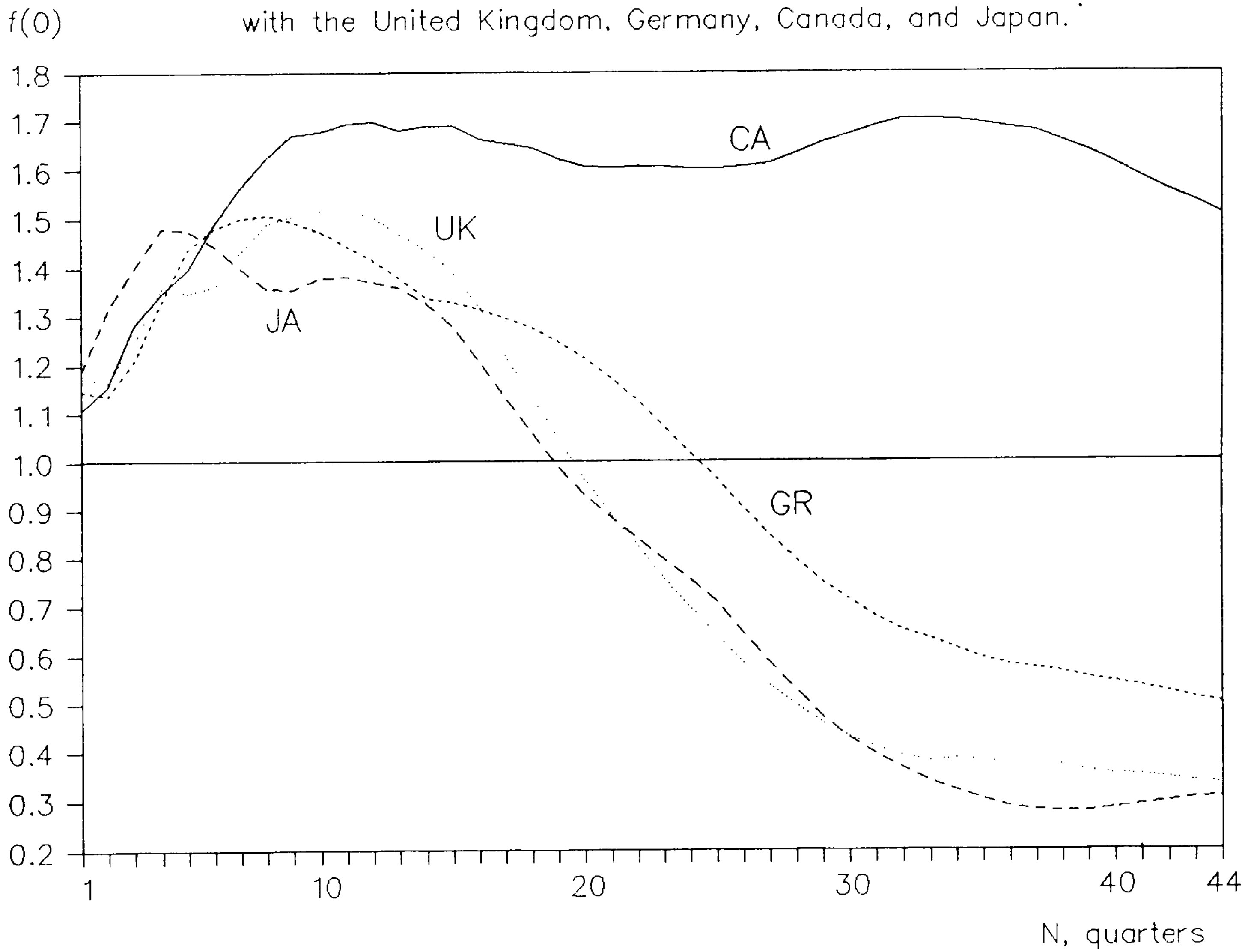

Table 6. Estimates of $\hat{f}^N(0)$ and Their Standard Errors, $\hat{\sigma}$, for Bilateral Dollar Nominal Exchange Rates 1/
Quarterly, 1974:1 to 1989:4

N	UK	$2*\hat{\sigma}$	GR	$2*\hat{\sigma}$	CA	$2*\hat{\sigma}$	JA	$2*\hat{\sigma}$
1	1.22	0.24	1.15	0.27	1.07	0.04	1.18	0.28
2	1.24	0.36	1.15	0.41	1.09	0.06	1.29	0.42
3	1.37	0.45	1.23	0.52	1.20	0.07	1.38	0.54
4	1.51	0.53	1.35	0.62	1.27	0.09	1.45	0.65
5	1.54	0.59	1.46	0.70	1.32	0.10	1.45	0.73
6	1.58	0.65	1.50	0.78	1.41	0.10	1.40	0.81
7	1.66	0.71	1.53	0.85	1.48	0.11	1.35	0.88
8	1.72	0.76	1.54	0.92	1.52	0.12	1.30	0.94
9	1.74	0.80	1.53	0.97	1.57	0.13	1.29	1.01
10	1.74	0.84	1.51	1.03	1.58	0.14	1.31	1.06
11	1.72	0.88	1.47	1.08	1.60	0.14	1.30	1.12
12	1.68	0.92	1.44	1.13	1.61	0.15	1.28	1.17
13	1.63	0.96	1.40	1.18	1.61	0.16	1.27	1.22
14	1.56	0.99	1.35	1.22	1.63	0.16	1.22	1.27
15	1.49	1.02	1.33	1.26	1.65	0.17	1.17	1.31
16	1.39	1.05	1.31	1.31	1.64	0.17	1.09	1.35
17	1.27	1.09	1.28	1.34	1.65	0.18	1.01	1.39
18	1.16	1.12	1.24	1.38	1.66	0.18	0.93	1.43
19	1.06	1.14	1.20	1.42	1.65	0.19	0.86	1.47
20	0.96	1.17	1.16	1.45	1.63	0.19	0.81	1.51
21	0.87	1.20	1.10	1.48	1.63	0.20	0.76	1.54
22	0.79	1.23	1.05	1.52	1.63	0.20	0.73	1.57
23	0.71	1.25	0.99	1.55	1.62	0.20	0.69	1.61
24	0.64	1.28	0.93	1.58	1.60	0.21	0.65	1.64
25	0.58	1.30	0.87	1.61	1.59	0.21	0.61	1.67
26	0.52	1.32	0.81	1.64	1.58	0.22	0.56	1.70
27	0.48	1.35	0.75	1.67	1.57	0.22	0.51	1.73
28	0.44	1.37	0.70	1.69	1.57	0.22	0.46	1.76
29	0.41	1.39	0.65	1.72	1.58	0.23	0.42	1.78
30	0.39	1.41	0.62	1.75	1.59	0.23	0.39	1.81
31	0.38	1.44	0.58	1.77	1.59	0.23	0.37	1.84
32	0.38	1.46	0.56	1.80	1.60	0.24	0.35	1.86
33	0.38	1.48	0.54	1.82	1.60	0.24	0.34	1.89
34	0.40	1.50	0.53	1.85	1.60	0.24	0.33	1.91
35	0.41	1.52	0.51	1.87	1.61	0.25	0.32	1.94
36	0.42	1.53	0.50	1.89	1.60	0.25	0.32	1.96
37	0.43	1.55	0.50	1.92	1.60	0.25	0.32	1.98
38	0.45	1.57	0.49	1.94	1.59	0.26	0.32	2.00
39	0.45	1.59	0.48	1.96	1.59	0.26	0.33	2.03
40	0.46	1.61	0.47	1.98	1.57	0.26	0.34	2.05
41	0.46	1.62	0.46	2.00	1.55	0.27	0.35	2.07
42	0.46	1.64	0.45	2.02	1.53	0.27	0.36	2.09
43	0.46	1.66	0.44	2.04	1.51	0.27	0.37	2.11
44	0.46	1.67	0.43	2.06	1.49	0.27	0.37	2.13

1/ Standard errors are constructed under the null hypothesis of the nominal exchange rate being a random walk, so that there is no autocorrelation in the first differences.

