Monetary Models of the Canadian-U.S. Exchange Rate: A Reexamination of Empirical Evidence, 1971-1986

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This paper reexamines the evidence to support a monetary model representation of the Canadian-U.S. exchange rate for the 1970s and 1980s. We find that the estimated monetary models are not robust to the data and that changes in sample definition cause significant changes in the estimated parameters of the models. An examination of the time-series structure of the variables indicates a nonstationarity condition in levels, which brings into question the validity of standard monetary models. The estimated monetary models do not represent long-run cointegrated transformations. We conclude that monetary model representations of the Canadian-U.S. exchange rate that are apparently supported by previous research probably result from spurious regressions due to trend.

INTRODUCTION

Boothe (1983) argues that monetary models were appropriate for describing the Canadian foreign exchange market for the 1971-1978 period and that such models could have been used to speculate profitably on the Canadian-U.S. exchange rate over the 1974-1978 period. These results diverge sharply from other research (Meese and Rogoff, 1983; Backus, 1984) which finds little statistical evidence to support such results and determines that the Canadian-U.S. exchange rate is approximated more closely by a random walk model.[1] The finding of either a random walk or a monetary model representation of the exchange rate does not provide a sufficient test of the efficient market hypothesis (Bilson, 1981; Longworth, Boothe and Clinton, 1983; Levich, 1985). Nevertheless, it is surprising that such opposing conclusions about the Canadian-U.S. foreign exchange rate have not been reconciled. Whether the Canadian-U.S. exchange rate should be modeled as white noise or some other process is of interest equally to economists and to hommes d'affaires.

The purpose of this paper is to reexamine the data available for the 1970s and 1980s and to test whether there is support for a monetary model representation of the Canadian-U.S. exchange rate. The objectives are twofold: first, we estimate monetary models using

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[1] In a recent article, Meese and Rose (1991) examine the performance of monetary models respecified to include nonlinearities. They conclude that the generally poor performance of monetary models cannot be explained by nonlinearities.

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quarterly data for the period 1971-1978, consistent with the work of Boothe (1983), and examine the statistical evidence to support the conclusion that variations in the Canadian-U.S. exchange rate are explained by these models. Second, the monetary models are re-estimated using alternative definitions of some variables, monthly observations, and alternative periods. We find that the estimated models are not robust to the data and that minor variations in sample definition cause significant changes in the estimated parameters of the models. Further, an examination of the time-series structure of the monetary variables indicates a nonstationarity condition which questions the validity of a monetary model representation of the Canadian-U.S. exchange rate.

THE MODELS

Monetary models of exchange rate determination start from an assumption of perfect capital mobility. Differences among models are based on choices regarding the applicability of three theoretical principles: purchasing power parity (PPP) (Dornbusch, 1976; Frenkel, 1980; Levich, 1985); real or nominal interest rate parity (Clendenning, 1970; Aliber, 1973; Frenkel and Levich, 1977); and the Fisher equation (Krueger, 1983).

The purchasing power parity doctrine and the interest rate parity theorem are used in model development to define equilibrium conditions. The former maintains the existence of an equilibrium relationship between the purchasing power of currencies over time. The latter maintains an equilibrium between the difference in the spot and equilibrium exchange rates[2] and the interest rate differential (nominal or real depending on inflationary expectations). With inflationary expectations, the Fisher equation must be used to set the real rate of interest equal to the nominal rate, less the expected rate of inflation. If real rates of interest are equalized between two countries through capital mobility, then nominal interest rate differentials must reflect differences in expected inflation rates. We will examine the most common monetary models.

In presenting the models, the following symbols are used: m is nominal money demand, p is the price level, y is real national income, pfx is the price of one U.S. dollar in Canadian dollars, r is the nominal interest rate, π is the expected inflation rate, β_{ij} represents regression coefficients, and ε_i is a random error term. We define U.S. variables using superscript * and Canadian variables with no superscript. Lower case letters indicate a logarithmic transformation.

The purchasing power parity doctrine holds that the exchange rate (pfx) and the national price level will adjust to maintain a given currency's purchasing power across countries (Levich, 1985). The strict purchasing power parity hypothesis can be expressed as:

$$(1)\ pfx = p - p^*$$

If prices in Canada and the U.S. are determined by an identical demand for money function relating real money demand to real national income, we can write

[2] The spot exchange rate is the current rate for an exchange of currencies. The equilibrium exchange rate is that rate that would prevail in the absence of exchange control. (Krueger, 1983).

(2) $m - p = \gamma_0 + \gamma_1 y$ and $m^* - p^* = \gamma_0 + \gamma_1 y^*$

By combining equations (1) and (2), we define the purchasing power parity plus money equation as,

(3) $pfx = \beta_{01} + \beta_{m1}\ (m - m^*) + \beta_{y1}\ (y - y^*) + \varepsilon_1$

The purchasing power parity plus money equation represents the exchange rate as a linear function of differences in nominal money demand $(m - m^*)$ and real national income $(y - y^*)$. Variation in the exchange rate caused by variation in $(m - m^*)$ is measured by the parameter β_{m1}, which is positive and equal to one based on the neutrality of money. Variation in the exchange rate caused by variation in $(y - y^*)$ is measured by the parameter β_{y1} which is negative, indicating that an increase in Canadian income will increase the demand for money balances and increase the price of Canadian currency on the foreign market (i.e., pfx will decrease).

