NBER WORKING PAPER SERIES

MONETARIST MONETARY POLICY, EXCHANGE RISK, AND EXCHANGE RATE VARIABILITY

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Working Paper No. 1306

NATIONAL BUREAU OF ECONOMIC RESEARCH
1050 Massachusetts Avenue
Cambridge, MA 02138
March 1984

I am grateful to Eleanor Brown, David Denslow, Robert Flood, Jeffrey Frankel, Robert Hodrick, Howard Kaufold, Michael Melvin, Mark Rush, Michael Smirlock, Lars Svennsson, and to the participants at the 1983 NBER Summer Institute and the 1983 Econometric Society Winter Meetings, for their comments. The research reported here is part of the NBER's research program in International Studies. Any opinions expressed are those of the author and not those of the National Bureau of Economic Research.

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ABSTRACT

This paper investigates the relationship between the new monetary control procedures, implemented by the Federal Reserve Board in October 1979, and the subsequent increase in exchange rate variability for the United States. It shows that, in the context of a stochastic, rational expectations model, exchange rate variability minimizing monetary policy is identical to the policy which, in a deterministic, perfect foresight model, would place the economy on the borderline between exchange rate overshooting and undershooting. The model is estimated for the United States since generalized floating began in 1973. The new monetary control procedures have had two opposite effects. Monetary policy has become less accommodative, increasing exchange rate variability through overshooting. On the other hand, systematic deviations from uncovered interest rate parity, which can be attributed to exchange risk, have also increased. These increase exchange rate variability through undershooting. It is shown that the latter dominate the former, providing an explanation of increased exchange rate variability consistent with undershooting, not with overshooting.

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I. Introduction

The new monetary control procedures, implemented by the Federal Reserve Board in October 1979, have been the subject of extensive scrutiny. One major item of interest has been the impact of these procedures on financial markets in general and, in particular, on the foreign exchange market. A focus of this interest has been on exchange rate variability which, like the variability of other financial assets, has increased substantially since 1979[1].

This paper considers the relationship between the conduct of monetary policy and the variability of exchange rates[2]. It shows that, in the context of a stochastic, rational expectations model, exchange rate variability minimizing monetary policy is identical to the policy which, in a deterministic, perfect foresight model, would place the economy on the borderline between exchange rate overshooting and undershooting. Policy which would cause either overshooting or undershooting would increase variability.

In this context, the change in the conduct of monetary policy in the United States can be expected to have two opposite effects. Monetary policy which is less accommodative of prices and/or interest rates, "monetarist" monetary policy, can affect exchange rate variability through overshooting. On the other hand, the change in the conduct of monetary policy was accompanied by a good deal of uncertainty regarding the exact nature of the new policy. It is shown below how this increase in uncertainty, or increase in exchange risk, will increase deviations from uncovered interest rate parity in a predictable manner. These deviations, in turn, can affect exchange rate variability through undershooting.

Using constrained maximum likelihood methods, the model is estimated for the United States since generalized floating began in 1973. The estimation procedures incorporate both the rational expectations restrictions and the policy rules. Over the period 1973-79, the dollar experienced slight undershooting. Over the full period, 1973-82, the effects of less accommodative monetary policy were overwhelmed by those of the increase in exchange risk, causing exchange rate undershooting. The explanation of increased exchange rate variability as being caused by undershooting, as opposed to overshooting, is confirmed by estimating a less constrained version of the model within which the undershooting hypothesis can be directly tested.

The model is presented in Section II. In Section III, it is shown how variable output, risk aversion, and accommodative monetary policy affect exchange rate variability. The model is estimated in Section IV and conclusions are presented in Section V.

II. The Model

The model is based on Dornbusch (1976), although it extends his work in a number of directions. It is a two-country model, incorporating variable output, deviations from uncovered interest rate parity, and both domestic and foreign money supply reaction functions. The two country specification, rather than a single, small country specification, was chosen to avoid making exogeneity assumptions regarding foreign prices and interest rates which cannot be supported empirically and to allow for the foreign money supply, as well as the domestic money supply, to be determined endogenously. This is shown below to be quite important, both theoretically and empirically, in determining the magnitude of exchange rate variability. In order to provide clear theoretical results that could be tested empirically, a number of simplifying assumptions were made so that the model could be solved analytically. The model consists of the following equations:

(1) $m_t - m_t^* - q_t = a_1(y_t - y_t^*) - a_2(i_t - i_t^*) + \varepsilon_{1t}$

(2) $y_t - y_t^* = (y_0 - y_0^*) + a_3(e_t - q_t) - a_4(r_t - r_t^*) + \varepsilon_{2t}$

(3) $q_{t+1} - q_t = a_5(e_t - q_t) - a_6(r_t - r_t^*) + \varepsilon_{3t}$

(4) $i_t - i_t^* = (\hat{e}_{t+1} - e_t) - a_7(e_t - q_t) + \varepsilon_{4t}$

(5) $m_t = m_0 + a_8\tilde{e}_t + a_9\tilde{q}_t + a_{10}(i_t - i_t^*) + \varepsilon_{5t}$

(6) $m_t^* = m_0^* - a_{11}\tilde{e}_t - a_{12}\tilde{q}_t - a_{13}(i_t - i_t^*) + \varepsilon_{6t}$

where m is the logarithm of the domestic money supply,

y is the logarithm of domestic real output,

i is the domestic nominal interest rate,

r is the domestic real interest rate,

e is the logarithm of the exchange rate (domestic currency price of foreign exchange),

* associated with a variable indicates that it refers to the foreign country,

q is the logarithm of the ratio of domestic to foreign prices, i.e., $q_t = p_t - p_t^*$, where p is the logarithm of the domestic price level,

$\sim$ over a variable indicates deviation from the steady state level,

y_0 is the exogenous component of output,

m_0 is the exogenous component of the money supply,

$\hat{e}_{t+1}$ is the expectation of the exchange rate for period t+1, conditional on information available in period t,

the ε's are random variables, which may be serially correlated.

