Federal Reserve Bank of San Francisco Economic Review, Fall 1986, No. 4

Real Exchange Rates, Imperfect Information, and Economic Disturbances

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This paper provides theoretical and empirical explanations for short-term fluctuations in the real value of the dollar. It formulates a model in which the imperfect information of economic agents about disturbances causes the real exchange rate to respond to monetary as well as real shocks. Empirical evidence from vector autoregressions support the hypothesis that increases in the U.S. money supply induce declines in the real value of the dollar, while increases in real demand in the U.S. generate rises in the dollar's value. Foreign disturbances were also found in some instances to influence the value of the dollar.

Since 1973 the relative values of the currencies of major industrial countries have been determined primarily by free-market forces in a floating exchange rate system. Fluctuations in nominal exchange rates over this period have been substantial. Real exchange rates — nominal exchange rates adjusted for differences in national price levels — have been almost as volatile, since nominal exchange rate movements have exceeded those of national price levels.[1]

The chart graphs an index of the real dollar value of the yen and German mark, defined as the dollar "value" of the foreign wholesale price index divided by the U.S. wholesale price index. A rise in this index represents an increase in the dollar price of foreign goods relative to the price of U.S. goods and hence a real dollar depreciation. The chart shows substantial fluctuations of the dollar in real terms over the entire floating rate period.

Variation in underlying economic conditions has undoubtedly contributed directly to exchange rate fluctuations. Indeed, the floating exchange rate period has been characterized by frequent and varied economic disturbances. In the 1970s, when nations were first freed from the constraint of pegging exchange rates by coordinating their monetary policies, great variations in money supply growth emerged. Oil-related price shocks also occurred in that decade. In the 1980s, differences in real aggregate demand among countries, in part related to differences in fiscal policy stimuli, have been apparent.

This paper seeks to explain movements in real exchange rates in terms of these underlying determinants. In particular, it provides both a theoretical and empirical analysis of the role of monetary and real disturbances in explaining the direction and magnitude of exchange rate changes. Real exchange rate fluctuations, because of their implications for the international competitiveness of countries, have important resource and output effects. A real dollar appreciation, for example, raises the relative international cost of U.S. goods and thereby dampens the demand for U.S. output. Understanding the magnitude and origin of causes of real exchange rate changes is thus important for formulating effective policies to reduce exchange rate variability.

Section I contains the formulation of a model of real exchange rate determination based on the assumption that economic agents possess imperfect information about disturbances such as changes in money supply growth or in real demand and supply

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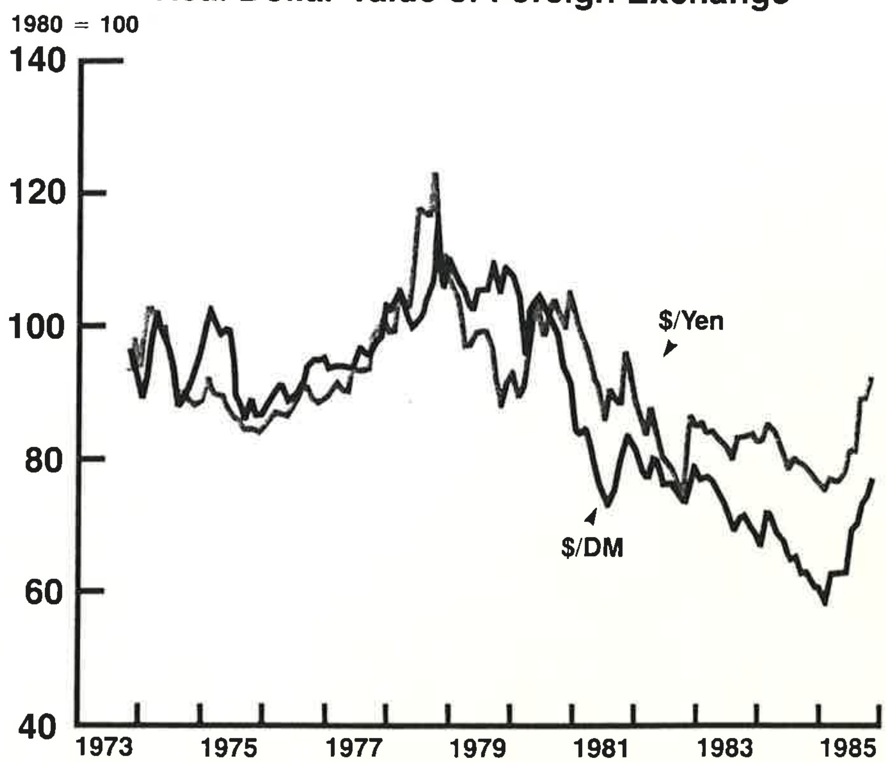
conditions.[2] The resulting confusion among agents about the relative magnitudes of monetary and real disturbances implies that the real exchange rate will be influenced by monetary as well as real disturbances. The model provides indications of both the direction and magnitude of response of the real exchange rate to such disturbances.[3]

Section II examines several hypotheses suggested by the theoretical framework using the technique of vector autoregressions. Real depreciations of the dollar are found to be associated with U.S. money supply increases, and appreciations of the dollar with fluctuations in expansionary U.S. real demand. The section also provides estimates of the relative amounts of exchange rate variability that can be attributed to various disturbances. Conclusions are presented in the final section.

Real Dollar Value of Foreign Exchange



Note: An increase in the real $/Yen(deutschemark) rate represents a decrease in the real value of the dollar in terms of the yen(mark).

I. A Model of Exchange Rates and Disturbances

As mentioned, real exchange rate fluctuations may be viewed as reflections of variations in underlying economic conditions. This section formulates a small-country model of the equilibrium response of the real exchange rate to domestic real demand, real cost, and nominal money supply disturbances. The small-country assumption is employed for convenience to simplify the structure of the model formulated. How the results can be generalized to include foreign disturbances as well is discussed briefly at the end of this section.

The key feature of the model is its treatment of information among economic agents. Within the model, economic agents are aware that different disturbances to the economy occur each period but cannot observe them directly and are unable to determine their magnitudes. Agents are assumed to form rational expectations of each period's disturbances on the basis of available past information and current "signals" obtained by observing current goods and asset market prices and conditions. These signals enable agents to infer information about the underlying disturbances.

In the model, observation of market prices and conditions provides partial, but not perfect, information about the current magnitudes of disturbances. Thus, for example, observation of domestic interest rate and money market conditions may indicate the presence of an excess supply of money but not reveal the extent to which the excess is due to a positive money supply disturbance or a negative real demand disturbance that has dampened money demand. Within this framework, we show how the real exchange rate is affected by both monetary and real disturbances.