The next two models are a real interest parity equation and a nominal interest parity equation. Both equations are based on an uncovered interest parity condition, where Canadian and U.S. interest rates differ by the change in the expected exchange rate (d) or:

(4) $d = r - r^*$

If the expected rate of exchange depreciation is also a function of the difference between the spot exchange rate (pfx) and the equilibrium exchange rate $(\overline{pfx})$ and the expected rates of change of Canadian and U.S. inflation, the Fisher equation can be used to specify the change in the expected exchange rate as an equation of expectations formation:

(5) $d = -c(pfx - \overline{pfx}) + \pi - \pi^*$

where:

c = The speed of adjustment of the exchange rate to its equilibrium value.

Equating equations (4) and (5) generates

(6) $pfx - \overline{pfx} = \frac{1}{c}\ [(r - \pi) - (r^* - \pi^*)]$

The equilibrium exchange rate is defined using a purchasing power parity condition and allows us to define the real interest parity model as:

(7) $pfx = \beta_{02} + \beta_{p2}\ (p - p^*) + \beta_{r2}[(r - \pi) - (r^* - \pi^*)] + \varepsilon_2$

If expectations of future exchange rates do not depend on expected rates of inflation, equation (6) can be rewritten as

$$pfx - \overline{pfx} = \frac{1}{c(r - r^*)}$$

and a nominal interest parity model results or

(8) $pfx = \beta_{03} + \beta_{p3}\ (p - p^*) + \beta_{r3}\ (r - r^*) + \varepsilon_3$

Both the real and nominal interest parity models include the difference in current prices to explain the variation in exchange rates, as measured by the parameters β_{p2} and β_{p3}, respectively. Based on the purchasing power parity doctrine, an increase in the Canadian price level will be offset by a depreciation in the currency and both β_{p2} and β_{p3} will be positive. The two models differ in the definition of the interest rate differential used, either real or nominal. The change in the exchange rate caused by a change in the interest rate variables is measured by the parameters β_{p2} and β_{p3} respectively. An increase in Canadian interest rates will decrease the demand for money balances by increasing the opportunity cost of holding money balances, thus causing the Canadian dollar to appreciate and β_{r2} and β_{r3} will be negative.

The Dornbusch (1980) sticky-price model, which is somewhat more complicated than the previous specifications, incorporates imperfect commodity substitution and price rigidity. Purchasing power parity is assumed not to hold in the short run. The change in the expected exchange rate is defined as the difference between the spot and equilibrium exchange rates

$$d = -c(pfx - \overline{pfx}),$$

and is combined with an uncovered interest parity condition to form

(9) $pfx - \overline{pfx} = \dfrac{1}{c(r - r^*)}$

Again, imposing the restriction that the equilibrium exchange rate depends on a purchasing power parity condition, define money demand functions that depend on real income and the nominal interest rate as:

(10) $m = p + \alpha_1 y + \alpha_2 r$ and $m^* = p^* + \alpha_1 y^* + \alpha_2 r^*$

By combining these equations and noting that in equilibrium the real interest rate differential is zero, the sticky-price model is defined as:

(11) $pfx = \beta_{04} + \beta_{m4}\ (m - m^*) + \beta_{r4}\ (r - r^*) + \beta_{y4}\ (y - y^*) + \varepsilon_4$

where variations in the exchange rate are explained by variations in the differences in nominal money demand, nominal interest rates, and real national income. The expected sign of the coefficients follows directly from arguments presented earlier and β_{m4} will be positive and equal to one and β_{r4} and β_{y4} will be negative.

Our interest in estimating the monetary models developed here is to evaluate statistically whether such models are appropriate to represent the Canadian-U.S. exchange rate. The empirical procedure will be to replicate the estimation reported in Boothe (1981) using a similar data series and equations (3), (7), (8) and (11). The purpose is to determine whether our results are consistent with Boothe and a monetary model representation of the exchange rate. The empirical work also will evaluate the stability of the estimated parameters by reestimating the models under alternative variable definitions and sample sizes.

EMPIRICAL RESULTS AND DISCUSSION

The definitions of variables used in the estimation are listed in the appendix and are similar to those used by Boothe (1981 and 1983). Boothe's data set could not be replicated exactly because observations on Canadian M2 money supply reflect revisions to the series up to 1987. Comparable data for Boothe reflect revisions only up to 1979. A major revision and recalculation of the U.S. index of industrial production also occurred in July 1976. Data collected from the *International Finance Statistics* (IFS), the *Federal Reserve Bulletin* (FRB), and the *Bank of Canada Review* are used to obtain a continuous consistent time series that reflects changes to the index. As Boothe cites only the IFS, which shows revisions to the index only to October 1975, it is not clear how he dealt with this issue. These problems make it unclear whether we will be able to replicate Boothe's regression results exactly.

The nominal interest rate is proxied using the commercial rate. Although Boothe (1983) used the finance paper (FP) rate, the rate on short-term paper issued by financial corporations, the commercial paper (CP) rate, the rate on short-term paper issued by nonfinancial corporations, also is used (Backus, 1984). These rates represent alternative measures of the opportunity cost of holding money. In model specification, we first use the FP rate and then respecify the models using the CP rate. Our purpose is to test for parameter stability based on the two different proxies for the interest rate. Finally, in defining the expected long-run inflation differential ($\pi - \pi^*$) and the monetary aggregate differential ($m - m^*$), U.S. variables are calculated as weekly averages while the corresponding Canadian variables are Wednesday closing values. We assume the different measurements will not affect the estimation seriously.

