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A MODEL OF EXCHANGE-RATE DETERMINATION WITH POLICY REACTION: EVIDENCE FROM MONTHLY DATA

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I. ABSTRACT

During the 1970s an extensive theoretical literature has developed analyzing market determination of freely floating exchange rates. At the same time, there has been extensive and continuous intervention in the market by central banks. Exchange rates have not been floating freely; they have been managed, or manipulated, by central banks. However, most of the description of exchange rate policy, as actually practiced, has been informal, or "literary," not integrated with the formal theoretical literature. Recent examples are the surveys in Branson (1981a) and Mussa (1981).

In this paper I integrate exchange-rate policy into a model of exchange-rate behavior, and examine the monthly data from the 1970s econometrically, to infer hypotheses about policy behavior. I focus on four major currencies, the U.S. dollar, the Deutschemark, Sterling, and the Japanese yen, and analyze movements in their effective (weighted) exchange rates as calculated by the IMF.

In section II a model of market determination of a floating exchange-rate is laid out. It is a rational-expectations version of the model in Branson (1977), and it draws on the model of Kouri (1978). It is the same as the model in Branson (1983). The model shows how unanticipated movements in money, the current account, and relative price levels will cause first a jump in the exchange rate, and then a movement along a "saddle path" to the new long run equilibrium. Here the role of "news" in moving the exchange rate, as recently emphasized by Dornbusch (1980) and Frenkel (1981), is clear. The model emphasizes imperfect substitutability between domestic and foreign bonds, in order to prepare for the analysis of intervention policy in section III.

Exchange-rate policy is introduced in section III. We analyze the options available to the central bank that wants to reduce the jump in the exchange rate following a real or monetary disturbance--"news" about the current account, relative prices, or money. This is the policy characterized as "leaning against the wind" in Branson (1976). The distinction is made between monetary policy and sterilized intervention.

In section IV we turn to the monthly data. The quarterly data were analyzed in Branson (1983). Systems of vector autoregressions (VARs) are estimated for each of the countries, and the correlations among their residuals are studied. These represent the "innovations," or "news" in the time series. A clear pattern emerges in these correlations, in which policy in the U.S. and Japan drives exchange rates, and policy in Germany and the U.K. reacts by moving interest rates, and by sterilized intervention. This is essentially the same result that appeared on the quarterly data in Branson (1983). Thus the analyses tend to reinforce each other; both data sets tell basically the same story.

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II. An Asset-Market Model with Rational Expectations

II.A. Introduction

The purpose of this section is to lay out a simple asset-market model of exchange-rate determination within which, in the next section, monetary policy reaction to movements in the exchange rate can be analyzed. The literature of the 1970s has identified three principal macroeconomic variables that influence movements in exchange rates. These are money supplies, relative price levels, and current-account balances. Here I develop a representative model that explicitly includes all three elements. The model is an extension of the asset-market model sketched in Branson (1975), and developed in full in Branson (1977). It is a close relative of Kouri (1982). In the early versions of this model the focus was on the roles of relative prices and asset markets, and static expectations were assumed. Here the model is extended to study the effects of underlying "real" disturbances influencing the current account and to include explicitly policy intervention in a rational expectations framework.

II.B. Asset-market specification.

To make the analysis manageable, let us consider one country in a many-country world. We can aggregate the assets available in this country into a domestic money stock M, which is a nonearning asset, holdings of domestically-issued assets B, which are denominated in home currency, and net holdings of foreign-issued assets F, which are denominated in foreign exchange._/ B^P (for bonds) is government debt held by the private sector,

_/Since the analysis here applies to any single country in the international financial system, I use the terms 'home' and 'foreign' to denote the country being discussed and the rest of the system, respectively. At the level of generality of this discussion no damage would be done if the reader substituted "US for 'home country', 'dollar' for 'home currency' and 'Fed' for 'central bank'.

and B^c is government debt held by the central bank. Total government debt $B = B^p + B^c$. F^p (for foreign assets) is the net claims on foreigners held by the domestic private sector and R is central bank foreign reserves. Total national net claims on foreigners $F = F^p + R$. The money stock M is equal to $R + B^c$, with a 100% reserve system. I assume the initial exchange rate is indexed to unity, and that the central bank does not permit capital gains or losses in R to influence M. The current account in the balance of payments gives the rate of accumulation of F over time. The rate of accumulation of B is the government deficit. M is controlled by central bank purchases (or sales) of B or F from (or to) the domestic private sector.

The rate of return on F is given by $\bar{r}$, fixed in the world capital market, plus the expected rate of increase in the exchange rate, $\hat{e}$. The rate of return on B is the domestic interest rate r, to be determined in domestic financial markets. Total private-sector wealth, at any point in time, is given by $W = M + B^p + eF^p$, so here the exchange rate e, in home currency per unit of foreign exchange (e.g. $0.50 per DM), translates the foreign-exchange value of F into home currency.

The total supplies of B and F to the national economy are given at each point in time. Each can be accumulated only over time through foreign or domestic investment.[2/] Given the existing stocks of B and F at any

2/Since F is home claims on foreigners less home liabilities to foreigners, an asset swap which exchanges a claim and a liability with a foreign assetholder is a transaction within F, changing claims and liabilities by the same amount. This transaction would leave F and B unchanged. The reason for using this particular aggregation will become clear when we study dynamic adjustment below. Basically, we want to define net foreign assets consistently with the balance of payments and national income and product accounts, which record the capital account balance as the change in U.S. private holdings of net foreign assets. The assumptions outlined above make M and B non-traded assets. This implies that the total stocks of M, B, and F in domestic portfolios are given at any point in time.

point in time, the central bank can make discrete changes in M by swapping either B or F with the domestic private sector; these are open-market operations in government debt or foreign assets.