The formal model is constructed by first specifying relationships for aggregate supply and demand in the domestic goods market, a domestic money market equilibrium condition, and an international interest rate relation linking domestic and foreign interest rates. All variables are defined in log terms (except for interest rates). These relationships are then used to obtain an expression relating the real exchange rate to the disturbances as well as to expectations of the future exchange rate. We complete the theoretical analysis by showing how expectations of the future exchange rate in turn depend on expectations of disturbances, and then deriving an expression indicating how the equilibrium real exchange rate responds to each individual disturbance.

The Goods Market

The supply of domestic output, y_t, is assumed to depend positively on the real domestic interest rate, r_t, and negatively on a random supply cost disturbance, c_t:

$$y_t = a_0 + a_1 r_t - c_t \tag{1}$$

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

$$c_t = \rho_c c_{t-1} + \epsilon_{ct} \tag{3}$$

The specification of supply (equation 1) as a function of the real interest rate reflects the intertemporal decision of producers concerning how much of their product to supply in the current period and how much to supply in the future. The real interest rate, given by equation 2, is defined as the difference between the domestic nominal interest rate, i_t, and the expected change in the overall domestic price level, p_t, where E_t denotes expectations formed at time t. The real rate may be interpreted as the price of current goods relative to the discounted price of future goods. An increase in r represents a rise in the price of current goods relative to the discounted return to selling in the future and, as implied by equation 1, induces producers to supply more current output.[4]

The supply cost disturbance at time t, described by equation 3, consists of two components: a serially correlated term, $\rho_c c_{t-1}$, linking the current disturbance to lagged shocks, and a current (white-noise) shock term, ϵ_{ct}. This disturbance can be associated with exogenous factor cost increases or adverse productivity movements.

The overall domestic price level, p_t, is expressed by equation 4 as a weighted average of the domestic currency price of domestic goods and foreign goods:

$$p_t = a p_t^d + (1-a)(p_t^f + s_t), \tag{4}$$

where p_t^d is the domestic currency price of domestic goods, p_t^f is the foreign currency price of foreign goods, s_t is the nominal exchange rate defined as the domestic currency price of foreign currency, and a is the share (assumed constant) of domestic goods in domestic consumption. Note that a *rise* in s represents an increase in the amount of domestic currency necessary to buy a unit of foreign currency and hence a nominal *depreciation* in domestic currency value.

The real exchange rate, q_t, is defined by equation 5 as the nominal exchange rate plus the difference between the foreign price level of foreign goods and the domestic price level of domestic goods:

$$q_t = s_t + p_t^f - p_t^d \tag{5}$$

A *rise* in q represents an increase in the relative domestic currency price of foreign goods and hence a real domestic *depreciation*.

Aggregate real demand for the domestic good (equation 6) depends negatively on the real interest rate, r_t, and positively on the real exchange rate, q_t, and a random demand disturbance term, d_t:[5]

$$y_t = b_0 - b_1 r_t + b_2 q_t + d_t \tag{6}$$

$$d_t = \rho_d d_{t-1} + \epsilon_{dt} \tag{7}$$

A higher real interest rate induces reduced current consumption (and investment) and hence current demand, while a rise in the real exchange rate, that is, a real depreciation of the domestic currency, induces greater demand for domestic output. The demand disturbance term, as described by equation 7, is serially correlated with a (white-noise) shock term, ϵ_{dt}. It may be interpreted as representing the effects on domestic demand of autonomous private and foreign spending, or of domestic fiscal expenditures.

The Asset Market

Money market equilibrium requires the domestic real money supply to balance domestic real money demand, where the latter depends positively on domestic output and negatively on the domestic nominal interest rate:

$$m_t - p_t = c_0 y_t - c_1 i_t \tag{8}$$

We assume that m_t, the nominal money supply, is determined exogenously as the sum of a serially-correlated term and a white-noise term, ϵ_{mt}:

$$m_t = \rho_m m_{t-1} + \epsilon_{mt} \tag{9}$$

A more general formulation would allow the money supply to be determined in part by considerations of domestic or international policy targets. Such a formulation would include the addition of terms related to current deviations from, for example, output or exchange rate targets to the right-hand side of equation 9.

Assuming risk neutrality on the part of agents and perfect capital mobility, equilibrium in the international bond market requires that the domestic nominal interest rate, i_t, equal the foreign nominal interest rate, i_t^f, plus the expected depreciation of the domestic currency:

$$i_t = i_t^f + (E_t s_{t+1} - s_t) \tag{10}$$

This condition implies that the returns, in terms of domestic currency, to holding domestic and foreign assets become equal. An exogenous risk-premium term could be introduced without affecting the analysis.

For the remainder of this analysis, we will use the small-country assumption, and treat the foreign country variables p_t^f and i_t^f as exogenous, constant, and, for convenience, equal to zero.

Equilibrium Conditions

We are now in position to address the implications of the equilibrium conditions in the goods and asset markets for the determination of the real exchange rate and for the response of the real exchange rate to the various lagged disturbances — d_{t-1}, c_{t-1}, and m_{t-1} — and current shocks — ϵ_{dt}, ϵ_{ct}, and ϵ_{mt}. Note that the term "shock" is used to refer to the random, unserially correlated component of each disturbance occurring in a given period. In the absence of any shocks prior to the previous period, any lagged disturbances can be associated entirely with lagged shocks, since in that case, for example, $d_{t-1} = \epsilon_{dt-1}$.

Observe first that equations 4 and 5 imply the following relationship between the nominal and real exchange rates and the overall domestic price level (assuming $p_t^f = 0$):[6]

$$s_t - p_t = aq_t \quad (11)$$

Consequently equations 2, 10, and 11 imply that the real domestic interest rate is positively related to the expected change in the real exchange rate (assuming $i_t^f = 0$):[7]

$$r_t = a(E_t q_{t+1} - q_t) \quad (12)$$

The domestic goods market equilibrium condition implies, upon substitution of equations 3 and 12 in 1, and equations 7 and 12 in 6, and simultaneous solution for q_t:

$$q_t(b_2 + e_0) = a_0 - b_0 + e_0 E_t q_{t+1} - (\rho_c c_{t-1} + \rho_d d_{t-1} + \epsilon_{dt} + \epsilon_{ct}) \quad (13)$$

where $e_0 = a(a_1 + b_1) > 0$.