Table 7. Estimates of $\hat{f}^N(0)$ and Their Standard Errors, $\hat{\sigma}$, for Bilateral Dollar Real Exchange Rates 1/
Quarterly, 1974:1 to 1989:4

N	UK	$2*\hat{\sigma}$	GR	$2*\hat{\sigma}$	CA	$2*\hat{\sigma}$	JA	$2*\hat{\sigma}$
1	1.17	0.23	1.14	0.27	1.11	0.04	1.19	0.30
2	1.16	0.35	1.14	0.41	1.16	0.05	1.31	0.45
3	1.25	0.44	1.21	0.53	1.28	0.07	1.40	0.58
4	1.36	0.52	1.33	0.62	1.35	0.08	1.48	0.68
5	1.35	0.58	1.44	0.71	1.40	0.09	1.48	0.77
6	1.36	0.65	1.48	0.78	1.49	0.10	1.45	0.86
7	1.43	0.70	1.50	0.85	1.56	0.10	1.40	0.93
8	1.49	0.75	1.51	0.91	1.62	0.11	1.36	1.00
9	1.50	0.80	1.49	0.97	1.67	0.12	1.35	1.06
10	1.52	0.84	1.47	1.02	1.68	0.13	1.38	1.12
11	1.52	0.89	1.44	1.07	1.69	0.13	1.38	1.18
12	1.50	0.92	1.42	1.12	1.70	0.14	1.37	1.23
13	1.47	0.96	1.38	1.17	1.68	0.15	1.36	1.29
14	1.44	1.00	1.34	1.21	1.69	0.15	1.32	1.33
15	1.39	1.03	1.33	1.25	1.69	0.16	1.28	1.38
16	1.32	1.06	1.31	1.29	1.66	0.16	1.21	1.43
17	1.22	1.09	1.30	1.33	1.65	0.17	1.13	1.47
18	1.13	1.13	1.28	1.36	1.64	0.17	1.06	1.51
19	1.05	1.15	1.25	1.40	1.62	0.18	0.99	1.55
20	0.96	1.18	1.21	1.43	1.61	0.18	0.93	1.59
21	0.89	1.21	1.17	1.46	1.60	0.18	0.88	1.63
22	0.82	1.24	1.12	1.50	1.61	0.19	0.84	1.66
23	0.76	1.26	1.07	1.53	1.61	0.19	0.80	1.70
24	0.70	1.29	1.02	1.56	1.60	0.20	0.76	1.73
25	0.64	1.31	0.96	1.59	1.60	0.20	0.71	1.76
26	0.58	1.34	0.90	1.62	1.61	0.20	0.64	1.80
27	0.54	1.36	0.85	1.64	1.61	0.21	0.58	1.83
28	0.50	1.38	0.80	1.67	1.63	0.21	0.53	1.86
29	0.46	1.41	0.75	1.70	1.65	0.21	0.47	1.89
30	0.43	1.43	0.71	1.73	1.67	0.22	0.43	1.91
31	0.41	1.45	0.68	1.75	1.69	0.22	0.39	1.94
32	0.39	1.47	0.65	1.78	1.70	0.22	0.37	1.97
33	0.38	1.49	0.63	1.80	1.70	0.23	0.34	2.00
34	0.38	1.51	0.61	1.83	1.70	0.23	0.32	2.02
35	0.38	1.53	0.59	1.85	1.69	0.23	0.30	2.05
36	0.38	1.55	0.58	1.87	1.69	0.24	0.29	2.07
37	0.38	1.56	0.57	1.89	1.68	0.24	0.28	2.09
38	0.37	1.58	0.56	1.92	1.66	0.24	0.28	2.12
39	0.36	1.60	0.55	1.94	1.64	0.25	0.28	2.14
40	0.35	1.62	0.54	1.96	1.61	0.25	0.28	2.16
41	0.35	1.63	0.53	1.98	1.58	0.25	0.29	2.19
42	0.35	1.65	0.52	2.00	1.56	0.25	0.30	2.21
43	0.34	1.66	0.51	2.02	1.53	0.26	0.30	2.23
44	0.34	1.68	0.50	2.04	1.51	0.26	0.31	2.25

1/ Standard errors are constructed under the null hypothesis of the real exchange rate being a random walk, so that there is no autocorrelation in the first differences.

estimates in charts 1-2. 1/ Given the small number of degrees of freedom at long lags and the large variance of the nominal exchange rate, the estimates have large standard errors and it is virtually impossible to reject the null hypothesis that the spectral density is equal to unity. This is the case even in those instances where the spectral density is close to 0.3 in the long run. The only cases for which the null hypothesis could be rejected are the nominal and real rates with the Canadian dollar. In these cases, however, the finding that the spectral density function is above one suggests positive rather than negative autocorrelations, and no evidence of mean reversion.

From a statistical point of view, the unavoidable conclusion is that the null hypothesis of a random walk cannot be rejected at standard significance levels. Based on the estimates of the spectral density function, however, it could be conjectured that there may be mean reversion in the data but the tests applied simply do not have the power to reject the random walk. Nevertheless, we proceed under the assumption that exchange rates are statistically indistinguishable from a random walk and are nonstationary, while noting that it could be misleading to place too much weight on the random walk in trying to identify the kinds of shocks that have moved exchange rates, or the models that are appropriate for analyzing them. The tests that are available possibly do not have the power to discriminate between a random walk and interesting alternative hypotheses that might imply 'small' deviations from a random walk.

IV. Multivariate Time Series Tests

A univariate random walk in exchange rates only implies that exchange rates cannot be predicted from their own history. This section takes an alternative approach by investigating whether movements in the dollar against other major currencies can be accounted for by the forcing variables included in exchange rate models. The approach thus seeks to determine whether the longer-run movements in exchange rates are linked to long-run movements in these variables, and whether deviations of exchange rates from any long-run cointegrating relationships contain information for predicting future exchange rate changes.