The demand for each asset by the private sector depends on wealth, $W = M + B^p + eF^p$, and both rates of return, r and $\bar{r} + \hat{e}$. As wealth rises, demands for all three assets increase. The demands for B and F depend positively on their own rates of return and negatively on those of the other assets. The demand for money depends negatively on both r and $\bar{r} + \hat{e}$; as either rises, asset-holders attempt to shift from money into the asset whose return has gone up.

These asset-market equilibrium conditions are summarized in equations (1) - (6).

(1) $M \equiv R + B^c = m(r, \bar{r} + \hat{e}) \cdot W.$

(2) $B^p = b(r, \bar{r} + \hat{e}) \cdot W.$

(3) $eF^p = f(r, \bar{r} + \hat{e}) \cdot W.$

(4) $W = M + B^p + eF^p.$

(5) $B^c + B^p = \bar{B}.$

(6) $F^p + R = F.$

Equation (4) is the balance sheet constraint, which ensures that $m + b + f = 1$. The three demand functions give the desired distribution of the domestic wealth portfolio W into the three assets. Specifying the asset demand functions as homogeneous in wealth eliminates the price level from the asset-market equilibrium conditions. Given the balance sheet constraint (4), and gross substitutability of the three assets, we have the constraints on partial derivatives of the distribution functions:

$$m_r + f_r = b_r < 0: \qquad m_{\bar{r}} + b_{\bar{r}} = f_{\bar{r}} < 0.$$

Here a subscript denotes a partial derivative. The three market equilibrium conditions (1)-(3) contain two independent equations given the balance sheet constraint (4). In equation (5) the bar over B indicates that the total supply of government debt is fixed.

II.C. Asset accumulation and the current account.

Equations (1)-(6) provide the specification of asset markets in the model. The other main building block of the model is the current-account equation. The balance-of-payments accounts provide the identity

$$\dot{F} \equiv \dot{F}^P + \dot{R} \equiv X + \bar{r}(F^P + R) \equiv X + \bar{r}F.$$

where X is net exports of goods and non-capital services in terms of foreign exchange. Net exports depend on the real exchange rate e/p, private sector wealth W, (given by equation (4) above), and an exogenous shift factor z which represents real events such as changes in tastes in technology, oil discoveries, etc., which increase net exports for given values of e/p and W. Thus we can write

$$X = X(e/P,\ W,\ z);\ X_e > 0,\ X_W < 0;\ X_z > 0.$$

The sign of X_e assumes the Marshall-Lerner condition holds; X_W reflects wealth effects on import demand.

Substitution of the function for net exports into the balance-of-payments identity gives us the equation for accumulation of national net foreign assets:

(7) $\dot{F} = X(e/p, W, z) + \bar{r}F.$

It is important to note that open-market swaps between the central bank and the domestic private sector have no direct effect on W <u>or</u> F in (7). And the effect of accumulation of <u>national</u> net foreign assets through a current-account surplus ($\dot{F} > 0$) on W <u>and</u> F is the same regardless of the distribution of $\dot{F}$ between $\dot{F}^P$ and $\dot{R}$. Since an increase in R, ceteris paribus, increases the money stock, which is part of W, any increase in F will raise W by dF independently of the split between $\dot{F}^P$ and $\dot{R}$. Thus the central bank's intervention policy will have no effect on how a current-account balance moves F and W in (7).

The effect of an increase in F on $\dot{F}$ in (7) is unclear.

$$\frac{\partial \dot{F}}{\partial F} = X_W + \bar{r},$$

with $X_W < 0$ and $\bar{r} > 0$. Below we will conveniently assume that $\partial\dot{F}/\partial F = 0$; it will quickly become apparent why this is convenient. In Branson (1981), the case where $\partial\dot{F}/\partial F < 0$ is analyzed.

Equations (1)-(7) plus the assumption of rational expectations (or, more precisely, perfect foresight in this non-stochastic model) give us a complete dynamic model in $\dot{F}$ and $\hat{e}$. Price dynamics are suppressed, but we will discuss below exogenous price movements as delayed response to monetary shocks.

II.D. <u>Solution of the model</u>.

Solution of the model proceeds as follows. First, the rational expectations assumption is that $\hat{e}$ is the rate of change of e. Then two equations of (1)-(3), with wealth substituted from (4) can be used to solve for r and $\hat{e}$ as functions of M, W, eF^P. The $\hat{e}$ and $\dot{F}$ equations then are two dynamic equations in e and F that can be solved for the movement in these two variables.

Divide equations (1) and (3) by W and differentiate totally, holding $\bar{r}$ constant:

$$(8) \qquad d(\frac{M}{W}) = m_r dr + m_{\hat{e}} d\hat{e} \; ;$$

$$d(\frac{eF^P}{W}) = f_r dr + f_{\hat{e}} d\hat{e} \; .$$

These can be solved in matrix form as:

$$(9) \qquad \begin{pmatrix} dr \\ d\hat{e} \end{pmatrix} = \frac{1}{(m_r f_{\hat{e}} - f_r m_{\hat{e}})} \begin{bmatrix} f_{\hat{e}} & -m_{\hat{e}} \\ -f_r & m_r \end{bmatrix} \begin{pmatrix} d(\frac{dF^P}{W}) \\ d(\frac{M}{W}) \end{pmatrix} .$$

The solution for $d\hat{e}$ is then

$$(10) \qquad d\hat{e} = \frac{1}{m_r f_{\hat{e}} - f_r m_{\hat{e}}} [-f_r d(\frac{M}{W}) + m_r d(\frac{eF^P}{W})]$$

The coefficients of eF^P/W and M/W are the partial derivatives of the $\hat{e}$ adjustment function,

$$(11) \qquad \hat{e} = \phi(\frac{eF^P}{W}, \frac{M}{W}); \; \phi_1 > 0; \; \phi_2 < 0.$$

This is the dynamic equation to be solved along with (7) for $\dot{F}$ to obtain equilibrium e and F^P.