The current real exchange rate, q_t, depends negatively on (positive) current and lagged real demand and cost shocks, and positively on the expected future real exchange rate. Intuitively, an increase in domestic demand or costs creates excess demand pressure in the domestic goods market. This induces a lower real exchange rate, that is, a stronger domestic currency, to shift demand away from domestic output and to maintain goods market equilibrium. A higher expected future real exchange rate, that is, an expected depreciation of the domestic currency, implies a higher domestic real interest rate due to the international mobility of capital (see equation 12). This creates excess supply pressure by inducing greater current supply and lower current demand for domestic output. Consequently, a higher current real exchange rate, that is, a current domestic currency depreciation, is necessary to stimulate current demand.

The money market equilibrium expression (equation 8) yields the following relationship for the nominal exchange rate upon substitution of equations 6, 7, 9, 10, 11 and 12 for d_t, y_t, m_t, i_t, p_t, and r_t, respectively:

$$s_t(1 + c_1) = e_1 q_t + c_1 E_t s_{t+1} + \rho_m m_{t-1} + \epsilon_{mt} - c_0(\rho_d d_{t-1} + \epsilon_{dt}) \quad (14)$$

where $e_1 = a + c_0(b_1 a - b_2) > 0$ by assumption. The current nominal exchange rate depends positively on the current real exchange rate, the expected future nominal exchange rate, and (positive) current and lagged money shocks; it depends negatively on current and lagged real demand shocks.

Intuitively, a rise in the expected future nominal exchange rate implies a greater domestic interest rate because of the mobility of international capital and, consequently, a dampening of real money demand. A higher current exchange rate is then necessary to raise the domestic price of foreign goods and the overall domestic price level, and implies a decline in the real money supply. Current or lagged money supply shocks induce an excess supply of money and hence a rise in s_t, that is, a nominal depreciation of the domestic currency. Current or lagged demand shocks in the goods market correspondingly raise money demand, induce excess money demand, and cause a fall in s_t.

Expectations and Equilibrium Solution

Equations 13 and 14 describe how the current real and nominal exchange rates each depend on current and lagged shocks and on expectations of the future exchange rate. Determining the overall equilibrium response of the current real exchange rate to these shocks thus requires specifying how the shocks in turn affect expectations of the future exchange rate.

It should be apparent that only current and lagged shocks should have any influence on future expectations through the serial-correlated disturbance component because any further shocks occurring in the future are assumed to be random (white-noise) and therefore unforeseeable. This implies that the equilibrium real exchange rate depends only on current and lagged shocks, which, in turn, suggests that the equilibrium real exchange rate may be expressed as a function of these shocks in the following way:

$$q_t = \bar{q} + B_d d_{t-1} + B_{\epsilon d}\epsilon_{dt} + B_c c_{t-1} + B_{\epsilon c}\epsilon_{ct} + B_m m_{t-1} + B_{\epsilon m}\epsilon_{mt} \quad (15)$$

where $\bar{q}$ is the long-run average real exchange rate and the B coefficients indicating the sensitivity of the exchange rate to current and lagged disturbances depend on the parameters of the structural relationships in the model already specified.

Equation 15 implies that the equilibrium current real exchange rate will differ from its long-run average level only with the occurrence of current and lagged shocks. To ascertain the direction of change of the equilibrium exchange rate to each of these shocks, it is necessary to determine the signs of the B coefficients.[8]

We proceed to determining the signs of the B coefficients by first discussing the formation of expectations. According to the assumption of rational expectations, current expectations of the future exchange rate should be consistent with the equilibrium exchange rate prevailing in the next period. In particular, expectations in period t of the forward-dated equivalent of equation 15 for period t+1 are given by

$$E_t q_{t+1} = \bar{q} + E_t(B_d d_t + B_c c_t + B_m m_t), \quad (16)$$

or, after substituting equations 7, 3, and 9 for d_t, c_t, and m_t, respectively,

$$E_t q_{t+1} = \bar{q} + E_t(\rho_d B_d d_{t-1} + \rho_c B_c c_{t-1} + \rho_m B_m m_{t-1}) + E_t(B_{\epsilon d}\epsilon_{dt} + B_{\epsilon c}\epsilon_{ct} + B_{\epsilon m}\epsilon_{mt})$$

Note that expectations formed in period t of the white-noise shocks in period t+1 — ϵ_{dt+1}, ϵ_{ct+1}, and ϵ_{mt+1} — are zero.

To proceed further, it is necessary to discuss the information sets of agents at the time their expectations are formed in any given period t. For simplicity, agents are assumed to have full information about the magnitudes of the lagged disturbances — d_{t-1}, c_{t-1}, and m_{t-1}. While they cannot directly observe current shocks at time t, they may infer partial knowledge of these shocks by extracting information from "signals" provided by observable market conditions and prices, including q_t, the real exchange rate; s_t, the nominal exchange rate; i_t, the domestic interest rate; and p_t, the price level. We also assume that their information sets include the parameters of all structural equations and the moments of all random variables. Neither current output quantities nor the money supply are treated as observable. This distinction between observable and unobservable market variables is intended to capture the property that market prices convey at least partially useful information to agents about underlying conditions.

The content of the signals provided to an agent at any time t may be determined from inspection of the output and asset market equilibrium expressions, equations 13 and 14, both of which are known to agents. Given the knowledge of lagged disturbances and market prices by agents, each expression implies knowledge of a residual term related to the underlying current shocks. Specifically, knowledge of c_{t-1}, d_{t-1}, q_t, and $E_t q_{t+1}$ in equation 13 reveals to agents the term $Z^G \equiv \epsilon_{dt} + \epsilon_{ct}$, a composite signal of the current real demand and cost shocks.

While agents cannot observe the demand and cost shocks individually, the knowledge of Z_t^G obtained from observing market conditions provides a signal of excess domestic demand that reflects their net effect in the goods market. For example, observation of a high value of Z_t^G by agents provides a signal of excess demand in the goods market, information which is of value to agents even though it is not sufficient to reveal precisely how much of the excess demand is due to a demand shock boosting demand as opposed to a cost shock reducing supply.

Analogously, the condition in equation 14 reveals to agents the composite signal $Z_t^M \equiv \epsilon_{mt} - c_0\epsilon_{dt}$. Z_t^M may be interpreted as a signal of excess money supply reflecting the net effect of money supply shocks and disturbances to money demand caused by real demand and income shocks.[9]

Agents are able to form expectations of each of the current shocks conditional on the information set including these signals. In the appendix, we show how these expectations take the following form:

$$E_t\epsilon_{dt} = C_{dG}Z_t^G - C_{dM}Z_t^M \quad (17)$$

$$E_t\epsilon_{ct} = C_{cG}Z_t^G + C_{cM}Z_t^M \quad (18)$$

$$E_t\epsilon_{mt} = C_{mG}Z_t^G + C_{mM}Z_t^M, \quad (19)$$

where the C coefficients are positive parameters indicating the extent to which the expectations of each current shock are attributed by agents to the goods and money market signals that they observe.