The approach is based on the methodology of cointegration and error-correction as developed by Engle and Granger (1987). Cointegration can be defined as follows. The components of the vector Z_t are said to be cointegrated of order d,b (denoted $Z_t \sim CI(d,b)$) if all components of Z_t are I(d) and there exists a vector $\alpha \neq 0$ such that $X_t = \alpha' Z_t \sim I(d-b)$,

---

1/ In the absence of information on the distribution of the spectral density, as an approximate procedure we examine whether the value of f(0) is more than two standard errors from unity. Kaminsky (1987) uses monte-carlo techniques to determine the distribution of f(0) under the null hypothesis that a series follows a random walk.

b>0. The vector α is then called the cointegrating vector. 1/ Several observations can be made about the concept of cointegration. Cointegration applies to the long-run relationships between variables, and describes a situation in which variables that may drift apart in the short run have a tendency to move together in the long run. As such it is well suited for determining the long-run link between the forcing variables in structural exchange rate models and exchange rates. Second, a necessary condition for exchange rates to be cointegrated with a set of variables is that all these variables are integrated of order one given that the exchange rate is an I(1) variable. It is possible, however, to have variables that are integrated of a higher order, provided that there are cointegrating relationships among these variables that reduce their collective order of integration to that of the exchange rate. 2/ Finally, if cointegrating relationships can be found it is possible to specify an error-correction mechanism in which either the exchange rate or the forcing variables can be used to predict the rate at which the economy will return to long-run equilibrium. 3/

The methodology of cointegration is applied in this section in three steps. In the first, the forcing variables identified in structural exchange rate models are individually tested to determine their order of integration. In the second, tests are undertaken to determine whether exchange rates are cointegrated with these variables, yielding a number of cointegrating relationships. Finally, at the last stage, we test to see whether deviations of exchange rates from long-run values implied by the cointegrating vectors contain information for predicting future movements in exchange rates.

Based on the review of structural exchange rate models, four sets of forcing variables are tested: money supplies and interest rate differentials; fiscal variables, including government spending, fiscal deficits, and stocks of outstanding public sector debt; current account balances, in level terms and cumulated to give net foreign asset positions; and measures of economic activity or productivity, including real GNP/GDP, industrial production, labor productivity, and--as a proxy for capital productivity--real share prices. Given the large number of possible combinations of these variables, some simplification is obviously necessary. To make the number of tests manageable, all domestic variables

---

1/ For a simplified approach to cointegration, see Hendry (1986), and Granger (1986).

2/ Hence, for example, individual variables such as the stock of foreign assets can be integrated of higher order than the exchange rate provided that there are linear combinations of these and other variables that are integrated of the same order as the exchange rate.

3/ As discussed in Section II, an ability to predict changes in the exchange rate is not necessarily inconsistent with market efficiency or the random walk property of exchange rates. A univariate random walk in exchange rates only implies that exchange rates cannot be predicted from their own history.

are measured relative to their foreign counterparts. In the case of money supplies or interest rates this is a reasonable approximation: the (logarithmic) difference between domestic and foreign money supplies appears in many structural models as does the differential between domestic and foreign interest rates. It is less apparent, however, how variables such as government expenditures, fiscal deficits, and public debt stocks should be treated. The approach adopted was to use the difference between domestic and foreign government expenditures as shares of GNP, and differences in the ratio to GNP of fiscal deficits and public debt across countries. 1/ Details on how other variables are measured are provided in the accompanying tables.

The results for the order of integration of forcing variables are presented in Table 8. For each variable, Dickey-Fuller and augmented Dickey-Fuller tests were used to test the null hypothesis that a given series was either integrated of order one or two. The results can be summarized as follows. Among the monetary variables, relative money supplies in all cases are integrated of order one, implying that they can potentially account for the nonstationarity in exchange rates. Interest differentials, both nominal and real, on the other hand, appear to be stationary and cannot therefore be cointegrated with exchange rates. The finding that real interest rate differentials are stationary is consistent with the findings of Meese and Rogoff (1985). 2/ They interpreted this result to imply that the variance of the real exchange rate reflects changes in the (expected) long-run real exchange rate. 3/

All the fiscal variables, with the exception of the (relative) U.K. fiscal deficit to GNP ratio, are integrated of order one and thus potential candidates for explaining the long-run variance of exchange rates. We interpret this to mean that differences in fiscal policy across countries hold the potential for explaining the long-run variance of exchange rates, independently of any short-run impact on interest rate differentials. The current account and cumulative net foreign asset positions of major industrial countries are also integrated of order one. All the measures of economic activity and productivity with the exception of relative unit labor costs for the United Kingdom are also characterized by the same order of integration as exchange rates. Explanations for the

---

1/ Combining domestic and foreign variables in this way also ensures that the forcing variables are all integrated of the same order as exchange rates. (See below.)

2/ See also, Meese and Singleton (1982).

3/ This can be seen by writing the difference between the period t real exchange rate and the expected future real exchange rate in period t+k in terms of the real interest rate differential over k periods; ie $E_t q_{t+k} - q_t = k \cdot [r_t - r_t^*]$. If the nonstationarity in q_t is not accounted for by the real interest differential, it must be accounted for by $E_t q_{t+k}$. Of course, if uncovered interest rate parity does not hold, the non-stationarity in the real exchange rate could be explained by non-stationarity in the risk premium.

Table 8. Estimated Order of Integration for Forcing Variables from Dickey-Fuller and Augmented Dickey-Fuller tests 1/

	UK	GR	CA	JA
Money and interest rates				
Log(M1)	I(1)	I(1)	I(1)	I(1)
3-month differential	I(0)	I(0)	I(0)	I(0)
5-year differential	I(0)	I(0)	I(0)	n.a.
10-year differential	I(0)	I(0)	I(0)	I(0)
3-month real differential	I(0)	I(0)	I(0)	I(0)
5-year real differential	I(0)	I(0)	I(0)	n.a.
10-year real differential	I(0)	I(0)	I(0)	I(0)
Fiscal measures				
Log(G/Y)	I(1)	I(1)	I(1)	I(1)
D/Y	I(0)	I(1)	I(1)	n.a.
(∫D)/Y	I(1)	I(1)	I(1)	n.a.
Output and productivity				
Log(Y')	I(1)	I(1)	I(1)	I(1)
Log(RY)	I(1)	I(1)	I(1)	I(1)
Log(RV)	I(1)	I(1)	I(1)	I(1)
Log(X/L)	I(1)	I(1)	I(1)	I(1)
Log(ULC)	I(0)	I(1)	I(1)	I(1)
Current account and foreign asset stocks				
CAB/Y	I(1)	I(1)	I(1)	I(1)
(∫CAB)/Y	I(1)	I(1)	I(1)	I(1)

1/ Note:

1. All data are from International Financial Statistics.

2. All variables are measured as the the value for the United States minus the value for the foreign country.

3. Variable Notation: G denotes nominal government consumption; Y denotes Gross National Product at market prices; D denotes the central government balance; ∫ is used to denote cumulative value of; Y' denotes Industrial Production; RY denotes real Gross National Product; RV denotes real industrial share prices; (X/L) denotes output per man hour in manufaturing; ULC denotes unit labor costs in manufacturung; CAB denotes the domestic currency value of the multilateral current account balance.

4. Table entries. "I(n)" denotes variable is integrated of order n, i.e., needs to be differenced n times to obtain a stationary variable; "n.a." denotes data was unavailable.

5. The Dickey-Fuller and Augmented-Dickey-Fuller Regressions include a constant and three seasonals.

6. Real interest rates are computed using an AR(2) process for predicting inflation.

dollar's movements based on real factors such as productivity developments may therefore be able to explain long-run exchange rate movements.

The tests for cointegration are based on the maximum likelihood procedures developed by Johansen (1988), and Johansen and Juselius (1989). Unlike the Granger-Engle procedure, which presumes the (potential) presence of exactly one cointegrating vector among a set of variables, estimated by regressing one of the variables on the contemporaneous levels of the other variables, the Johansen procedure allows for as many cointegrating vectors as the number of variables.