The money and output market equilibrium conditions are standard. The supply of and demand for real balances are equated in equilibrium for each country, with the demand for real balances depending positively on income and negatively on the interest rate[3].

(1a) $$m_t - p_t = a_1 y_t - a_2 i_t + \eta_{1t}$$

(1b) $$m^*_t - p^*_t = a_1 y^*_t - a_2 i^*_t + \eta_{2t}$$

Equation (1) is obtained by subtracting (1b) from (1a) and by setting $\varepsilon_{1t} = \eta_{1t} - \eta_{2t}$. Real output in each country is demand determined, with output demand depending positively on the real exchange rate, (the relative price of foreign to domestic goods), and negatively on the real interest rate. An exogenous term and a stochastic disturbance term are also included. While deviations from purchasing power parity are allowed in the short run, it is assumed that long run purchasing power parity hold ($\bar{e} = \bar{q}$).

(2a) $$y_t = y_0 + b_1(e_t - q_t) - a_4 r_t + \eta_{3t}$$

(2b) $$y^*_t = y^*_0 - b_2(e_t - q_t) - a_4 r^*_t + \eta_{4t}$$

Equation (2) is obtained by subtraction and by setting $a_3 = b_1 + b_2$ and $\varepsilon_{2t} = \eta_{3t} - \eta_{4t}$. Keeping the two-country model tractable requires equating the income elasticity of the demand for money (a_1), the interest rate semi-elasticity of the demand for money (a_2), and the real interest rate semi-elasticity of output (a_4) in the two countries.

The rate of inflation in each country, as in Dornbusch (1976), is assumed to depend on excess demand in the goods market,

(3a) $$p_{t+1} - p_t = b_3\ (y_t - \bar{y}) + \eta_{5t},$$

(3b) $$p^*_{t+1} - p^*_t = b_4\ (y^*_t - \bar{y}^*) + \eta_{6t},$$

where $\bar{y} = y_0 - a_4\bar{r}$ and $\bar{y}^* = y^*_0 - a_4\bar{r}^*$ are the steady state levels of output. The steady state real interest rates, $\bar{r}$ and $\bar{r}^*$, are equal because, in long run equilibrium, there can be no depreciation or inflation. Substituting (2a) into (3a) and (2b) into (3b), and subtracting (3b) from (3a), we obtain equation(3), where $a_5 = b_3b_1 + b_4b_2$, $a_6 = b_3a_4 = b_4a_4$, and $\varepsilon_{3t} = b_3\eta_{3t} - b_4\eta_{4t} + \eta_{5t} - \eta_{6t}$.[4] Note that both domestic and foreign prices are pre-determined.[5]

If capital were perfectly mobile and economic agents risk neutral, uncovered interest rate parity would require that the interest rate differential equal the expected rate of depreciation.

$$i_t - i_t^* = \hat{e}_{t+1} - e_t$$

Recent empirical work by Cumby and Obstfeld (1983) and Hansen and Hodrick (1983) provides evidence that this relationship does not hold for most bilateral exchange rates, even when there do not appear to be constraints on the mobility of capital between the countries involved. In particular, the evidence suggests that risk premia are significant and vary over time. For the United States' effective exchange rate, an additional consideration is that, while capital may be perfectly mobile with regard to the U.S., the weighted average of countries that comprises the foreign "country" includes some, such as Japan, that clearly restricted capital flows over at least part of the sample period.

Much of the theoretical work on the determinants of the risk premium involves considerations of portfolio balance, such as relative supplies of wealth, that are beyond the scope of this paper. Instead, we use some of the concepts in Dornbusch's (1983) mean-variance model of international portfolio choice to relate deviations from uncovered interest rate parity to deviations from purchasing power parity.

We begin by formalizing the relationship between real interest rates in the two countries and the structure of expected real asset returns faced by investors in either country. By the Fisher relation with pre-determined prices, either country's real interest rate equals its nominal interest rate minus its expected, (equal to actual), rate of inflation,[6]

$$r_t = i_t - (p_{t+1} - p_t),$$

$$r_t^* = i_t^* - (p_{t+1}^* - p_t^*),$$

implying the following real interest rate differential:

(4a) $$r_t - r_t^* = i_t - i_t^* - (q_{t+1} - q_t).$$

Assuming that covered interest parity, where the (nominal) interest rate differential equals the forward premium, holds at all times produces the following expression for the real interest rate differential,

(4b) $$r_t - r_t^* = f_t - e_t - (q_{t+1} - q_t),$$

where f_t is the one period forward exchange rate. For the moment, assume that capital is perfectly mobile, so that risk neutrality implies uncovered interest rate parity. In that case, (which we do not generally assume to hold), the real interest rate differential equals the expected real rate of depreciation,

(4c) $$r_t - r_t^* = (e_{t+1} - e_t) - (q_{t+1} - q_t).$$

From the perspective of a domestic investor, the real return on a domestic asset (R_t) is just the domestic real interest rate. His or her expected real return, (in terms of purchasing power over domestic goods), on a foreign asset (R_t^*) is the foreign interest rate plus the expected rate of depreciation minus the domestic inflation rate,

$$R_t^* = i_t^* + (\hat{e}_{t+1} - e_t) - (p_{t+1} - p_t),$$

which is not the foreign real interest rate. The domestic investor's real return differential is

$$R_t - R_t^* = i_t - i_t^* - (\hat{e}_{t+1} - e_t).$$

Adding and subtracting the inflation differential, we obtain the relation between the real return differential and the real interest rate differential,

$$\text{(4d)} \qquad R_t - R_t^* = (r_t - r^*_t) - ((\hat{e}_{t+1} - e_t) - (q_{t+1} - q_t)).$$