Intuitively, the stronger the signal of excess demand in the goods market (the higher is Z_t^G) the stronger the perception of both positive real demand and cost shocks. A stronger excess money supply signal (higher Z_t^M) leads to the inference of a more positive money supply shock, but also to the inference that a more negative real demand shock may have occurred and dampened money demand. Correspondingly, the excess money market signal implies expectation of a more positive cost shock. A stronger goods market signal leads to the expectation of larger money supply shock, since, to the extent that it is attributed to a positive real demand shock, a signal of a stronger goods market lessens the extent to which an excess money supply signal is perceived to have resulted from a negative real demand shock.

The extent to which the signals influence expectations of the current shocks is reflected in the magnitude of the C coefficients. To understand this, it is helpful to view equations 17-19 as the result of regressing historical observations of realizations of each of the individual shocks (which are known with a lag) on the goods and money market signals. The magnitudes of the C coefficients obtained from these regressions depend on the relative variability of the different disturbances. Thus, for example, if demand shocks have been relatively more prevalent historically than cost and money supply shocks, then agents will attribute relatively more of any current excess demand signal to a current demand shock. This implies that the coefficient C_{dG} will be of greater magnitude than C_{cG}.

Equilibrium Response of the Real Exchange Rate

We are now in a position to determine the equilibrium response of the real exchange rate to individual shocks. The appendix describes in detail how this is done by deriving the explicit values of the B coefficients in equation 15, denoting the sensitivity of the exchange rate to individual shocks. Table 1 indicates the signs of these coefficients under the conditions of imperfect information, positively correlated disturbances (ρ_d, ρ_c, $\rho_m > 0$), and demand disturbances that persist more strongly than cost disturbances ($\rho_d > \rho_c$).

A current positive real demand or cost shock induces real appreciation of the domestic currency, that is, a fall in q ($B_{\epsilon d}$, $B_{\epsilon c} < 0$). Intuitively, either shock creates an excess demand for domestic output — the former by boosting demand and the latter by dampening production. Excess demand then induces an increase in the real value of domestic currency to shift demand away from the domestic market. Lagged demand or cost disturbances, when they are positively correlated over time, induce a real appreciation (B_d, $B_c < 0$) as well.

TABLE 1

Real Exchange Rate Response Coefficients to Domestic Market Shocks

$$q_t = \bar{q} + \overset{(-)}{B_d d_{t-1}} + \overset{(-)}{B_{\epsilon d}\epsilon_{dt}} + \overset{(-)}{B_c c_{t-1}} + \overset{(-)}{B_{\epsilon c}\epsilon_{ct}} + \overset{(0)}{B_m m_{t-1}} + \overset{(+)}{B_{\epsilon m}\epsilon_{mt}}$$

Domestic currency *Appreciates* (q falls) in response to a positive

- lagged demand shock
- current demand shock
- lagged cost shock
- current cost shock

Domestic currency *Depreciates* (q rises) in response to a positive

- current money supply shock

Note: Effect of foreign market shocks are the opposite of those above.

In the case of imperfect information, current money supply shocks also influence the real exchange rate (since $B_{\epsilon m} \neq 0$). The reason is that without the ability to distinguish perfectly among individual shocks, agents confuse money and real disturbances. If, for example, a positive money supply has occurred, agents will attribute the resulting excess money signal observed in part to negative real demand shocks. The perception of a demand shock, even if none has actually occurred, implies that the money supply shock will have real effects.[10] More particularly, the perception of lower current real demand arising from a positive money supply shock causes the domestic currency to depreciate to stimulate domestic demand ($B_{\epsilon m} > 0$).

Note that in this model, lagged money disturbances have no effect on the exchange rate ($B_m = 0$). The reason is related to the assumption that agents know all past disturbances with a one period lag. That assumption implies that lagged money is not a source of confusion when agents attempt to infer the magnitudes of current shocks to the real exchange rate.

The analysis above yields implications about the effect of domestic real and money supply disturbances on the exchange rate within a small-country framework. It is fairly straightforward to incorporate the effects of foreign real and money supply disturbances into a two-country framework. By intuition, these disturbances should have effects opposite those of the domestic disturbances described in Table 1. In particular, positive real shocks creating an excess demand for foreign output should lead to a real appreciation of the foreign currency and hence a depreciation of the domestic currency. Under imperfect information, positive foreign money supply shocks should lead to a domestic appreciation.

II. Vector Autoregression Analysis

The model formulated in Section I suggests how fluctuations of real exchange rates can be attributed to fluctuations in various underlying disturbances, both monetary and real. In this section, empirical evidence is provided concerning the extent to which monthly bilateral real exchange rate movements of the dollar against the yen and German mark can be related to changes in monetary and real conditions in the United States and abroad.

Description of the VAR Method

To analyze the interrelationship of the real exchange rate with changing economic conditions, we employed the technique of vector autoregressions (VAR). The VAR technique imposes no restrictions on the relationships between different variables and treats them all as potentially endogenous. VARs are best thought of as a convenient way of summarizing empirical regularities and suggesting the predominant channels through which relations work.[11] While several other studies (for example, Branson, 1984; Kuszczak and Murray, 1986) have used the VAR approach to analyze exchange rate movements, they focus on nominal rather than real changes and effective rather than bilateral rates.

Applying the VAR technique involves transforming all data into first differences of natural logs (equivalent to forming percentage changes) and individually regressing each variable in the system (the vector) on lagged values of itself and of the other variables in the system (the autoregression) and on a common set of other terms including a constant, linear and quadratic time trends, and seasonal dummies.[12] A common lag length is imposed on all endogenous variables.[13]

The resulting estimates provide several useful insights. First, they indicate whether past values of other endogenous variable have a significant effect on a given variable through Granger-causality statistical tests on the values of lagged coefficients. If past values of, say, money supply changes have a significant effect on the real exchange rate, then the money supply is said to "Granger cause" the exchange rate.[14]

Secondly, since the autoregressive equations extract the effects of past movements of variables, the residuals from each of these equations provide measures of unanticipated movements of variables in the system and thus act as proxies for shocks. Correlations of these residuals may be interpreted as measures of the association of unanticipated variable movements. Thus, for example, a positive correlation between the U.S. money supply and the real dollar exchange rate residuals, or a negative correlation between U.S. demand disturbances and the real dollar exchange rate residuals, provide suggestive evidence for the theoretical prediction that the current real dollar should depreciate in response to a current domestic money shock and appreciate in response to a current domestic demand shock.[15]