Before considering the relationships between exchange rates and other economic variables, it is interesting to determine whether the nonstationarity in dollar exchange rates derives from a single source such as U.S. economic policies, i.e., there is a "dollar phenomenon", or reflects a more complex interaction with economic developments in particular countries. Accordingly, we tested whether the bilateral exchange rates of the dollar were themselves cointegrated and reflected a common source of nonstationarity. The results from these tests suggested that dollar exchange rates are not cointegrated, which means that long-run movements in the dollar are not dominated by developments in the United States and hence that if there are explanations of long-run movements in dollar exchange rates, they must be of a (relative) country specific nature. 1/

The results from individual bivariate cointegration tests of each exchange rate and other economic variables are summarized in Table 9. In order to highlight the central results, the table does not show the values of individual test statistics and only indicates whether cointegrating relationships were found for particular variables. 2/ The results suggest that little of the nonstationarity in exchange rates mirrors that of other economic variables in the long run. Nevertheless a number of cointegrating vectors are identified which carry implications for understanding exchange rate behavior.

Confirming results found with structural exchange rate models, monetary variables do not account for the long-run variance of nominal and real exchange rates. 3/ The lack of cointegration between real exchange rates and monetary variables is to be expected on the basis of most

---

1/ In order to conserve space, the results from these tests are not recorded in the tables.

2/ As indicated earlier the cointegration tests are based on the procedure developed by Johansen (1988). This procedure identifies a set of cointegrating relationships between the exchange rate and other economic variables. An alternative approach would use the cointegration procedures developed by Stock and Watson (1986).

3/ The failure to identify a role for monetary shocks over the recent floating rate period has led to some researchers to conclude that the monetary approach to exchange rates has failed. See, for example, Boughton (1985).

Table 9. Results of Bivariate Cointegration Tests
for Exchange Rates and Other Economic Variables

	Money	Fiscal Variables			Output and Productivity					Current account and foreign asset stocks	
	Log(M1)	Log(G/Y)	D/Y	$(\int D)/Y$	Log(Y')	Log(RY)	Log(RV)	Log(X/L)	Log(ULC)	CAB/Y	$(\int CAB)/Y$
Nominal											
UK	--	Yes	--	--	--	n.a.	Yes	--	n.a.	--	--
GR	--	--	--	--	--	--	Yes	--	--	--	--
CA	--	Yes	--	--	Yes	--	--	Yes	--	Yes	Yes
JA	--	--	n.a.	n.a.	--	--	--	--	--	--	--
Real											
UK	--	--	--	--	--	n.a.	--	--	n.a.	--	--
GR	--	--	Yes	--	--	--	Yes	--	Yes	Yes	--
CA	--	Yes	Yes	--	Yes	--	--	Yes	--	--	Yes
JA	--	--	n.a.	n.a.	--	--	--	Yes	--	Yes	--

<u>Notes</u>:

1. All variables are measured as the the value for the U.S. minus the value for the foreign country.
2. Variable Notation: G denotes nominal government consumption; Y denotes Gross National Product at market prices; D denotes the central government balance; $\int$ is used to denote cumulative value of; Y' denotes Industrial Production; RY denotes real Gross National Product; RV denotes real industrial share prices; (X/L) denotes output per man hour in manufaturing; ULC denotes unit labor costs in manufacturing; CAB denotes the domestic currency value of the multilateral current account balance.
3. Table entries:
   "--" : denotes no cointegrating vector found;
   "Yes" : denotes at least one cointegrating vector found at the 5 percent significance level.
   "n.a.": denotes either data unavailable or that the variable was found to be stationary (see Table 8).
4. A prior constant and three seasonals were first removed from the data.

structural models. The inability to find cointegration between nominal exchange rates and relative money supplies suggests that differences in monetary policy across major industrial countries have not been a major factor behind trends in nominal exchange rates over the recent floating rate period. This finding is also consistent with the observation in Section III that nominal exchange rates show some tendency for mean reversion, which implies an absence of permanent differences in nominal shocks across countries.

Fiscal variables explain some of the long-run variance in real and nominal exchange rates in all cases other than the U.S. dollar-yen exchange rate. In cases where cointegrating relationships are found, they either reflect the ratio of government spending to GNP or fiscal deficit positions. No cointegrating relationships were found between public sector debt stocks and nominal or real exchange rates. Current account variables account for some of the long-run variance in exchange rates, particularly in the case of the exchange rate with the Canadian dollar. There is also some evidence of cointegrating relationships for the deutsche mark and Japanese yen exchange rates but, contrary to the predictions of portfolio models, current account variables do not systematically account for the longer-run variance of most nominal and real exchange rates. Among the variables used to measure economic activity and productivity, there is a small number of cointegrating vectors. The real exchange rates with Canada and Japan appear to be cointegrated with labor productivity; those with Germany and the United Kingdom are cointegrated with the proxy for capital productivity. These relationships are open to a number of interpretations, but one possibility is that they reflect the impact of productivity shocks on the real exchange rate. 1/

In order to allow for the possibility that exchange rates could be cointegrated with a combination of the other economic variables, we also estimated a number of multivariate cointegrating vectors in which the nominal exchange rate was related to a complete set of monetary, fiscal, current account, and real productivity measures. For each bilateral nominal exchange rate at least two cointegrating vectors were found that were significant at the one percent level. One of these was picked and employed to measure the long-run level of the exchange rate as accounted for by the forcing variables. 2/ Deviations of the actual exchange rate from the long-run cointegrating vector can then be interpreted as measuring the equilibrium error in the system. Charts 3-6 plot the actual

---

1/ It is not clear, however, why capital productivity shocks matter for Europe while labor productivity shocks matter for Canada and Japan. The result may reflect the sizable shifts in income distribution in Europe in the 1970s and 1980s, but it is unclear what implications these shifts would have for exchange rates.

2/ There is no obvious criteria for which cointegrating vector to pick. We chose the one with the smallest variance for the equilibrium exchange rate error.

exchange rate and their long-run values as implied by the cointegrating vectors. As indicated in the charts, there are at times substantial and long-lived deviations from the long-run values, which tend at times to display greater variability than exchange rates.

There are two possible interpretations of the equilibrium errors shown in Charts 3-6. One is that they reflect bubbles in exchange markets, suggesting that exchange rates have at times deviated substantially from long-run economic fundamentals. An alternative explanation is that they reflect the systematic short-run movements in exchange rates identified in exchange rate models. In order to test this latter hypothesis, error-correction equations for exchange rates were estimated in which the change in each bilateral nominal exchange rate was related to its own equilibrium error and the changes in the forcing variables. Consistent with the methodology of cointegration and error-correction, these equations also included nominal interest rate differentials as a potential variable explaining short-run exchange rate movements. 1/

$$Ds(t) = \sum_{i=1}^{k} a_i \cdot U_{t-i} + \sum_{i=0}^{k} b_i \cdot R^{ST}_{t-i} + \sum_{i=0}^{k} c_i \cdot R^{LT}_{t-i} + \sum_{i=1}^{k} d_i \cdot DZ_{t-i} + \varepsilon_t \quad (9)$$

