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# Efficiency and a Simple Model of Exchange Rate Determination

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EFFICIENCY AND A SIMPLE MODEL OF EXCHANGE RATE DETERMINATION

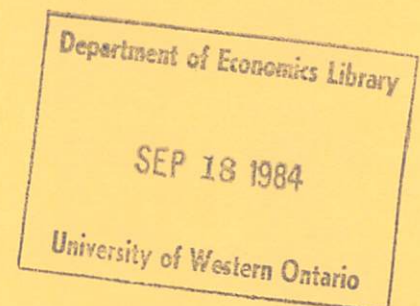
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This paper contains preliminary findings from research work still in progress and should not be quoted without prior approval of the author.

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**EFFICIENCY AND A SIMPLE MODEL OF EXCHANGE RATE DETERMINATION\***

by

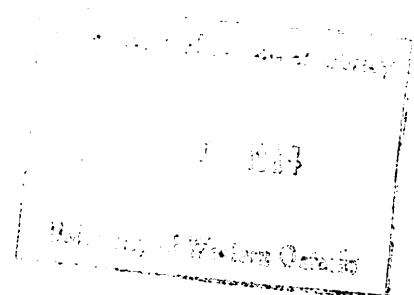
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## ABSTRACT

A monetary model has no intrinsic dynamics so the intertemporal behavior of exchange rates, spot and forward, depend entirely upon the time processes of the exogenous variables. For typical values of interest elasticities of money demand, only if all shocks are permanent do exchange rates follow random walks.

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4 6

Recently, changes in relative outputs in the Canadian-U.S. context have evidenced serial correlation so that shocks are not exclusively permanent ones. Nonetheless, exchange rates have followed a random walk. This suggests that the monetary model is an inappropriate specification so that models which pay attention to the choice of currency of denomination deserve greater attention.

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## I. INTRODUCTION

The "empirical regularities" characterization of exchange rate movements has had a strong influence recently (Mussa (1979), Frenkel (1981), Meese and Rogoff (1983)). The major conclusions of this research are: that the spot exchange rate closely approximates a random walk; and that there is close conformity of the spot and forward exchange rates.

A major question arises as to whether these regularities are consistent with popular models of exchange rate determination. A monetary model seems like the most promising since it has no intrinsic dynamics (Obstfeld and Stockman (1983)) which would, by themselves, lead to systematic movements on exchange rates.<sup>1</sup> Nonetheless, such a model would permit ex post explanations of exchange rate changes.

Section II presents such a model employing the standard assumptions: specialization in money holding; and one-period domestic bonds which are perfect substitutes for foreign ones. It is noted there that the non-tradability of money violates the implicit assumption upon which spot market efficiency tests rest.

Sections III and IV solve the model for general money supply processes, before examining some specific ones in greater detail. It is found for most processes there are roles for both interest rates and exchange rates to play in equilibrating financial markets. Only if the exogenous variables follow random walks, or if the interest elasticity of demand for money is very high, will the exchange rate move unpredictably in a monetary model.

Section V shows that during the 1970's the Canadian/U.S. dollar exchange rates' movements closely approximated random walks. Now, interest elasticities of money demand are typically much smaller than would be needed to generate such movements. Furthermore, relative outputs during that period departed from a random walk.

These results bring into question the applicability of such simple models of exchange rate determination. They suggest that greater attention should be directed to set-ups which focus on the choice of currency of denomination of asset holdings.

## II. A MONETARY MODEL

Consider the following specification of the popular monetary model, which is based on the usual assumptions: purchasing power parity, uncovered interest rate parity, and non-substitution between monies.

In the absence of barriers to trade, nominal prices in the two countries analyzed are linked through purchasing power parity which has the status of an arbitrage condition:

$$(1) \quad p_t = e_t + p_t^*$$

All variables are in logs (except interest rates and time):  $p_t$  ( $p_t^*$ ) denote domestic and foreign price levels at time  $t$ , and  $e$  is the exchange rate expressed as the domestic-currency price of a unit of foreign money. Price levels and the exchange rate are random variables, and according to (1) purchasing power parity holds for all realizations of these random variables.<sup>2</sup>

The domestic economy is small and takes as given the stochastic processes determining  $p_t^*$  and all other foreign variables.

One-period ex ante real interest rates on perfectly substitutable domestic and foreign bonds are given in (2) and (3) where  $r_t$  ( $r_t^*$ ) denote real interest rates,  $i_t$  ( $i_t^*$ ) nominal interest rates, and  ${}_t p_{t+1}$  ( ${}_t p_{t+1}^*$ ) denote subjective expectations held at time  $t$  for  $t+1$ :<sup>3</sup>

$$(2) \quad r_t = i_t + p_t - {}_t p_{t+1}$$

$$(3) \quad r_t^* = i_t^* + p_t^* - {}_t p_{t+1}^*$$

The forward exchange rate is determined by the covered interest rate parity condition (4) and is based on arbitrage; (5) is the uncovered interest rate parity condition and is based on the fact that risk neutral speculators are not willing to hold domestic and foreign bonds unless their expected real yields are equal.<sup>4</sup>

$$(4) \quad {}_t f_{t+1} = e_t + i_t - i_t^*$$

$$(5) \quad r_t = r_t^*$$

An implication of (4) and (5), along with (1), is that

$$(6) \quad {}_t f_{t+1} = {}_t e_{t+1}$$

Equilibrium in domestic financial markets is based on domestic residents' choices between holding domestic money and bonds. The difference between the rate of return on bonds and money is equal to the nominal interest rate giving rise to a monetary equilibrium condition:

$$M_t = p_t + \beta y_t - \alpha i_t.$$

Here,  $M_t$  denotes the exogenous supply of domestic money, and  $y_t$ , exogenous domestic output. The parameters  $\beta$  and  $\alpha$  are defined to be positive and  $\alpha$  captures the margin of substitution between money and bonds.