In the e, F^P space of Figure 1, the $\hat{e} = 0$ locus is a rectangular hyperbola. This can be seen by observing that in ϕ, e and F^P enter multiplicatively (in W as well as the numerator eF^P), so changes in e and F^P that

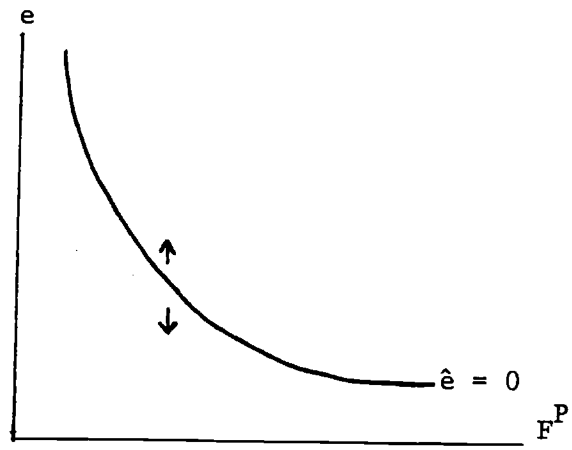

Figure 1: Locus where $\hat{e} = 0$

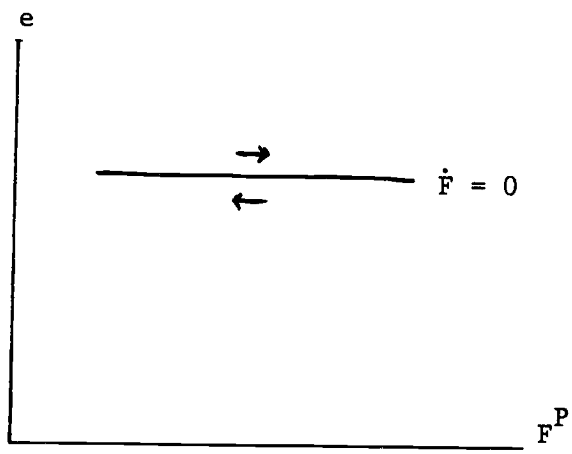

Figure 2: Locus where $\dot{F} = 0$

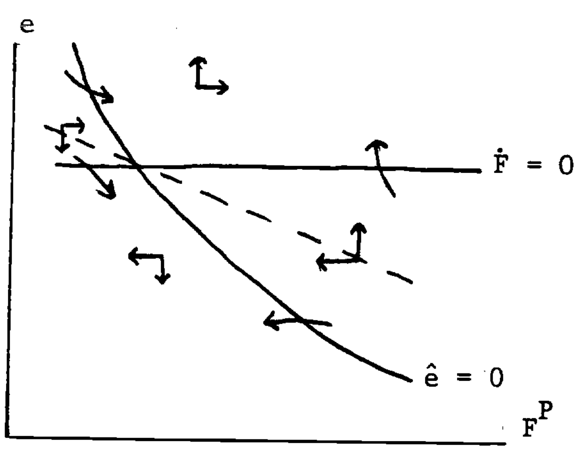

Figure 3: Equilibrium path for e, F^P

hold the product eF^p constant will hold $\hat{e}$ constant. Combinations of e and F^p off the locus move e away from it, as the arrows show. For example, since $\phi_1 > 0$ an increase in e or F^p from a point on the locus makes $\hat{e} > 0$.

An increase in M/W, holding eF^p/W constant, would shift the $\hat{e} = 0$ locus in Figure 1 up. This would be the result of an expansionary open-market operation in the government debt market with $dB^c = dM > 0$, and no change in F^c or F^p. An increase in eF^p/W, holding M/W constant, will shift $\hat{e} = 0$ down; this could result from an open-market swap between F and B. An expansionary open-market operation in the foreign asset market, with the central bank exchanging M for F with the private sector, would shift $\hat{e} = 0$ up both by increasing M/W and reducing eF^p/W. This will provide the difference between intervention in the bond or foreign-asset markets in the model.

For given values of z and p in the $\dot{F}$ equation (7), the $\dot{F} = 0$ locus in e, F^p space is a horizontal line at the e value where $X = -\bar{r}F$. This is shown in Figure 2. If e is above this value, the current-account is in surplus and $\dot{F} > 0$. In section III we will introduce a "leaning against the wind" exchange-rate policy in which the authorities attempt to reduce the extent of jumps in the exchange rate, but not to reverse them. Thus we rule out here the possibility that the monetary authority "over-intervenes," and assume that the sign of $\dot{F}^p$ is the same as the sign of $\dot{F}$; this is the same as assuming $|\dot{R}| < |\dot{F}^p|$. This essentially assumes that the authorities permit the market to guide the system towards its long-run equilibrium, but perhaps slow the movement. The assumption gives the arrows showing movement in Figure 2; above $\dot{F} = 0$, $\dot{F}^p > 0$, below it is negative.

An increase in z in (7) will shift the $\dot{F} = 0$ locus down. Given the assumption that $X_W + \bar{r} = 0$, the extent of the shift is simply given by the effect of a change in e on X:

$$\left.\frac{de}{dz}\right|_{\dot{F} = 0} = -\frac{1}{X_e} \ .$$

If z rises, increasing X and giving a current account surplus, e must fall (currency appreciate) enough to restore the original value of X. An increase in P will shift $\dot{F} = 0$ up, with

$$\left.\frac{de}{dp}\right|_{\dot{F} = 0} = 1 \ .$$

Equilibrium of the system is shown in Figure 3. There is one saddlepath into the equilibrium shown by the dashed line. For a given value of F^P, it is assumed that following a disturbance, the market will pick the value for e that puts the system on the saddlepath toward equilibrium. The system would have quite different properties under a policy regime of "over-intervention" that reversed the pattern of movement in the horizontal direction.