Under uncovered interest rate parity, since the real interest rate differential equals the expected real rate of depreciation, real returns are equalized,

$$\text{(4e)} \qquad R_t - R_t^* = 0.$$

Under covered interest rate parity, substituting (4b) into (4d) produces the result that the real return differential equals the risk premium,

$$\text{(4f)} \qquad R_t - R_t^* = f_t - \hat{e}_{t+1}.$$

The choices faced by a foreign investor can be similarly described. The foreign investor's real return on a foreign asset (F*) is the foreign real interest rate. His or her real return on a domestic asset (F) is the domestic interest rate minus the expected rate of depreciation minus the foreign inflation rate. The foreign investors real return differential is the same as that faced by the domestic investor,

$$F_t - F_t^* = i_t - i_t^* - (\hat{e}_{t+1} - e_t).$$

The assumption of long run purchasing power parity in a linear, rational expectations model ensures that an overvalued exchange rate ($e_t > q_t$) implies expected <u>real</u> appreciation while an undervalued rate ($e_t < q_t$) implies expected <u>real</u> depreciation. This can be seen by considering all possible monotonic adjustment paths toward the steady state ($\bar{e} = \bar{q}$) equilibrium. It should be noted that this statement contains no implications about the expected (or actual) movement of the nominal exchange rate.

Consider the case where $e_t > q_t$. With risk neutrality, real returns are equalized. Since there is expected real appreciation, equation (4d) requires that the real interest rate differential be negative, i.e., that $r_t^* > r_t$. Now consider risk aversion. Since nominal interest rates are known and price levels are pre-determined, the only source of risk is exchange rate risk. From the perspective of a domestic investor, since foreign assets are riskier, the real return on foreign assets must exceed the real return on domestic assets ($R_t^* > R_t$) to induce investment in foreign assets. From the perspective of a foreign investor, domestic assets are riskier, and it is necessary for $F_t > F_t^*$ to induce investment in them. These two conditions cannot occur simultaneously. With the world consisting of two countries, if one is a net lender the other must be a net borrower. Assuming that the real interest rate is the marginal product of capital, and assuming away all other considerations, such as differences in tastes, size, wealth, liquidity characteristics, and risk aversion, that could influence borrowing and lending, the country with the higher real rate of interest will borrow and the other will lend. In this case, since $r_t^* > r_t$, $R_t^* > R_t$ to induce domestic residents to invest in foreign assets. From equation (4f), $R_t^* > R_t$ implies that $\hat{e}_{t+1} > f_t$. Using covered interest rate parity, where $i_t - i_t^* = f_t - e_t$, this implies that $i_t - i_t^* = (\hat{e}_{t+1} - e_t) - z_t$, where $z_t > 0$. Since $e_t > q_t$, the risk premium can be related to the deviation from purchasing power parity by

$$(4g) \qquad i_t - i_t^* = (\hat{e}_{t+1} - e_t) - a_7(e_t - q_t).$$

To produce equation (4), a stochastic disturbance term is added to (4g) to capture factors that may cause deviations from uncovered interest rate parity but are not included in the model.

Now consider the case where $e_t < q_t$, implying expected real depreciation. With risk neutrality, real return equalization (in 4d) requires that $r_t > r_t^*$. This implies that the domestic country will borrow abroad and, with risk aversion, that $F_t > F_t^*$ to induce foreign investors to invest in the domestic asset. Since $F_t - F_t^* = R_t - R_t^*$, equation (4f) requires that $f_t > \hat{e}_{t+1}$. Using covered interest rate parity, $i_t - i_t^* = (\hat{e}_{t+1} - e_t) + z_t$. Since $e_t < q_t$,

(4h) $$i_t - i_t^* = (\hat{e}_{t+1} - e_t) - a_7(e_t - q_t),$$

which is both equations (4g) and (4).

Equation (4) relates deviations form uncovered interest rate parity to deviations from purchasing power parity in a systematic manner. The parameter a_7 represents both the degree of risk aversion on the part of investors and the degree of risk in the market. With risk neutrality, $a_7 = 0$. The more risk averse are investors, the larger is a_7. If there is no exchange risk, $a_7 = 0$. The greater the exchange risk, the larger is a_7.

The equation was derived, using risk aversion, assuming perfect capital mobility. An identical equation is derived, using a flow capital mobility specification, in Frenkel and Rodriguez (1982) and Papell (1983). In those models, the current account balance is postulated to depend on relative prices and the (flow) capital account to depend on the expectations adjusted interest rate differential. Using the constraint that, in the absence of central bank intervention, the current and capital accounts sum to zero, equation (4) is derived.

The parameter a_7 represents the degree of capital mobility, with $a_7 = 0$ being perfect mobility.

While these models are observationally equivalent from any single country at a point in time, they have the potential to be differentiated either by estimating a cross-section of countries or by estimating one country over different time periods. In this case, the hypothesis to be tested is that the change in the Fed's operating procedure increased uncertainty in financial markets, including the market for foreign exchange. This increase in foreign exchange risk increased the required expected real return differential for investing abroad, which would increase a_7. The alternative explanation for a rise in a_7, a decrease in the mobility of capital since 1979, does not seem tenable. Thus testing the model over these two periods for the United States provides the potential for differentiating between them.