The model is closed by specifying stochastic processes for the exogenous variables  $[M_t^*, y_t^*, r_t^*, i_t^*, p_t^*]$ , and the formation of subjective expectations. Foreign output,  $\bar{y}^*$ , and the foreign real interest rate,  $\bar{r}^*$ , denoted by  $\bar{r}$ , are assumed to be fixed. Therefore, the exogenous stochastic processes for foreign prices and interest rates depend upon the stochastic process on the foreign money supply,  $M_t^*$ :

$$M_t^* = p_t^* + \beta y_t^* - \alpha i_t^*.$$

Expectations are assumed to be rational such that for any variable  $x$

$${}_t x_{t+J} \equiv {}_t E x_{t+J} | \Omega_t \quad J=0,1,2,\dots$$

Here  $E$  is the mathematical expectations operator and  $\Omega_t$  the information set on which expectations are conditioned.  $\Omega_t$  is taken to include the model, current and lagged realizations of all variables, and the stochastic processes for the exogenous variables.

The model is representative of the popular monetary view of exchange rate determination. Noteworthy aspects of this view are: (1) No substitution across currencies implying that the real (pecuniary) yields on domestic and foreign money can differ in equilibrium.<sup>5</sup> (2) Interest bearing assets of different currency denomination are perfect substitutes.



In equilibrium, individuals are indifferent as between (interest bearing) assets and liabilities denominated in different currencies. (3) Exchange rates are fundamentally monetary variables determined by money supplies and demands.

These aspects of the model as well as the imposition of rational expectations have strong implications for the equilibrium behavior of asset prices and rates of return. In particular, when expectations are rational, or markets are efficient, prices of durable assets at any time fully reflect all available information (Fama and Miller (1972)). Empirical content for this idea has been based on assuming that it is possible to specify and evaluate the conditions of equilibrium for assets in terms of just expected returns or prices.

When there is no underlying flow of real services provided by it, the excess pecuniary returns sequence on an asset in an efficient market should be a fair game.<sup>6</sup> Now clearly monies provide an unspecified non-pecuniary flow of services and that is why they are held although having a (typically) lower real return than do bonds. Furthermore, it is possible that the service flows for monies of different denomination can be at quite unequal levels, due to alternative institutional arrangements or divergences in rates of inflation. As a result, the fair game condition cannot be applied to money in this simple framework.

No flow of real services is attributed to bonds so the excess pecuniary returns sequence should be a fair game if the market is efficient. Formally, with  $Z_{kt}$  the excess return on asset  $k$  over the period  $(t, t+1)$ ,  $i_{kt}$  the actual return on asset  $k$ , and  ${}_t E i_{kt} | \Omega_t$  the expected return, the condition for a fair game is that

$${}_t E Z_{kt} | \Omega_t \equiv {}_t E \{ (i_{kt} - {}_t E i_{kt} | \Omega_t) | \Omega_t \} = 0.$$

An equivalent fair game condition for the price of asset  $k$ ,  $q_k$ , is

$${}_t E Z'_{kt} | \Omega_t \equiv {}_t E \{ (q_{k,t+1} - {}_t E q_{k,t+1} | \Omega_t) | \Omega_t \} = 0.$$

It is important to note that the fair game condition cannot be interpreted as implying any particular pattern of behavior in the actual returns or price sequence of an asset. For example, under some conditions serial correlation in asset prices is consistent with a fair game. Conversely, under other conditions, randomness in actual asset prices would be inconsistent with a fair game (Levich (1979)). Thus, there is nothing in the notion of market efficiency which implies that random walks characterize the behaviour of asset prices.<sup>7</sup>

The appropriate fair game conditions for the model above are related to activities in the bond markets, or, equivalently, the forward exchange markets:

$${}_t E \{ r_t - {}_t E r_t | \Omega_t \} | \Omega_t = 0,$$

$${}_t E \{ r_t^* - {}_t E r_t^* | \Omega_t \} | \Omega_t = 0.$$

Note that  ${}_t E r_t | \Omega_t = {}_t E r_t^* | \Omega_t = \bar{r}$  as the foreign real rate is taken as constant.

These equations specify that the excess real returns sequences on domestic and foreign bonds, conditional on information at time  $t$ , have an expected value of zero. The assumption of rational expectations is that these equations hold for all  $t$ , and this implies that

$$(7) \quad {}_t E (e_{t+1} - {}_t e_{t+1}) | \Omega_t = 0, \text{ and } {}_t f_{t+1} = {}_t e_{t+1}.$$

Thus, with rational expectations the forward rate at time  $t$  is an unbiased forecaster of the spot rate at time  $t+1$ .

It should be noted that this equation arises from the need for equal expected real returns on bonds, as was noted earlier (equations (4)-(6)). In light of this, forward market tests (Hansen and Hodrick (1980)) should be seen as efficiency tests of bond markets.