II.E. Reaction to Exogenous Shocks.

II.E.1 Monetary disturbance.

Consider an (unanticipated) expansionary open-market operation in government debt. This initially leaves W and F^P unchanged. There are two extreme assumptions on price adjustment to consider: no change in P, or $dP/P = dM/M$ immediately.

With no change in P as M increases, the $\dot{F} = 0$ locus in Figure 4 does not shift, but $\hat{e} = 0$ shifts up. With F^P initially given, the exchange

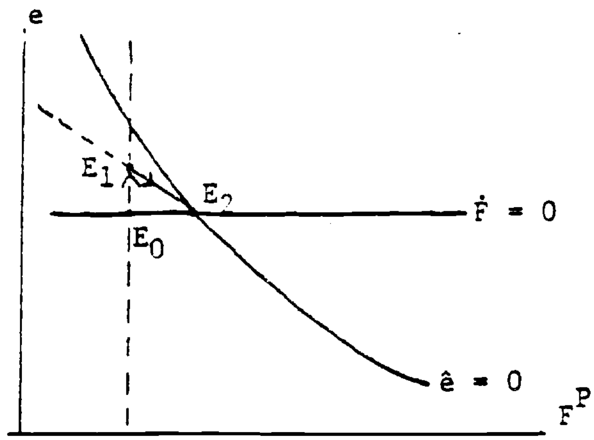

Figure 4: Open-market operation in B, no change in F^P

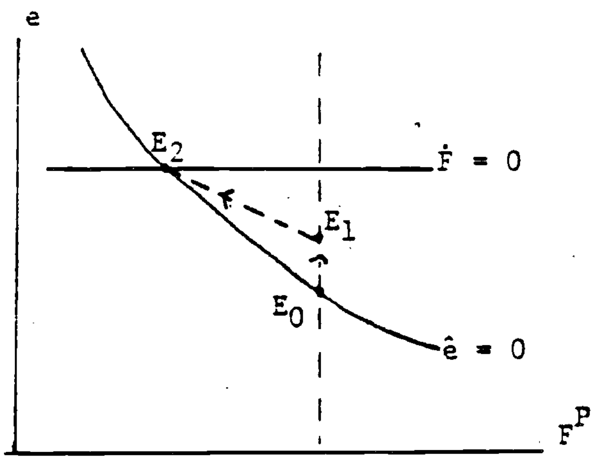

Figure 5: Deterioration in competitiveness

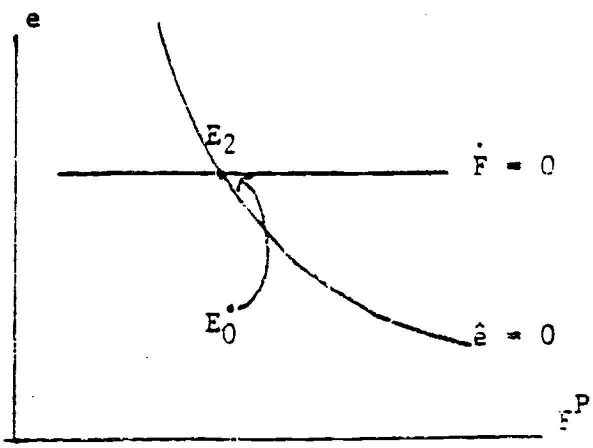

Figure 6: Sluggish price adjustment

rate jumps (currency depreciates) from initial equilibrium E_0 to E_1 on the new saddlepath. This establishes $\hat{e} < 0$ as needed for asset-holders to hold the existing stock of F^p given the lower interest rate. The rise in e/P generates a current-account surplus, and F^p rises with e falling toward E_2. This is an extreme form of "overshooting."

Suppose the domestic price level immediately reacts by rising by the same proportion as the money stock. Then $\dot{F} = 0$ also shifts up by that same proportion. The extent of the upward shift in $\hat{e} = 0$ depends on initial portfolio distribution and the degree of substitutability among F, M, and B. One borderline case would be $M = eF^p$ and $m_r = f_r$. It can be seen in the expression for $d\hat{e}$ in equation (10) that in this case a proportional increase in e will maintain $\hat{e} = 0$. To the extent that $M > eF^p$ or $|f_r| > |m_r|$, the $\hat{e} = 0$ curve would shift up more than $\dot{F} = 0$, requiring "overshooting" and $\hat{e} < 0$, $\dot{F}^p > 0$ moving to equilibrium. The reverse initial conditions would yield "undershooting" with $\hat{e} > 0$, $\dot{F}^p < 0$ in the movement to equilibrium.

II.E.2. <u>Real disturbance</u>.

The effect of an unanticipated fall in z (or an increase in P) is shown in Figure 5. The decrease in competitiveness shifts $\dot{F} = 0$ up from its initial intersection with $\hat{e} = 0$ at E_0. The exchange rate jumps (currency depreciates) from E_0 to E_1, and then gradually rises to E_2 as F^p falls. The depreciation of the currency restores current-account balance ($\dot{F} = 0$). The model "undershoots" in response to real disturbances.

II.E.3. Sluggish price adjustment.