As indicated in equation (9) each error-correction equation relates the change in the exchange rate to an error-correction term that measures the deviation of the exchange rate from the long-run value implied by the forcing variables, U, short and medium-run nominal interest differentials, R^{ST} and R^{LT}, and lagged changes in the forcing variables, Z. The estimates of this equation for each bilateral nominal exchange rate are recorded in Table 10. Several features of the estimates are noteworthy. First, all coefficients on the equilibrium error are negative, so that the current change in the exchange rate is a negative function of the deviation of last period's exchange rate from it's long-run equilibrium value. The estimated coefficient is, however, insignificant for the bilateral dollar rate with the pound sterling; for the deutsche mark and the Canadian dollar, the coefficients are only one standard error away from zero implying a marginal significance level of 30 percent; for the yen the coefficient is significant at 1 percent. The coefficient of 0.2 for the dollar-yen rate implies that 20 percent of any deviation of the exchange rate from its long-run level can be expected to be dissipated in the next quarter. Second, the coefficients on short and medium-term interest differentials are insignificant for all rates with the exception of the yen, where both differentials are significant. Third, the fit of the equations is on the whole rather poor with between 29 percent--of the

1/ See Granger (1986). Given that nominal interest rate differentials are stationary and all variables integrated of order one are first differenced, the error-correction equation is not subject to the spurious regression problem, and allows use of information on the levels of variables.

Chart 3. (Log of) Actual and Long-run Value of Nominal Dollar-Japanese Yen Exchange Rate.

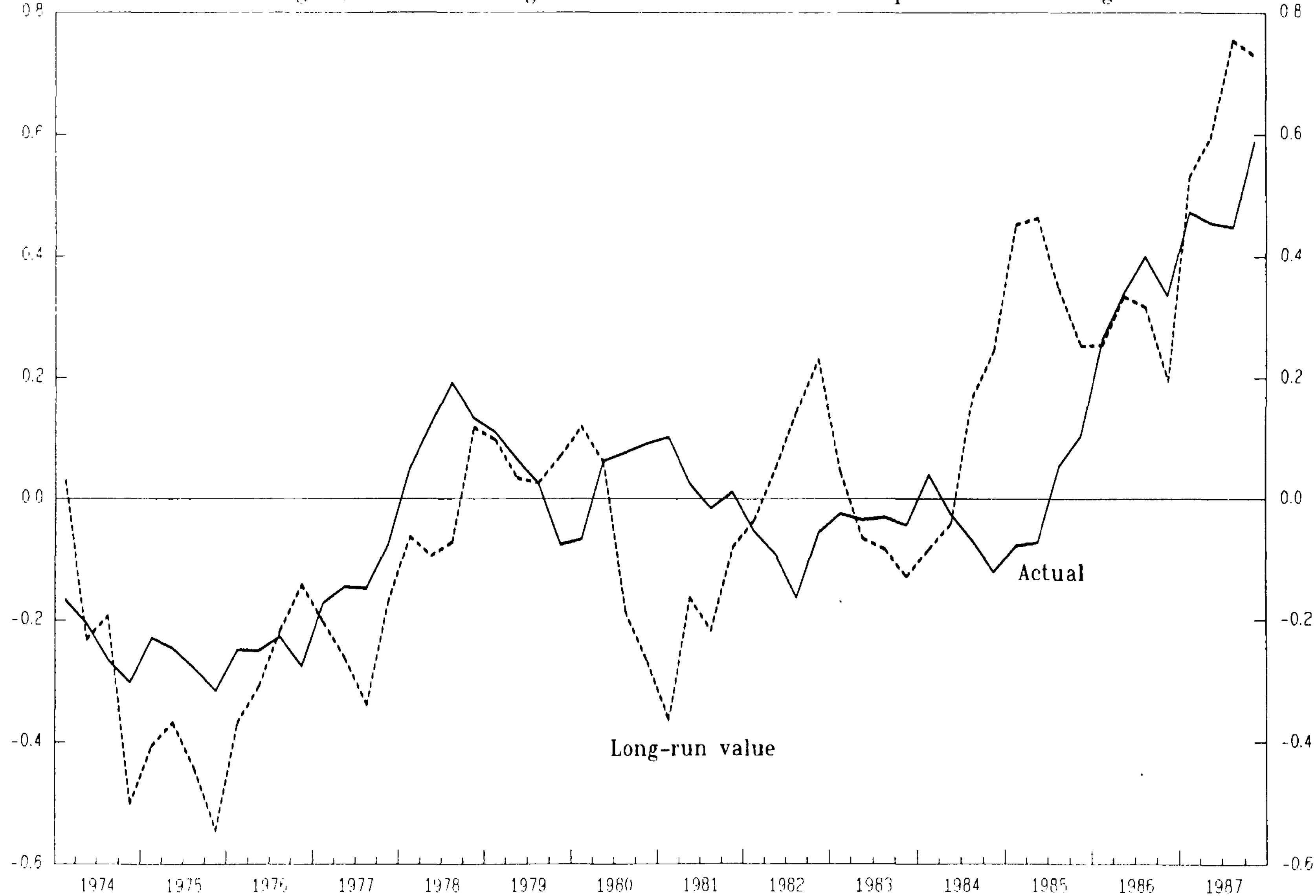

Chart 4. (Log of) Actual and Long-run Value of Nominal Dollar-Deutsche Mark Exchange Rate.