### III. THE GENERAL SOLUTION AND MODELLING OF MONEY SUPPLY PROCESSES

The solution to the model above has a conventional, forward-looking form. In particular, the exchange rate is related to expected future values of the money supply, output, foreign prices, and foreign interest rates:

$$(8) \quad e_t = \sum_{J=0}^{\infty} \alpha^J \delta^{J+1} [ {}_tM_{t+J} - \beta {}_tY_{t+J} - {}_tP_{t+J}^* + \alpha {}_tI_{t+J}^* ]$$

where  $\delta \equiv (1 + \alpha)^{-1}$ . This solution uses the following conditions:

- (a)  ${}_t x_t \equiv x_t$  since current values of variables are elements in the information set;
- (b)  ${}_t E({}_{t+k} x_{t+J}) \equiv {}_t x_{t+J}$  ( $k=0,1,2,\dots$ ) since all expectations are conditioned on the same information set. The important implication of (8), which has been stressed in particular by Mussa (1976), is that the exchange rate at any time depends on the entire expected time profiles of the right-hand side variables. Under rational expectations, individuals use efficiently the information they have in forming these expectations, and a major determinant of exchange rates is the amount of information individuals possess about current and future conditions. It should be noted that expectations about future conditions are discounted by the interest elasticity of money demand,  $\alpha$ . Thus this important parameter determines the speed with which the length of time into the future reduces the significance of events expected to occur then.

In order to solve the model in closed form, it is assumed that domestic output is fixed, while domestic and foreign money supplies evolve according to one of the processes modelled in Table 1.

Solutions to the model are derived, for each money supply process, using the method of undetermined coefficients and imposing the condition of convergent expectations. These solutions are reported in tabular form in Tables 2-4. These tables indicate the coefficient multiplying each exogenous variable in the solution for each endogenous variable.

The following features of these solutions are noteworthy.

1. Money prices in each country depend upon that country's output and worldwide real interest rates. Money supplies influence only own-currency prices, and the size of this influence depends upon the nature of the money supply process. If there are temporary and permanent shocks, as described by Process I, then, Table 2 notes, the coefficients attached to permanent money are unity and coefficients attached to transitory money are less than unity. If the levels of money supplies exhibit positive serial correlation, as in Process II, then, Table 3 records, the coefficients attached to money supply are also less than unity. Finally, if money supplies exhibit random walks around random trends, as in Process III, the solution, given in Table 4, notes that coefficients attached to permanent changes in money supply levels equal unity, and those attached to permanent changes in growth rates exceed unity.

TABLE 1

## Alternative Money Supply Processes

Process I: Money supplies are subjected to temporary  $v_t(v_t^*)$  and permanent  $\mu_t(\mu_t^*)$  shocks

$$M_t = \bar{m}_t + v_t$$

$$M_t^* = \bar{m}_t^* + v_t^*$$

$$\bar{m}_t = \bar{m}_{t-1} + \mu_t$$

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

$$v_t \sim \text{nid}(0, \sigma_v^2)$$

$$v_t^* \sim \text{nid}(0, \sigma_{v^*}^2)$$

$$\mu_t \sim \text{nid}(0, \sigma_\mu^2)$$

$$\mu_t^* \sim \text{nid}(0, \sigma_{\mu^*}^2)$$

Process II: Money supplies are subjected to shocks,  $v_t(v_t^*)$ , which are positively intertemporally correlated with correlation coefficient  $\rho(\rho^*)$

$$M_t = \bar{m} + v_t$$

$$M_t^* = \bar{m}^* + v_t^*$$

$$v_t = \rho v_{t-1} + \varphi_t$$

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

$$\varphi_t \sim \text{nid}(0, \sigma_\varphi^2)$$

$$\varphi_t^* \sim \text{nid}(0, \sigma_{\varphi^*}^2)$$

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

$$\rho^* \in (0, 1)$$

Process III: Money supplies follow random walks (with increment  $d_t(d_t^*)$ ) around random trends (with increment  $k_t(k_t^*)$ ) whose realizations are  $g_t(g_t^*)$

$$M_t = M_{t-1} + g_t + d_t$$

$$M_t^* = M_{t-1}^* + g_t^* + d_t^*$$

$$g_t = g_{t-1} + k_t$$

$$g_t^* = g_{t-1}^* + k_t^*$$

$$d_t \sim \text{nid}(0, \sigma_d^2)$$

$$d_t^* \sim \text{nid}(0, \sigma_{d^*}^2)$$

$$k_t \sim \text{nid}(0, \sigma_k^2)$$

$$k_t^* \sim \text{nid}(0, \sigma_{k^*}^2)$$

TABLE 2

Solution For Process I (in which money supplies  
are subjected to temporary and permanent shocks)