A limiting case of sluggish price adjustment could be modelled as a combination of Figures 4 and 5. Expansionary monetary policy would begin this process illustrated in Figure 4. The delayed price response would then resemble Figure 5. To the extent that the price response is lagged and unanticipated, the e, F^p point would follow a path illustrated in Figure 6. Quicker price response or anticipation would straighten the path to E_2, which may be to the right or left of E_0 depending on initial portfolio distribution and substitutability.

II.F. Conclusions and empirical implications.

It is convenient to summarize here the basic conclusions from the analysis so far.

1. Unanticipated changes in money, the price level, or underlying real conditions should cause a jump in the exchange rate toward the new rational-expectations saddle path.

2. Thus we should expect to see correlation between unanticipated movements in e and M, X, and P in the data. Evidence on quarterly data was presented in Branson (1983); monthly data are presented below.

3. Movement of the exchange rate following a real disturbance is likely to be monotonic, while monetary disturbances are likely to produce "overshooting." Lagged price adjustment makes "multiple overshooting" possible. This can be seen in a combination of Figures 4 and 6.

III. "Leaning Against the Wind" as Exchange Rate Policy

III.A. Introduction.

There is already ample evidence that monetary authorities have generally tried to slow the movement of exchange rates. This type of intervention has long been characteristic of U.S. domestic monetary policy; in Branson (1976) I labelled this "leaning against the wind" as exchange rate policy. Artus (1976) and Branson, Halttunen and Masson (BHM) (1977) presented evidence that German monetary policy responded to movements in the exchange rate in this fashion. BHM (1977) estimated a reaction function of the form $\Delta M = \alpha \Delta e + \ldots$, with $\alpha < 0$ for Germany. As the exchange rate rose (DM depreciated), the money supply was reduced (relative to its trend). Amano (1979) describes Japanese monetary policy as attempting to stabilize the exchange rate similarly. U.K. exchange rate policy was discussed briefly in OECD (1977), where a regression of the form $\Delta r_m = \beta \Delta e + \ldots$, with r_m the minimum lending rate (MLR) and $\beta > 0$ is reported. This suggests that when sterling depreciated (e rose), the MLR was increased as a policy reaction. More recently, Mussa (1981) has presented a thorough review of exchange-rate intervention which is consistent with a "leaning-against-the-wind" model.

The purpose of this section of the paper is to characterize policy intervention in terms of the model of section II, to prepare for interpretation of the empirical results in section IV below. The objective is not to evaluate policy; it is to describe it. The main difference from the previous models is the description of intervention as instantaneous and discrete changes in asset stocks via open-market operations to reduce the size of discontinuous jumps in exchange rates. This type of policy behavior is discernable in the "innovation" correlations in section IV below.

We will begin with the description of monetary policy reaction to real disturbances via open-market operations in government debt or foreign assets. Then we study sterilized intervention in the foreign asset market.

III.B. Monetary policy.

Consider a real disturbance to the current account that shifts $\dot{F} = 0$ up, (rise in e) to restore equilibrium. This is illustrated in Figure 7, where in the absence of policy intervention, the exchange rate would jump from the initial equilibrium E_0 to E_1 and then depreciate further to E_2. If the central bank tightened money by selling bonds to the public, holding F^p initially constant, the $\hat{e} = 0$ curve in Figure 7 would shift down as shown by the dashed $\hat{e} = 0$. This would shift the saddle path down to the path running to E_2', and reduce the exchange-rate jump to E_1'. Thus instantaneous intervention would reduce the initial jump in e. This would be an unexpected change in M, since the originating shift in z and X was unexpected. So this type of intervention could reduce the variability of e over time.

If the open-market operation were done in the foreign asset market, a smaller quantitative intervention would give the same shift in $\hat{e} = 0$ and in the saddle path in Figure 7, because eF^p/W in equation (8) would rise. In addition, since F^p would rise, the initial jump would be to a point on the new saddle path below E_1'. Thus intervention on the foreign-asset market would, in a sense, be more efficient than open-market operations in the bond market. This is essentially the same result that is obtained by Branson (1977) and Kenen (1982) under static expectations.

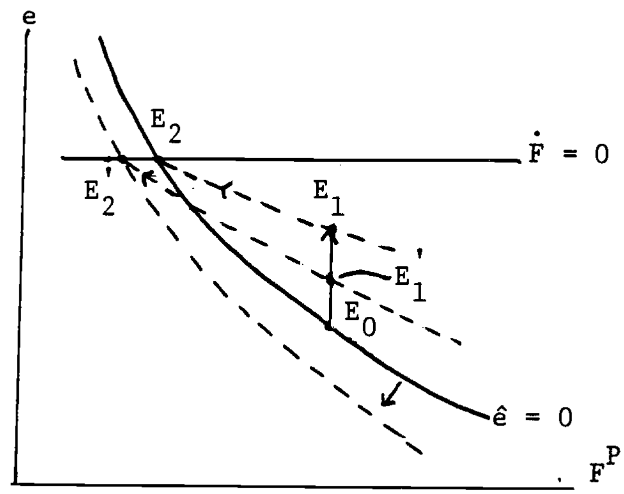

Figure 7: Monetary policy reaction

III.C. Sterilized Intervention.

There is by now ample evidence that central banks intervene in the foreign exchange markets but attempt to prevent the intervention from changing the path of M. The literature was cited in Whitman (1975); more recent results are discussed in Obstfeld (1980) (1982). In terms of the model of section III, this is an open-market exchange of foreign assets for bonds by the central bank, with $\Delta B^p = -e\Delta F^p$ initially. The result is again a downward shift in $\hat{e} = 0$, as in Figure 7, plus an outward shift in F^p. Thus the jump in the exchange rate is to a point below E_1', since F^p increases. This presents the possibility for intervention that does not move the path of the money supply.

III.D. Empirical implications.