The money supply for each country depends on the exchange rate, the difference between domestic and foreign prices, and the nominal interest rate differential. Monetary policy for either country is accommodative if that country's money supply increases when its exchange rate depreciates, when the difference between its prices and the other country's prices increases and/or when its nominal interest rate differential increases. Thus positive coefficients for $a_8 - a_{13}$ are accommodative, negative coefficients are offsetting. The money supply is constrained to respond to the price ratio, rather than to the levels separately, because, in the reduced form of the model, prices appear only in ratio form. While allowing the money supplies to respond separately to domestic and foreign price levels would be desirable, it would make the model analytically intractible. A number of analysts have proposed that the money supply be decreased when the real exchange rate depreciates and increased when it appreciates. This would involve offsetting the exchange rate and accommodating the price ratio so that $a_8 = - a_9$ and $a_{11} = - a_{12}$. The money supply rule for each country also includes an exogenous term and a stochastic disturbance term.

III. Exchange Rate Variability

In this section, we solve the model and show how variable output, risk aversion[7], and accommodative monetary policy affect exchange rate variability. We then describe the relationship between variability and the concepts of overshooting and undershooting.

Before solving the model, it is useful to simplify the price adjustment, output, and money supply equations. Substituting (4a) and (4) into (3), and collecting terms, we obtain,

$$(7) \qquad q_{t+1} - q_t = d_1(e_t - q_t) - d_2(\hat{e}_{t+1} - e_t) + \varepsilon_{7t},$$

where $d_1 = \dfrac{a_5 + a_7a_6}{(1 - a_6)}$, $d_2 = \dfrac{a_6}{1 - a_6}$, and $\varepsilon_{7t} = \dfrac{\varepsilon_{3t} - a_6\varepsilon_{4t}}{1 - a_6}$.

Substituting (4a), (4), and (7) into (2), we obtain,

$$(8) \qquad y_t - y^*_t = (y_0 - y^*_0) + d_3(e_t - q_t) - d_4(\hat{e}_{t+1} - e_t) + \varepsilon_{8t},$$

where $d_3 = a_3 + a_4(a_7 + d_1)$, $d_4 = a_4(1 + d_2)$, and $\varepsilon_{8t} = a_4(\varepsilon_{7t} - \varepsilon_{4t})$.

Finally, substituting (4) into (5) and (6), we obtain,

$$(9) \qquad m_t = m_0 + c_1\tilde{e}_t + c_2\tilde{q}_t + a_{10}(e_{t+1} - e_t) + \varepsilon_{9t}$$

$$m^*_t = m^*_0 - c_3\tilde{e}_t - c_4\tilde{q}_t - a_{13}(\hat{e}_{t+1} - e_t) + \varepsilon_{10t}$$

where $c_1 = a_8 - a_7a_{10}$ $\quad c_2 = a_9 + a_7a_{10}$ $\quad \varepsilon_{9t} = \varepsilon_{5t} + a_{10}\varepsilon_{4t}$

$c_3 = a_{11} - a_7a_{13}$ $\quad c_4 = a_{12} + a_7a_{13}$ $\quad \varepsilon_{10t} = \varepsilon_{6t} - a_{13}\varepsilon_{4t}$

It can be seen from (9) that the degree of a risk aversion affects the use of interest rate targets for the conduct of monetary policy. If the money supply accommodates the interest rate differential, (a_{10}, $a_{13} > 0$), then monetary policy becomes more offsetting towards the exchange rate but more accommodative towards prices. The magnitude of these effects depends on the degree of risk aversion. If investors were risk neutral ($a_7 = 0$), interest rate targeting would not affect the degree of accommodation.

Substituting (4), (8), and (9) into (1), and interpreting all variables as deviations from their steady state equilibrium values, we obtain:

$$(10) \qquad \begin{bmatrix} \hat{e}_{t+1} \\ q_{t+1} \end{bmatrix} = \begin{bmatrix} \delta_1 & \delta_2 \\ \gamma_1 & \gamma_2 \end{bmatrix} \begin{bmatrix} e_t \\ q_t \end{bmatrix} + \begin{bmatrix} u_{1t} \\ u_{2t} \end{bmatrix}$$

where the u's are combinations of the ε's, and,

$$\delta_1 = \frac{a_1 d_3 + a_2 a_7 - c_1 - c_3}{a_1 d_4 + a_2 + a_{10} + a_{13}} + 1 \qquad \delta_2 = \frac{1 - a_1 d_3 - a_2 a_7 - c_2 - c_4}{a_1 d_4 + a_2 + a_{10} + a_{13}}$$

$$\gamma_1 = d_1 - \delta_1 d_2 + d_2 \qquad \gamma_2 = 1 - d_1 - \delta_2 d_2$$

We solve the model by using the method of undetermined coefficients. Assuming that expectations are determined rationally and that e_t and q_t follow stationary stochastic processes, infinite order moving average representations of e_t and q_t can be written,

$$(11) \qquad \begin{aligned} e_t &= \sum_{i=0}^{\infty} \Pi_{1i}\, u_{1t-i} + \sum_{i=0}^{\infty} \Pi_{2i-1}\, u_{2t-i}, \\ q_t &= \sum_{i=1}^{\infty} \Theta_{1i-1}\, u_{1t-i} + \sum_{i=1}^{\infty} \Theta_{2i-1}\, u_{2t-i}, \end{aligned}$$

where the different representations for e_t and q_t reflect the assumption that prices are pre-determined. Solution of the model requires substituting (11) into (10) and solving the resultant set of identities. As is usual in rational expectations models with expectations of future values of variables, the solution is not unique without the usual assumption that the conditionally expected exchange rate and price paths are stable. In addition, we need to assume that the money supply either offsets or is not too accommodative of exchange rate movements, so that $\delta_1 > 1$, in order to guarantee that the stability assumption will produce a unique solution. Assuming that the disturbances are serially uncorrelated[8], the solution of the model is as follows,

$$(12) \qquad \begin{aligned} e_t &= B_1\, p_t + \Pi_{10}\, u_{1t} + \Pi_{20}\, u_{2t}, \\ p_t &= \lambda_1\, p_{t-1} + \theta_{10}\, u_{1t-1} + \theta_{20}\, u_{2t-1}, \end{aligned}$$

where λ_1 is the stable (< 1) characteristic root,

$B_1 = \delta_2(\lambda_1 - \delta_1)^{-1}$ is the characteristic vector associated with λ_1,

