

# REAL EXCHANGE-RATE VARIABILITY UNDER PEGGED AND FLOATING NOMINAL EXCHANGE-RATE SYSTEMS: AN EQUILIBRIUM THEORY

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## INTRODUCTION

Most economists and policymakers believe that economic performance differs across alternative exchange-rate systems. Moreover, many economists believe that there are clear policy implications that can be drawn from observations about past behavior under different exchange-rate systems and from economic theory.<sup>1</sup>

There is substantial evidence that the variability of real exchange rates differs across alternative nominal exchange-rate systems. A simple contrast of the variability before and after 1973, when widespread floating was adopted, is insufficient evidence for this proposition because the latter period may have been characterized by greater variability of real underlying disturbances.<sup>2</sup> However, Stockman (1983) studied monthly exchange rate and price series over a 23-year period for a sample of 36 countries and used observations on countries and time periods of floating exchange

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<sup>1</sup> There have, however, been few attempts to categorize differences in macroeconomic behavior across exchange-rate systems in a systematic way. See Baxter and Stockman (1988).

<sup>2</sup> This increase in variability may even have led nations to adopt floating exchange rates.

rates prior to 1973 and of countries with pegged exchange rates after 1973 to try to isolate the effects of the exchange-rate system per se from the effects of (possibly) greater variability of exogenous disturbances in the 1970s. The paper concluded that, although the period from 1973 through 1979 (the last year covered in the study) was characterized by greater variance of disturbances to real exchange rates than the previous period under Bretton Woods, the nominal exchange-rate system itself was associated with significantly greater variability of real exchange rates. A typical country that continued to peg its nominal exchange rate to the U.S. dollar after 1973, for example, experienced an increase in real exchange-rate variability that was about 40 percent as large as that experienced by countries that adopted floating rates, and the difference was significant at the 1-percent level. This relationship, of course, does not establish causality but is consistent with the view that pegged exchange-rate systems lead to less real exchange-rate variability for any given set of underlying shocks. Mussa (1986) examined this evidence further, adding additional observations and episodes that support this conclusion. In addition, Mussa adopted the usual argument that the explanation for this statistical relation is the sluggish adjustment of nominal goods prices.

This paper presents an alternative model, not based on sluggish nominal price adjustment, to explain the greater variability of real exchange rates under floating than under pegged nominal exchange-rate systems.<sup>3</sup> The basic argument is the following. Real disturbances, to supplies or demands for goods, alter real exchange rates. Under a system of floating exchange rates, these disturbances also affect the nominal exchange rate (which creates a correlation between nominal and real exchange rates, as observed in the data), but under pegged exchange rates the same disturbances cause changes in the level of international reserves (and nominal money and prices). Countries that choose a system of pegged exchange rates benefit from increases in reserves as a result of real disturbances that would otherwise (under floating rates) create a real and nominal appreciation, and suffer losses of reserves from real and nominal depreciation.

When countries suffer losses of international reserves, they are more

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<sup>3</sup>This paper develops formally an argument that was loosely outlined in Stockman (1987b). The model used here is a variant of that in Stockman and Hernandez (1988), which is based on Stockman (1980), Lucas (1982), Svensson (1985a), and Stockman and Svensson (1987).

likely to impose trade restrictions such as tariffs and quotas, or exchange controls and capital controls -- or the equivalent taxes -- to prevent further losses in reserves that might otherwise create a balance-of-payments crisis and "force" a devaluation. With some intertemporal substitution, so that increases in expected future prices tend to increase current prices, it turns out that the expectation that policies to stem reserve losses will be followed also tends to stabilize the real exchange rate. This makes the response of the real exchange rate to a given real disturbance smaller under a system of pegged exchange rates than under a system of flexible exchange rates. This conclusion is obtained regardless of whether the underlying shocks are changes in productivity or changes in tastes (or household productivity).

Essentially, a disturbance that would raise the relative price of foreign goods in terms of domestic goods by 10 percent under a system of floating rates has the same effect under a system of pegged exchange rates, but it also has an additional effect. Under floating rates, the domestic currency would depreciate by about 10 percent. (This result must be predicted by any reasonable model of exchange rates, because empirically nominal and real exchange rates move together very closely.) Under pegged exchange rates, however, the domestic central bank will lose reserves (as it acts as a residual buyer/seller to peg its currency). The loss in reserves raises the probability of future tariffs, quotas, and exchange and capital controls. This raises the expected future (world) relative prices of domestic goods. Intertemporal substitution, whether operating through storage and investment, substitution of labor effort, or direct substitution by consumers of goods now rather than goods later, tends to raise the current relative price of domestic goods. But this effect partly offsets the direct effect of the disturbance, which was to raise the relative price of the foreign good. As a consequence, the same underlying disturbance has a smaller relative price effect under pegged than under floating rates.

The argument is reasonably robust to alternative parameter values. The key assumption is that changes in the level of reserves, i.e., balance of payments deficits and surpluses, lead to changes in the conditional probability of future trade and financial taxes and controls. While there are parameter values for which, for example, a higher tariff might reduce rather than raise the world relative price of the domestic good, these parameter values are generally fairly special and not likely to characterize most economies most of the time.

It is important that the argument presented in this paper not be particularly sensitive to parameter values or characteristics of the economy, because the observations that the paper seeks to explain appear to characterize a wide variety of countries. Aside from the sluggish nominal-price explanation of the greater variability of real exchange rates under the floating nominal rate system, I know of no explanation other than the one proposed here that is robust to many variations in parameter values or characteristics of the economy.

The explanation proposed in this paper works regardless of whether the main sources of exogenous disturbances to the economy are from shocks to technology that affect current output of market goods or shocks to tastes or household production functions that affect consumer valuations of goods even if supplies are unaffected. That is, the explanation is consistent with the predominance of either aggregate supply shocks or aggregate demand shocks. It does not rely on a particular market structure or on the absence of markets for certain types of risk-sharing. The model below, however, makes the assumption of complete markets for analytical convenience. Finally, the argument does not imply that the average level of tariffs or capital controls be greater under pegged exchange rates; instead, it is based on the different covariation of trade and payments restrictions with various exogenous disturbances that accompanies the pegged rate system.

As Karl Brunner and Allan Meltzer (1986) say, in commenting on the greater variability of real exchange rates under floating exchange rate systems, "The findings raise a question about whether the additional variability is an excess burden, borne under fluctuating rates, a response to policy differences in a fluctuating rate regime, or a substitution of exchange-rate variability for other effects of underlying variability." This paper is an attempt to work out the implications of what seems to be a clear and almost universal policy difference under the two regimes, and to argue that this policy difference can in principal account for the observed difference in variability without strong restrictions on parameters of the model.

## A MODEL OF FLEXIBLE EXCHANGE RATES

Consider a model with two countries, each producing a different internationally-traded good. Denote the goods X and Y, with the home country producing X and the foreign country producing Y. The home country

has access to a technology that creates  $\theta_{t+1} \phi(k_{t+1})$  units of good X at date t+1 if  $k_{t+1}$  units of X were invested as an input at date t, where  $\theta$  is a positive stationary random variable represented by a Markov process.<sup>4</sup> Assume that  $E(\theta) = 1$  and  $E[(\theta_t - 1)(\theta_{t+1} - 1)] > 0$ . This positive autocorrelation in  $\theta$  will tend to induce positive autocorrelation in the real exchange rate, as shown below. The foreign country has access to a technology that turns an investment of  $k_{t+1}^*$  units of good Y at date t into  $\theta_{t+1}^* \phi^*(k_{t+1}^*)$  units of Y at date t+1, where  $\theta^*$  is also a positive random variable with  $E(\theta^*) = 1$  and  $E[(\theta_t^* - 1)(\theta_{t+1}^* - 1)] > 0$ . The deterministic parts of the production functions  $\phi$  and  $\phi^*$  are increasing and concave. It is assumed that the invested input depreciates completely after one period of use.