Lastly, the VAR estimates may be transformed in a manner to yield estimates of how much of the variance of any variable in the system is attributable to itself and other variables in the system.[16] These so-called "variance decompositions" can be used to infer the relative effect of money and real disturbances on exchange rate fluctuations.[17]

Results

Two VAR systems were estimated with monthly data, each containing six variables. The first consisted of the real dollar/yen rate, the real price of oil, and money supplies and industrial production for

Table 2

VAR Equation Estimates for United States - Japan[a]

Dependent Variable[b]:	United States Money Supply	Japan Money Supply	Real Price of Oil	United States Industrial Production	Japan Industrial Production	Real Exchange Rate
Significance of lagged variables[c]						
United States Money Supply	.06	.66	.07	.07	.29	.17
Japan Money Supply	.28	.00	.27	.74	.16	.64
Real Price of Oil	.52	.39	.46	.23	.07	.79
United States Industrial Production	.06	.24	.30	.35	.06	.63
Japan Industrial Production	.75	.14	.38	.01	.05	.86
Real Exchange Rate	.39	.96	.21	.30	.52	.69
$\bar{R}^2$	.89	.86	.21	.86	.97	−.16
SEE	.006	.017	.023	.011	.012	.034

Correlation Matrix of Residuals[d]

	United States Money Supply	Japan Money Supply	Real Price of Oil	United States Industrial Production	Japan Industrial Production	Real Exchange Rate
United States Money Supply	—	−.14*	.15*	−.06	−.09	.19*
Japan Money Supply		—	−.13*	−.31***	−.17*	.07
Real Price of Oil			—	.21**	−.04	−.11
United States Industrial Production				—	.43***	−.23**
Japan Industrial Production					—	.17*
Real Exchange Rate						—

[a]Monthly data, Nov. 1973 - Oct. 1985

[b]All variables expressed in percentage change form. Note the real exchange rate is defined as the real dollar price of foreign exchange.

[c]Regressions contain 12 lags of each variable, as well as a constant, linear and quadratic time trends, and monthly seasonal dummies. Joint significance of the lagged coefficients for each variable is measured by the marginal significance level of the F-statistic. A marginal significance level smaller than .10 indicates a greater than ninety percent probability of rejection of the null hypothesis that the lagged coefficients have no effect.

[d]Correlation levels significant at marginal significance levels greater than .05, .1, and .2 are indicated by ***, **, and *, respectively. For example, a correlation level marked by * indicates there is less than a twenty percent probability of obtaining that level if the null hypothesis that no correlation exists is true.

Table 3

VAR Equation Estimates for U.S. - Germany[a]

Dependent Variable[b]:	United States Money Supply	West German Monetary Base	Real Price of Oil	United States Industrial Production	West German Industrial Production	Real Exchange Rate
Significance of lagged variables[c]						
United States Money Supply	.67	.25	.35	.59	.88	.14
West German Monetary Base	.51	.00	.57	.51	.93	.76
Real Price of Oil	.85	.13	.08	.79	.67	.71
United States Industrial Production	.05	.93	.83	.27	.14	.54
West German Industrial Production	.94	.44	.66	.90	.01	.44
Real Exchange Rate	.91	.08	.87	.84	.87	.69
R^2	.88	.58	.02	.83	.88	−.01
SEE	.006	.027	.026	.013	.032	.033

Correlation Matrix of Residuals[d]

	United States Money Supply	West German Monetary Base	Real Price of Oil	United States Industrial Production	West German Industrial Production	Real Exchange Rate
United States Money Supply	—	−.16*	.04	.02	.02	.15*
West German Monetary Base		—	−.31***	−.01	.01	−.28***
Real Price of Oil			—	.03	.09	−.03
United States Industrial Production				—	.34***	−.13*
West German Industrial Production					—	−.09
Real Exchange Rate						—

[a]Monthly data, Nov. 1973 - Oct. 1985

[b]All variables expressed in percentage change form. The real exchange rate is defined as the real dollar price of foreign exchange.

[c]See Table 2, note c.

[d]See Table 2, note d.

Table 4

Decomposition of Variance

	Percentage of Variance in Exchange Rate Explained by[a]					
	United States Money Supply	Foreign Money Supply[b]	Real Price of Oil	United States Industrial Production	Foreign Industrial Production[b]	Real Exchange Rate[b]
Japan	11	16	9	12	14	38
West Germany	17	9	8	15	8	43

[a]Figures represent percentage of variance of (48-month ahead forecast errors in predicting) exchange rate attributable to each variable. For example, 11% of the variance in real dollar/yen rate is due to U.S. money. Note that figures sum to 100% when added horizontally.

[b]Of country in first column.

both the United States and Japan. The second consisted of the dollar/German mark rate, the real price of oil, and money supplies and industrial production for the United States and Germany.[18] Difficulties in obtaining data with monthly frequency limited the inclusion of other possibly relevant variables, such as government spending.

Note that the real exchange rate was defined as the real dollar price of foreign exchange, with an increase in the real exchange rate indicating a real depreciation of the dollar. To provide an adequate time period for adjustment to the system of floating exchange rates, the observation period began in November 1973 and ended with October 1985. Concern about degrees of freedom limitations precluded the examination of results for subperiods.

The results of the VAR equation estimates for the U.S.-Japan and U.S.-Germany systems are presented in Tables 2 and 3, respectively. Observe in the last column of each table that the real dollar/yen and dollar/mark rates were not significantly influenced (Granger-caused) by lagged values of any of the variables in the system (the marginal significance levels were .17 or much higher). For the other equations, lagged values of particular sets of variables are occasionally seen to influence (Granger-cause) either themselves or other variables, using a ten percent marginal significance standard.

The bottom panels of Tables 2 and 3 present the correlations of the residuals from the estimated VAR equation. Of primary interest are the correlations of the real exchange rate with those of other variables of the system, reported in the last column. Here we find some suggestive evidence for the association of real exchange rate movements and money and real shocks that accords with the theoretical implications of the model in Section I.