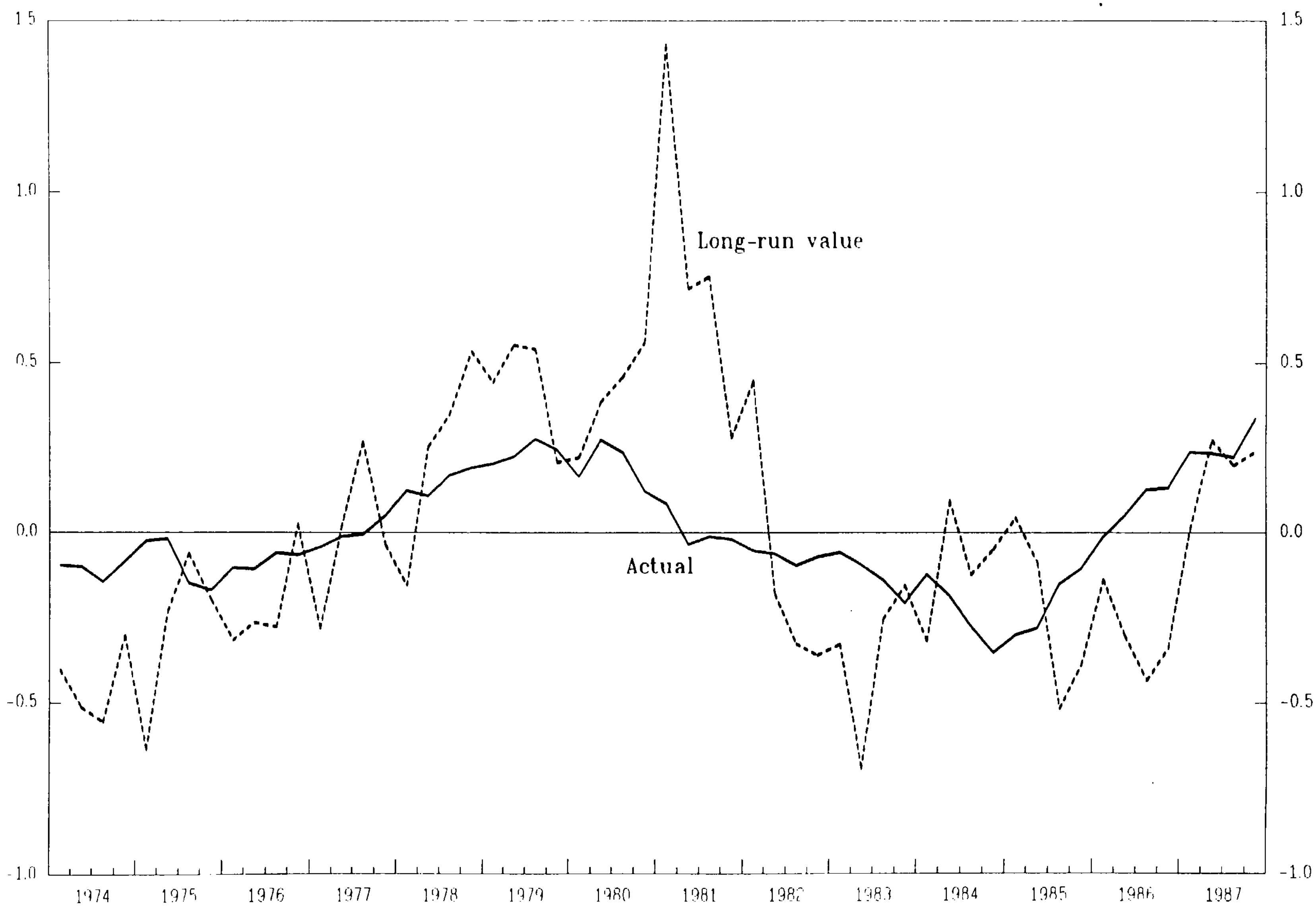

Chart 5. (Log of) Actual and Long-run Value of Nominal Dollar-Canadian Dollar Exchange Rate.

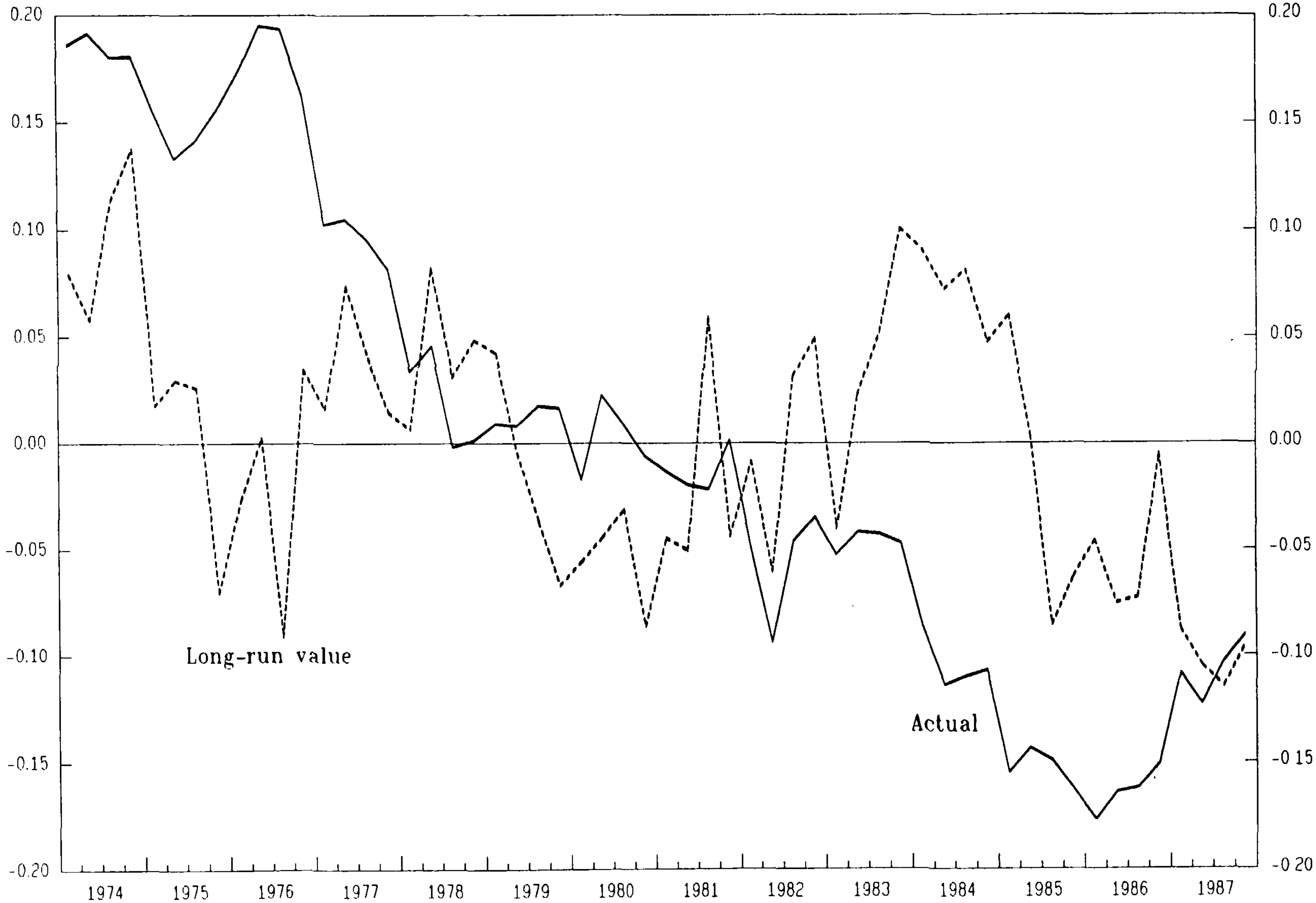

Chart 6. (Log of) Actual and Long-run Value of Nominal Dollar-Pound Sterling Exchange Rate.