There is a representative household in each country that maximizes an intertemporally-separable utility function defined over consumption of X and Y. Tastes may differ across countries, but the discount rate  $\beta$  will be assumed to be common to the two countries. The representative domestic household maximizes discounted expected utility,

$$E_0 \sum_{t=0}^{\infty} \beta^t [u(x_t^d) + v(y_t^d)], \quad (1)$$

where  $x_t^d$  and  $y_t^d$  are the domestic household's consumptions of X and Y at date t and  $u(\cdot)$  and  $v(\cdot)$  are increasing and concave. The household is constrained by its wealth,

$$A_0 = \sum_{t=1}^{\infty} \int [P_B(s_t)B(s_t) + P_F(s_t)F(s_t)] r(s_t | s_0) ds_t \quad (2)$$

where  $B(s_t)$  and  $F(s_t)$  are contingent claims to deliveries of domestic or foreign moneys at date t in state-of-the-world  $s_t$  (to be defined below), and  $P_B$  and  $P_F$  are the prices of the state contingent claims at period-zero asset markets divided by the probability densities of those states, and  $r(s_t)$  is the probability density function of  $s_t$ . It is assumed that markets are complete - except for one restriction to be specified below - so that claims to moneys can be purchased for each of the infinitely many states  $s$  at each time period t, and for all t. The exogenously-imposed restriction on available markets is one that allows money to have positive value: only

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<sup>4</sup>The model ignores subsequent resale, by import specialists, of imported goods.

claims to physical payments of moneys (or other assets) are permitted, while claims to physical deliveries of goods X and Y are not permitted. Instead, these goods must be purchased with money obtained in advance. The money that a household has available for spending on goods at date t is given by

$$M(s_t) = m(s_{t-1}) + p(s_{t-1})\theta_{t-1} \phi(k_{t-1}) + B(s_t) + w(s_t) \quad (3)$$

and

$$N(s_t) = n(s_{t-1}) + F(s_t)/(1+\tau_t) \quad (4)$$

where  $m(s_{t-1})$  and  $n(s_{t-1})$  are the quantities of domestic and foreign moneys M and N that are carried over, into period t, from period t-1. The second term in (3),  $p(s_{t-1})\theta_{t-1} \phi(k_{t-1})$ , is the quantity of money that the household obtains as dividends at date t from its ownership of a representative domestic "firm" that sold  $\theta_{t-1} \phi(k_{t-1})$  units of good X at date t-1, each at a nominal domestic-money price  $p(s_{t-1})$ .  $B(s_t)$  is the quantity of domestic money the household receives as principal or interest on previously acquired state-contingent assets, and  $w(s_t)$  is a lump-sum transfer from the domestic government. In (4), F is divided by  $1+\tau$ , where  $\tau$  is (as in Stockman and Hernandez, 1988) a tax on acquisitions of foreign currency, which will be referred to as a "capital control" or "exchange control," because it could be replaced in the model with an economically equivalent quantitative restriction.

Variables are dated according to the timing convention that each period consists of two subperiods: AM for "asset market," followed by PM for "product market." At period-t AM, households trade assets and moneys, and all payments required by previously-held assets are completed. The domestic government makes transfer payments  $w(s_t)$  in state s to domestic households and collects any taxes that it levies on asset trades, interest payments, etc. (These taxes will be discussed below.) Then, during period-t PM, the household uses money that it held at the end of period-t AM to buy goods. Domestic money, M, must be used to buy domestic goods, while foreign money, N, is required for foreign goods. Because markets are complete except for the restriction that assets must make payments in moneys rather than in goods, trading at each AM is redundant. Instead, payments required by previously-held assets are made at each AM. The budget constraint (2) describes the representative domestic household's opportunities to buy or sell assets at the date-0 asset market. Then, at each PM, households buy and consume goods. The constraints faced by the domestic households at each

PM are the cash-in-advance constraints. With the usual assumption that all transactions use the seller's currency, these cash-in-advance constraints are

$$m(s_t) = M(s_t) - p(s_t)[x^d(s_t) + K(s_t)] \geq 0, \quad (5)$$

and

$$n(s_t) = N(s_t) - q(s_t)(1+T_t)y^d(s_t) \geq 0. \quad (6)$$

Equation (5) states formally the definition of  $m(s_t)$ : the amount of money that the representative domestic household held when it left asset markets at date  $t$  minus its expenditure on goods at date- $t$  PM. The household's spending on goods has two components. First, it buys goods for consumption purposes. Second, it buys goods at date  $t$  for investment purposes (for the "firm" owned by the household). Nominal investment spending at date  $t$  is  $p(s_t)K(s_t)$  where  $K(s_t)$  goods are used for investment. It is assumed that domestic households own, and buy investment goods for, domestic firms, while foreign households own and buy investment goods for foreign firms.<sup>5</sup> Then

$$K_t = k_{t+1} \equiv K(s_t). \quad (7)$$

The household pays a price  $q(1+T)$  for the foreign good, where  $T$  is a tariff on imports levied by the government in the home country. Tariff proceeds, like proceeds from exchange and capital controls, are refunded in a lump-sum fashion to domestic households as part of the transfer  $w$  in equation (3).

The representative domestic household chooses a complete contingency plan for  $\{x^d, y^d, B, F, M, N, m, n, K\}_t, t=0, \dots, \infty$ , to maximize (1) subject to (2)-(7), initial conditions on  $A_0$  and  $k_0, n_{-1} = 0, m_{-1} + p_{-1}\theta_{-1}\phi(k_{-1}) = M_0^S$ , and parametric stochastic processes on  $\{P_B, P_F, \theta, p, q, w, \tau, T\}$ .

There is an analogous utility-maximization problem for the representative foreign household. The foreign household chooses a complete

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<sup>5</sup>See Stockman and Svensson (1987). In contrast to that paper, this paper imposes the assumption that only domestic households work as purchasing agents for domestic firms, and vice versa. Because state-contingent bonds can be used to duplicate exactly the returns on investments, this assumption is unimportant.

contingency plan for  $\{x^{d*}, y^{d*}, B^*, F^*, M^*, N^*, m^*, n^*, K^*\}_t, t=0, \dots, \infty$ , to maximize

$$E_0 \sum_{t=0}^{\infty} \beta^t [u^*(x_t^{d*}) + v^*(y_t^{d*})] \quad (8)$$

subject to

$$A_0^* = \sum_{t=0}^{\infty} \int [P_B(s_t)B^*(s_t) + P_F(s_t)F^*(s_t)] r(s_r|s_0) ds_t, \quad (9)$$

$$M^*(s_t) = m^*(s_{t-1}) + B^*(s_t)/(1+\tau_t^*), \quad (10)$$

$$N^*(s_t) = n^*(s_{t-1}) + q(s_{t-1})\theta_{t-1}^* \phi^*(k_{t-1}^*) + F(s_t) + w^*(s_t), \quad (11)$$

$$m^*(s_t) = M^*(s_t) - p(s_t) (1+\tau_t^*)x^{d*}(s_t) \geq 0, \quad (12)$$

and

$$n^*(s_t) = N^*(s_t) - q(s_t) [y^{d*}(s_t) + K^*(s_t)] \geq 0, \quad (13)$$

with

$$K_t^* = k_{t+1}^* \equiv K^*(s_t), \quad (14)$$

initial conditions ( $n_0^*$ , and  $k_0^*$ ,  $m_{-1}^* = 0$ ,  $n_{-1} + q_{-1}\theta_{-1}^* \phi^*(k_{-1}^*) = N_0^S$ , and parametric stochastic processes on  $\{P_B, P_F, \theta^*, p, q, w^*, \tau^*, T^*\}$ ).

The domestic household's maximization problem has a solution with, in addition to (2)-(6),

$$\beta^t u_1(x_t^d) = \lambda P_B(s_t)p(s_t), \quad (15)$$

$$\beta^t v_1(y_t^d) = \lambda P_F(s_t)q(s_t)(1+g_t), \quad (16)$$

$$\alpha(s_t) = u_1(x_t^d)/p(s_t) - \beta E_t\{u_1(x_{t+1}^d)/p(s_{t+1})\}, \quad (17)$$

$$\delta(s_t) = v_1(y_t^d)/q(s_t)(1+\tau_t) - \beta E_t\{v_1(y_{t+1}^d)/q(s_{t+1})(1+\tau_{t+1})\}, \quad (18)$$

and

$$\beta E_t\{u_1(x_{t+1}^d)p(s_t)/p(s_{t+1})\} + \alpha(s_t)p(s_t) = \quad (19)$$

$$\beta^2 E_t\{u_1(x_{t+2}^d)\theta_{t+1} \phi_1(k_{t+1})p(s_{t+1})/p(s_{t+2})\}$$

where  $\lambda$  is the multiplier on (2),  $\alpha \geq 0$  is the multiplier on (3),  $\delta \geq 0$  is the multiplier on (4), where  $\alpha(s_t)m(s_t) = \delta(s_t)n(s_t) = 0$  for all  $s$  and  $t$ , and where