Endogenous Variables	Exogenous Variables								
	$\bar{m}_{t-1}$	$\bar{m}_{t-1}^*$	$y$	$\bar{y}^*$	$\bar{r}$	$\mu_t$	$\mu_t^*$	$v_t$	$v_t^*$
$P_t$	1	0	$-\beta$	0	$-\alpha$	1	0	$(1 + \alpha)^{-1}$	0
$P_t^*$	0	1	0	$-\beta^*$	$-\alpha^*$	0	1	0	$(1 + \alpha^*)^{-1}$
$i_t$	0	0	0	0	1	0	0	$-(1 + \alpha)^{-1}$	0
$i_t^*$	0	0	0	0	1	0	0	0	$-(1 + \alpha^*)^{-1}$
$e_t$	1	-1	$-\beta$	$-\beta^*$	$(\alpha - \alpha^*)$	1	-1	$(1 + \alpha)^{-1}$	$-(1 + \alpha^*)^{-1}$
$t^e_{t+1}$	1	-1	$-\beta$	$\beta^*$	$(\alpha - \alpha^*)$	1	-1	0	0

TABLE 3

Solution For Process II (in which money supplies  
are subjected to shocks which are positively  
intertemporally correlated)

Endogenous Variables	Exogenous Variables						
	m	m*	$\bar{y}$	$\bar{y}^*$	$\bar{r}$	$v_t$	$v_t^*$
$P_t$	1	0	$-\beta$	0	$-\alpha$	k	0
$P_t^*$	0	1	0	$-\beta^*$	$-\alpha^*$	0	$k^*$
$i_t$	0	0	0	0	1	$k(\rho - 1)$	0
$i_t^*$	0	0	0	0	1	0	$k^*(\rho^* - 1)$
$e_t$	1	-1	$-\beta$	$\beta^*$	$(\alpha - \alpha^*)$	k	$-k^*$
$e_{t+1}$	1	-1	$-\beta$	$\beta^*$	$(\alpha - \alpha^*)$	$k\rho$	$-k^*\rho^*$

where  $k \equiv [1 + \alpha(1-\rho)]^{-1}$

$k^* \equiv [1 + \alpha^*(1-\rho^*)]^{-1}$

TABLE 4

Solution For Process III (in which money supplies  
follow random walks around random trends)

Endogenous Variables	Exogenous Variables										
	$M_{t-1}$	$M_{t-1}^*$	$\bar{y}$	$\bar{y}^*$	$\bar{r}$	$d_t$	$d_t^*$	$g_{t-1}$	$g_{t-1}^*$	$k_t$	$k_t^*$
$p_t$	1	0	$-\beta$	0	$-\alpha$	1	0	$(1+\alpha)$	0	$(1+\alpha)$	0
$p_t^*$	0	1	0	$-\beta^*$	$-\alpha^*$	0	1	0	$(1+\alpha^*)$	0	$(1+\alpha^*)$
$i_t$	0	0	0	0	1	0	0	1	0	1	0
$i_t^*$	0	0	0	0	1	0	0	0	1	0	1
$e_t$	1	-1	$-\beta$	$\beta^*$	$(\alpha-\alpha^*)$	1	-1	$(1+\alpha)$	$-(1+\alpha^*)$	$(1+\alpha)$	$-(1+\alpha^*)$
$t^e_{t+1}$	1	-1	$-\beta$	$\beta^*$	$(\alpha-\alpha^*)$	0	0	$(2+\alpha)$	$-(2+\alpha^*)$	$(2+\alpha)$	$-(2+\alpha^*)$



2. In each country, the wedge between nominal and real interest rates depends upon transitory shocks to money supplies and when there is growth in money supplies, as in Table 4, nominal interest rates adjust to the expected growth in own money supplies.

3. Exchange rates, spot and forward, depend in general on relative money supplies, outputs, the real interest rate and the nature of 'permanent' and 'transitory' shocks.

Solutions of this type are consistent with previous research (for example, Barro (1978)).

#### IV. EXCHANGE RATE BEHAVIOR IN THE MONETARY MODEL

The solutions in Tables 2-4 are of interest because they provide us with possible ex post explanations for observed movements in exchange rates. Also of concern here is what proportion of these movements is predictable. In order to determine this proportion, note that the random change in the exchange rate can be written as

$$e_{t+1} - e_t \equiv ({}_t e_{t+1} - e_t) + (e_{t+1} - {}_t e_{t+1}).$$

The first term on the right-hand side is the systematic (predictable) component of the change, and the second term is the non-systematic (unpredictable) component. The fair game condition on exchange rates (7) asserts that the expected value of the unpredictable component is zero. If the systematic portion is zero, then the exchange rate follows a random walk.

An analogous division for the forward exchange rate is given by

$${}_{t+1}f_{t+2} - {}_t f_{t+1} \equiv ({}_t E_{t+1} f_{t+2} - {}_t f_{t+1}) + ({}_{t+1} f_{t+2} - {}_t E_{t+1} f_{t+2}),$$

where again the first term is the predictable component and the second the unpredictable component.

The division of these movements for the three money supply processes are reported in Tables 5-7.

a. Process I: Money supplies Are Subjected to Temporary And Permanent Shocks

Table 5 indicates that the amount of systematic change in the spot exchange rate depends on the temporary changes in money supplies. The amount of non-systematic change depends on the realizations of both permanent and temporary shocks at  $t+1$ . In contrast, there is no systematic movement in the forward exchange rate while the non-systematic movement depends only on the realizations of permanent money supply shocks at  $t+1$ . Thus, the forward rate follows a random walk for this money supply process.

