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Monetary and Fiscal Policy under Floating Exchange Rates : A Two-Country Simulation Analysis

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Abstract

This paper develops a two-country model with sticky nominal wages and prices to examine the effects of monetary and fiscal policy in a variable output floating exchange rate framework. The model is an extension of the single country framework developed by Dornbusch [5] in the appendix to his seminal paper on exchange rate dynamics. Such a model permits one to derive short-run policy impacts in the context of the asset market approach to exchange rate determination.[1]

The major conclusions of this paper are that monetary expansion in the home country causes the home currency to depreciate, output at home to expand, and output abroad to move in an uncertain direction. Also, the current account may either improve or deteriorate. Moreover, in most cases fiscal expansion in the home country causes the home currency to appreciate, output at home and abroad to expand, and the current account to deteriorate.

I. The Model

The model describes two countries under flexible exchange rates, perfect asset

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1. Other recent two-country models include Buiter [3] and Turnovsky [16], who develop a symmetric extension of Dornbusch's model ; and Frenkel and Razin [9] and Masson and Knight [11], who develop full employment models of fiscal transmission. For a discussion of possible transmission effects involving terms of trade and wage considerations outside the scope of the present framework, see Corden [4, pp. 147-65]. See also Argy and Salop [1] and Branson and Rotemberg [2], who develop two-country models of nominal and real wage rigidity with a different price determination mechanism from the one used in this paper ; and Obstfeld [14, pp. 387-400] for a two-country model in which nominal wages are adjusted to expected output prices.

substitutability, and variable national outputs. The following equations constitute the model :

(1) $r_1 = r_2 + \dot{e}$

(2) $q_1 - p_1 = -\beta_1 r_1 + \phi_1 y_1$

(3) $\dot{p}_1 = \pi_1(y_1 - \overline{y}_1)$

(4) $\mu_1 + \delta(e + p_2 - p_1) + (\gamma_1 - 1)y_1 - \sigma_1 r_1 + m_2 y_2 = 0$

(5) $q_2 - p_2 = -\beta_2 r_2 + \phi_2 y_2$

(6) $\dot{p}_2 = \pi_2(y_2 - \overline{y}_2)$

(7) $\mu_2 - \delta(e + p_2 - p_1) + (\gamma_2 - 1)y_2 - \sigma_2 r_2 + m_1 y_1 = 0$

Equation (1) describes perfect asset substitutability between domestic and foreign securities. r_1 and r_2 are the two countries' interest rates, and $\dot{e}$ is the rate of change of the foreign exchange rate. Assuming rational expectations and no stochastic disturbances, this corresponds with the expected rate of change of the foreign exchange rate. Equations (2) and (5) are the money market conditions in the two countries, where the demand for the real money stocks is a conventional transactions demand. Here q_1 and q_2 are the logs of the nominal money stocks, p_1 and p_2 the logs of the price levels of the two countries outputs, and y_1 and y_2 the logs of the outputs of each country. Equations (3) and (6) are simple Phillips Curves describing the rate of inflation in each country. $\overline{y}_1$ and $\overline{y}_2$ are the natural levels of output. Finally, equations (4) and (7) are the goods market equilibrium conditions, where demand for each country's output depends on that country's income, interest rates, relative prices with respect to the other country's goods, and the other country's income. μ is a parameter that will be used to reflect government spending on domestic output. The endogenous variables of the model are the levels of output, y_1 and y_2, the two interest rates, r_1 and r_2, the two price levels, p_1 and p_2, and the log of the foreign exchange rate, e. However, because of sticky wages the price levels are constant in the short-run, although the rate of inflation can still be altered.