$$(1+g) \equiv (1+\tau)(1+T). \quad (20)$$

There are analogous conditions for the representative foreign household. These are

$$\beta^t u_1^*(x_t^{d*}) = \lambda^* (P_B(s_t)p(s_t)(1+g_t^*)) \quad (21)$$

$$\beta^t v_1^*(y_t^{d*}) = \lambda^* P_F(s_t)q(s_t), \quad (22)$$

$$\alpha^*(s_t) = u_1^*(x_t^{d*})/p(s_t)(1+T_t^*) - \beta E_t \{u_1^*(x_{t+1}^{d*})/p(s_{t+1})(1+T_{t+1}^*)\}, \quad (23)$$

$$\delta^*(s_t) = v_1^*(y_t^{d*})/q(s_t) - \beta E_t \{v_1^*(y_{t+1}^{d*})/q(s_{t+1})\}, \quad (24)$$

and

$$\beta E_t \{v_1^*(y_{t+1}^{d*})q(s_t)/q(s_{t+1})\} + \delta^*(s_t)q(s_t) = \quad (25)$$

$$\beta^2 E_t \{v_1^*(y_{t+2}^{d*})\theta_{t+1}^* \phi_1^*(k_{t+1}^*)q(s_{t+1})/q(s_{t+2})\}$$

where  $\lambda^*$  is the multiplier on (2),  $\alpha^* \geq 0$  is the multiplier on (3),  $\delta^* \geq 0$  is the multiplier of (4), where  $\alpha^*(s_t)m^*(s_t) = \delta^*(s_t)n^*(s_t) = 0$  for all  $s$  and  $t$ , and where

$$(1+g^*) \equiv (1+\tau^*)(1+T^*). \quad (26)$$

The equilibrium of the economy is a set of functions  $\{x^d, y^d, x^{d*}, y^{d*}, K, K^*, B, F, B^*, F^*, M, N, M^*, N^*, m, n, m^*, n^*, \lambda, \lambda^*, \alpha, \alpha^*, \delta, \delta^*, P_B, P_F, p, q, w, w^*\}$ . These functions are defined over the state of the economy, defined as

$$s_t = (\{\theta_j, \theta_j^*, \tau_j, \tau_j^*, T_j, T_j^*, \mu_j, \mu_j^*\}_{j=-\infty}^t, M_t^S, N_t^S, R_t^*) \quad (27)$$

where  $\mu$  and  $\mu^*$  denote growth rates of nominal money supplies  $M^S$  and  $N^S$ , and where  $\theta, \theta^*, \tau, \tau^*, T, T^*, \mu,$  and  $\mu^*$  are independent stationary random variables and, except for  $\theta$  and  $\theta^*$ , are i.i.d. The productivity terms  $\theta$  and  $\theta^*$  are Markov.  $R_t^*$  is an exogenous constant under flexible exchange rates. (It will represent the level of the foreign governments' international reserves under pegged exchange rates.) These functions must satisfy conditions (2)-(7) and (15)-(20), the analogous conditions (9)-(14) and (21)-(26), the initial conditions, and the equilibrium conditions

$$x_t^d + x_t^{d*} = \theta_t \phi(k_t) - K_t, \quad (28)$$

$$y_t^d + y_t^{d*} = \theta_t^* \phi^*(k_t^*) - K_t^*, \quad (29)$$

$$M(s_t) + N^*(s_t) = M_{t+1}^S, \text{ and} \quad (30)$$

$$N(s_t) + N^*(s_t) = N_{t+1}^S, \quad (31)$$

for all  $t$ , where  $M_{t+1}^S$  and  $N_{t+1}^S$  denote post-transfer nominal money supplied at date  $t$ . The equilibrium functions must also satisfy the government budget constraints

$$i(s_t) = [\tau_t F(s_t) + q(s_t) T_t y_t^d(s_t)] P_F(s_t) / P_B(s_t) + M_{t+1}^S - M_t^S \quad (32)$$

and

$$i^*(s_t) = [\tau_t^* B^*(s_t) + p(s_t) T_t^* x_t^{d*}(s_t)] P_B(s_t) / P_F(s_t) + N_{t+1}^S - N_t^S \quad (33)$$

for all  $t$ , and initial conditions on  $A_0$ ,  $A_0^*$ ,  $m_{-1}$ ,  $n_{-1}$ ,  $k_0$ ,  $m_{-1}^*$ ,  $n_{-1}^*$ , and  $k_0^*$ , where  $\mu_t \equiv M_{t+1}^S / M_t^S$ ,  $\mu_t^* \equiv N_{t+1}^S / N_t^S$ , and  $A_0 + A_0^* =$  total world wealth, given exogenous stochastic processes on  $\theta$ ,  $\theta^*$ ,  $\mu$ ,  $\mu^*$ ,  $\tau$ ,  $\tau^*$ ,  $T$ ,  $T^*$ , and an arbitrary normalization for asset prices.

The four equations (15, 16, 21, 22) and the equilibrium conditions (28) and (29) can be solved for consumption levels  $x^d$ ,  $y^d$ ,  $x^{d*}$ , and  $y^{d*}$  conditional on the levels of initial capital, investment, tariffs, and capital controls, using

$$u_1(x_t^d) (1+g_t^*)^{\lambda^*} / \lambda = u_1^*(\theta_t \phi(K(s_{t-1})) - K(s_t) - x_t^d) \quad (34)$$

and

$$v_1(y_t^d) \lambda^* / \lambda = (1+g_t) v_1^*(\theta_t^* \phi^*(K^*(s_{t-1})) - K^*(s_t) - y_t^d). \quad (35)$$

In the absence of investment, the solution for allocations is discussed in Stockman and Hernandez (1988). As discussed in the introduction, investment is included in the model for purposes of intertemporal substitution so that higher expected future prices raise prices currently.

Equations (17) and (19) imply

$$u_1(x_t^d) = \beta^2 E_t \{ u_1(x_{t+2}^d) \theta_{t+1} p_{t+1} / p_{t+2} \} \phi_1(k_{t+1}). \quad (36)$$

Stockman (1981) and Abel (1985) discuss effects of inflation on capital accumulation in models related to the one in this paper. But

inflation will typically differ across alternative exchange-rate systems, and this difference could then cause differences in capital accumulation and other features of the equilibrium. In order to focus on other issues, I assume that under flexible exchange rates the domestic money supply is chosen such that the domestic (production price index) inflation rate  $P_{t+1}/P_{t+2}$  is deterministic, and (without loss of generality) equal to unity. This corresponds to a type of nominal interest rate rule.<sup>6</sup>

Then (36) becomes

$$u_1(x^d(s_t)) = \beta^2 \int u_1(x^d(s_{t+2})) \theta_{t+1} r(s_{t+2}|s_t) ds_{t+2} \phi_1(K(s_t)). \quad (37)$$

If monetary policy were set so that the nominal interest rate were zero, then equation (37) would reduce to the standard condition.

Similarly, if foreign monetary policy were determined so that  $q_{t+1}=q_t$  for all  $t$ , then equations (23) and (25) would imply

$$v_1^*(y^{d*}_t) = \beta^2 E_t \{ v_1^*(y^{d*}_{t+2}) \theta_{t+1}^* \phi_1^*(k_{t+1}^*) \}. \quad (38)$$

The world relative price of  $Y$  in terms of  $X$  is

$$\Pi(s_t) = P_F(s_t)q(s_t)/P_B(s_t)p(s_t). \quad (39)$$

where  $P_F/P_B$  is the exchange rate. Equations (15) and (16) imply that this "real exchange rate"  $\Pi$  can be written as

$$\Pi(s_t) = v_1(y^d(s_t))/u_1(x^d(s_t))(1+g_t). \quad (40)$$

Alternatively, equations (21) and (22) give another expression for the real exchange rate:

$$\Pi(s_t) = (1+g_t^*)v_1^*(y^{d*}(s_t))/u_1^*(x^{d*}(s_t)). \quad (41)$$

An approximation to the variance of  $\Pi(s_t)$  can be obtained by taking a first-order Taylor series approximation of  $\Pi_t$  around the mean of  $s_t$ ,

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<sup>6</sup>See Goodfriend (1987) and Barro (1987).

$$\Pi(s_t) \approx \Pi(\bar{s}_t) + (s_t - \bar{s}_t) \frac{\partial \Pi(\bar{s}_t)}{\partial s_t} . \quad (42)$$