Observe first that U.S. money supply residuals are positively and significantly correlated with residuals in both the real dollar/yen and dollar/mark rates, while German money supply residuals are negatively correlated with the dollar/mark rate. The industrial production residuals may be interpreted as business-cycle demand shocks since, through the VAR estimates, they have been "purged" of the effects of money changes and supply disturbances, such as oil price changes, as well as of trend effects. Observe that U.S. industrial production residuals are negatively correlated with each bilateral real exchange rate, while Japanese industrial production residuals are positively correlated with the dollar/yen rate, as expected.[19]

Table 3 presents results from the decomposition of variances.[20] Observe first that foreign money and industrial production innovations account for relatively more of the variance of the dollar/yen rate (16 percent + 14 percent = 30 percent), while U.S. money and industrial production innovations account for relatively more of that of the dollar/mark (17 percent + 15 percent = 32 percent). In other words, foreign disturbances appear to have played a greater role in influencing movements of the dollar/yen rate; U.S. disturbances were more significant for dollar/mark fluctuations.

Note second that, for the dollar/yen rate, U.S. and Japanese monetary disturbances account for (11 percent + 16 percent =) 27 percent and U.S. and Japanese demand disturbances for (12 percent + 14 percent =) 26 percent of the exchange rate variance. For the dollar/mark rate, money and demand disturbances account for 26 percent and 23 percent, respectively, of the exchange rate variance. Thus, for both bilateral rates, money and real shocks appear separately to account for a roughly comparable proportion of the exchange rate variance.

Observe finally that the variance of the dollar/yen and dollar/mark rates explained by themselves are rather large (38 and 43 percent respectively). These figures represent the part of the real exchange rate that cannot be forecast by the other variables in the analysis and which reflects the influence of unincluded variables and pure innovations in the exchange rate itself. Their magnitude suggests that a sizeable proportion of real exchange rate fluctuations still remains to be explained by other variables and better proxies for monetary and demand conditions.

III. Conclusions

This paper has provided both a theoretical and empirical framework for analyzing the response of the real exchange rate to monetary and real disturbances. The sensitivity of the real exchange rate to these disturbances was shown to depend on the degree of information possessed by economic agents. When agents have imperfect information and are confused about the relative magnitudes of monetary and real disturbances, the real exchange rate depends on monetary as well as real disturbances.

The empirical analysis indicates that movements in the real value of the dollar can indeed be associated with real and monetary disturbances. In particular, support was found for hypotheses suggested by the theory that U.S. money supply increases induce falls in the real value of the dollar while real demand expansions generate rises in real dollar value. Foreign shocks were also seen in some instances to influence the value of the dollar. They were found to play a greater role in influencing fluctuations in the real dollar/yen rate than in the dollar/mark rate.

Our analysis suggests that governments can and do influence the real exchange rate through policies affecting money and goods market conditions. We conclude that policies designed to reduce money and real market disturbances should also reduce the variability of the real exchange rate. Our findings also suggest an alternative means of achieving such a goal of stability, namely, increasing the extent of knowledge in the economy about underlying economic conditions. In particular, policies that result in less confusion and more information about the relative magnitudes of money and real disturbances may decrease the sensitivity of the real exchange rate to existing money shocks.

Appendix

This appendix describes the derivation of expressions for the rational expectations of current disturbances from existing market signals, and also of the equilibrium real exchange rate response coefficients.

The general expression for rational expectations of any given disturbance ϵ_{kt}, $k=d,c,m$, formed conditionally on an information set containing the signals Z_t^G and Z_t^M is given by (see Sargent, 1979, pp. 208-209)

$$E_t[\epsilon_{kt} | Z_t^G, Z_t^M] = E_t[\epsilon_{kt} | Z_t^G] + E_t[(\epsilon_{kt} - E_t[\epsilon_{kt} | Z_t^G])|(Z_t^M - E_t[Z_t^M | Z_t^G])]$$

where for any variable X and Y

$$E_t[X_t|Y_t] = (Cov[X_t,Y_t]/Var[Y_t])Y_t,$$

and Cov and Var represent the covariance and variance operators. Evaluation of this expression for $k=d,c,m$ implies

$$\text{(A.1)}\ E_t\epsilon_{dt} = (\sigma_d^2\sigma_m^2/\Delta)Z_t^G - (c_0\sigma_c^2\sigma_d^2/\Delta)Z_t^M$$

$$\text{(A.2)}\ E_t\epsilon_{ct} = [(\sigma_c^2\sigma_m^2 + c_0^2\sigma_d^2\sigma_c^2)/\Delta]Z_t^G + (c_0\sigma_c^2\sigma_d^2/\Delta)Z_t^M$$

$$\text{(A.3)}\ E_t\epsilon_{mt} = (c_0\sigma_d^2\sigma_m^2/\Delta)Z_t^G + [\sigma_m^2(\sigma_d^2 + \sigma_c^2)/\Delta]Z_t^M$$

where $\Delta = \sigma_m^2\sigma_d^2 + \sigma_m^2\sigma_c^2 + c_0^2\sigma_d^2\sigma_c^2$; and σ_d^2, σ_c^2, and σ_m^2 are the absolute variances of the demand, cost, and money shocks, respectively. The coefficients in these expressions represent the explicit formulas for the C coefficients in equations 17-19 in the text. Substitution by $Z_t^G = \epsilon_{dt} + \epsilon_{ct}$ and $Z_t^M = \epsilon_{mt} - c_0\epsilon_{dt}$ and rearrangement gives:

$$\text{(A.4)}\ E_t\epsilon_{dt} = \epsilon_{dt} - (\theta_d\epsilon_{dt} - \theta_c\epsilon_{ct} + \theta_m\epsilon_{mt})$$

$$\text{(A.5)}\ E_t\epsilon_{ct} = \epsilon_{ct} + (\theta_d\epsilon_{dt} - \theta_c\epsilon_{ct} + \theta_m\epsilon_{mt})$$

$$\text{(A.6)}\ E_t\epsilon_{mt} = \epsilon_{mt} - c_0(\theta_d\epsilon_{dt} - \theta_c\epsilon_{ct} + \theta_m\epsilon_{mt})$$

where $\theta_d = \sigma_c^2\sigma_m^2/\Delta$, $\theta_c = \sigma_d^2\sigma_m^2/\Delta$,

$\theta_m = c_0\sigma_d^2\sigma_c^2/\Delta$; $0 \leq \theta_d, \theta_c, \theta_m \leq 1$.

Equations A.4-A.6 relate the conditional expectations of current disturbances to their actual levels. The parameters θ_d, θ_c, and θ_m represent the relative variances of demand, cost, money shocks, respectively. They reflect the noisiness of market conditions and hence the degree of confusion by agents about the shocks that they cannot directly observe. Thus, for example, θ_d measures the degree of confusion about demand conditions. The definition of θ_d indicates that such confusion is high when the variances of cost and money shocks (σ_c^2, σ_m^2) are relatively large since, in that case, market conditions primarily reflect fluctuations due to cost and money disturbances, and reveal relatively little about demand conditions.