OLS parameter estimates of the four monetary models are reported in Table 1. For comparison purposes, Boothe's (1981) results using quarterly data are shown in the first column. The second column, mid-quarter FP shows our results using—as did Boothe—mid-quarter observations of quarterly data and the finance paper (FP) rate as a proxy for short-term interest rates. To investigate whether the rather tedious calculation of mid-quarter sample observation points affects the results, the third column, end-quarter FP, uses the readily available end-quarter observation points. In the fourth column, mid-quarter CP, the commercial paper rate is used as a proxy for the interest rate, rather than the finance paper rate.

To satisfy hypotheses generated by the various models, we expect the coefficient β_m and β_y in the purchasing power parity plus money model to be positive (and equal to one) and negative respectively; β_p and β_r in the real and nominal interest parity models to be

Table 1—OLS Parameter Estimates of Four Monetary Exchange Rate Models, Quarterly Data 1971-1978 (standard errors in parentheses)

Purchasing Power Parity Plus Money[1]	$pfx = \beta_{01} + \beta_{m1}(m - m^*) + \beta_{y1}(y - y^*) + \varepsilon_1$
Real Interest Parity	$pfx = \beta_{02} + \beta_{p2}(p - p^*) + \beta_{r2}[(r - \pi^*) - (r^* - \pi^*)] + \varepsilon_2$
Nominal Interest Parity	$pfx = \beta_{03} + \beta_{p3}(p - p^*) + \beta_{r3}(r - r^*) + \varepsilon_3$
Dornbusch Sticky-Price	$pfx = \beta_{04} + \beta_{m4}(m - m^*) + \beta_{r4}(r - r^*) + \beta(y - y^*) + \varepsilon_4$

	Boothe	Mid-Quarter FP	End-Quarter FP	Mid-Quarter CP
PPP plus Money				
β_{01}[2]	0.855* (0.163)	0.775* (0.163)	0.807* (0.168)	-
β_{m1}	0.307* (0.061)	0.283* (0.062)	0.295* (0.064)	-
β_{y1}	-0.708* (0.277)	-0.540* (0.251)	-0.577* (0.262)	-
R squared[3]	0.49	0.39	0.39	-
DW[4]	0.33	0.32	0.30	-
Real Interest Parity				
β_{02}	0.032* (0.008)	-0.032* (0.008)	0.034* (0.008)	-0.032* (0.010)
β_{p2}	1.189* (0.217	1.685* (0.176)	1.802* (0.205)	1.619* (0.238)
β_{r2}	-9.944* (2.175)	-8.328* (2.008)	-9.331* (2.031)	-5.627* (1.974)
R squared	0.71	0.68	0.71	0.59
DW	0.51	0.57	0.56	0.42
Nominal Interest Parity				
β_{03}	0.004 (0.006)	0.0007 (0.007)	0.007 (0.006)	-0.010 (0.007)
β_{p3}	1.875* (0.184)	1.685* (0.176)	1.86* (0.177)	1.693* (0.211)
β_{r2}	-8.784* (1.440)	-7.32* (1.30)	-8.114* (1.36)	-5.900* (1.441)
R squared	0.78	0.74	0.77	0.67
DW	0.60	0.61	0.57	0.48
Dornbusch Sticky-Price				
β_{04}	1.487* (0.123)	1.253* (0.125)	1.335* (0.130)	1.131* (0.166)
β_{m4}	0.536* (0.045)	0.458* (0.047)	0.488* (0.048)	0.416* (0.063)
β_{r4}	-11.094* (1.424)	-9.972* (1.485)	-11.021* (1.602)	-6.88* (1.86)
β_{y4}	-0.654* (0.130)	-0.356* (0.161)	-0.434* (0.164)	-0.375**(0.214)
R squared	0.84	0.76	0.76	0.57
DW	0.76	0.87	0.86	0.56

* Statistically significant at $\alpha = 0.05$ level
** Statistically significant at $\alpha = 0.10$ level

[1] A superscript * represents a U.S. variable and no superscript represents a Canadian variable, and pfx is the Canada-U.S. exchange rate. Source: *Bank of Canada Review*; $m - m^*$ is monetary aggregate differential. Source: *Bank of Canada Review* and Federal Reserve Bank of San Francisco; $y - y^*$ is real income differential. Source: IMF, *International Finance Statistics, Federal Reserve Bulletin,* and *Bank of Canada Review*; $p - p^*$ is price differential. Source: IMF, *International Financial Statistics*; $r - r^*$ is nominal interest differential. Source: *Bank of Canada Review* and *Federal Reserve Bulletin*; and $\pi - \pi^*$ is expected long-run inflation differential. Source: *Bank of Canada Review* and *Federal Reserve Bulletin*

[2] β represents the estimated regression coefficients

[3] R squared represents the multiple regression coefficient

[4] DW represents the Durbin-Watson statistic

positive and negative respectively; and β_m and β_r in the Dornbusch sticky-price model to be positive (and equal to one) and negative respectively.