According to Table 5 the spot rate also follows a random walk if the system is dominated by permanent shocks to the level of the money supply ( $v_t = v_t^* = 0, \forall t$ ); or if interest rate elasticities,  $\alpha$  and  $\alpha^*$ , are very large. Under these circumstances, the movements in the exchange rates are

$$e_{t+1} - e_t = w_{t+1} \qquad {}_{t+1}f_{t+2} - {}_t f_{t+1} = w_{t+1}$$

where  $w_{t+1} = \mu_{t+1} - \mu_{t+1}^*$ , and so  ${}_t E w_{t+1} = 0$ .

Then both spot and forward exchange rates follow the same random walk process and, given that  ${}_t E w_{t+1} = 0$ , the process exhibits no drift. This implies that at any  $t$ ,  ${}_t E e_{t+1} = e_t = {}_t f_{t+1}$ , so that the current spot, and forward rates, are the best predictors of the future spot rate, and domestic and foreign nominal interest rates are constant. In this situation predicting ex ante

TABLE 5

Systematic and Non-systematic Components of Exchange  
Rate Movements for Process I (in which money  
supplies are subjected to temporary and permanent shocks)

	<u>Spot Rate</u>	<u>Forward Rate</u>
Systematic	$-(1+\alpha)^{-1}v_t + (1+\alpha^*)^{-1}v_t^*$	0
Non-systematic	$[\mu_{t+1} - \mu_{t+1}^*] + (1+\alpha)^{-1}v_{t+1} - (1+\alpha^*)^{-1}v_{t+1}^*$	$\mu_{t+1} - \mu_{t+1}^*$

where  $v(v^*)$  are temporary shocks and  $\mu(\mu^*)$  are permanent shocks.

actual exchange rate changes is not possible; however, ex post, exchange rate changes would be explained by realization to money supply levels,  $\mu_t(\mu_t^*)$ . That both spot and forward rates should be characterized by the same random walk process when all the money supply shocks are expected to be permanent is not a surprising result.

These conditions are special. With some combination of transitory and permanent shocks the spot and forward exchange rates are not both characterized by random walks. To illustrate, consider the implications of assuming that all shocks are transitory so that  $\mu_{t+1} = \mu_{t+1}^* = 0$  in Table 5. In this case there is both systematic and non-systematic variation in the spot exchange rate, while the forward rate is constant. Therefore, the time series are characterized by variation in the spot exchange rate around a given forward rate. Clearly, then, the spot rate is not characterized by a random walk. Rather

$${}_t E e_{t+1} \stackrel{III}{\neq} e_t$$

according to whether realizations of money supply shocks are positive or negative; that is, on whether

$$-(1+\alpha)^{-1} v_t + (1+\alpha^*)^{-1} v_t^* \cong < 0.$$

Furthermore, such temporary shocks imply that domestic and foreign nominal interest rates should not move consistently together.

In general, both the exchange rate and the interest rate have a role to play in the domestic economy's adjustment to temporary shocks. The exchange rate's role is a compound one, captured in the two elements in  $(1+\alpha)^{-1}$ . One mechanism is through influencing prices ( $p_t$ ); the other is, for a given expected future spot rate, through altering the nominal interest rate. The relative

importance of these mechanisms depends on the interest elasticity of money demand ( $\alpha$ ). If this is low ( $\alpha \rightarrow 0$ ) there is considerable joint variability in the spot exchange rate and domestic nominal interest rate. If  $\alpha$  is large ( $\alpha \rightarrow \infty$ ) the variation in these variables is small.

b. Process II: Money Supplies Are Subjected to Shocks  
Which Are Positively Intertemporally Correlated

Shocks to money supply levels may be expected to last for more than one period. Such money supply processes are represented by Process II, and the solutions for this case are given in Table 3. Under these conditions, domestic and foreign money supplies have a fixed mean but current shocks to money supply levels exhibit first-order serial correlation. The movements in the exchange rates in this case are reported in Table 6.

The amount of systematic variation in the spot exchange rate depends on how rapidly money supply shocks are expected to die out. When  $\rho$  and  $\rho^*$  are close to zero, money supplies are expected to return rapidly to their average levels. Conversely, if  $\rho(\rho^*)$  are close to unity, money supply levels are expected to deviate from their means for an extended period. Similarly, there is a systematic movement in the forward rate which depends on the sizes of  $\rho$  and  $\rho^*$ .

Spot and forward rates however do not move together one-for-one, nor are they subject to random walks. It should be noted that shocks to money supply levels produce more variation in the spot exchange rate than the forward rate the closer are  $\rho$  and  $\rho^*$  to zero. This implies both more systematic and non-systematic variation in spot exchange rates than forward rates. Further, when money supply levels are serially correlated, changes in spot and forward rates are themselves characterized by serial correlation.

TABLE 6

Systematic and Non-systematic Components of Exchange Rate  
Movements for Process II (in which money supplies are  
subjected to shocks which are positively  
intertemporally correlated)

	<u>Spot Rate</u>	<u>Forward Rate</u>
Systematic	$k(\rho-1)v_t - k^*(\rho^*-1)v_t^*$	$k(\rho-1)\rho v_t - k^*(\rho^*-1)\rho^*v_t^*$
Non-systematic	$k\varphi_{t+1} - k^*\varphi_{t+1}^*$	$k\rho\varphi_{t+1} - k^*\rho^*\varphi_{t+1}^*$

where  $k \equiv [1 + \alpha(1-\rho^*)]^{-1}$

$k^* \equiv [1 + \alpha^*(1-\rho^*)]^{-1}$

and  $v(v^*)$  are shocks to money supply levels,  $\varphi(\varphi^*)$  are shocks to  $v(v^*)$   
with correlation coefficient  $\rho(\rho^*)$ .

c. Process III: Money Supplies Follow Random Walks  
Around Random Trends

A popular assumption about money supplies is that they follow random walks around random trends (Frankel (1981)), as described by Process III. For this process shocks both to levels and to growth rates of money supplies are expected to be permanent.