Now consider the following exchange rate expectations scheme :

(8) $\dot{e} = \theta_1(\overline{e} - e) + \theta_2(\overline{p}_1 - p_1)$

where the bars represent long-run equilibrium levels. It is shown in the Appendix that this is the scheme consistent with perfect foresight. Equations (1)−(8) then constitute a simultaneous differential equation system, which, if stable, describes a saddle point path to a long-run equilibrium steady state.[2] The values of θ_1 and θ_2 are obtained from the characteristic equation of this system by using the two stable characteristic roots of system (1)−(7) one at a time. The result is a system of two equations in θ_1 and θ_2 which can be solved simultaneously. We concentrate in the following sections on monetary and fiscal policy actions that shift the system to a new saddle-point path and discuss the impact on the system at the new initial point.

Ⅱ. Effects of Monetary Policy

When symmetry is not imposed on the two countries' economic structures(see footnote 1), analytical solutions cannot be obtained from the model, and it is necessary to resort to numerical simulation. The strategy employed was to impose low and high values for each of the 13 parameters in the model. Hence, 2^{13} (=8192) simulations were undertaken for a given simulation run. A Fortran program of the model was constructed, and the simulations were performed using a WATFOR-77 compiler. The first set of values chosen for the parameters is shown in *Table 1*. A wide range was permitted for each parameter in order to include all plausible values. (Relevant empirical studies are listed at the end of the paper.) Note that β_1, β_2, σ_1 and σ_2 are semi-interest elasticities. Therefore, to obtain the implied interest ela-

Table 1

Parameter Values When Interest Rates are 10%

$\beta_1 = 1.0,\ 5.0$	$\sigma_1 = 1.0,\ 5.0$
$\beta_2 = 0.9,\ 4.9$	$\sigma_2 = 1.1,\ 5.1$
$\phi_1 = 0.50,\ 1.00$	$m_1 = 0.05,\ 0.25$
$\phi_2 = 0.51,\ 1.01$	$m_2 = 0.05,\ 0.25$
$\delta = 0.2,\ 2.0$	$\pi_1 = 0.10,\ 1.0$
$\gamma_1 = 0.5,\ 0.7$	$\pi_2 = 0.11,\ 1.01$
$\gamma_1 = 0.5,\ 0.7$	

2. System (1)-(7) has three characteristic roots, one of which is positive because of the rational expectations assumption. The other two have negative real parts and indicate a stable saddle point path.

sticities, divide the values by 10. The ranges for these parameters appear quite reasonable in view of empirical studies on these interest elasticities. The same is true of ϕ_1 and ϕ_2. In addition, δ measures the sum of the demand elasticities for imports and exports minus 1, and the range for δ includes most empirical estimates. Next, γ_1 and γ_2 were chosen to yield open economy multipliers of between 2.00 and 3.33, a reasonable range for large countries. Similarly, the range for m_1 and m_2 is reasonable for large countries. Finally, π_1 and π_2 represent the slopes of the Phillips curves. Thus, a 1% increase in the output gap is estimated to increase inflation by 0.1−1.0% in country 1 and 0.11−1.01% in country 2. While all of these parameter values may seem sensible, two additional checks were performed. First, interest rates were given the alternative value of 5%, which doubled the values of β_1, β_2, σ_1, and σ_2. Second, the range for each parameter was widened by halving the low value and doubling the high value. In both cases, the simulation results were in line with those obtained from *Table 1.*

Now consider monetary expansion in country 1. From equations (2), (4), (5), and (7) we obtain

$$(9)\ \delta de + (\gamma_1 - 1)dy_1 - \sigma_1 dr_1 + m_2 dy_2 = 0$$

$$(10)\ dq_1 + \beta_1 dr_1 - \phi_1 dy_1 = 0$$

$$(11)\ -\delta de + (\gamma_2 - 1)dy_2 - \sigma_2 dr_2 + m_1 dy_1 = 0$$

$$(12)\ \beta_2 dr_2 - \phi_2 dy_2 = 0$$

From (9)−(12) one then obtains

$$(13)\ dy_1 = \frac{-(\sigma_1\beta_1)(\gamma_2 - 1 - \sigma_2\phi_2/\beta_2)dq_1}{Z} - \frac{\delta(\gamma_2 + m_2 - 1 - \sigma_2\phi_2/\beta_2)de}{Z}$$

and

$$(14)\ dy_2 = \frac{(\sigma_1 m_1/\beta_1)dq_1}{Z} + \frac{[\delta(\gamma_1 + m_1 - 1 - \sigma_1\phi_1/\beta_1)]de}{Z}$$

where

$$Z = (\gamma_1 - 1 - \sigma_1\phi_1/\beta_1)(\gamma_2 - 1 - \sigma_2\phi_2/\beta_2) - m_1 m_2.$$