Boothe's quarterly results (column 1) show that the estimated coefficients are consistent with the hypothesized sign for each coefficient in each of the models, i.e., the coefficients for nominal money demand (β_m) and for the price level (β_p) are positive, and the coefficients for real national income (β_y) and for the interest rate (β_r) are negative. In all cases, the estimated coefficients are statistically significant from zero at the 95 percent confidence level. A null hypothesis of a neutral money effect (i.e., H_0: $\beta_m = 1$) is rejected, however, for both the purchasing power parity plus money and Dornbusch sticky-price models.

In column 2 of Table 1, we report our mid-quarter FP results. The estimated coefficients match with the hypothesized sign for each coefficient. The nominal money demand variables (β_m) and the price level variables (β_p) are positive and statistically significant from zero at the 95 percent confidence level. But again a null hypothesis of a neutral money effect (i.e., H_0: $\beta_m = 1$) is rejected for both the purchasing power parity plus money and the Dornbusch sticky-price models. The estimated coefficients for the real national income variables (β_y) and for the interest rate variables (β_r) are negative and statistically significant. Our results match closely those reported by Boothe, with estimated coefficients having the same sign and statistical significance. Moreover, our results support a monetary model representation of the exchange rate. Our results, however, show a smaller absolute value for each coefficient (except β_{p3}) compared to Boothe's results.[3]

Although the monetary models appear to fit the data reasonably well, the Durbin-Watson (DW) statistic for each model suggests potentially serious problems. A low DW statistic indicates first order autocorrelation. Therefore, we consider a Cochrane-Orcutt (CORC) transformation of the four monetary models. The results of the estimation and Boothe's corresponding results are reported in Table 2. Again, our estimated coefficients and Boothe's results match closely in terms of parameter size and sign. Exceptions are a sign reversal for real income (β_{y1}) in the purchasing power parity plus money equation and relatively smaller values for the estimated parameters in the Dornbusch sticky-price equation. A more serious problem is that under a CORC transformation almost all parameter estimates are not significantly different from zero. The estimated models clearly are not stable under the CORC transformation.[4] Consequently, the low DW statistic in levels combined with the inability to reject a null hypothesis of zero-valued parameter estimates for the CORC transformed regressions lead us to suspect that the monetary models defined in equations (3), (7), (8) and (11) are misspecified.

Returning to Table 1, the third column, end-quarter FP, shows results based on repeating the regression exercise using end-quarter observation points. The end-quarter FP results match the estimated coefficients obtained using the mid-quarter FP data in sign and statistical significance. What is more, the end-quarter FP results match more closely the estimated coefficients reported in Boothe than do the mid-quarter FP results. Given the

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[3] This finding is perhaps the result of our variables representing more recent revisions to the data series compared to Boothe's variables.

[4] Boothe and Glassman (1987) show similar poor performance of monetary models under autocorrelation using data for Germany.

Table 2—Parameter Estimates of Monetary Exchange Rate Models Using Cochrane-Orcutt Transformation, Quarterly Data 1971-1978 (standard errors in parentheses)

Purchasing Power Parity Plus Money[1]	$pfx = \beta_{01} + \beta_{m1}(m - m^*) + \beta_{y1}(y - y^*) + \varepsilon_1$
Real Interest Parity	$pfx = \beta_{02} + \beta_{p2}(p - p^*) + \beta_{r2}[(r - \pi^*) - (r^* - \pi^*)] + \varepsilon_2$
Nominal Interest Parity	$pfx = \beta_{03} + \beta_{p3}(p - p^*) + \beta_{r3}(r - r^*) + \varepsilon_3$
Dornbusch Sticky-Price	$pfx = \beta_{04} + \beta_{m4}(m - m^*) + \beta_{r4}(r - r^*) + \beta(y - y^*) + \varepsilon_4$

	Boothe		Mid-Quarter FP	
PPP plus Money				
β_{01}[2]	0.531	(0.628)	0.567	(0.372)
β_{m1}	0.126	(0.286)	0.191	(0.141)
β_{y1}	-0.013	(0.151)	0.030	(0.136)
R squared[3]	0.923		0.891	
ρ[4]	0.984		0.979	
Real Interest Parity				
β_{02}	0.235	(0.212)	0.056	(0.078)
β_{p2}	0.513	(0.688)	0.542	(0.585)
β_{r2}	-3.070*	(1.59)	-2.530	(1.70)
R squared	0.936		0.898	
ρ	0.986		0.982	
Nominal Interest Parity				
β_{03}	0.194	(0.171)	0.063	(0.071)
β_{p3}	0.631	(0.670)	0.561	(0.563)
β_{r3}	-3.174*	(1.392)	-3.060*	(1.52)
R squared	0.939		0.900	
ρ	0.984		0.981	
Dornbusch Sticky-Price				
β_{04}	1.480*	(0.573)	0.544	(0.351)
β_{m4}	0.547*	(0.203)	0.179	(0.133)
β_{r4}	-4.890*	(1.60)	-3.320*	(1.54)
β_{y4}	-0.287**	(0.157)	-0.027	(0.131)
R squared	0.928		0.907	
ρ	0.979		0.980	

* Statistically significant at $\alpha = 0.05$ level
** Statistically significant at $\alpha = 0.10$ level

[1] A superscript * represents a U.S. variable and no superscript represents a Canadian variable, and pfx is the Canada-U.S. exchange rate. Source: *Bank of Canada Review*; $m - m^*$ is monetary aggregate differential. Source: *Bank of Canada Review* and Federal Reserve Bank of San Francisco; $y - y^*$ is real income differential. Source: IMF, *International Finance Statistics, Federal Reserve Bulletin,* and *Bank of Canada Review*; $p - p^*$ is price differential. Source: IMF, *International Financial Statistics*; $r - r^*$ is nominal interest differential. Source: *Bank of Canada Review* and *Federal Reserve Bulletin*; and $\pi - \pi^*$ is expected long-run inflation differential. Source: *Bank of Canada Review* and *Federal Reserve Bulletin*

[2] β represents the estimated regression coefficients

[3] R squared represents the multiple regression coefficient

[4] ρ represents first order autocorrelation

similarity of regression estimates, the choice between using mid- or end-quarter observations does not appear to be significant.