$\Pi_{10} = -(\delta_1 - B_1\gamma_1)^{-1}$, $\qquad \Pi_{20} = B_1(\delta_1 - B_1\gamma_1)^{-1}$,

$\theta_{10} = \gamma_1 \Pi_{10}$, $\qquad \theta_{20} = \gamma_1 \Pi_{20} + 1$.

Exchange rate variability can be characterized either by the asymptotic or the conditional variance of the exchange rate around its steady state level.[9] The asymptotic variance of the exchange rate is $s_e^2 = B_1^2 s_p^2 + \Pi_{10}^2 s_{u1}^2 + \Pi_{20}^2 s_{u2}^2$. This is the appropriate measure if we want to look at data ex post, such as to compare variability over different time periods. The conditional variance of the exchange rate is $\sigma_e^2 = B_1^2 \sigma_p^2$. This is the appropriate measure to evaluate policy in the absence of information on the distribution of future disturbances. The conditional variance of the exchange rate is zero, and the asymptotic variance minimized, if $B_1 = 0$.[10] This can only occur if $\delta_2 = 0$. The sign of δ_2 is determined by the income (a_1) elasticity and the interest rate (a_2) semi-elasticity of the demand for money, the elasticity of the demand for output with respect to the real exchange rate (d_3), the degree of risk aversion on the part of investors (a_7), and the degree of accommodation of domestic (c_2) and foreign (c_4) money supplies to price movements. It should be stressed that output variability, risk aversion, and accommodative monetary policy all decrease δ_2.

The intuition behind these results is provided by examining the relationship between exchange rate variability and overshooting. In response to a permanent, unanticipated increase in (for example) the money supply, which causes a proportionate long run depreciation of the exchange rate, overshooting occurs if the exchange rate first depreciates by more than its long run value, and then appreciates over time back to the steady state. Undershooting occurs if the exchange rate first depreciates by less than its long run value, and then continues to depreciate until the steady state is attained. In Papell (1983b), it is shown that in the perfect foresight version of the flow capital mobility version of this model, $\delta_2 = 0$ is the borderline case between overshooting and undershooting. Overshooting occurs when $\delta_2 > 0$, undershooting when $\delta_2 < 0$. It is important to remember that, at any instant of time, prices are pre-determined while the exchange rate is free to jump. When $\delta_2 = 0$, the exchange rate immediately jumps to its new long run equilibrium value. This corresponds, in the present stochastic context, to zero conditional and minimum asymptotic exchange rate variability.

The overshooting hypothesis was motivated as an explanation for high exchange rate variability. Our results show that there is not a one-to-one relation between variability and overshooting. High exchange rate variability can be produced by undershooting as well as overshooting. Furthermore, changes in the structural and policy parameter which decrease δ_2, (and hence reduce overshooting), only will be certain to decrease variability if the country begins at a position of overshooting and does not move into undershooting. Otherwise, variability may actually be increased. For example, consider a country that is characterized by overshooting. By making monetary policy more accommodative of prices, (either directly or through accommodating interest rates), exchange rate variability can be reduced. If monetary policy becomes too accommodative, undershooting will result and variability increased.

IV. Empirical Results

We now examine the effects of the changes in the conduct of monetary policy in the United States since October 1979. In order to accomplish this, using quarterly data, we estimate the model separately for the periods 1973 (II) - 1979 (III) and 1973 (II) - 1982 (III), and then compare the results. The model is estimated by constrained maximum likelihood techniques, with the constraints on the parameters caused by the form of the structural equations, assumption of rational expectations, and the stability condition necessary to achieve a unique solution. The structural (a_1 - a_7) and policy (a_8 - a_{13}) coefficients are jointly estimated. Combined with the imposition of rational expectations, this satisfies several aspects of Lucas' (1976) critique of econometric policy evaluation.

Estimation of the model first requires deriving the reduced form. Substituting the expression for $\hat{e}_{t+1}$ from (10) into (4), (8), and (9) and taking variables as deviations from their steady state values, we obtain:

(13) $$i_t - i_t^* = (\delta_1 - 1 - a_7)e_t + (\delta_2 + a_7)q_t + u_{3t}$$

(14) $$y_t - y_t^* = (d_3 - d_4(\delta_1 - 1))e_t - (d_3 + \delta_2 d_4)q_t + u_{4t}$$

(15) $$m_t = a_8 e_t + a_9 q_t + a_{10}(i_t - i_t^*) + u_{5t}$$

(16) $$m_t^* = - a_{11} e_t - a_{12} q_t - a_{13}(i_t - i_t^*) + u_{6t}$$

where the u's are combinations of u_{1t}, u_{2t}, and the ε's.