In the absence of any confusion about current shocks, θ_d, θ_c, and θ_m equal zero, and equations A.4-A.6 imply that agents will fully perceive all shocks. In general, however, confusion will exist and agents will misperceive shocks. Equation A.4, for example, describes how agents misperceive demand shocks. The extent of the misperception diminishes the smaller are the variances of cost and money supply shocks since the confusion about demand disturbances (θ_d) then diminishes.

Equation A.4 also says that, with imperfect information, expectations of real demand shocks will depend on money (and cost) shocks. More specifically, positive money shocks result in lower expectations of demand shocks. The effect of a given money shock on perceptions of real demand disturbances is magnified the greater are the relative variances of real disturbances (the greater is θ_m). Expectations of cost and money shocks may be interpreted similarly.

To solve explicitly for the B coefficients whose signs are given in Table 1 in the text, note that at time t, d_{t-1}, c_{t-1}, and m_{t-1} are assumed to be known. Substitution of Equations A.4-A.6 in Equation 16 subsequently implies

$$\begin{aligned} E_t q_{t+1} = \bar{q} &+ \rho_d B_d d_{t-1} + \rho_c B_c c_{t-1} + \rho_m B_m m_{t-1} \\ &+ B_{\epsilon d}[\epsilon_{dt} - (\theta_d \epsilon_{dt} - \theta_c \epsilon_{ct} + \theta_m \epsilon_{mt})] \\ &+ B_{\epsilon c}[\epsilon_{ct} + (\theta_d \epsilon_{dt} - \theta_c \epsilon_{ct} + \theta_m \epsilon_{mt})] \\ &+ B_{\epsilon m}[\epsilon_{mt} - c_0(\theta_d \epsilon_{dt} - \theta_c \epsilon_{ct} + \theta_m \epsilon_{mt})] \end{aligned}$$

Table A

Real Exchange Rate Response Coefficients

$$q_t = \bar{q} + B_d d_{t-1} + B_{\epsilon d}\epsilon_{dt} + B_c c_{t-1} + B_{\epsilon c}\epsilon_{ct} + B_m m_{t-1} + B_{\epsilon m}\epsilon_{mt}$$

$\bar{q} = (a_0 - b_0)/(b_2 + e_0)$	
$B_d = -\rho_d D_d$	$\lesseqgtr 0$ as $\rho_d \gtreqless 0$
$B_{\epsilon d} = -D_d + a_2\theta_d(\rho_d D_d - \rho_c D_c)$	< 0 if $\rho_d, \rho_c > 0$
$B_c = -\rho_c D_c$	$\lesseqgtr$ as $\rho_c \gtreqless 0$
$B_{\epsilon c} = -D_c - a_2\theta_c(\rho_d D_d - \rho_c D_c)$	< 0 if $\rho_d, \rho_c > 0$
$B_m = 0$	
$B_{\epsilon m} = a_2\theta_m(\rho_d D_d - \rho_c D_c)$	$\gtreqless 0$ as $\rho_d \gtreqless \rho_c \gtreqless 0$

where
$a_2 = e_0/(b_2 + e_0) < 1$
$D_d = 1/(b_2 + e_0(1 - \rho_d))$
$D_c = 1/(b_2 + e_0(1 - \rho_c))$
$\theta_d = \sigma_c^2\sigma_m^2/\Delta,\ 0 \leq \theta_d \leq 1$
$\theta_c = \sigma_d^2\sigma_m^2/\Delta,\ 0 \leq \theta_c \leq 1$
$\theta_m = c_0\sigma_d^2\sigma_c^2/\Delta,\ 0 \leq \theta_m \leq 1$
$\Delta = \sigma_c^2\sigma_m^2 + \sigma_d^2\sigma_m^2 + c_0^2\sigma_d^2\sigma_c^2$

Substituting the above expression in turn into Equation 13 yields, upon rearrangement:

$$q_t(b_2 + e_0) = a_0 - b_0 + e_0\bar{q} + \rho_d(e_0B_d - 1)d_{t-1}$$
$$+ \{e_0[B_{\epsilon d} - \theta_d(B_{\epsilon d} - B_{\epsilon c} + c_0B_{\epsilon m})] - 1\}\epsilon_{dt}$$
$$+ \rho_c(e_0B_c - 1)c_{t-1} +$$
$$\{e_0[B_{\epsilon c} + \theta_c(B_{\epsilon d} - B_{\epsilon c} + c_0B_{\epsilon m})] - 1\}\epsilon_{ct}$$
$$+ \rho_m e_0 B_m m_{t-1} +$$
$$[e_0(B_{\epsilon m} - \theta_m(B_{\epsilon d} - B_{\epsilon c} + c_0B_{\epsilon m})]\epsilon_{mt}$$

Dividing through by $b_2 + e_0$, equating coefficients term-by-term with Equation 15, and solving for the B coefficients gives the expressions in Table A.

The perfect information case is characterized when the relative confusion parameters θ_d, θ_c, and θ_m in the coefficients are equal to zero. In this instance, the real exchange rate depends only on real demand and cost shocks, and not on current or lagged money shocks ($B_m = B_{\epsilon m} = 0$). In the case of imperfect information, current money supply shocks will influence the real exchange rate (since $B_{\epsilon m} \neq 0$). If demand disturbances persist more strongly than cost disturbances ($\rho_d > \rho_c > 0$) then a positive money supply shock causes a real depreciation ($B_{\epsilon m} > 0$). The larger is θ_m and the degree of confusion about money disturbances, the greater is the response of the real exchange rate. Finally, note that the response of q to current demand and cost shocks differs from the full information response and also depends on the degree of confusion about these shocks (θ_d, θ_c) and on the serial correlation parameters (ρ_d, ρ_c).

FOOTNOTES

1. The variability of real exchange rates over the floating rate period has been well documented. See, for example, Frenkel (1981) and Cumby and Obstfeld (1984). For discussion of the welfare effects of exchange rate variability, see Obstfeld (1985) and Frankel (1985, pp. 23-32).

2. The assumption that agents have imperfect information because they are unable to observe directly or to infer from market conditions the magnitude of current disturbances to the economy is characteristic of so-called "island" models first developed by Phelps (1970) and Lucas (1972, 1975) to analyze domestic macroeconomic adjustment. More recently, this approach has been employed in international macroeconomic models as well, for example, Bhandari (1982), Kimbrough (1983, 1984), Flood and Hodrick (1985a, 1985b), and Glick and Wihlborg (1986). These models, however, have generally focused on issues other than real exchange rate behavior.