In the fourth column, mid-quarter CP, the commercial paper rate replaces the finance paper rate as a proxy for the short term interest rate and causes a reduction in the estimated value of the interest rate variable (β_{ri}) by a quarter to a half.[5] Otherwise, however, the results match closely the estimated coefficients in the other columns. The appropriate proxy for the interest rate should be based on information regarding which financial instruments are more likely to be used by actors in the exchange market.[6]

In general, the results reported in Table 1 are favorable to a monetary model representation of the Canadian-U.S. exchange rate. These results differ sharply, however, from those obtained by Backus (1984), who also estimates a number of monetary models to represent the Canadian-U.S. exchange rate using quarterly data for the 1971-1980 period. Backus not only finds autocorrelation, but reports many parameters that are either statistically insignificant or had the wrong sign. Backus does use M1 rather than M2 in defining the money supply. Except for the Dornbusch sticky-price model, the estimated coefficients for this variable are similar to those obtained here. The income variable used by Backus always is of the hypothesized sign and statistically significant but larger in magnitude relative to our corresponding estimates. We speculate that the difference is due to his use of GNP compared to the Index of Industrial Production used here.[7] The short-term interest rate used by Backus is proxied by the 90 day financial paper rate for Canada and the 90 day commercial paper rate for the U.S., but unlike our results, Backus reports estimated coefficients that are insignificant and sometimes of the wrong sign. In short, although Backus uses a similar but longer data series than used here, his results can not support a monetary model representation of the Canadian-U.S. exchange rate. This leads us to question whether the results reported in Table 1 are specific to the 1971-1978 time period examined

To compare stability of the models across different observation periods, we reestimate the four monetary models for 1971-1978 using monthly data. Next, based on economic conditions that prevailed in Canada, we divide the 1971-1978 period into two subperiods: 1971-1973 and 1974-1978. Then we perform separate regressions using monthly data for each subperiod. For 1971-1973, Canada experienced favorable terms of trade, a balanced current account, and a strong dollar relative to the U.S. dollar. By 1974 inflation in Canada had reached double digits, the current account was in deficit, and the exchange rate was under pressure to fall. Subsequently, the Canadian dollar depreciated approximately 15 percent relative to the U.S. dollar. These developments may have caused significant changes in the parameters of the models between the two periods. We test for this possi-

[5] Because the interest rate does not appear in the PPP plus money model, the mid-quarter CP and mid-quarter FP results are identical and, as such, the mid-quarter CP results are not reported.

[6] Both the end-quarter FP and the mid-quarter CP results show a low DW statistic for each model, indicating first order autocorrelation. But, as with the mid-quarter FP models, correcting for autocorrelation causes some parameter sign changes and almost all parameters are not significantly different from zero.

[7] Both GNP and the Index of Industrial Production are proxies for income; however, GNP is a broader measure of production, but has a smaller variance compared to the industrial index. These differences apparently cause the real income parameter in the Backus model to be larger in magnitude compared to our estimate.

bility using a Chow-test procedure. Finally, to examine how robust the results are outside the 1971-1978 period we reestimate the four monetary models using monthly data for 1979-1986. Several authors have argued that monetary models break down in the late 1970s (Frenkel, 1980; Boothe and Glassman, 1987). The purpose of extending the monthly data set for seven years is to complement the earlier seven year period 1971-1978 and to test for monetary model breakdown in the latter period.

Table 3 reports the results of OLS regressions for the four monetary models. The use of monthly rather than quarterly observations for the 1971-1978 period in the first column yields estimates that differ only in the magnitude of the interest rate parameter. The estimated parameters all maintain their hypothesized sign and, as expected with the increase in sample size, the standard error on all parameters is smaller with monthly than quarterly data.[8] The use of monthly observations, as with quarterly, for the 1971-1978 period provides results that are favorable to a monetary model representation of the Canadian-U.S. exchange rate.

The regression results for the subperiods 1971-1973 (36 observations) and 1974-1978 (60 observations) are reported in columns 2 and 3 of Table 3. There are many insignificant parameter estimates and incorrect signs in each of the models estimated. A Chow-test applied to each monetary model indicates that the two subperiods are not equivalent and, therefore, the data series cannot be pooled.[9] In short, the results obtained for the period 1971-1978 do not hold true for the subperiods 1971-1973 and 1974-1978 and cannot support monetary models. Consequently, the results obtained for the 1971-1978 period are not robust.