Then, using the facts that  $\tau$  and  $T$  affect  $\Pi$  only through  $g$ , defined in equation (20), and defining

$$\rho(a_{t-j}) \equiv \frac{\partial \Pi(\bar{s}_t)}{\partial a_{t-j}} \text{ and } \sigma_{z, z-j} \equiv \text{cov}(z_t, z_{t-j}) , \quad (43)$$

we have

$$\begin{aligned} \sigma_{\Pi}^2 &= E[(\Pi(s_t) - E\Pi(s_t))^2] \\ &\approx [\rho(\theta_t)^2 + \rho(\theta_{t-1})^2 + \dots] \sigma_{\theta}^2 \\ &\quad + [\rho(\theta_t) \rho(\theta_{t-1}) + \rho(\theta_{t-1}) \rho(\theta_{t-2}) + \dots] \sigma_{\theta, \theta-1}^2 \\ &\quad + [\rho(\theta_t) \rho(\theta_{t-2}) + \rho(\theta_{t-1}) \rho(\theta_{t-3}) + \dots] \sigma_{\theta, \theta-2}^2 + \dots \\ &\quad + [\rho(\theta_t^*)^2 + \rho(\theta_{t-1}^*)^2 + \dots] \sigma_{\theta^*}^2 + [\rho(\theta_t^*) \rho(\theta_{t-1}^*) + \dots] \sigma_{\theta^*, \theta^*-1}^2 + \dots \\ &\quad + [\rho(g_t)^2 + \dots] \sigma_g^2 + [\rho(g_t) \rho(g_{t-1}) + \dots] \sigma_{g, g-1}^2 + \dots \\ &\quad + [\rho(g_t^*)^2 + \dots] \sigma_{g^*}^2 + [\rho(g_t^*) \rho(g_{t-1}^*) + \dots] \sigma_{g^*, g^*-1}^2 + \dots . \end{aligned} \quad (44)$$

This expression can be used to determine the variance of the real exchange rate as a function of the variance of the exogenous variables and the autocovariances of  $\theta$  and  $\theta^*$ . The expression involves properties of the function  $\Pi(s)$  evaluated at  $\bar{s}$ , and these properties can be obtained by differentiation of equations (34), (35), (37), and (38).

Although it can be assumed that both governments choose monetary policies to keep  $p$  and  $q$  constant over time under flexible exchange rates, it is not possible to make that assumption when the exchange rate is pegged by monetary policy. Generally, pegging the nominal exchange rate will turn out to require variations in either  $p$  or  $q$  or both. These price variations, however, will have effects on capital accumulation and other features of the equilibrium, including relative prices. In order to emphasize the new points to be made in this paper, and not confound these points with effects of the exchange-rate system that operate through effects of inflation on investment decisions, I will make four assumptions. First, the one-period

domestic and foreign nominal interest rates are strictly positive in all states. As in Lucas (1982), this amounts to a restriction on the stochastic processes on exogenous variables. In contrast to Lucas's model, this assumption does not imply a unit velocity of money in this model, for the reasons explained in Stockman and Hernandez (1988). The purpose of this first assumption is to guarantee feasibility of the following two assumptions. Second, domestic monetary policy is chosen to keep  $p$  constant. (This prevents effects on domestic investment of the kind discussed by Abel (1985).) Because the nominal interest rate is strictly positive,  $m(s_t)$  is identically zero. Consequently, increases or decreases in  $p_t$  can be engineered by increases or decreases in  $M_t^S$ , so it is feasible to vary the domestic money supply to keep  $p_t$  constant. Third, foreign monetary policy is chosen to make  $q$  constant under a flexible exchange-rate system, and (instead) to make the nominal exchange rate  $e$  constant under a pegged exchange-rate system. That is, the foreign country is entirely responsible for pegging the exchange rate. Fourth, I will assume that the foreign capital stock is fixed -- it does not depreciate and cannot be augmented. This assumption guarantees that the differences in foreign nominal price behavior under flexible and pegged exchange-rate systems do not affect foreign investment. Any differences in the behavior of real exchange rates, then, will be due to features of the model other than the nonsuper-neutralities of money. (One reason this is desirable is that, for moderate levels of inflation, these nonsuperneutralities are probably of negligible magnitude empirically. See, e.g., Danthine, Donaldson, and Smith (1987).)

With these assumptions, equation (35) determines the  $y^d$  function, and  $x^d$  and  $K$  are to be determined from equations (34) and (37) and the transversality condition.

Consider a rise in  $\theta_t$ . Equation (34) implies that  $x_t^d$  and  $x_t^{d*}$  respond in the same direction to a change in  $\theta_t$  (or a change in  $K(s_{t-1})$ ). But it is straightforward to show, via differentiation, that  $\partial x_t^d / \partial \theta_t$  is indeterminate in sign. While a rise in  $\theta_t$  raises total current resources for consumption and investment, the assumption that  $\theta$  is positively autocorrelated implies that the (conditional) expectation of future  $\theta$  also rises. This increase in the prospective rate of return to current investment can (depending on parameter values) lead households to reduce current consumption in order to invest more. The effect of a rise in  $\theta$  on the real exchange rate  $\pi_t$  depends on which case applies: if a rise in  $\theta_t$  raises  $x_t^d$ , then  $\pi(s_t)$  rises; otherwise it falls. For concreteness of discussion, assume that  $\partial x_t^d / \partial \theta_t > 0$ . Similarly, investment can rise or fall in response to a rise in  $\theta$ .

Because the expected future rate of return to capital is higher, expected future output is higher even if investment is unchanged.

Consider next a rise in any lagged exogenous variable. Lagged  $\theta$  or lagged  $g^*$  affect  $x^d$  and  $K$  only through their effects on the initial capital stock. It is straightforward to show that a rise in the initial capital stock in place at date  $t$ ,  $k_t$  raises both consumption  $x_t^d$  (and  $x_t^{d*}$ ) and investment  $K_t$ . Let  $b \in (0,1)$  denote the fraction of an increment to the initial capital stock that is invested when all random variables are evaluated at their unconditional means, i.e., solve equations (34) and (37)

for  $K(\theta, g^*, k)$  and then  $b \equiv \frac{\partial K(\bar{\theta}, \bar{g}^*, \bar{k})}{\partial k}$  where  $\bar{k} \equiv K(\bar{s})$ . Then, differentiating equations (34) and (37), it is easy to show that, with the

notation  $\bar{x}_{\theta-i}^d = \frac{\partial x^d(\bar{s}_t)}{\partial \theta_{t-i}}$ ,

$$\bar{x}_{\theta-i}^d = \bar{x}_{\theta-1}^d b^{i-1}, \quad i = 2, 3, \dots \quad (45)$$

and

$$\bar{x}_{g^*-i}^d = \bar{x}_{g^*-1}^d b^{i-1}, \quad i = 2, 3, \dots \quad (46)$$

But,

$$\rho(\theta_{t-i}) = \frac{v_1(y^d(\bar{s}_t)) u_{11}(s^d(\bar{s}_t))}{(1+\bar{g})[u_1(x^d(\bar{s}_t))]^2} \bar{x}_{\theta-i}^d \quad (47)$$

$$= \frac{v_1(y^d(\bar{s}_t)) u_{11}(x^d(\bar{s}_t))}{(1+\bar{g})[u_1(x^d(\bar{s}_t))]^2} \bar{x}_{\theta-1}^d b^{i-1},$$

and, using equation (41),

$$\rho(g_{t-i}^*) = \frac{(1+\bar{g}^*) v_{11}^*(y^{d*}(\bar{s}_t))}{u_1^*(x^{d*}(\bar{s}_t))} [\bar{\theta}^* \phi^*(R^*) - R^* - \bar{y}_{g^*-i}^d] \quad (48)$$

where  $R^*$  is the exogenously-fixed level of the foreign capital stock, and

$$\bar{y}_{g^*-i}^d \equiv \frac{\partial y^d(\bar{s}_t)}{\partial g_{t-i}^*}, \quad \text{which from equation (35) is zero for all } i \neq 0.$$

Similarly, it is easy to show that, with  $\bar{k}^*$  fixed,  $\rho(\theta_{t-i}^*) = 0$  for  $i \neq 0$ .