3. Other explanations exist for real exchange fluctuations in response to both monetary and real disturbances. For example, in so-called "sticky-price" models, it is assumed that domestic and foreign goods prices adjust more slowly than the exchange rate to disturbances because of labor and/or goods market rigidities, such as fixed wage contracts (see Dornbusch, 1976; Obstfeld, 1985). When domestic and foreign prices are relatively rigid in the short run, real as well as nominal exchange rates will be affected by disturbances. This paper does not attempt to distinguish among competing hypotheses.

4. This particular specification emphasizes the role of expected price changes in current supply decisions. If the price level in natural units is denoted by P_t, then the relevant price ratio is $P_t/[E_tP_{t+1}/(1+i)]$. The logarithmic analogue to this price ratio is $p_t + \ln(1+i) - E_tp_{t+1}$, or, noting that $\ln(1+i) \approx i$, by $i - (E_tp_{t+1} - p_t)$, which is the definition of the real interest rate. Work employing this specification includes Barro (1980), Bhandari (1982), and Kimbrough (1984). Note that this specification, which emphasizes the role of anticipated price changes in supply decisions, differs from the Lucas-type supply function which depends on $p_t - E_{t-1}p_t$ and emphasizes the role of unanticipated price changes.

5. Note that, in addition to the effect of the real exchange rate on demand by foreigners for domestic output, the constant b_0 and the disturbance term d_t may also be interpreted as including foreign influences.

6. With $p_t^f = 0$, equation 4 implies that $p_t = a(p_t^d - s_t) + s_t$ and equation 5 that $q_t = s_t - p_t^d$. Substitution of the latter expression in the former and rearrangement gives equation 11 in the text.

7. Substituting equation 10 in equation 2 and assuming $i_t^f = 0$ gives $r_t = E_t(s_{t+1} - p_{t+1}) - (s_t - p_t)$. Use of equation 11 gives equation 12 in the text. The parameter a, the share of domestic goods in consumption, appears in equation 12 since the real domestic interest rate is defined in terms of the expected inflation rate in the *overall* domestic price level, while the real exchange rate is defined in terms of the price of domestic goods alone.

8. Equation 15 may be interpreted as a "guess" about the general form of the equilibrium expression for the real exchange rate. The technique of "guessing" the general form of the equilibrium solution and then determining the values of the coefficients in this equilibrium explicitly is standardly employed in linear stochastic difference models of the type formulated in this paper. See, for example, Bhandari (1982) Flood and Hodrick (1985a, 1985b), Glick and Wihlborg (1986), and Kimbrough (1983, 1984). A similar procedure could also have been applied to the determination of the equilibrium nominal exchange rate.

9. Note that the model contains two signals and three disturbances. This implies that agents cannot perfectly infer the magnitudes of the individual disturbances merely from observing market conditions. See Glick and Wihlborg (1986) for a model of exchange rates which illustrates how

under these circumstances a demand for information purchase can arise.

It should also be pointed out that if in any period t agents lack full information about the disturbances in periods t-1 or earlier, then lagged disturbances will pose an additional source of confusion for agents when they attempt to infer the magnitude of current shocks and to form expectations about the future exchange rate. In such cases, the signals obtained in period t will reflect not only current shocks but also unobservable lagged shocks. Correspondingly, the equilibrium exchange rate will depend on the same lagged shocks as well as whatever disturbances in the past are observable and useful for inferring the magnitudes of subsequent shocks.

10. That monetary disturbances affect real variables under imperfect information is a feature of the closed-economy macro models of Lucas (1972, 1975) and the open-economy macro models of Bhandari (1982), Flood and Hodrick (1985a, 1985b), Glick and Wihlborg (1986) and Kimbrough (1983, 1984).

11. The VAR technique presumes that the variables in the system are covariance stationary and that any relationships among them are linear. The procedure of transforming variables into percentage changes, described below, is the standard means of achieving covariance stationarity. Discussions of the VAR technique may be found in Sims (1980) and Hakkio and Morris (1984).

12. An alternative approach is to use pre-whitened data in the VAR system by, in addition to taking first differences of logs, further filtering the data to remove all trend and seasonality before performing the regressions. A difficulty with this procedure is that the detrending and deseasonalization may remove evidence of the interrelationships among variables that one is seeking.

13. The assumption of a common lag length is necessary for the VARs to provide consistent estimates. There are several tests available for determining the proper lag length, but alternative tests often provide different results. In addition, degrees of freedom must be considered. Thus, ultimately, the choice of lag length is a subjective matter. A 12-month lag specification is employed in this paper.

14. There are a number of difficulties with interpreting Granger causality tests. First, the test may indicate a causal relation when in fact each variable is reacting to a common third variable but with a different lag, or anticipating a common third variable but with a different lead. Second, the tests cannot detect contemporaneous relations among variables.

15. Note that, to the extent government monetary policy is determined by a reaction to undesired exchange rate changes, the positive correlation between money shocks and the exchange rate will be dampened.

16. The transformation involves obtaining the moving average representation of the VAR system whereby each of the variables in the system is expressed as a moving average function of the residuals.

17. One potential problem in interpreting the variance decomposition results is that the use of lagged endogenous variables only in each equation of the VAR system forces all contemporaneous shocks that affect the endogenous variables to feed through the residuals of each equation. While this poses no problem in the estimation stage of the analysis, if the estimated residuals have high contemporaneous correlations, the order in which the variables are entered in the system could cause certain variables to take on exaggerated importance in the variance decompositions, while other, perhaps more significant, variables take on little or no weight.

This problem arises because the Choleski decomposition (see Hakkio and Morris, 1984) used to convert the VAR model into its moving average form attributes all of the contemporaneous correlation between any two variables to the one ordered first. To minimize this problem, the order of any variables that were highly correlated was switched to check the sensitivity of results. No major problems resulted.

18. The money supply figures were derived from end-of-month M1 stock data for the United States and Japan and monetary base data for Germany. The real value of the dollar was defined as the U.S. producer price of oil divided by the U.S. wholesale price. The real value of the dollar was defined as the monthly foreign wholesale price times the end-of-month dollar price of foreign exchange divided by the U.S. wholesale price. All data came from the *IMF International Financial Statistics*.

19. The correlation levels corresponding to marginal significance levels (with the 46 degrees of freedom in the VAR estimates) of .2, .1 and .05 are given by .12, .18, and .24, respectively. Thus, for example, there is a less than twenty percent probability of observing a correlation larger than .12 if the null hypothesis that no correlation exists were true.

20. Technically, the figures given are the percentage of variance of the 48-month ahead forecast errors in predicting the exchange rate attributable to individual variables. The errors over this long a horizon, it can be shown, approximate the variance of the predicted variable.

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