The principal empirical implication of the present model of policy intervention is that we should observe the intervention in the correlation of unexpected movements or "innovations" in exchange rates with innovations in money and/or reserves. Monetary intervention would give a negative correlation between exchange-rate and money innovations. Intervention with interest-rate control would give a positive correlation between exchange-rate and interest-rate innovations. If the monetary intervention is done in the foreign-asset market, a positive correlation between exchange-rate innovations and reserves would result. Sterilized intervention would give the reserve-exchange rate correlation without a money-exchange rate correlation. Thus we can study the correlation matrix of innovations in section IV below to infer hypotheses about policy behavior.

IV. Empirical Results Using Vector Autoregression

IV.A. Introduction.

A useful technique for studying the relationships between the innovations in money, the current account balance, relative price levels, interest rates, reserves, industrial production, and the exchange rate is vector autoregression (VAR). Here each variable of a system is regressed against the lagged values of all variables (including itself) in the system, to extract any information existing in the movements of these variables. The residuals from these "vector autoregressions" are the innovations -- the unanticipated movements -- in the variables. We can study the correlations of the residuals to see if they are consistent with the hypotheses implied by the theory of sections II and III. The vector autoregression technique is introduced and justified by Sims (1980). A clear exposition is presented in Sargent (1979). Interesting and instructive applications are discussed in Taylor (1980), Ashenfelter and Card (1981), and Fischer (1981).

Here I estimate systems of VARs on monthly data for each of the four countries, the U.S., the U.K., Germany, and Japan. The data are described in Table 1. Two systems were estimated for each country. Both include the effective exchange rate e, the current account balance CAB, and the effective relative price $P/\bar{P}$, the interest rate IS, industrial production Y, reserves R; the difference between the two is that one includes M1 and the other M3. Industrial production is added to control for business-cycle effects on the demand for money.

Table 1: VARIABLE DEFINITIONS AND DATA

I. Variable Name

e	effective nominal exchange rate, in units of domestic currency per unit of foreign currency as computed by the IMF.
$P/\bar{P}$	relative wholesale prices (ratio of home to competitors indices).
M1	narrow money, as defined by the IMF in the International Financial Statistics (IFS).
M3	broad money, as defined by the IMF (M1 plus quasi-money) in the IFS .
CAB	current account balance .
IS	short-term interest rate.
R	reserves.
Y	industrial production.

II. Countries

United States
United Kingdom
Federal Republic of Germany
Japan

III. Data

1. All data are monthly, and cover 1971:1 to 1980:12 unless otherwise noted.

2. Exchange Rates: e_t is the log of the average effective exchange rate during month t. The units are domestic currency per unit of foreign currency. The index is based on a geometrically weighted average of bilateral rates between the home and 13 other industrial countries. The weights are the same as those used to calculated $P/\bar{P}$. Base: 1975 = 100. Source: IMF. Note that these are not the MERM rates published in IFS.

3. Relative Prices: The index is a log of the ratio of home to foreign monthly wholesale price indices. P is a composite and uses the same weights as e does (see above). Base = 1975. Source: IMF. This index is not the same as that published in the IFS. Our data is based on indices in local (not a common) currency. Series length: 1971:7 to 1980:12

4. Money Stocks: This is the log of the monthly money stock. German and Japanese data are end of the period money stocks from IFS, "money" for M1 and "money + quasi-money" for M3. UK data are from OECD, Main Economic Indicators, various issues. Series length: 1971:10-1980:12. U.S. data are monthly averages from Citibank Economic Data Base.

5. Current Account: This is the dollar value of the flow during the month (not measured in logs). German data are from Deutsche Bundesbank, Monthly Report, various issues converted to U.S. dollars using line rf of IFS. Japanese data are from Bank of Japan, Economic Statistics Monthly, various issues. U.S. and U.K. monthly data are quarterly data from IFS (described in Branson (1983)), interpolated following the monthly trade balance from IFS converted to dollars using line rf in the case of the U.K. The interpolation was performed using the procedure of Chow and Lin (1971).

6. Short-term interest rate: Data are taken from IFS as indicated in the Table on "Money Market and Euro Dollar Rates." Source: IFS country pages

7. Reserves: These are the dollar value of reserves measured at end of period. Source: IFS. These series did not vary significantly from the series adjusted for valuation changes provided by the IMF.

8. Industrial Production: This is the log of the monthly index of industrial production. Source: IFS.

The lengths of the lags in the VARs were chosen by a series of preliminary univariate autogressions for each variable. The lag length in the VAR for each variable was set at the maximum number of significant lags in the univariate autoregression for that variable. The procedure is described in some detail in Branson (1983). The one exception is Japan, where the current-account balance has significant lags at one month and five months. Separate VAR systems were estimated for Japan using one and five lags on CAB. The results were essentially the same, so only the one-lag system is reported here. The lag lengths and details of specification are summarized in Table 2.

The VARs, then, are a system of regressions of the current value of each of the variables listed in Table 2 on the indicated lags on all the variables, with the same set of regressors for each equation. A separate system is estimated for each country. The residuals from the VARs are denoted by a $\sim$ over the dependent variable.