Finally,

$$\rho(g_{t-i}^*) = \frac{\rho(\theta_{t-i}) \bar{x}_{g_{t-i}^*}^d}{\bar{x}_{\theta_{t-i}}^d b^{i-1}} = \frac{\rho(\theta_{t-i}) \bar{x}_{g_{t-i}^*}^d}{\bar{x}_{\theta_{t-i}}^d} \quad (49)$$

Because  $b \in (0,1)$ ,  $\rho(\theta_{t-i})$  and  $\rho(g_{t-i}^*)$  decline geometrically with increases in  $i$ , so the infinite sums in equation (44) are finite, and  $\sigma_{\Pi}^2$  is finite.

It remains to find  $\bar{x}_{\theta_{t-1}}^d$  and  $\bar{x}_{g_{t-1}^*}^d$ . From equation (34) we have (with all derivatives evaluated at  $\bar{s}$ ),

$$\bar{x}_{\theta_{t-1}}^d = \frac{u_{11}^* [\theta \phi_1 - b]}{u_{11}^* (1+g^*) \frac{\lambda^*}{\lambda} + u_{11}^*} \frac{\partial K(\bar{s}_t)}{\partial \theta_t} > 0 \quad (50)$$

and similarly,  $\bar{x}_{g_{t-1}^*}^d > 0$ . So we have a real exchange-rate function  $\Pi(s)$  with derivatives (evaluated at  $\bar{s}$ )  $\rho(\theta_t) > 0$ ,  $\rho(\theta_{t-i}) > 0$  for all  $i > 0$ ,  $\rho(\theta_t^*) < 0$ ,  $\rho(\theta_{t-i}^*) = 0$  for all  $i > 0$ ,  $\rho(g_t) < 0$ ,  $\rho(g_{t-i}) = 0$  for all  $i > 0$ ,  $\rho(g_t^*) > 0$ , and  $\rho(g_{t-i}^*) > 0$  for all  $i > 0$ . An increase in domestic productivity at date  $t$ , i.e., a high realization of  $\theta$ , raises current consumption of the good in both countries and can either raise or lower domestic investment, but (because utility is additively separable) it has no effect on consumption of  $Y$  in either country. An increase in the initial capital stock has the same effects as an increase in  $\theta$  except that, because it does not affect future productivity (i.e.,  $\theta$ ) prospects, it unambiguously raises domestic investment. An increase in the supply of domestic output, whether due to a rise in productivity or a higher initial capital stock, raises the relative price of the foreign good. An increase in domestic tariffs or taxes on acquisitions of foreign currency lower domestic consumption of the imported good  $Y$  and raises foreign consumption of  $Y$ , without changing consumption of  $X$  or domestic investment. The real exchange rate  $\Pi$  falls with a rise in  $g$  because the increase in  $g$  raises  $y^{d*}$ , lowering  $v_1^*$ , without changing anything else on the right-hand side of equation (41). An increase in foreign tariffs or taxes on acquisitions of foreign currency reduces foreign consumption of  $X$ , raises domestic consumption of  $X$ , and lowers the marginal cost of domestic investment, which raises investment. The increase in domestic consumption of  $X$ , given consumption of  $Y$ , implies that the real exchange rate  $\Pi$  rises with  $g^*$ .

Equation (40) implicitly defines the function  $\pi(\theta_t, k_t, g_t, g_t^*)$ . Under these assumptions it can be shown to have the properties

$$\pi_\theta > 0, \pi_k > 0, \pi_g < 0, \text{ and } \pi_{g^*} > 0. \quad (51)$$

A change in the real exchange rate, resulting from an exogenous change in productivity or from exogenous government tax policies, can occur either through changes in  $p$ ,  $q$ ,  $P_B/P_F$ , or a combination of changes in these variables. Generally, the effects of a change in output on the nominal exchange rate  $e = P_B/P_F$  can be divided into two effects (see Stockman, 1987a). First, given nominal domestic producer prices  $p$  and  $q$ , the entire change in the real exchange rate would occur through a change in the nominal exchange rate. In the case of an exogenous rise in domestic output, the fall in its relative price would occur as a domestic currency depreciation. Second, the nominal output prices  $p$  and  $q$  are usually not given, but are affected by changes in output: an exogenous rise in domestic output raises the demand for money and -- given the nominal money supply -- reduces the level of nominal domestic money prices. Given the real exchange rate, this leads to a domestic currency appreciation. If the first, "relative price," effect on the nominal exchange rate dominates the second, "money-demand," effect, then domestic currency depreciates with an exogenous rise in the supply of domestic output. In this case, changes in nominal and real exchange rates are positively correlated. This positive correlation is clearly borne out by the data on changes in real and nominal exchange rates.

The relative price effect will dominate the money-demand effect, when the nominal money is fixed, if the elasticity of substitution between foreign and domestic goods is sufficiently small, so that the relative price effect is large, or if the income elasticity of money demand is small, so that the money demand effect is small. The relative price effect will also dominate the money-demand effect, leading to a positive correlation between changes in real and nominal exchange rates, if the nominal money supply changes endogenously to prevent the large counter-cyclical swings in nominal prices that would otherwise accompany changes in output (given that those changes affect the demand for money). For example, a monetary policy of "accommodating" changes in output would lessen or prevent the fall in nominal prices when output rises exogenously, which would lessen or eliminate the "money-demand effect" of the change in output on the nominal exchange rate. This would make it more likely that the



"relative price effect" would dominate. The assumptions made above -- that monetary policies are adjusted to keep  $p$  and  $q$  constant -- are sufficient for the relative price effect to dominate. With these assumptions, the entire change in the real exchange rate  $\pi$ , in response to any disturbance, occurs through a change in the nominal exchange rate  $e = P_B/P_F$ . The strong assumptions made here are not necessary to obtain a positive covariance of real and nominal exchange rates, as observed in the data. All that is necessary is that the countercyclical effect of exogenous output shocks on nominal prices is not the dominant effect on nominal exchange rates. As will be seen below, the main argument in this paper rests on this positive covariation of real and nominal exchange rates which, as noted above, is clearly supported by the data. The point to be made is that, while the assumptions of fixed  $p$  and  $q$  are very special, the results of those assumptions are much more general. As argued earlier in the paper, the point of this paper is to present a theory explaining differences in real exchange-rate variability across nominal exchange-rate systems that does not rely on special assumptions that would make it unlikely to account for a wide variety of experiences.

A property of the model to be used below is the following. The foreign money supply required to keep  $q$  constant does not depend on realizations of  $\theta$ . To see this, notice that equations (4), (5), (11), (12), (16), (18), (22), (24), (29), and (31) determine  $n$ ,  $n^*$ ,  $N$ ,  $N^*$ ,  $F$ ,  $F^*$ ,  $y^d$ ,  $y^{d^*}$ ,  $\delta$ ,  $\delta^*$ ,  $P_F$ , and  $q$  for given initial conditions (including a choice of numeraire for  $P_B$ ,  $P_F$ ,  $A$ ,  $A^*$ ,  $\lambda$ , and  $\lambda^*$ , and exogenously given on  $A/A^*$  or  $\lambda/\lambda^*$ ). Similarly, the domestic money supply required to keep  $p$  constant does not depend on realizations of  $\theta^*$ .

## PEGGED EXCHANGE RATES

The model is the same as above, but there are two modifications. First, the government of the foreign country pegs its nominal exchange rate to the currency of the home country (the "reserve-currency country") by acting as a residual buyer or seller of its own currency using a class of assets called "international reserves." These reserves may consist of interest-bearing assets, or foreign currency. The division between assets owned by the central bank into "international reserves" and "other assets" is largely arbitrary. Because the foreign country's currency is pegged, the foreign country no longer conducts changes of its money supply to keep  $q$

fixed. In fact, because the home country continues to choose its money supply to keep  $p$  fixed, and because the nominal exchange rate is pegged, all variations in the real exchange rate occur through changes in  $q$ .

Second, the government uses a variety of policies to prevent losses in its reserves. In particular, when the foreign country loses reserves, the probability distribution of future tariffs and future exchange controls and capital controls shifts making these taxes and controls more likely. In particular,

$$\Pr[g^*(s_{t+j}) < a | R^* = R_0^*] \leq \Pr[g^*(s_{t+j}) < a | R^* = R_1^*] \quad (52)$$

for all  $t, j > 0, a, R_0^*$  and  $R_1^* > R_0^*$ . This states that a lower level of international reserves held by the foreign country implies a lower probability that future foreign composite tax rates  $g_{t+j}$  will fall below any arbitrary level, i.e., a higher probability that they will be above any arbitrary level. Note that inequality (52) implies nothing about the level of  $g$  under alternative exchange-rate systems. Instead, it imposes a particular covariance of  $g$  with exogenous disturbances that affect the level of reserves.