Equation (13) shows that output in country 1 is affected directly by the monetary expansion and secondly by the exchange rate change resulting from the monetary expansion. In country 2 output is affected by the usual trade linkage mechanism and by the exchange rate change. Therefore, it is necessary to derive the exchange rate movement accompanying the monetary expansion. To do so, substitute dy_1 from (13) into (10) to obtain

$$(15)\ dr_1 = [-\frac{1}{\beta_1} - \frac{(\phi_1\sigma_1/\beta_1^2)(\gamma_2-1-\sigma_2\phi_2/\beta_2)}{Z}]dq_1 - \frac{(\phi_1\delta/\beta_1)(\gamma_2+m_2-1-\sigma_2\phi_2/\beta_2)de}{Z}$$

which shows that monetary expansion at a given exchange rate lowers interest rates in country 1, and depreciation raises them by expanding output. Next, substitute dy_2 from (14) into (12) to obtain

$$(16)\ dr_2 = \frac{(\phi_2 m_1\sigma_1/\beta_1\beta_2)dq_1}{Z} + \frac{(\phi_2\delta/\beta_2)(\gamma_1+m_1-1-\sigma_1\phi_1/\beta_1)\ de}{Z}$$

which shows that monetary expansion in country 1 raises interest rates in country 2 because of the trade linkage effect on country 2's income ; and depreciation of country l's currency lowers interest rates in country 2 by contracting output there.

Now from (1), monetary expanison in country 1 initially causes $\dot{e}$ to equal $dr_1 - dr_2$. Then from (15) and (16)

$$(17)\ \dot{e} = vdq_1 + wde$$

where

$$v = -(1/\beta_1) - \frac{(\phi_1\sigma_1/\beta_1^2)(\gamma_2-1-\sigma_2\phi_2/\beta_2)}{Z} - \frac{(m_1\phi_2\sigma_1/\beta_1\beta_2)}{Z}$$

and

$$w = -\frac{\phi_1}{\beta_1}\frac{\delta(\gamma_2+m_2-1-\sigma_2\phi_2/\beta_2)}{Z} - \frac{\phi_2}{\beta_2}\frac{[\delta(\gamma_1+m_1-1-\sigma_1\phi_1/\beta_1)]}{Z}.$$

Then substituting $\dot{e}$ from (17) into the expectations scheme (8) yields

$$(18)\ \theta_1(\overline{e}-e) + \theta_2(\overline{p}_1-p_1) = vdq_1 + wde.$$

Now initially $\overline{e}-e$ is given by $d\overline{e}-de$, or dq_1-de by virtue of the long-run neutrality of the sytem ; $d\overline{p}_1$ equals dq_1 because of neutrality ; and dp_1 initially equals zero because of sticky wages and prices. Then (18) yields

$$(19)\ \frac{de}{dq_1} = (\theta_1+\theta_2-v)/(\theta_1+w).$$

Equations (13), (14), and (19) along with information on θ_1, θ_2, v, and w then yield the desired results below about the effects of monetary expansion.