Consider next the results for the regressions of the four models of exchange rate determination using monthly data for the period 1979-1986 reported in column four of Table 3.[10] Here there are some significant estimates with hypothesized signs, but there are also many significant estimates with incorrect signs, such as those in the Dornbusch sticky-price model. Overall the results differ dramatically from those for the earlier period. It appears that monetary models cannot represent consistently the Canadian-U.S. exchange rate. The poor performance of monetary models in the late 1970s and 1980s also is reported by Boothe and Glassman (1987) and Meese and Rogoff (1983). Hence, results reported in Table 1 appear to be merely a statistical anomaly specific to the time period examined.

Perhaps a clue to the poor performance of monetary models is provided by the low DW statistic reported for all models in Tables 1 and 3. Granger and Newbold (1974) and Granger (1986) suggest that a low DW statistic may indicate a misspecified equation due to nonstationarity in the variables. Nonstationarity implies that the underlying character-

[8] It should be noted, however, that if the models are autoregressive or represent a cointegrated system, the standard errors are biased seriously.

[9] We carried out the Chow test under the assumption that the regression error terms satisfy the classical properties. Because the Durbin-Watson statistics for the two subsamples regressions are low, we correct for first-order autocorrelation and repeat the Chow test using the transformed data. The Chow-test results for the transformed data are similar to those using the original data series.

[10] Some additional regressions using subsamples of the 1979-1986 data period generate similar results to the complete period sample.

Table 3—OLS Parameter Estimates of Four Monetary Exchange Rate Models Monthly Data, Various Periods (standard errors in parentheses)

Purchasing Power Parity Plus Money[1]	$pfx = \beta_{01} + \beta_{m1}(m - m^*) + \beta_{y1}(y - y^*) + \varepsilon_1$
Real Interest Parity	$pfx = \beta_{02} + \beta_{p2}(p - p^*) + \beta_{r2}[(r - \pi^*) - (r^* - \pi^*)] + \varepsilon_2$
Nominal Interest Parity	$pfx = \beta_{03} + \beta_{p3}(p - p^*) + \beta_{r3}(r - r^*) + \varepsilon_3$
Dornbusch Sticky-Price	$pfx = \beta_{04} + \beta_{m4}(m - m^*) + \beta_{r4}(r - r^*) + \beta(y - y^*) + \varepsilon_4$

	1971-1978	1971-1973	1974-1978	1979-1986
PPP plus Money				
β_0[2]	0.752* (0.095)	0.091 (0.124)	0.0024(0.082)	-1.215*(0.356)
β_{m1}	0.275* (0.036)	0.036 (0.045)	0.003 (0.030)	-0.482*(0.129)
β_{y1}	-0.475* (0.139)	0.359*(0.090)	0.097 (0.073)	-0.992*(0.192)
R squared[3]	0.38	0.28	0.02	0.29
DW[4]	0.19	0.81	0.23	0.80
Real Interest Parity				
β_{02}	-0.030* (0.005)	-0.002 (0.003)	-0.006 (0.004)	0.173*(0.013)
β_{p2}	0.1625*(0.121)	-0.349*(0.134)	0.243 (0.164)	1.032*(0.181)
β_{r2}	-22.811* (3.306)	1.710*(2.181)	-3.77 (2.74)	14.910*(6.18)
R squared	0.65	0.13	0.01	0.39
DW	0.37	0.44	0.20	0.98
Nominal Interest Parity				
β_{03}	-0.001 (0.004)	-0.0003(0.002)	-0.0015(0.003)	0.153*(0.012)
β_{p3}	1.658* (0.109)	-0.348*(0.128)	0.303**(0.177)	1.185*(0.168)
β_{r3}	-20.65* (2.35)	-3.819**(2.053)	-3.78 (2.39)	8.42 (5.36)
R squared	0.71	0.19	0.02	0.37
DW	0.45	0.50	0.21	0.91
Dornbusch Sticky-Price				
β_{04}	1.195* (0.080)	0.978*(0.123)	0.174 (0.113)	-1.529*(0.354)
β_{m4}	0.437* (0.028)	0.038 (0.045)	0.065 (0.041)	-0.592*(0.127)
β_{r4}	-27.339* (2.748)	-2.485*(0.123)	-6.190* (2.89)	17.73* (5.62)
β_{y4}	-0.321* (0.098)	-0.341*(0.091)	0.059 (0.073)	0.930*(0.184)
R squared	0.70	0.29	0.07	0.35
DW	0.56	0.83	0.26	0.93

* Statistically significant at $\alpha = 0.05$ level
** Statistically significant at $\alpha = 0.10$ level

[1] A superscript * represents a U.S. variable and no superscript represents a Canadian variable, and pfx is the Canada-U.S. exchange rate. Source: *Bank of Canada Review*; $m - m^*$ is monetary aggregate differential. Source: *Bank of Canada Review* and Federal Reserve Bank of San Francisco; $y - y^*$ is real income differential. Source: IMF, *International Finance Statistics, Federal Reserve Bulletin,* and *Bank of Canada Review*; $p - p^*$ is price differential. Source: IMF, *International Financial Statistics*; $r - r^*$ is nominal interest differential. Source: *Bank of Canada Review* and *Federal Reserve Bulletin*; and $\pi - \pi^*$ is expected long-run inflation differential. Source: *Bank of Canada Review* and *Federal Reserve Bulletin*

[2] β represents the estimated regression coefficients

[3] R squared represents the multiple regression coefficient

[4] DW represents the Durbin-Watson statistic

istics of the stochastic process change over time. Several authors have reported that exchange rates exhibit characteristics of nonstationarity (Meese and Rose, 1991; Boothe and Glassman, 1987; Frenkel and Meese, 1987; Nelson and Plosser, 1982).