There is substantial justification for the assumption in equation (51) in the descriptive and analytical literature on government policies under pegged exchange rates. Countries frequently imposed trade restrictions in the forms of tariffs, quotas, licensing requirements, and so on, and controls, regulations, and taxes on acquisitions of foreign currencies of interest-bearing assets denominated in foreign currencies.<sup>7</sup> Edwards (1987) has recently studied eighteen devaluations by Latin American countries and concludes that "Typically, the authorities will try to stop this process [loss of reserves] by imposing exchange controls, hiking tariffs, and imposing quantitative controls." He shows that

... in the great majority of cases the devaluation was preceded by an important piling up of exchange controls and trade restrictions. In some episodes, such as Columbia in 1962 and 1967, Ecuador in 1961, and Peru in 1975, the initial conditions (two years prior to the

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<sup>7</sup>Besides the references in the text, see Friedman (1951), Johnson (1972), and Krueger (1981). Curiously, there seems not to have been any formal studies of the effects of balance-of-payments deficits on the aggregate level of protectionism and financial restrictions.

crisis) were already extremely restrictive, and became even tighter as the erosion of reserves became severe... (Edwards 1987)

(Many of these countries had price controls, so losses in reserves were accompanied by apparent real appreciations rather than depreciations.) Park and Sachs (1987) have shown that capital controls can delay, though not prevent, the collapse of a peg. As they state, there has been "widespread use of capital controls to forestall exchange rate changes." Marston (1987) concludes that, on the basis of historical evidence, "Fixed exchange rates cannot be maintained without extensive capital controls." Halm (1971) cites International Monetary Fund, Annual Report, 1969 and concludes that, "Quite generally the Report agrees 'that adjustments in par values have in a number of cases been unduly delayed,' that 'these delays have sometimes tended to aggravate problems of domestic economic management, and have sometimes also aggravated the external disequilibrium'". The Report conceded, furthermore, that these delays have fostered the use of trade and payments restrictions... As Marston (1987) states, "That solution (controls) was adopted widely under the Bretton Woods System. The recent period of exchange rate flexibility, by no coincidence, has witnessed the progressive dismantling of controls..." Taiwan, for example, has reduced restrictions on international capital flows, capital controls, and exchange controls (and most observers expect additional reductions in controls in the near future), as a consequence of its accumulation in recent years of additional foreign-exchange reserves. (Taiwan's reserves have risen to about 60 billion U.S. dollars in mid-1987 from less than 10 billion in 1980.) Nations in the European Monetary System, however, have continued to use restrictions to reduce losses of reserves. Marston concludes that "controls were the norm during the Bretton Woods period. They are also a prevalent feature of the European Monetary System." These conclusions have also been reached by Rogoff (1985) and Giavazzi and Giovannini (1986). Clearly, not only current policies but expectations of future trade and financial restrictions are important in this regard. As Edwards (1987) notes, "...expectations regarding political events are fundamentally important, since they reflect possible future changes in the extent of exchange controls, and other important policies."

Although the assumption in equation (52) seems to describe accurately the behavior of governments under pegged exchange rates, it raises the question of why governments choose pegged as opposed to floating exchange rates. This paper does not attempt to answer that question. The explanation

of why a particular exchange-rate system is chosen might be an important component of an explanation of the different behavior of real exchange rates under alternative nominal exchange-rate systems. But there is not a a priori reason to assume that we must answer the question of why the system is chosen before we can analyze the effects of the system, or as a part of that analysis. It might be, for example, that pegged exchange rates are chosen as discipline devices for monetary policy (which subsequent governments attempt, often but not always successfully, to avoid). The different behavior of nominal money and prices under pegged rates might have different redistributive effects, so that a political equilibrium model might be required to explain the choice. But these determinants of the exchange-rate system are not necessarily related in any important way to the behavior of real exchange rates or economic aggregates that result under that system.

Consider the following example, which outlines a simple model of the choice of an exchange-rate system. Assume that the population of the foreign country (which chooses the exchange-rate system) consists of two types of households, called  $p$  and  $f$ . Each type  $j = p, f$  maximizes

$$E_0 \sum_{t=0}^{\infty} \beta^t [U^*(x_t^{d*}) + U^*(y_t^{d*}) - c_t^j] \quad (53)$$

where  $c_t^j$  is a utility cost representing foregone leisure due to certain transactions costs. Consider first households of type  $p$ . These households incur time costs of converting nominal values in one currency into nominal values in terms of the other currency, and these time costs of multiplying or dividing by the exchange rate are particularly high when the exchange rate is floating rather than pegged. For simplicity, assume  $c_t^p = 0$  if the exchange rate is pegged but  $c_t^p > 0$  if the exchange rate is floating. Households of type  $p$ , then, prefer a pegged exchange-rate system to a floating exchange-rate system because of these time costs of currency conversion.

Next, consider households of type  $f$ . Assume that these households bear little time costs from calculations involving the exchange rate, but instead bear time costs from unexpected changes in the price  $q_t$ . That is, these households prefer floating exchange rates to pegged rates because the floating rate system relaxes a constraint on monetary policy and permits it to achieve a preferred path of inflation (which I have assumed above to be zero, for simplicity).

$$c_t^j = \begin{cases} 0 & \text{if } j = p \text{ and the nominal exchange rate is pegged.} \\ \bar{c}_t^f > 0 & \text{if } j = f \text{ and the nominal exchange rate is pegged.} \\ \bar{c}_t^p > 0 & \text{if } j = p \text{ and the nominal exchange rate is floating.} \\ 0 & \text{if } j = f \text{ and the nominal exchange rate is floating.} \end{cases} \quad (5^*)$$

Aside from the  $c_t^j$  term, the utility function in expression (54) is the same as in expression (8) with the function  $v^*$  replaced by  $u^*$ . The reason for this assumption is to make utility homothetic. Then, conditional on the exchange-rate system, the equilibrium is the same as that when households maximize expression (8), except for the level of foreign utility. The homotheticity assumption implies that redistributions of wealth between the two types of households leaves all equilibrium prices unchanged.

The exchange-rate system can be thought of as the outcome of a political process, determined by the relative numbers of households of each type (which may change over time), the magnitudes of  $\bar{c}_t^f$  and  $\bar{c}_t^p$ , and other exogenous variables associated with political skills, and so on. One special case of this would be a political process that minimizes some weighted average of  $\bar{c}_t^f$  and  $\bar{c}_t^p$ , which would correspond to the choice of an exchange-rate system to maximize a social-welfare function.

If the political process results in a pegged exchange-rate system, it will be optimal, under a wide variety of circumstances, for the government to choose a stochastic process for  $g_t^*$  that corresponds to inequality (52). Typically, a fall in the level of international reserves makes a future balance-of-payments crisis more likely, because the excess of reserves, above the minimum level consistent with no crisis, becomes smaller.<sup>8</sup> Generally, there are several policies that governments could vary in order to mitigate a loss in reserves. Two types of policies, tariffs or taxes on acquisitions of foreign currency, were discussed above. In addition, a government might raise spending on domestic goods in order to raise the relative price of those goods. (The relative price of the domestic good would rise as long as the government's marginal propensity to spend on domestic goods exceeds that of households who pay the higher taxes to finance the spending.) As long as all such policies have costs (e.g., if the goods purchased by the government have little utility value to

<sup>8</sup>See, e.g., Krugman (1979), Flood and Garber (1983, 1984), Calvo (1986), and Baxter (1987).

households), an optimal response by the government to a loss in reserves will typically involve changing all such policies somewhat to mitigate the reserve loss.

Let  $\hat{N}_t^S = \hat{N}^S(s_t)$  denote the foreign nominal money under pegged exchange rates, i.e., the money supply required to keep the nominal exchange rates,  $e$ , constant over time. Similarly, let  $\hat{\pi}(s_t)$  denote the real exchange rate under a pegged exchange-rate system, and continue to let  $\pi(s_t)$  denote the real exchange rate under the flexible exchange-rate system. Then, because  $\pi(s_t)/e(s_t)$  is a constant under flexible exchange rates, the foreign nominal money supply required to peg the nominal exchange rates is

$$\hat{N}(s_t) = N(s_t) \hat{\pi}(s_t) \quad (55)$$

multiplied by an arbitrary constant term that I will set to unity. Intuitively, if the nominal exchange rate does not change between periods  $t-1$  and  $t$  under flexible exchange rates, then the same monetary policy is consistent with a pegged exchange rate (assuming the economy is subject to the same shocks). On the other hand, if the monetary policy under flexible exchange rates results in a  $k$  percent rise in  $e$  (and  $\pi$ ) under flexible exchange rates, then a  $k$  percent higher foreign nominal money supply would be required to keep  $e$  constant.