It is necessary to make some assumptions about the structure of the error terms. We assume that they are generated by first order autoregressive processes, i.e., $u_{jt} = \alpha_j u_{jt-1} + \psi_{jt}$, $j = 1,\ldots,6$, where the ψ's are serially uncorrelated. We then take the infinite moving average representation implicit in the above autoregressive process and truncate it at third order for u_1 and fourth order for the others. This produces a first order autoregressive fourth order moving average model. Assuming that expectations are determined rationally and solving by the method of undetermined coefficients, the reduced form of (10) is derived,

$$(17) \qquad \begin{bmatrix} e_t \\ \\ z_t \end{bmatrix} = A \begin{bmatrix} e_{t-1} \\ \\ z_{t-1} \end{bmatrix} + B(L) \begin{bmatrix} v_{1t} \\ \\ v_{2t} \end{bmatrix}$$

where $z_t = q_{t+1}$ and A and B are 2 x 2 matrices. The elements of A and B are non-linear combinations of the δ's, γ's, and α's. The v's are combinations of the Ψ's, written so as to make the zero lag coefficient matrix the identity matrix.[11] The model to be estimated consists of equations (13) - (17). Maximum likelihood estimates (conditional on the initial disturbances being set equal to zero) are obtained under the assumption that $(v_{1t}\ v_{2t}\ u_{3t}\ u_{4t}\ u_{5t}\ u_{6t})'$ is multivariate normal. The Davidon-Fletcher-Powell algorithm is used to find the optimum.

As described above, the model is estimated for the United States, beginning with the advent of generalized floating in 1973 (II) and ending either in 1979 (III), before the change in the Fed's operating procedure, or in 1982(III). While it would have been preferable to estimate the model over non-overlapping sub-periods, this was precluded by the limited number of quarterly observations since 1979. We considered using monthly data, but it did not seem sensible to estimate monthly money demand, output demand, and money supply equations without incorporating lags. Unfortunately, incorporating lags was precluded by our desire to keep the model analytically representable. Our results should therefore be interpreted with caution, remembering that, if the data were available, the model would be estimated separately for the period since 1979 (III).

We use the effective exchange rate (MERM) calculated by the International Monetary Fund. Real GNP (or GDP) is used to measure output, MI for the money supply, the GNP deflator for the price level, and representative three month money market rates for the interest rate. The foreign variables were constructed by taking weighted averages, with the weights taken from those used to construct the MERM rates. In order to achieve stationarity, all variables, after taking logarithms (except for the interest rate), were detrended by regression on a constant and a linear time trend.[12]

We use a two-step method of estimation. First, we estimate the money market equilibrium equation (1) by a single equation method, and then use the estimates from the regression as constants for the constrained maximum likelihood estimates[13]. There are several advantages to this procedure. First, it enables us to get estimates of the income elasticity and the interest rate semi-elasticity of the demand for money directly from data on income and interest rates. Second, the unstable nature of money demand estimates during the 1970's raises the possibility that these parameters are inconsistently estimated. In that case, estimating them by maximum likelihood would spread inconsistency throughout the model. Finally, it reduces the number of parameters to be estimated by maximum likelihood. The disadvantages of the procedure are twofold. First, if the inconsistency in the money demand estimates is caused by the use of single equation methods this may introduce inconsistency into the model. Second, because for the maximum likelihood procedure it is assumed that a_1 and a_2 are estimated without error, the standard errors of the other variables will be biased downward.[14]

The maximum likelihood estimates of the structural (a_3 - a_7), policy (a_8 - a_{13}) and, serial correlation (α_1 - α_6) parameters are given in Table 1 along with their asymptotic "t-ratios", the ratio of the coefficients to their standard errors computed from the inverse of the second derivative matrix of the likelihood function. Single equation estimates for a_1 and a_2, as well as parameter values for the reduced form coefficients implied by the estimates, are also presented.

The central result of the estimates is that δ_2 is close to zero (-.09) during 1973-79 and negative (-2.58) during 1973-82, indicating that the observed increase in exchange rate variability was caused, not by overshooting, but by undershooting. The principal reason for this was the dramatic change in the risk parameter (a_7), which increased from .56 to 3.17. With the decrease in the interest rate semi-elasticity of the demand for money being comparatively small, a_2a_7 increased from .39 to 1.90, causing much of the decline in δ_2. By way of illustration, if a_7 stayed at .57 while all the other parameters took on their 1973-82 estimates, the value of δ_2 would be .07. Another important determinant in the change in δ_2 is the decrease in the real interest rate semi-elasticity of output demand (a_4), which by causing d_4 to decrease, increases δ_2 (in absolute value) by decreasing its denominator. With δ_2 close to zero, (as in the 1973-79 estimates) B_1 will be close to zero whatever the values of λ_1 (the stable root) and δ_1. With δ_2 not close to zero, (as in 1973-82), the values of λ_1 and δ_1 matter. Changes in λ_1 between the two periods were small. The value of δ_1 increased during 1973-82, making $(\lambda_1 - \delta_1)^{-1}$ less negative. This affect, however, was swamped by the increase (in absolute value) of δ_2, causing B_1 to increase from .08 to .71 between the periods.

We now examine the changes in the money supply reaction functions. For the United States, looking directly at the structural parameter, the money supply because more accommodative of prices, (a_9 increased from 1.43 to 1.79), but more offsetting of interest rates, (a_{10} decreases from -.94 to -1.14). However, when one includes the offsetting of prices implicit in offsetting interest rates with a positive risk parameter, ($c_2 = a_9 + a_7 a_{10}$), domestic monetary policy (c_2) switched from being quite accommodative (.90) to very offsetting (-1.82). With foreign monetary policy, in contrast, the direct and combination results coincide. There is a decrease in the amount that foreign monetary policy offsets prices, (a_{12} changes from -1.19 to -.81), and a switch from offsetting to accommodating interest rates, (a_{13} increases from -.61 to .19). Including the impact of the risk parameter, foreign monetary policy becomes less offsetting of prices; c_4 increases from -1.56 to -.21. The switch from accommodative to offsetting monetary policy in the United States dominates the decrease in offsetting abroad; $c_2 + c_4$ decreases from -.66 to -2.03. Taken in isolation, this would have caused exchange rate overshooting. The increase in the risk parameter, however, dominates the increase in offsetting monetary policy to cause undershooting.