After the VAR systems are estimated, we correlate their residuals to study the relationship among innovations. The correlations are given for the systems with M1 for the U.S., Germany, and Japan, and both M1 and M3 for the U.K. in Tables 3-7 below. The two sets of correlations are sufficiently similar in the cases of the U.S., Germany; and Japan, that separate discussions of them are unnecessary. Each table includes the correlation coefficients among the VAR "innovations" and in parentheses the probability of that correlation occurring under the null hypothesis that the true correlation is zero. In discussing the correlations, we will focus on the correlations particularly relevant for analyzing exchange-rate

Table 2: Variables Included in Vector Autoregression Systems

Variable	Length of Lag			
	U.K.	Germany	U.K.	Japan
ln e	2	2	2	2
ln $P/\bar{P}$	2	2	2	2
ln M	2	3	1	2
R	2	1	2	2
IS	3	2	2	2
CAB	3	2	2	1
ln Y	2	1	1	1

1. All VARs included 11 monthly dummies and an intercept.
2. Regressions estimated in monthly data 1973:7 to 1980:12.
3. Two VAR systems were estimated for each country, one with M1, the other with M3.

determination and policy. Detailed discussion of all the results would be far too tedious.

IV.B. United States

The correlations of VAR innovations for the U.S. M1 system are shown in Table 3. Remember that the effective nominal exchange rate is defined in units of home currency per unit of foreign exchange. So an increase in e is a depreciation.

The first row of Table 3 gives the correlations of exchange-rate innovations with those in the other variables. The positive sign for M1 and the negative sign for the short-term interest rate IS are consistent with monetary policy driving the exchange rate. The negative correlation of $\tilde{e}$ and $\tilde{R}$, and the positive correlation of $\widetilde{CAB}$ and $\tilde{R}$ are both consistent with "leaning against the wind" intervention in the exchange markets. An unanticipated increase in the current account surplus or appreciation of the dollar (a negative $\tilde{e}$) is significantly associated with an increase in U.S. reserves. The reserve and M1 innovations have an insignificant negative correlation, indicating that exchange-market intervention is sterilized. The M3 VAR innovations for the U.S. have the same pattern.

The hypotheses that I would infer from the U.S. data are as follows. On a monthly time scale money and interest rates move the exchange rate, with little role for relative prices. Monetary policy is essentially oriented toward domestic targets; movement in the exchange rate is a side effect. The U.S. monetary authorities intervene and sterilize, but do not follow a tight rule. This shows up in the strong correlation between $\tilde{R}$ and $\widetilde{CAB}$, and in the correlation between $\tilde{R}$ and $\tilde{e}$.

Table 3 : Correlations of Innovations from U.S. Monthly Vector Autoregression System with M1

	$\tilde{e}$	$\widetilde{P/\bar{P}}$	$\widetilde{M1}$	$\tilde{R}$	$\widetilde{IS}$	$\widetilde{CAB}$	$\tilde{Y}$
$\tilde{e}$	1.00	-.00	.18	-.24	-.48	-.08	.11
		(.99)	(.10)	(.02)	(.00)	(.43)	(.29)
$\widetilde{P/\bar{P}}$		1.00	-.12	.01	.27	-.19	-.07
			(.25)	(.93)	(.01)	(.08)	(.49)
$\widetilde{M1}$			1.00	-.17	-.05	.06	-.02
				(.11)	(.67)	(.57)	(.85)
$\tilde{R}$				1.00	-.08	.21	.02
					(.48)	(.06)	(.85)
$\widetilde{IS}$					1.00	.06	-.02
						(.58)	(.85)
$\widetilde{CAB}$						1.00	-.04
							(.74)
$\tilde{Y}$							1.00

Note : CAB is the monthly interpolation of the quarterly current account using the monthly trade data and the Chow-Lin interpolation procedure.

IV.C. Germany

The innovation correlations of the M1 system for Germany are shown in Table 4. In the first row we see a very strong positive correlation between exchange-rate and relative price innovations. This could come from exchange rates causing prices or vice versa, but through innovations and market expectations rather than a tight PPP relationship. The correlation of exchange-rate innovations with reserves must reflect leaning-against-the-wind policy in terms of exchange-market intervention. The lack of correlation between money and reserves or exchange rates indicates that intervention is sterilized. The negative correlation between money and industrial production could indicate that monetary policy attempts to stabilize real output. The German M3 VAR correlations show essentially the same pattern.

Thus the German data suggest fairly strongly a situation in which (a) price and exchange-rate innovations go together, and (b) the authorities react to exchange-rate movements through sterlized intervention. This is consistent with the earlier results of BHM (1977) and of Herring-Marston (1977) for the fixed-rate regime.

IV.D. United Kingdom

The U.K. correlations are shown in Tables 5 and 6 for the M1 and M3 systems, respectively. Comparison of the correlations between exchange-rate and money innovations suggests that news about M3, but not M1, moves the exchange rate. The monthly correlation between innovations in relative prices and the exchange rate is virtually zero. In both tables we see correlations between exchange-rate innovations and those in reserves

Table 4 : Correlations of Innovations from German Monthly Vector Autoregression System with M1

	$\tilde{e}$	$\widetilde{P/\bar{P}}$	$\widetilde{M1}$	$\tilde{R}$	$\widetilde{IS}$	$\widetilde{CAB}$	$\tilde{Y}$
$\tilde{e}$	1.00	.22	-.05	-.33	.14	.16	-.01
		(.04)	(.64)	(.00)	(.21)	(.14)	(.96)
$\widetilde{P/\bar{P}}$		1.00	-.00	.13	.07	.16	.03
			(.97)	(.23)	(.52)	(.15)	(.78)
$\widetilde{M1}$			1.00	.03	-.17	.11	-.24
				(.81)	(.12)	(.32)	(.02)
$\tilde{R}$				1.00	-.08	.02	.08
					(.46)	(.84)	(.48)
$\widetilde{IS}$					1.00	.04	-.09
						(.69)	(.41)
$\widetilde{CAB}$						1.00	-.06
							(.58)
$\tilde{Y}$							1.00

Note : CAB are the monthly data from Monthly Report of the Deutsche Bundesbank.

Table 5 : Correlations of Innovations from U.K. Monthly Vector Autoregression System with M1.