The movements in the exchange rates for this process are reported in Table 7. There is systematic change in the spot exchange rate which depends upon expected differences in the growth rates of money supplies. Non-systematic change in the spot exchange rate depends on innovations in both money supplies and their growth rates at time  $t+1$ . The systematic component in the forward exchange rate also depends on the expected difference in the growth rates of money supplies; and the non-systematic component depends on innovations in levels, and growth rates of money supplies at  $t+1$ . In short, there are random walk processes for both spot and forward exchange rates which exhibit random drift, mirroring the money supply processes.

Define  $w_{t+1}$  as

$$w_{t+1} \equiv d_{t+1} - d_{t+1}^* + (1+\alpha)k_{t+1} - (1+\alpha^*)k_{t+1}^*$$

Then the changes in the spot and forward rates can be written as:

$$e_{t+1} - e_t = (g_t - g_t^*) + w_{t+1}$$

$${}_{t+1}f_{t+2} - {}_t f_{t+1} = (g_t - g_t^*) + (k_{t+1} - k_{t+1}^*) + w_{t+1}$$

These imply time series for spot and forward rates characterized by a random walk process ( $w_{t+1}$ ) and random drift captured by terms like  $(g_t - g_t^*)$  and  $(k_{t+1} - k_{t+1}^*)$ . The presence of an additional term in the second equation implies that there is greater variability in forward rates than in spot rates. These conditions imply that differences in nominal interest rates ( $i_t - i_t^*$ ), as given

TABLE 7

Systematic and Nonsystematic Components of  
Exchange Rate Movements for Process III  
(in which money supplies follow random walks around random trends)

	<u>Spot Rate</u>	<u>Forward Rate</u>
Systematic	$g_t - g_t^*$	$g_t - g_t^*$
Nonsystematic	$(d_{t+1} - d_{t+1}^*) + (1+\alpha)k_{t+1} - (1+\alpha^*)k_{t+1}^*$	$(d_{t+1} - d_{t+1}^*) + (2+\alpha)k_{t+1} - (2+\alpha^*)k_{t+1}^*$

where  $k(k^*)$  are shocks to money supply growth rates,  $g(g^*)$  are growth rates of money supplies, and  $d(d^*)$  are shocks to money supply levels.



in Table 4, display variability related to the innovations in money supply growth rates,  $k_{t+1}(k_{t+1}^*)$ .

If the money supply processes are characterized: by deterministic growth in money supplies,  $g(g^*)$ , so that  $k_t = k_t^* = 0$  for all  $t$ ; and by random walks on levels of money supplies; then both exchange rate series exhibit the same random walks on levels with drift. In particular, the non-random drift is equal to  $(g-g^*)$ , and the random walk process for the levels of the rates is given by  $w_{t+1} = d_{t+1} - d_{t+1}^*$ . Under these conditions, nominal interest rates are given, with their difference equalling the differential in deterministic money supply growth rates.

#### d. Concluding Remarks

The conditions under which the model implies that exchange rates conform to the "empirical regularities" are clearly limited. Essentially, the exogenous variables must be characterized by driftless random walks for such behavior. Under more general stochastic processes, the model allows a wide range of behavior in the spot and forward exchange rates, and interest rate differentials.

Fundamentally, this arises for two related reasons: (i) The conditions for market efficiency are conditions on the forward rather than spot exchange market; and (ii) exchange rates are viewed as being determined by the choice between holding money and perfectly substitutable domestic and foreign bonds. This allows a role for not only the spot exchange rate, but for changes in the expected change in the exchange rate, through interest rate differentials, to adjust to maintain equilibrium in financial markets. Under these conditions both systematic and non-systematic movements in exchange rates characterize the data, with no a priori presumption that random walk type characteristics should dominate.

These conclusions are based upon a highly simplified model in which the focus has been on the implications of alternative money supply processes. Nonetheless, our conclusions would carry through with a more detailed specification, such specifications typically introduce intrinsic dynamics into the model. Any such mechanism would imply that there should be more rather than less systematic movement in exchange rates. As a result, these models are less consistent with the "empirical regularities" than is that analyzed here.

#### V. CANADIAN EXPERIENCE DURING THE SEVENTIES

The standard empirical evidence suggests that the Canadian exchange rate experience in the 1970s conforms to the "empirical regularities". For example, Backus (1983) presents evidence that the Canadian dollar/U.S. dollar spot exchange rate followed a random walk in the 1970s; Longworth (1981) finds that the spot and forward rates were unbiased predictors of the future spot. In addition, Boyer (1983) documents the close conformity between Canadian and U.S. interest rates, especially long-term bond rates.