The foreign nominal money supply changes under pegged exchange rates through foreign-exchange market operations with international reserves. Let  $R^*$  denote the value of international reserves held by the foreign government.<sup>9</sup> Then  $R_t^* = R^*(s_t)$  and

$$\frac{\partial R_t^*}{\partial \theta_t} = \frac{\partial \hat{N}_t^S}{\partial \theta_t} = N_t^S \frac{\partial \hat{\pi}_t}{\partial \theta_t} > 0 \quad (56)$$

so a rise in  $\theta_t$  leads to an increase in the foreign government's international reserves.

Now consider the effect of a change in domestic productivity on the real exchange rate under the pegged nominal exchange-rate system. Let

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<sup>9</sup>The model can be generalized easily to include nonzero transfer payments of newly-issued foreign money under pegged exchange rates.

$$\hat{\rho}(a_{t-j}) = \frac{\hat{\partial} \Pi(\bar{s}_t)}{\partial a_{t-j}} \quad (57)$$

Then

$$\begin{aligned} \hat{\rho}(\theta_t) &= \left[ \frac{-v_1 u_{11}}{(1+g)(u_1)^2} \right] \frac{\partial x_t^d}{\partial \theta_t} \\ &= \left[ \frac{-v_1 u_{11}}{(1+g)(u_1)^2} \right] \left[ \frac{\partial x_t^d}{\partial \theta_t} + \frac{\partial x_t^d}{\partial R_t^*} \frac{\partial R_t^*}{\partial \theta_t} \right] \quad (58) \end{aligned}$$

$$\begin{aligned} &= \left[ \frac{-v_1 u_{11}}{(1+g)(u_1)^2} \right] \left[ x_\theta^d + \hat{\rho}(\theta_t) N_t^S \frac{\frac{\partial E[u_1(x_{t+2}^d) \theta_{t+1}]}{\partial R_t^*}}{\frac{u_{11}}{\phi_1} + \frac{u_1 \phi_{11}}{\phi_1^2} \left[ \frac{u_{11}(1+g)\lambda^*}{u_{11}\lambda^*} + 1 \right]} \right] \\ &= \frac{\left[ \frac{-v_1 u_{11}}{(1+g)u_1^2} \right] x_\theta^d}{1 - \left[ \frac{-v_1 u_{11}}{(1+g)u_1^2} \right]} \frac{\frac{\partial E[u_1(x_{t+2}^d) \theta_{t+1}]}{\partial R_t^*}}{\frac{u_{11}}{\phi_1} + \frac{u_1 \phi_{11}}{\phi_1^2} \left[ \frac{u_{11}(1+g)\lambda^*}{u_{11}\lambda^*} + 1 \right]} \end{aligned}$$

which shows that

$$\rho(\theta_t) > \hat{\rho}(\theta_t) > 0. \quad (59)$$

A fall in  $\theta_t$  lowers foreign reserves  $R^*$ . Foreign reserves decrease because the fall in  $\Pi_t$  must now occur entirely through a fall in  $q_t$  (because  $p_t$  and  $e_t$  are fixed by assumption). The fall in  $q_t$  requires a fall in the foreign nominal money supply to keep the exchange rate pegged, which results in a loss of foreign international reserves as the foreign central bank conducts open-market sales of those reserves to peg the exchange rate. The loss of foreign reserves, by equation (52), raises the probability that future tariffs and exchange and capital controls of any given magnitude will be imposed by the foreign country at each future date. Consequently,  $E_t\{u_1(x_{t+2}^d) \theta_{t+1}\}$  falls and equations (28), (34), and (37) imply that  $\phi_1(k_{t+1})$  rises, i.e.  $k_{t+1}$  falls. The fall in  $k_{t+1}$  raises  $x_t^d$  and  $x_t^{d*}$ , with no effect on  $y_t^d$  or  $y_t^{d*}$ , and equation (40) implies that this tends to raise

$\pi_t$ . This positive effect on the relative price of the foreign good partly offsets the direct negative effect of the fall in the current supply, leading to a smaller decrease in  $\pi_t$  for a given fall in  $\theta_t$ .

Similarly, one can show that

$$\rho(g_t^*) > \hat{\rho}(g_t^*) > 0. \quad (60)$$

From these differences in the responses of the real exchange rate to exogenous disturbances, it is straightforward to show, using the formula (44), that

$$\sigma_{\Pi}^2 > \hat{\sigma}_{\Pi}^2 \quad (61)$$

where  $\hat{\sigma}_{\Pi}^2$  denotes the variance of  $\hat{\Pi}$ , i.e., the variance of the real exchange rate under the pegged nominal exchange-rate system.

## CONCLUSIONS

An equilibrium model of exchange rates has been developed to explain the observation that real exchange rates vary less under pegged than under floating nominal exchange-rate systems. The explanation is intended to be robust to the specific assumptions made in the presentation of the formal model. Aside from explanations that rely on sluggish nominal price adjustment, no (or few) alternative explanations have been proposed.

There are several problems with the sluggish price explanation of the difference in real exchange-rate variability across nominal exchange-rate systems. The main problem is that, however important sluggish nominal price behavior might be for explaining business cycles, the timing and the observed dynamics in real exchange rates appear inconsistent with most reasonable stories of sluggish price adjustment. Studies of the real exchange rate show that it is very close to a random walk, though there is weak evidence of mean-reversion (see, e.g., Huizinga, 1987).<sup>10</sup>

I want to make four distinct arguments. First, the length of time before the real exchange rate returns part way toward a mean is too long,

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<sup>10</sup>Also see, e.g., Roll (1979), Adler and Lehmann (1983), Meese and Rogoff (1983a,b), (1985), and Mark (1986).



on a priori grounds, for plausible nominal price rigidity. (Huizinga finds evidence of a mean-reversion only after 3-6 years in the recent floating-rate period, and in longer data samples mean-reversion is slower still.) It is difficult to see how menu costs or other rationale for sluggish nominal prices could make them adjust so slowly.

Second, if nominal disturbances in the presence of nominal price rigidities accounted for most of the variation in real exchange rates under flexible-rate systems, the exchange rate would eventually return to roughly its original starting point. If the nominal disturbance had no permanent real effects, the real exchange rate would return exactly to its original position. But temporary real effects of nominal shocks might have permanent effects on the distribution of wealth, etc., so that there could be permanent effects on the level of the real exchange rate. Nevertheless, one would expect the return to be closer than suggested in the evidence.<sup>11</sup>

Third, the length of the average business cycle provides a guide as to the duration of nominal price sluggishness (on the assumption that business cycles involve this sluggishness). The typical length of a recession is an overestimate of the length of time that it takes nominal prices to adjust most of the way back to equilibrium following a disturbance. It is an overestimate because there are many reasons (associated with adjustment costs in labor markets, inventories, etc.) why changes in output and employment tend to persist, once started, even if the original disturbance to the economy has vanished. Observations on the lengths of typical business cycles suggest that, if nominal price rigidities were also responsible for most variations in real exchange rates, we would see real exchange rates return most of the way toward their means, following a shock, after a period of no more than about two years.

Of course, the assertion that real exchange-rate variability is not (mainly) explained by nominal price rigidities does not imply that those rigidities do not play major roles in business cycles. As long as business cycles are highly correlated across countries -- as they are -- and nominal prices adjust toward their equilibrium values with roughly the same speed in different countries, short-run price rigidities that are common across countries may play major roles in business cycles without playing any major role in fluctuations of real or nominal exchange rates.

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<sup>11</sup>See Huizinga (1987).