	$\tilde{e}$	$\widetilde{P/\bar{P}}$	$\tilde{M1}$	$\tilde{R}$	$\tilde{IS}$	$\tilde{CAB}$	$\tilde{Y}$
$\tilde{e}$	1.00	-.02	-.08	-.36	.30	-.05	-.07
		(.83)	(.47)	(.00)	(.00)	(.65)	(.52)
$\widetilde{P/\bar{P}}$		1.00	.03	.18	-.05	-.11	.09
			(.80)	(.10)	(.63)	(.31)	(.41)
$\tilde{M1}$			1.00	-.23	-.25	-.09	-.13
				(.03)	(.02)	(.39)	(.24)
$\tilde{R}$				1.00	-.09	-.27	.27
					(.41)	(.01)	(.01)
$\tilde{IS}$					1.00	-.06	-.14
						(.55)	(.19)
$\tilde{CAB}$						1.00	-.14
							(.19)
$\tilde{Y}$							1.00

Note : CAB is interpolated quarterly data as in U.S. case.

Table 6 : Correlations of Innovations from U.K. Monthly Vector Autoregression System with M3.

	$\tilde{e}$	$\widetilde{P/\bar{P}}$	$\widetilde{M3}$	$\tilde{R}$	$\widetilde{IS}$	$\widetilde{CAB}$	$\tilde{Y}$
$\tilde{e}$	1.00	-.07 (.52)	.25 (.02)	-.42 (.00)	.35 (.00)	-.05 (.66)	-.03 (.76)
$\widetilde{P/\bar{P}}$		1.00	-.19 (.08)	.28 (.01)	-.17 (.12)	-.09 (.42)	.02 (.83)
$\widetilde{M3}$			1.00	-.36 (.00)	.16 (.15)	.25 (.02)	-.17 (.11)
$\tilde{R}$				1.00	-.25 (.02)	-.17 (.12)	.12 (.27)
$\widetilde{IS}$					1.00	-.12 (.29)	-.02 (.85)
$\widetilde{CAB}$						1.00	-.14 (.20)
$\tilde{Y}$							1.00

and short-term interest rates that are a strong indication of leaning-against-the-wind intervention and interest rate policy. The negative correlations between reserve and money innovations suggest that exchange-market intervention is over-sterilized; unanticipated increases in reserves go along with decreases in both M1 and M3 on a monthly basis. Thus the U.K. data show a strong policy reaction to exchange-rate changes, with some independent effect of M3 on the exchange rate.

IV.E. Japan

The results from the M1 system for Japan are shown in Table 7. The results from the M3 system are essentially the same. The correlations of exchange-rate innovations with those in M1 and CAB indicate that both of those variables drive the exchange rate, consistent with the theory of section II. There is also a strong positive correlation between exchange-rate and relative price innovations.

The reserve correlations with the exchange rate and $\widetilde{CAB}$ strongly suggest "leaning-against-the-wind" intervention, with the central bank absorbing part of the CAB innovations to reduce movement in the exchange rate. The lack of correlation of $\widetilde{M1}$ with reserves or the exchange rate indicates sterilization. The negative correlation of $\widetilde{M1}$ with industrial production suggests that, as in Germany, monetary policy is aimed at stabilizing real output.

An interesting story emerges from the Japanese correlations. They suggest that monetary policy is oriented towards domestic objectives, and moves the exchange rate, as in section II. The authorities intervene to neutralize this effect, and they also attempt to sterilize M1 from the intervention.

IV.F. Summary of VAR Results on Policy

An interesting view of how the monetary system and interdependence have worked in the 1970s emerges from the VAR innovation correlations. My interpretation, or inferred set of hypotheses, is as follows. The U.S. sets monetary policy, largely by controlling quantities, with domestic objectives foremost. On a monthly basis the market looks to innovations in money and interest rates to set the U.S. exchange rate. The U.S. or foreign monetary authorities attempt sterilized intervention occasionally.

In Japan, monetary policy is also set according to domestic objectives. As in the U.S., this moves the exchange rate, but a stronger attempt is made to neutralize this effect through sterilized intervention in Japan than in the U.S.

Movements in the U.S. and Japanese effective rates, caused partly by fundamentals and partly by policy, are mirrored instantaneously in the U.K. and German effective rates, and their policy reacts. The reaction appears as "defensive" interest-rate movements sensitive to exchange-rate innovations, and largely sterilized intervention in the foreign exchange market. Thus a story in which domestically-oriented policy in the U.S. and Japan is transmitted to the U.K. and Germany is consistent with the VAR innovation results. This is a familiar story in Europe.

Table 7 : Correlations of Innovations from Japan Monthly Vector Autoregression System with M1.

	$\tilde{e}$	$\widetilde{P/\bar{P}}$	$\widetilde{M1}$	$\tilde{R}$	$\widetilde{IS}$	$\widetilde{CAB}$	$\tilde{Y}$
$\tilde{e}$	1.00	.31	.21	-.42	.16	-.26	.05
		(.00)	(.06)	(.00)	(.13)	(.02)	(.64)
$\widetilde{P/\bar{P}}$		1.00	.23	-.16	.23	-.27	.05
			(.03)	(.15)	(.03)	(.01)	(.63)
$\widetilde{M1}$			1.00	-.10	.29	-.11	-.34
				(.35)	(.01)	(.31)	(.00)
$\tilde{R}$				1.00	-.11	.31	.08
					(.33)	(.00)	(.49)
$\widetilde{IS}$					1.00	-.11	.06
						(.30)	(.60)
$\widetilde{CAB}$						1.00	-.09
							(.43)
$\tilde{Y}$							1.00

Note : CAB are monthly data from Bank of Japan, Economic Statistics Monthly.

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