Table 8 presents the results of some simple regressions which support these contentions about exchange rate behavior. Equations T8.1 and T8.2 regress spot and forward rates, respectively, against their lagged values. They find that one cannot reject the hypothesis that the coefficients on the lagged dependent values are unity and that the constants are zero. The  $R^2$ 's indicate that the equations have reasonably high explanatory power

TABLE 8

## OLS Regressions of Exchange Rates on Lagged Values

	<u>Equation</u>	<u>Constant</u>	<u>Coefficient on Lagged Value</u>	<u>R<sup>2</sup></u>	<u>Durbin h</u>
T8.1	Spot Rate on Lagged Value	.509 (.409)	.989 (.0356)	.943	.0769
T8.2	Forward Rate on Lagged Value	.499 (.396)	.991 (.0342)	.947	.102
T8.3	Spot Rate on Lagged Forward Rate	.00408 (.00411)	.989 (.0356)	.943	.177
T8.4	Change in Spot on Lagged Change	.00405 (.00321)	.00110 (.149)	-.0222	undefined*
T8.5	Change in Forward on Lagged Forward	.00409 (.00309)	.00499 (.149)	-.0222	undefined*

Period of regressions is 1971.I-1983.I. Spot exchange rate is B 3414, and 90-day forward rate is B 3417 from CANSIM Data Bank. Number in parentheses are standard errors. Number of observations is 49.

\*Undefined using conventional formula for Durbin's h statistic.

lagged dependent values are unity and that the constants are zero. The  $R^2$ 's indicate that the equations have reasonably high explanatory power and the Durbin-h statistics (distributed  $N(0,1)$ ) indicate the absence of serial correlation in the residuals. The similarity between these two equations suggests that the spot and forward rates followed the same random walk.

Equation T8.3 regresses the spot exchange rate against the lagged forward rate with similar results. The unit coefficient on the lagged forward rate and the zero value for the constant demonstrate that the forward rate is an unbiased predictor of the future spot rate. Again, this is consistent with the exchange rates following the same random walk.

With such a process changes in exchange rates are not intertemporally correlated. A further test of whether the exchange rates follow a random walk is to regress changes in them against lagged values. Results from such regressions are reported as T8.4 and T8.5 which indicate that one cannot dismiss the hypothesis that the coefficient on the lagged dependent variable is zero.

These results must be interpreted as only suggestive because of some well-known statistical difficulties. In particular, we know very little about the small-sample properties of our estimators and such work as there is (Evans and Savin (1981)) suggests that the coefficient on the lagged dependent variable will be biased towards unity in levels-equations. This, of course, makes the random walk hypothesis difficult to reject and equations "confirming" random walks very suspect.

More conclusive results can be obtained by the use of Box-Jenkins time-series techniques which seek to estimate a filter which will reduce any given series to white noise. For the two exchange rate series the best filters were

found to have the form  $(1-L)$ , indicating that the series in question are random walks. In addition, application of the filter  $(1-L)$  was enough to reduce the residuals to a process indistinguishable from white noise.<sup>8</sup> More complicated filters with autoregressive or moving-average terms were found to be inferior to the simple random walk. Such additional terms had statistically insignificant coefficients and increased the Akaike-Information Criterion (AIC), both of which suggest that by the principle of "parsimony" the random walk is to be preferred.

The analysis of Section IV concluded that in the confines of a simple monetary model these random walk results should mirror similar behavior on the part of the exogenous variables. Table 9 presents the results of regressions of these variables--relative money supplies in Canada and the U.S., and the relative outputs--on their lagged values. If one further assumes that these variables are exogenous to all other variables in the information set, then one could collapse the two variables into one and take their ratio. But since the data are already in logarithmic form, this means we should take their difference instead.

Our regression results show that for none of these three equations can one accept the null hypothesis that the coefficient on the lagged dependent variable is unity. Since the estimators are likely to be biased towards unity (Evans and Savin (1981)), then we might conclude that none of the three processes in question is a random walk.

We next derived the time-series filters for relative money supplies, relative outputs and their (logarithmic) difference. We found that the random walk filter  $(1-L)$  for relative money supplies could not be rejected,

TABLE 9

## OLS Regressions of Exogenous Variables on Lagged Values

<u>Equation</u>	<u>Constant</u>	<u>Coefficient on Lagged Value</u>	<u>R<sup>2</sup></u>	<u>Durbin h</u>
1. Relative Money Supplies on Lagged Value	.938 (.338)	.786 (.0772)	.715	-.327
2. Relative GNPs on Lagged Value	.610 (.228)	.864 (.0509)	.859	1.67
3. Relative Money Supplies Minus Relative GNPs on Lagged Value	-.0300 (.0124)	.700 (.117)	.458	1.15

Period of regressions on quarterly data is 1971.I-1983.I for GNPs (49 observations), and 1971.I-1981.III (43 observations) for others. Canadian money supply (M1B) is B2014, Canadian seasonally-adjusted output is D40593, U.S. seasonally-adjusted output is B50301. All these data are from the CANSIM Data Bank. U.S. money supply (M1) is from OECD Main Economic Indicators.

which contradicts our previous regression results and shows that the estimator-bias need not always be towards accepting the random walk hypothesis.<sup>9</sup>

For relative outputs the best-fitting process was

$$\Delta y_t = (1 - .964L)e_t$$

$$(.0383)$$

$$\text{AIC} = -187.1$$

which is a moving average on the first-difference and is to be compared against the random walk model

$$\Delta y_t = e_t$$

$$\text{AIC} = -160.3.^{10}$$

Both the statistical significance of the extra coefficient in the first equation and its lower AIC indicate that that equation is superior to the random walk.