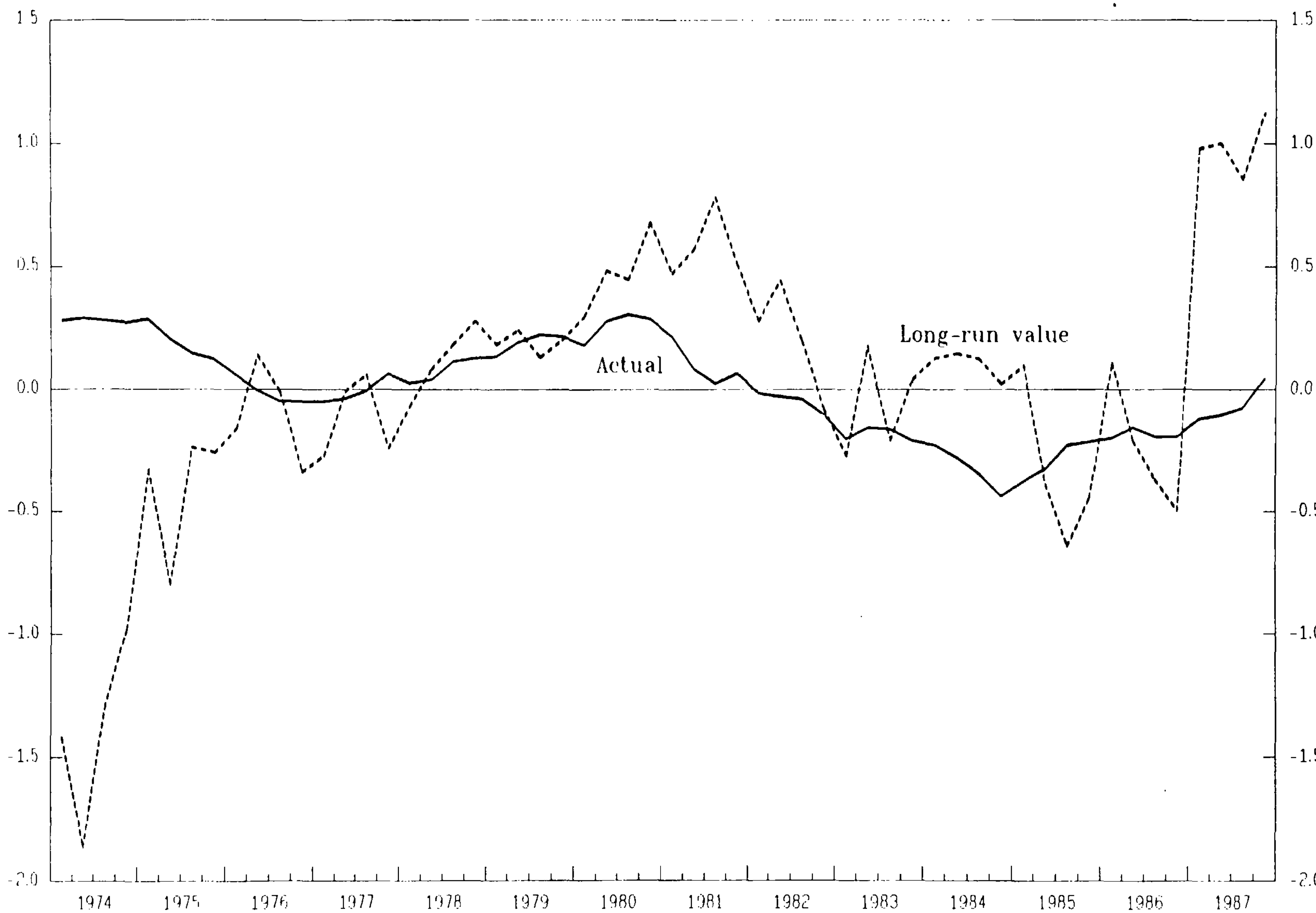

Table 10. Estimates of Error Correction Equation for Nominal Dollar Exchange Rates 1/

$$Ds_t = a_1 u_{t-1} + \sum_{i=0}^{1} b_i \cdot R^{ST}_{t-i} + \sum_{i=0}^{1} C_i \cdot R^{LT}_{t-i} + \sum_{i=1}^{3} d_i \cdot DZ_{t-i} + \varepsilon_t$$

	a_1	$\sum_{i=0}^{1} b_i$	$\sum_{i=0}^{1} C_i$	R^2
UK	-0.01 (-0.16)	-0.010 (-1.42)	-0.005 (-0.67)	0.59
GR	-0.05 (-1.03)	-0.003 (-0.29)	-0.01 (-0.93)	0.38
CA	-0.08 (-0.98)	-0.001 (-0.10)	(-0.05) (-0.56)	0.29
JA	-0.20 (-2.32)	-0.014 (-2.09)	0.02 (1.65)	0.59

1/ t-ratios are in parentheses.

Canadian dollar's--to 59 percent--of the yen's--movements being explained by the error correction equations.

V. Conclusions

This paper has addressed a number of questions about the time series processes dollar exchange rates are likely to follow, and the conditions under which they would be expected to be described by random walks. Most structural exchange rate models were shown to generate departures from a random walk, even when all shocks were expected to be permanent. The random walk in exchange rates can therefore be viewed neither as an implication of market efficiency, nor as a guide to the kinds of shocks that have been important in moving exchange rates.

An examination of the univariate time-series properties for exchange rates showed that while there was some evidence for departures from a random walk and for the presence of mean reversion, there was a basic difficulty in establishing the statistical significance of the deviations. Under these conditions, we are forced to conclude that exchange rates are statistically indistinguishable from random walks, though we are reluctant to draw strong conclusions from this result.

Finally, we tested whether the forcing variables in structural exchange rate models were characterized by a similar order of nonstationarity as exchange rates. While many of these variables were found to be integrated of the same order as exchange rates, and hence could potentially account for their nonstationarity, only a small number of cointegrating relationships were found. Moreover, deviations from these cointegrating relationships were found to play only a limited role in predicting changes in dollar exchange rates.

References

Adams, C. and, R. Boyer, "Efficiency and a Simple Model of Exchange-Rate Determination", Journal Of International Money and Finance, Vol.5, No. 3 (1987), pp. 285-302.

Adler, M., and B. Lehman, "Deviations from Purchasing Power Parity in the Long-Run", Journal of Finance, 5 (1983), pp.1471-78.

Beveridge, S., and Nelson, C.R., "A New Approach to the Decomposition of Economic Time Series into Permanent and Transitory Components, with Particular Attention to the Measurement of the 'Business Cycle'", Journal of Monetary Economics, 7 (1981), pp. 151-74.

Bilson, J.F.O., "Rational Expectations and the Exchange Rate," in Frenkel J.A. and H.G. Johnson (eds.), The Economics of Exchange Rates, (Reading, MA, Addison-Wesley, 1978).

Boughton, J.A, "An Investigation of the Empirical Performance of Several Exchange Rate Models," International Monetary Fund, DM/85/40 (1985).

Branson, W.H, "Asset Markets and Relative Prices in Exchange Rate Determination," Reprints in International Finance, No. 20, (Princeton University, Princeton, New Jersey, 1977).

———, H. Halttunen, and P. Masson, "Exchange Rates in the Short Run," European Economic Review, 10 (1977), pp. 395-402.

——— and D.W. Henderson, "The Specification and Influence of Asset Markets," in R.W. Jones and P.B. Kenen (eds.), Handbook of International Economics, Vol. 2, (North Holland, 1985).

Campbell, J.Y., and R.H. Clarida, "The Dollar and Real Interest Rates", in K. Brunner and A. Meltzer (eds.), Empirical Studies of Velocity, Real Exchange Rates, Unemployment and Productivity, Carnegie-Rochester Conference Series on Public Policy, (North-Holland: Amsterdam, 1987).

Chadha, B., "Contract Length, Monetary Policy, and Exchange Rate Variability", Journal of International Money and Finance, 6 (1987), 491-504.

Cochrane, J, 1986, "How Big is the Random Walk in GNP?", (mimeographed, University of Chicago, 1986).

Dickey, D.A., and W.A. Fuller, "Distribution of the Estimators for Autoregressive Time Series with a Unit Root", Journal of the American Statistical Association, 74 (1979), 1057-72.

——— and ———, "Likelihood Ratio Statistics for Autoregressive Time Series with a Unit Root", Econometrica, 52 (1981), 1241-69.

Dooley, M., and P. Isard, "Country Risk, International Lending, and Exchange Rate Determination", International Finance Discussion Paper, Federal Reserve Board (1983).

——— and ———, "Tax Avoidance and Exchange Rate Determination, International Monetary Fund, DM/86/1, Washington D.C. (1986).

Dornbusch, R., "Expectations and Exchange Rate Dynamics," Journal of Political Economy, 84 (1976), 1161-76.