Finally, models that rely on sluggish nominal price adjustment to explain the behavior of real exchange rates imply that changes in real exchange rates are related to international differences in real interest rates. Campbell and Clarida (1987) showed that, under some reasonable assumptions, the real exchange rate can be written as the sum of three terms: an undiscounted sum of expected future real interest rate differentials, an undiscounted sum of expected future risk premia, and the long run real exchange rate. Campbell and Clarida estimated a state-space model that treated the expected real interest differential and the long-run real exchange rate as unobserved variables. Their results showed that (for the US-Canadian, US-UK, US-German, US-Japanese, and US-trade weighted real exchange rates from 1979 to 1986) only a small fraction of the variance of innovations to the real exchange rate can be attributed to expected real interest differentials. In contrast, most of the variance in real exchange rates can be attributed to changes in the long-run real exchange rate. These results are consistent with a model of the kind proposed in this paper, and inconsistent with models that attribute most of the movements in real exchange rates to nominal price sluggishness.

There are other explanations of the difference in real exchange-rate variability across regimes that do not (necessarily) involve sluggish nominal price adjustments; some of these were discussed in Stockman (1983). Some arguments base the difference in real equilibria under alternative nominal exchange-rate systems on incomplete markets. Recent work with these implications includes Hsieh (1984), Greenwood and Williamson (1987), and Persson and Svensson (1987). In the absence of complete markets, the state-contingent pattern of monetary policy can affect the real equilibrium.

Similarly, in models in which money is not superneutral, the difference of inflation paths across alternative exchange-rate systems can affect the real equilibrium (as in Greenwood and Williamson (1987), or Aschauer and Greenwood, 1983).<sup>12</sup> The real equilibrium can also differ across alternative exchange-rate systems in the absence of Ricardian

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<sup>12</sup>However, real effects of expected inflation seem to have been too small to estimate empirically in most cases.

equivalence, as in Helpman and Razin (1987).<sup>13</sup>

While these models correctly analyze channels through which the nominal exchange-rate system can affect characteristics of equilibria, no model along these lines has been developed to try to explain the systematically higher variance of real exchange rates under flexible exchange-rate systems. Explanations could probably be constructed based on any of these models, but it appears likely that the explanations would be sensitive to special properties of the model or parameter values. For example, the absence of markets for certain types of contingencies can clearly affect real equilibrium allocations, but the effects on the variance of relative price changes would seem to depend on the sources of disturbances, the state-contingent path of monetary policy, and so on. It seems unlikely that arguments like these could account for the wide range of evidence on real exchange-rate variability. The explanation presented in this paper, in contrast, does not rely on any specific parameter values but on a general property of government behavior under pegged exchange-rate systems, namely, the propensity to implement policies that help prevent reserve losses, and the greater propensity to implement these policies when their benefits -- in terms of preventing a run on the currency -- are greater.

The model in this paper assumes that tariffs and taxes on acquisitions of foreign currency are imposed independently, under flexible exchange rates, of the other exogenous disturbances that affect the exchange rate. On the other hand, equation (52) implies that these policies are correlated with exogenous disturbances under pegged exchange rates. It is easy to generalize the model to allow  $g$  and  $g^*$  to be correlated with  $\theta$  and  $\theta^*$  under flexible exchange rates. Formally, this results in additional terms in equation (44). But the conclusions of this paper are still obtained as long as higher  $g$  (higher tariffs, and so on) tends to accompany domestic currency appreciation. This is the likely pattern of covariance under flexible exchange rates: countries with real and nominal appreciation

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<sup>13</sup>Other explanations based on the absence of Ricardian equivalence face the problems that most reserves are held in interest-bearing form, and, in any case, are a small fraction of private wealth. Also, life-cycle models of non-Ricardian equivalence generate results that are quite close to Ricardian models when reasonable parameter values are used, as Poterba and Summers (1987), have shown. Finally, the results of Backus and Kehoe (1987) could be applied to show that absence of Ricardian equivalence is not sufficient for differences in real equilibria across alternative exchange-rate systems.

experience complaints from businesses about losses in international "competitiveness," and this raises the probability of tariffs and similar measures. But, as long as the imposition of a tariff raises the world terms of trade, an increase in the probability of a tariff exacerbates the real appreciation, and raises the variability of real exchange rates in the flexible-rate system. As a result, the model continues to predict lower variability of the real exchange rate under the pegged rate system.

It is straightforward to apply the results of this paper to a mixed exchange-rate system such as the EMS. To the extent that governments intervene in exchange markets and experience changes in the level of international reserves, such systems resemble pegged exchange rates and should be associated with less variability in relative prices. Realignments of exchange-rate bands alter the expected path of future losses in reserves and, by so altering the probability of future restrictive government policies, these realignments should be accompanied by changes in real exchange rates.

The model discussed here has a number of subsidiary implications. For example, the model implies that a disturbance to productivity has a larger effect on investment under pegged exchange rates than under flexible rates. While this implication is testable, it relies on the particular way that intertemporal substitution was built into the model. The model was developed with stationary productivity shocks and government policies. As a result, it implies that the real exchange rate is stationary. There is evidence that the real exchange rate is nonstationary, and it is not difficult to modify the assumptions about the probability laws for  $\theta$  and  $\theta^*$  to produce a nonstationary real exchange rate.

The model in this paper has welfare implications that have yet to be developed fully. Even if the average level of restrictions on international trade and financial flows is the same under both exchange rate systems, as assumed in this paper, it is likely that the flexible exchange rate system is superior to the pegged rate system on welfare grounds. Under floating rates, the pattern of tariffs or taxes on acquisitions of foreign currency could be chosen to follow an optimal pattern over time (even if the average level is constrained, e.g. by a government revenue constraint). On the other hand, under pegged exchange rates the additional government concern with avoiding losses of international reserves operates as an additional constraint; it changes the time path of these taxes and may reduce expected utility. (In a more general model, it might also raise the level of restrictions under pegged rates.) A formal case for flexible exchange rates

similar to the one proposed by Friedman (1951) might be developed along these lines.<sup>14</sup>

The model assumes that, under flexible exchange rates, the governments follow monetary policies that resulted in constant  $p$  and  $q$ . This assumption can be relaxed, without any major changes in the model's implications, at the cost of introducing additional complications associated with the nonsuperneutrality of money. Similarly, investment in the foreign country could be introduced in the model, but the different behavior of foreign inflation under pegged and floating exchange-rate systems would add terms associated with the nonsuperneutrality of money. As long as those effects are relatively small in magnitude, all of the implications discussed above would continue to be obtained. Disturbances to productivity could be replaced by disturbances to tastes in the model with little effect on its implications.

It would be useful to extend the analysis in this paper to incorporate a better model of the choice of an exchange-rate system. It would also be useful to examine a broader range of government policies that might be followed in response to a loss in reserves under pegged exchange rates. Perhaps policy responses other than those discussed in this paper would reinforce the conclusions reached here. These policies could include changes in government spending, taxes, or monetary policy (with real effects). Similarly, additional implications could be obtained by adding nontraded goods to the model, to determine how the relative price of nontraded goods should behave -- under the assumptions above -- under alternative exchange-rate systems. Drazen and Helpman (1987, 1988) examine related issues. Further work needs to be done to develop these other implications of the model and to test them empirically.<sup>15</sup>

One interesting implication of the model (with auxiliary assumptions) is that the probability distribution of small real exchange-rate changes

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<sup>14</sup>I am indebted to Neil Wallace for this suggestion.

<sup>15</sup>There have been few attempts to categorize systematically the differences in the behavior of main economic aggregates under alternative exchange-rate systems. Baxter and Stockman (1988) have found little in the way of systematic differences. However, their results do not necessarily falsify the predictions of this model regarding variables other than the real exchange rate, such as investment. Indeed, it seems difficult to reconcile their results with models based on sluggish nominal price adjustment, since most of those models imply substantial differences in the behavior of aggregates across alternative exchange-rate systems.

may be nearly the same under the two exchange-rate systems. Small disturbances may be associated with only second-order effects on expectations of future policy changes, so that the resulting changes in real exchange rates would be independent of the system. Large disturbances, in contrast, would have sizable effects on expectations of future policies to stem reserve losses and so would have smaller effects on the real exchange rate under the pegged exchange-rate system.

Direct empirical tests of the model would require the construction of time-series of aggregate measures of barriers to international trade and payments. A time-series is required because the model's key implications follow from the different covariances between these barriers and other exogenous disturbances under alternative exchange-rate systems. While some of the additional variability of real exchange rates under the flexible-rate system may be attributable to nominal price sluggishness, it is difficult to view that as the major part of the explanation for the reasons I have outlined. This paper has suggested another explanation that seems consistent with the actual behavior of governments when faced with reserve losses and seems robust to many variations in parameter values and sources of disturbances.

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