A series, x_t, is defined as integrated of order d ($x_t \sim I(d)$), if after differencing d times the series is stationary. Consequently, a series is stationary in levels if it is $\sim I(0)$. Dickey and Fuller (1979; 1981) provide a convenient test for stationarity based on a null hypothesis that the series is $\sim I(1)$ against an alternative hypothesis that the series is $\sim I(0)$ (i.e., stationary). The test requires forming the following regression for each series:

$$(12)\ \Delta X_t = \beta_0 + \beta X_{t-1} + \sum_{i=1}^{k} \beta_i \Delta X_{t-i} + \varepsilon_t$$

The standard Dickey-Fuller (D-F) test is defined by setting $k = 0$ whereas, the augmented D-F (AD-F) test is defined by setting the length of k to achieve a white noise structure in ε_t. The null hypothesis of nonstationarity is rejected if β is negative and significantly different from zero with significance levels provided by Dickey and Fuller (1979).

Table 4—Tests for Stationarity in Levels Using the Dickey-Fuller (D-F) and Adjusted Dickey-Fuller (AD-F) Tests

Variables[1]	D-F[2]	Q[3]	AD-F[4]	Q	TD-F[5]	Q
pfx	0.034	28.08	1.099 (1)	18.65	-1.36	27.84
$m - m^*$	-0.611	88.55	-0.908 (10)	28.40	-2.29	81.04
$y - y^*$	-2.130	62.86	-1.538 (8)	13.13	-2.10	62.83
$p - p^*$	-0.892	21.74	-0.672 (2)	14.43	-2.59	19.86
$r - r^*$	-1.166	18.82	-2.140 (2)	16.46	-1.70	18.38
$\pi - \pi^*$	-2.370	28.27	-2.400 (1)	19.51	-2.06	28.54
$(r - \pi) - (r^* - \pi^*)$	-1.670	18.74	-2.160 (2)	16.07	-1.73	18.25

[1] pfx is Canada-U.S. exchange rate. Source: Bank of Canada Review; $m - m^*$ is monetary aggregate differential. Source: *Bank of Canada Review* and Federal Reserve Bank of San Francisco; $y - y^*$ is real income differential. Source: IMF, *International Finance Statistics, Federal Reserve Bulletin* and *Bank of Canada Review*; $p - p^*$ is price differential. Source: IMF, *International Financial Statistics*; $r - r^*$ is nominal interest differential. Source: *Bank of Canada Review* and *Federal Reserve Bulletin*; and $\pi - \pi^*$ is expected long-run inflation differential. Source: *Bank of Canada Review* and *Federal Reserve Bulletin*

[2] For the Dickey-Fuller tests the critical value at the 10 percent level is -2.88

[3] Box-Pierce Portmanteau Q-statistic and is distributed as $(\chi^2_{\alpha=0.10}) = 32.01$

[4] The number in parentheses represents the lag order, k in equation (12), to achieve white noise residuals

[5] D-F test for the alternative hypothesis of trend stationarity

The D-F and AD-F tests are applied to the levels of all variables defined in the four monetary models using monthly observations for the period 1971-1989 and the results are reported in Table 4.[11] To test that the estimated residuals are white noise, we calculate a

[11] Monthly observations are used because they provide more information than do quarterly observations, and because they will provide a better test of stationarity.

Box-Pierce Portmanteau Q-statistic for each D-F regression. If the estimated residuals are white noise, the autocorrelation coefficients should not differ significantly from zero. The Q-statistic tests the joint hypothesis that all autocorrelation coefficients are zero. The Q-statistic is distributed as chi-square with 23 degrees of freedom ($\chi^2_{\alpha=0.10}$ = 32.01). In Table 4, the D-F and AD-F test statistics are evaluated using a one tailed test at a 10 percent significance level of -2.88 (Granger, 1986).

The D-F statistic calculated for each series cannot reject nonstationarity. Further, the Q-statistic indicates nonwhite noise residuals for the money supply ($m - m^*$) and income variables ($y - y^*$). The AD-F test ensures that for all variables the estimated residuals are white noise (i.e., an insignificant Q-statistic), but again the AD-F statistics are less than their critical value and we cannot reject a null hypothesis of nonstationarity. To allow for the possibility that each series is trend stationary, we add a time trend to equation (5) and test the null hypothesis of nonstationarity against the alternative of trend stationary. The results of these tests are reported in column five (TD-F) in Table 4. Removing a trend from each series increases the D-F statistics substantially, but a null hypothesis of nonstationarity still cannot be rejected.

The Dickey-Fuller tests indicate that the monetary variables used in estimation are nonstationary. Granger (1986) and Stock and Watson (1988) argue that nonstationarity and trends in variables can lead one to accept an otherwise spurious regression. The problem for regression analysis is that nonstationary variables may cause a serious bias in the estimated coefficients toward rejection of the null hypothesis of no relationship among the variables (Phillips, 1986). Nelson and Kang (1984) show that standard econometric analysis of nonstationary series can result in random R^2 and estimated residuals that exhibit spurious periodicity. The low DW statistics obtained for the estimated monetary models reported here and the instability of the regression coefficients may be explained by this spurious relationship.