The best fitting equation for the logarithmic difference between the two relative variables is

$$(1 - .492L^5)\Delta y_t = e_t$$

$$(.1343)$$

$$\text{AIC} = -309.2$$

which is a seasonal autoregression on the first difference with a significant autoregressive coefficient. The random walk model

$$\Delta y_t = e_t$$

also has a higher AIC (= -299.5) so that it can be easily rejected.<sup>11</sup>

In summary, both regression and time series methods indicate that nominal variables, like exchange rates, follow random walks, while real variables

like relative outputs and the logarithmic difference between relative money supplies and output do not. The two methods tend to contradict each other on whether or not relative money supplies follow a random walk. In summary, these results would conflict with the monetary view which says that exchange rate behavior should mirror that of the exogenous variables. Yet exchange rates are random walks and at least one of the exogenous processes is not.

An alternative explanation for the random walk behavior is that there are high interest rate elasticities of demand for money. From Table 2 it can be verified that with an arbitrary distribution of temporary and permanent shocks, only the permanent ones cause movements in the exchange rate when  $\alpha, \alpha^* \rightarrow \infty$ .

The reason for such a result is clear. The elasticities measure the degree of substitution between money and the bond of the same denomination. A high elasticity is consistent with a high degree of substitution, an assumption which is already imposed for bonds of different denomination. Thus, though the monetary model imposes zero direct substitution between money and foreign-currency-denominated assets, a high degree of indirect substitution, via the intermediation of domestic-currency bonds, can have much the same effect. Namely, such substitution generates the random walk behavior often found in financial asset prices.

Numerous estimates have been made of the interest elasticity in both Canada and the U.S. The conclusion is uniformly that such elasticities are low. For example, Laidler (1977) cites approximately twenty studies from a number of countries whose estimates range from 0.12 to 0.8. In all cases, the values are sufficiently low that transitory shocks would cause substantial systematic movement of the exchange rate, since the coefficients



attached to such shocks are equal to  $(1+\alpha)^{-1}$  and  $-(1+\alpha^*)^{-1}$ .

The conclusion which must be drawn is that the monetary model is an inappropriate characterization of Canadian experience during the seventies: exchange rate movements were consistent with the empirical regularities view even though a monetary model says they should not be.

#### CONCLUSIONS

The results presented here suggest that alterations need to be made to the asset market specification of conventional monetary models before they are suitable for dealing with exchange rate determination.

It is shown that, from a monetary perspective, there is no reason for thinking that the exchange rate, in general, should follow a random walk: such an efficiency test is inappropriate for this sort of model. Nonetheless, exchange rate movements do tend to be consistent with such a process even though the exogenous variables in the Canadian-U.S. case have changed predictably recently.

The modifications which suggest themselves have been incorporated into models which draw attention to the choice of currency of denomination of asset holdings.<sup>12</sup> Since such currency substitution models automatically yield the empirical regularities (Mussa (1979)), further research efforts should be directed towards them.

Footnotes

<sup>1</sup>Popular models which contain intrinsic dynamics base them on the following mechanisms: movement in the real exchange rate, Stockman (1980); sluggishness of prices of goods, Dornbusch (1976); accumulation effects of current account imbalances, Kouri (1976), Branson et al. (1977), Dornbusch and Fischer (1980); the possibility of diverse information, Harris and Purvis (1981).

<sup>2</sup>Evidence on purchasing power parity (ppp) suggests that there are departures from the simple expression given in (1) over both the short and medium runs. Handling random deviations from ppp would simply amount to adding a white noise error term to that equation. Systematic deviations from ppp would be more difficult to handle, and would not help to explain why movements in the exchange rate are unpredictable.

<sup>3</sup>All expectations are uniformly held so that problems involving diverse information, as in Harris and Purvis (1981), for example, do not arise.

<sup>4</sup>The evidence on covered interest rate parity is quite convincing. Small deviations do occur, but they appear to be consistent with transactions costs (Levich (1978)).

<sup>5</sup>There are examples of monetary models which have permitted substitution across currencies. Notable examples are: Barro (1978), Frenkel (1979), Bilson (1979), Harris and Purvis (1981).

<sup>6</sup>The various efficiency tests we discuss here, and the stochastic processes we consider below, have arisen in the context of risk unadjusted tests of market efficiency. Tests which take risk into account involve difficult issues in determining appropriate measures of risk (Levich (1979)).

<sup>7</sup>In practice, the prices of many assets do appear to be characterized by random walks, and exchange rates are no exception to this. In the case of equity markets (Fama and Miller (1972)) this has been explained by a constant underlying real return earned on equity.

<sup>8</sup>The significance levels for rejecting the hypothesis of absence of skewness and kurtosis in the residuals are .505 and .786 respectively, which are far above usual significance levels employed.

<sup>9</sup>The significance levels for skewness and kurtosis are .273 and .445 respectively.

<sup>10</sup>The significance levels are zero in all cases except for skewness in the random walk case where it is .856.

<sup>11</sup>Significance levels here are:

	<u>Skewness</u>	<u>Kurtosis</u>
Autoregressive	.506	.676
Random Walk	.136	.644

<sup>12</sup>Simple models which attempt to capture this phenomenon include: Calvo and Rodriguez (1977), Girton and Roper (1981), Liviatan (1981), and Boyer and Kingston (1984).

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