Since δ_2 is not estimated directly, but is implied by the values of the estimated coefficients, it is legitimate to ask how significant is the undershooting result for the 1973-82 estimates. In order to answer that question, a "semi-constrained" version of the model was estimated. In this version, δ_1 and δ_2 are estimated directly, rather than being implied by the structural and policy coefficients. All of the other coefficients of the model are estimated as in the constrained version above. This enables us to test for undershooting directly by examining the sign and significance level of δ_2. The results of this procedure support the results found above, with δ_2 = -.26 (-.36) for 1973-82 and -2.18 (-2.65) for 1973-82, (asymptotic "t-ratios" are in parentheses). This indicates not only that the undershooting result is not simply a construct of the structural and policy parameters but also that it is significant[15].

Another possibility which we consider is that the deviations form uncovered interest rate parity in the 1973-82 estimates were caused by the imposition of credit controls in 1980. Interest rates in the United States, (and the interest rate differential), were very high in 1980 (I). With the credit controls, they fell dramatically in 1980 (II) and (III), but returned to almost their original levels in 1980 (IV). In order to test whether the increase in the estimated value of a_7 was caused by the controls, we replaced the actual values of the interest rate differential in 1980 (II) and (III) with values that were calculated by taking the figure for 1980 (I) and (IV) and interpolating. We then estimated the model for 1973-82, and found that a_7 was 2.76 (2.61). This indicates that most of the increase in a_7 was not caused by the imposition of credit controls. Using the same data, we estimated the semi-constrained version of the model, and found that δ_2 equaled -2.44 (-9.54). Thus the undershooting results are not affected by correcting for credit controls.

We have characterized the changes in exchange rate variability strictly in terms of changes in B_1 which, while appropriate for conditional variability, is not necessarily appropriate for asymptotic variability. In order to consider asymptotic variability, we have to examine the parameters of the price adjustment equation (γ_1 and γ_2).

Note that both parameters change very little over the periods and that γ_1 is quite small (.04), indicating that we can approximately characterize asymptotic variability in terms of δ_1 and δ_2. Thus the above analysis of conditional variability also applies to asymptotic variability.

We conclude by evaluating the success of the estimates. The positive result is that the individual parameter estimates are very successful. All of the estimates, (except for the relative price elasticity of output demand), are of the "correct" sign. For 1973-82, most of the parameters are significant; for 1973-79, the results are mixed. It is especially noteworthy that the risk parameter, upon which much of the analysis rests, is small and insignificant for 1973-79 and large and significant for 1973-82. In addition, the correlations between the actual and predicted values of the variable are fairly high.[16] The negative result is provided by the likelihood ratio test. Comparing the constrained version of the model to an "unconstrained" version, which imposes the same policy equations (15-16) and serial correlation structure as the constrained version described above, but does not impose the forms of the structural equations or the rational expectations restrictions, we can reject the constrained model at standard significance levels for both periods[17]. This accords with the results of previous work involving the United States since 1973, including Driskill and Scheffrin (1981), Glaessner (1982), and Papell (1983b)[18].

V. Conclusion

In this paper, we investigate the relationship between the changes in the conduct of monetary policy in the United States following the new monetary control procedures in October 1979 and the increase in exchange rate variability experienced since then. We find two major effects, although the estimation procedures necessatated by the small number of observations since 1979 suggest that our results be interpreted with caution. American monetary policy has become substantially less accommodative and there has been a significant increase in the risk parameter measuring systematic deviations from uncovered interest rate parity. Our estimation results indicate that the latter dominates the former, providing an explanation of increased exchange rate variability consistent with exchange rate undershooting. This is in contrast with the generally accepted association between high variability and overshooting.

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Footnctes

1 Levich (1981) and Truman and others (1981) provide evidence on the increase in exchange rate variability in the first year following the new monetary control procedures.

2 Truman (1981) and Black (1982) also consider this issue, but in the context of quite different models from this paper.

3 Deflating the money supply in each country by a price index composed of a weighted average of domestically produced goods and imports makes only a minor theoretical difference by introducing another possible channel for undershooting. Empirically, however, it is impossible to identify the weights in a two country model of this type. For the estimation, we use the GNP deflator as the price level. This incorporates the exchange rate and foreign price level into the domestic price level through imports of intermediate goods, but not through imports of consumer goods.

4 We have imposed the constraint that $b_3 = b_4$, which is necessary because the real interest rate enters equation (3) in difference form, on a_6 but not on a_5. If the constraint was applied consistently, equation (3) would read,

$$(3') \qquad q_{t+1} - q_t = b_3\, a_3(e_t - q_t) - b_3 a_4(r_t - r_t^*) + \varepsilon_{3t}.$$

When the model was estimated with this constraint, it was clearly rejected in favor of the model reported in the text. We felt that the misspecification from the unsupported constraint was worse than the inconsistency in the less constrained model.

5 Mussa (1981, 1982) argues that a superior formulation to Dornbush's price equation would have the rate of inflation equal the expected rate of change of the equilibrium price level, plus some proportion (<1) of the difference between the equilibrium and the actual price level. As emphasized both by Mussa and by Obstfeld and Rogoff (1983), Dornbusch's price equation is inappropriate either when disturbances become anticipated long before they occur or when the long run equilibrium of the economy moves over time. Neither situation is considered in this paper.