It is possible, however, that the monetary models represent long-run equilibrium relationships. In other words, although individually for each variable a null hypothesis of nonstationarity cannot be rejected, a linear combination of the variables may represent a stationary cointegrated series (Engle and Granger, 1987). A cointegrated series requires that each variable be integrated of the same order and that the estimated residuals from the cointegrating regression be integrated of order zero (Hall, 1986). For example, if the series x_t and y_t are each ~ I(1) and $z_t = x_t + by_t$ is ~ I(0) then b is defined as a cointegrating parameter and z_t represents a long-run equilibrium relationship.

To apply this procedure to the monetary models used here, we first test whether each series is integrated of order one using the D-F and AD-F tests. The results are reported in Table 5. For all variables, the D-F and AD-F statistics strongly reject a null hypothesis of nonstationarity in favor of the alternative of stationary in first differences. We proceed to test, with each variable integrated of the same order (one), that the monetary models defined earlier represent co-integrating transformations. A Dickey-Fuller test is applied to the residuals of each regression from the estimated models. The D-F statistic for each equation (i.e., -1.49, -2.57, -2.73, -2.79 for equations (3), (7), (8) and (11), respectively) is less than the critical value; a null hypothesis of noncointegration cannot be rejected.

Table 5—Tests for Stationarity in First Differences Using the Dickey-Fuller (D-F) and Adjusted Dickey-Fuller (AD-F) Tests

Variables[1]	D-F[2]	Q[3]	AD-F[4]	Q
Δpfx	-13.40	18.08	-13.40 (0)	18.08
$\Delta(m - m^*)$	-12.32	85.09	-10.91 (10)	23.55
$\Delta(y - y^*)$	-7.65	35.47	-7.45 (8)	14.98
$\Delta(p - p^*)$	-10.35	22.95	-10.11 (2)	19.21
$\Delta(r - r^*)$	-9.03	18.47	-9.19 (2)	16.94
$\Delta(\pi - \pi^*)$	-8.43	25.45	-8.43 (0)	25.45
$\Delta[(r - \pi) - (r^* - \pi^*)]$	-9.00	18.30	-9.19 (1)	16.61

[1] pfx is Canada-U.S. exchange rate. Source: Bank of Canada Review; $m - m^*$ is monetary aggregate differential. Source: *Bank of Canada Review* and Federal Reserve Bank of San Francisco; $y - y^*$ is real income differential. Source: IMF, *International Finance Statistics*, *Federal Reserve Bulletin* and *Bank of Canada Review*; $p - p^*$ is price differential. Source: IMF, *International Financial Statistics*; $r - r^*$ is nominal interest differential. Source: *Bank of Canada Review* and *Federal Reserve Bulletin*; and $\pi - \pi^*$ is expected long-run inflation differential. Source: *Bank of Canada Review* and *Federal Reserve Bulletin*

[2] For the Dickey-Fuller tests the critical value at the 10 percent level is -2.88

[3] Box-Pierce Portmanteau Q-statistic and is distributed as $(\chi^2_{\alpha=0.10}) = 32.01$

[4] The number in parentheses represents the lag order, k in equation (12), to achieve white noise residuals

Consequently, a long-run equilibrium relationship as defined by the monetary models examined here is not supported by the data.

CONCLUDING COMMENTS

The results of this study are not favorable to a monetary approach to exchange rate determination. The estimated models reported here show parameter estimates that are not stable to variations in the sample period and to changes in variable definition. The models generate low DW statistics and collapse under standard corrections for autocorrelation. Moreover, the monetary variables used here show characteristics of nonstationarity, and the monetary models do not represent long-run cointegrated series. We conclude that this evidence casts considerable doubt on the reliability of monetary models to explain exchange rate movements.

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Appendix A—Variable Definitions and Sources

pfx = Wednesday closing Canada-U.S. exchange rates (Canadian dollars per U.S. dollar). Source: *Bank of Canada Review*

$r - r^*$ = Nominal interest differential. Represented by Canadian and U.S. 90 day finance company paper yields or commercial paper rate. Rates are expressed in annual percentage terms and are divided by 400.[1] Sources: *Bank of Canada Review* and *Federal Reserve Bulletin*

$\pi - \pi^*$ = Expected long-run inflation differential. Proxied by Canadian and U.S. long term (over ten years) government bond yields. Canadian data are as at Wednesday, U.S. data are averages of weeks ending Wednesday. Rates are expressed in annual percentage terms and are divided by 400. Sources: *Bank of Canada Review* and *Federal Reserve Bulletin*

$m - m^*$ = Monetary aggregate differential. Canadian and U.S. M2. Canadian data are as at Wednesday, U.S. data are averages of weeks ending Wednesday. Sources: *Bank of Canada Review* and *Federal Reserve Bank of San Francisco*

$y - y^*$ = Real income differential. Canadian and U.S. seasonally adjusted index of industrial production. Source: *IMF, International Finance Statistics, Federal Reserve Bulletin* and *Bank of Canada Review*

$p - p^*$ = Price differential. Canadian and U.S. seasonally adjusted consumer price indices (all items). Source: *IMF, International Financial Statistics*

[1] Boothe divides the percentage short-term and long-term interest rates expressed in annual terms by 400 when using quarterly data. The effect of this transformation is to convert percentage annual interest rates into quarterly decimal rates. To maintain consistency, we divide monthly data on interest rates by 1200 in order to use monthly decimal rates