——— and S. Fischer, "Exchange Rates and the Current Account," American Economic Review, 70 (1980), 960-971.

Driskill, R.A, "Exchange Rate Dynamics: an empirical investigation," Journal of Political Economy, 89 (1981), 357-71,

Engle, R.F., and C.W.J. Granger, 1987, "Cointegration and Error-Correction: representation, estimation and testing," Econometrica, 55 (1987), 251-276.

Fama, E.F., and K.R. French, "Permanent and Temporary Components of Stock Prices," (mimeographed, University of Chicago, 1986).

Frankel, J.A., "On the Mark: a theory of floating exchange rates based on real interest rate differentials," American Economic Review, 619 (1979), 610-622.

———, "Tests of Monetary and Portfolio Balance Models of Exchange Rate Determination," in J.F.O. Bilson and R.C. Marston (eds.), Exchange Rate Theory and Practice, (Chicago, University of Chicago Press, 1984).

Frenkel, J., "Exchange Rates, Prices and Money, Lessons from the 1920s," American Economics Association, Papers and Proceedings, (1980), 235-242.

——— and M. Mussa, "The Efficiency of the Foreign Exchange Market and Measures of Turbulence," American Economic Review, 70 (1980), 374-381.

——— and ———, "Asset Markets, Exchange Rates and the Balance of Payments," in R.W. Jones and P.B. Kenen (eds.), Handbook of International Economics, Vol. 2, (North Holland, 1985).

Granger, C.W.J, "Developments in the Study of Cointegrated Economic Variables," Oxford Bulletin of Economics and Statistics, 48 (1986), 213-227.

——— and P. Newbold, Forecasting Economic Time Series, (New York: Academic Press, 1977).

Hall, S.G., and S.G.B. Henry, Macroeconomic Modelling, (North Holland, 1988).

Hodrick, R., The Empirical Evidence on the Efficiency of Forward and Futures Foreign Exchange Markets, (Harwood Academic Publishers, 1987).

Hendry, D.F, "Econometric Modelling with Cointegrated Variables: An Overview," Oxford Bulletin of Economics and Statistics, 48 (1986), 201-212.

Huizinga, J., "An Empirical Investigation of the Long-run Behavior of Real Exchange Rates," in K.Brunner and A. Meltzer (eds), Empirical Studies of Velocity, Real Exchange Rates, Unemployment and Productivity, Carnegie-Rochester series on Public Policy, (Amsterdam: North-Holland, 1987).

Isard, P., "Expected and Unexpected Changes in Exchange Rates: the roles of relative price levels, balance of payments factors, interest rates and risk", International Finance Discussion Papers, Federal Reserve Board (1980).

———, "How Far Can We Push the Law of One Price?", American Economic Review, 67 (1987), 942-48.

Johansen, S., "Statistical Analysis of Cointegration Vectors", Journal of Economic Dynamics and Control, 12 (1988), 231-54.

——— and K. Juselius, "Maximum Likelihood Estimation and Inference on Cointegration--with Applications to the Demand for Money," (mimeographed, University of Copenhagen, 1989).

Kaminsky, G., "The Real Exchange Rate in the Short and in the Long Run," University of California, (mimeographed, 1987).

Kouri, P.J.K., "The Exchange Rate and the Balance of Payments in the Short Run and in the Long Run: a monetary approach," Scandinavian Journal of Economics, 78 (1976), 280-304.

Levich, R.M, "On the Efficiency of Markets for Foreign Exchange," in R. Dornbusch and J. Frenkel (eds.), International Economic Policy: Theory and Evidence, (Baltimore, MD, Johns Hopkins, 1979).

Meese, R.A. and K. Rogoff, 1983a, "Empirical Exchange Rate Models of the Seventies: Do they fit out of sample?", Journal of International Economics, 14 (1983), 3-24.

Meese, R.A. and K. Rogoff, 1983b, "The Out of Sample Behavior of Empirical Exchange Rate Models: sampling error or misspecification?", in J.A. Frenkel (ed.), Exchange Rates and International Macroeconomics, NBER, (Chicago, 1983).

Meese, R.A. and K. Rogoff, "Was it Real? The Exchange Rate-Interest Differential Relation, 1973-84", Journal of Finance, 37 (1985), 1029-35.

Meese, R.A. and K. Singleton, 1982, "On Unit-Roots and the Empirical Modeling of Exchange Rates," Journal of Finance, 37, pp. 1029-35.

Mussa M., 1976 "The Exchange Rate, the Balance of Payments, and Monetary and Fiscal Policy under a Regime of Controlled Floating," Scandinavian Journal of Economics, 2, pp. 229-248.

———, "Empirical Regularities in the Behavior of Exchange Rates and Theories of the Foreign Exchange Market," in K. Brunner and A. Meltzer (eds.), Policies for Employment, Prices and Exchange Rates, Carnegie-Rochester Conference series, 11, (Amsterdam: North Holland, 1979).

———, "The Theory of Exchange Rate Determination", in Exchange Rate Theory and Practice, eds. J.F.O. Bilson and R.C. Marston, University of Chicago Press, (Chicago, Illinois, 1984), 13-78.

———, 1986, "Nominal Exchange Rate Regimes and the Behavior of Real Exchange Rates: Evidence and Implications," in K. Brunner and A. Meltzer (eds), Real Business Cycles and Actual Policies, Carnegie-Rochester Conference Series on Public Policy, (North-Holland, 1986).

Nelson, C.R., and Plosser, C.I., "Trends and Random Walks in Macroeconomic Time Series", Journal of Monetary Economics, 10 (1982), 129-62.

Obstfeld, M., "Floating Exchange Rates: experience and prospects", Brookings Papers on Economic Activity, 2, Brookings Institution, (Washington, D.C., 1985).

——— and K.Rogoff, 1984, "Exchange Rate Dynamics with Sluggish Prices Under Alternative Price-Adjustment Rules," International Economic Review, 25 (1984), pp. 159-174.

——— and A.C. Stockman, "Exchange-rate dynamics", in R.W. Jones and P.B. Kenen (eds.), Handbook of International Economics, Vol. 2, (North Holland, 1985).

Phillips, P.C.B., and P. Perron, "Testing for a Unit Root in Time Series Regressions", (mimeographed, 1988).

Roll, R., "Violations of Purchasing Power Parity and Their Implications for Efficient International Commodity Markets", in M. Sarnat and G.P. Szego (eds.), International Finance and Trade, Vol. 1, (Cambridge MA, Ballinger Publishing Company, 1979).

Schwert, W.G., "Tests for Unit Roots: A Monte Carlo Investigation", National Bureau of Economic Research, Technical Working Paper No. 73, (1988).

Stock, J.H., and Watson M.W., "Testing for Common Trends," Northwestern University (mimeographed, 1986).

——— and M.W. Watson, "Variable Trends in Economic Time Series", Journal of Economic Perspectives, Vol. 2, No. 3 (1988), pp. 147-174.

Stockman, A.C., "A Theory of Exchange Rate Determination", in Journal of Political Economy, 88 (1980), pp. 673-98.

———, "Real Exchange Rates Under Alternative Nominal Exchange Rate Systems", Journal of International Money and Finance, 2 (1983), 147-66.

Takagi, S., "Exchange Rate Expectations: A Survey of Survey Studies", IMF working paper, WP/90/52 (1990).