6 Dornbusch's price level was a weighted average of domestic and import price levels. This does not affect the results.

7 We use the term "risk aversion" in this section as a shorthand for saying "either an increase in the level of risk aversion or in the degree of exchange risk" repeatedly.

8 Serial correlation of the disturbances has only a minor effect on the theoretical results. We incorporate serially correlated disturbances in the empirical work.

9 Meese and Singleton (1980) use the variance of the first difference of the exchange rate. This concept is similar to ours given the different methods used to achieve stationarity. Frankel (1983) and Frenkel and Mussa (1980) use the conditional variance around the forward rate, while Flood (1981) uses the conditional variance around the expected spot rate. These measures are appropriate if it is desired to equate the concepts of risk and variability. Since we do not wish to make normative statements about variability, we have no need to equate these two concepts.

10 If δ_2 and γ_1 are of opposite signs, Π_{10}^2 will decrease if $B_1 \neq 0$. It is possible that the decrease in Π_{10}^2 outweights the increases in B_1^2 and Π_{20}^2 to decrease s_e^2. This is the only case where $B_1 = 0$ does not minimize the asymptotic variance. The conditional variance is always minimized when $B_1 = 0$.

11 We do not impose the cross error constraints between the v's and the u's. Otherwise, there would be contemporaneous correlation among the errors and the estimates would be inconsistent.

12 The interest rates used for the estimation were representative money market rates, taken from World Financial Markets. All other data were taken from International Financial Statistics. The real output, price level, and money supply data were seasonally adjusted. The countries (and weights) used for constructing the foreign variables were; Canada (.263), France (.131), Germany (.168), Italy (.097), Japan (.275) and the United Kingdom (.066).

13 We used the ARI procedure of TSP, which provides efficient estimates of an equation whose disturbances display first order serial correlation.

14 We tested these conjectures by estimating all of the parameters of the model by maximum likelihood. The major problem was that the interest rate semi-elasticity of the demand for money was positive for both time periods. Rehm (1983) was able to get plausible maximum likelihood estimates for (in our notation) a_1 and a_2 for the United States by incorporating lags in the money demand specification, an option precluded in this paper by the desire for an analytic solution. Using maximum likelihood estimates of a_1

and a_2 that appear to be clearly misspecified seemed to be a worse choice than adopting the technique used in the paper.

15 Since the parameters a_1 and a_2 enter the model only through the definitions of δ_1 and δ_2 in (10), and since δ_1 and δ_2 are not constrained in this version, the values of a_1 and a_2 are irrelevant. Thus the support for undershooting provided by estimating the semi-constrained version is not contingent on the questions involved in the estimation of the money demand parameters.

16 One disturbing aspect of the estimates is that α_1, the serial correlation coefficient in the exchange rate equation, is greater than unity for 1973 (III) - 1982 (III). We experimented with both a second order autoregressive and third order moving average representation for u_{1t}, but the result did not change. We also attempted to estimate the model using first -differenced, rather than detrended, data but could not get the estimates to converge at an optimum.

17 The unconstrained log likelihood is 517.875 for 1973-79 and 679.176 for 1973-82. There are 17 parameters in the constrained version; 22 in the unconstrained version.

18 Driskill and Sheffrin (1981) and Papell (1983a) use maximum likelihood estimates and likelihood ratio tests. Glaessner (1982) uses generalized method of moments estimates and chi-squared test.

Table 1

Constrained Maximum Likelihood Estimates

Parameter	1973 (II)-1979 (III) Estimate	Asymptotic "t ratio"	1973 (II)-1982 (III) Estimate	Asymptotic "t ratio"
a_3	-.08	-.18	-.12	-1.51
a_4	1.59	2.97	.43	1.30
a_5	.09	1.13	.08	3.92
a_6	.22	2.33	.18	2.63
a_7	.56	.80	3.17	2.15
a_8	-.37	-1.68	.21	2.15
a_9	1.43	2.54	1.79	6.04
a_{10}	-.94	-1.15	-1.14	-2.43
a_{11}	.09	.25	-.29	-3.25
a_{12}	-1.19	-2.05	-.81	-1.91
a_{13}	-.61	-.57	.19	.49
α_1	.81	5.77	1.04	16.26
α_2	.13	.73	.10	.53
α_3	.79	9.70	.35	3.19
α_4	.83	15.14	.83	12.76
α_5	.93	17.78	.76	9.28
α_6	.56	4.27	.26	2.14

Single Equation Estimates

	Estimates	t Statistic	Estimate	t Statistic
a_1	1.13	3.32	.91	2.99
$-a_2$	.69	1.65	.60	2.77

Parameter Values Implied by the Estimates

	1973 (II)-1979 (III)	1973 (II)-1982 (III)
δ_1	1.83	4.42
δ_2	-.09	-2.58
γ_1	.04	.04
γ_2	.75	.78
c_1	.16	3.82
c_2	.90	-1.82
c_3	.43	-.89
c_4	-1.56	-.21
d_1	.27	.79
d_2	.28	.22
d_3	1.24	1.58
d_4	2.04	.52
λ_1	.75	.81
B_1	.08	.71

Correlation Between Actual and Estimated Values

	1973 (II)-1979 (III)	1973 (II)-1982 (III)
e	.84	.86
q	.94	.93
m	.92	.84
m*	.90	.93
y-y*	.78	.78
i-i*	.83	.65

Log Likelihood

1973 (II)-1979 (III)	1973 (II)-1982 (III)
491.548	669.465