Given the parameter values in *Table 1*, one obtains the following results, summarized in *Table 2*. First note that the model was dynamically stable in every trial since two roots of the system's characteristic equation always had negative real parts.[3] Next, monetary expansion always causes the domestic currency to depreciate, as expected. Also, the effect on domestic output is always expansionary. On the other hand, output declines overseas in a majority, but not all, cases because the contractionary effect of the appreciation there swamps the positive trade linkage effect. This result is reminiscent of Mundell's well-known finding [12, p. 269] that monetary expansion at home is contractionary abroad. However, Mundell's result is based on a steady-state rigid wage-price model, as opposed to the framework used here. Moreover, the effect on output overseas is in general uncertain in the present model.[4]

Table 2

Effects of Monetary Expansion in Country 1

TRIALS = 8192	$(dy_2/dq_1 < 0) = 6976$
STABLE =8192	$(dy_1/dq_1+dy_2/dq_1 < 0) = 531$
$(de/dq_1 > 0) = 8192$	$(dr_1/dq_1 < 0) = 4696$
$(dy_1/dq_1 > 0) = 8192$	$(dCA/dq_1 > 0) = 6976$

A few more results should be noted. First, in about 6% of the cases, the contraction in output in country 2 is sufficiently strong to cause world output to decline. This happens when the multiplier is sufficiently large overseas that the currency appreciation there produces a contraction that exceeds the expansion in country 1. Second, in about 40% of the cases country 1's interest rate rises in response to monetary expansion because the increase in country 1's income is sufficiently large due to the currency depreciation to outweigh the *liquidity effect* on interest rates.[5]. Finally, country 1's current account improves in a majority of the cases, a

3. See footnote 2.
4. This conclusion is consistent with some simulation evidence on individual cross-country effects. See Edison, *et. al.*, [6, pp. 61-64] ; and Helliwell and Padmore [10, pp. 1131-32]. Also see Frankel [8, pp. 23-25].
5. This possibility was first pointed out by Dornbusch [5, p.1172].

number in fact which must corresponed to the count for dy_2/dq_1.[6,7]

Ⅲ. Effects of Fiscal Policy

Fiscal expansion in country 1 is represented in the model by an increase in the parameter μ_1. From equations (2), (4), (5) and (7) we obtain

(22) $d\mu_1 + \delta de + (\gamma_1 - 1)dy_1 - \sigma_1 dr_1 + m_2 dy_2 = 0$

(23) $\beta_1 dr_1 = \phi_1 dy_1$

(24) $-\delta de + (\gamma_2 - 1)dy_2 - \sigma_2 dr_2 + m_1 dy_1 = 0$

(25) $\beta_2 dr_2 = \phi_2 dy_2$

From (22)-(25) one then obtains

$$(26)\ dy_1 = \frac{-(\gamma_2 - 1 - \sigma_2\phi_2/\beta_2)d\mu_1}{Z} - \frac{\delta(\gamma_2 + m_2 - 1 - \sigma_2\phi_2/\beta_2)de}{Z}$$

$$(27)\ dy_2 = \frac{m_1 d\mu_1}{Z} + \frac{\delta(\gamma_1 + m_1 - 1 - \sigma_1\phi_1/\beta_1)de}{Z}$$

Equation (26) shows that output in country 1 is affected directly by the fiscal expansion and secondly by the exchange rate movement resulting from the fiscal expansion. In country 2 output is again affected by the usual trade linkage mechanism and by the exchange rate movement.

In order to derive the exchange rate movement resulting from fiscal expansion, substitute dy_1 from (26) into (23) to obtain

$$(28)\ dr_1 = -\frac{\phi_1}{\beta_1}\frac{(\gamma_2 - 1 - \sigma_2\phi_2\beta_2)}{Z}d\mu_1 - \frac{(\phi_1\delta/\beta_1)(\gamma_2 + m_2 - 1 - \sigma_2\phi_2/\beta_2)de}{Z}$$

which shows that fiscal expansion raises interest rates in country 1, and depreciation of the home currency raises them by expanding output. Next, substitute dy_2 from (27) into (25) to obtain

$$(29)\ dr_2 = (\phi_2 m_1/\beta_2)d\mu_1 + \frac{(\phi_2\delta/\beta_2)(\gamma_1 + m_1 - 1 - \sigma_1\phi_1/\beta_1)de}{Z}.$$

6. The current account surplus is obtained by calculating

$$\delta\frac{de}{dq_1} + m_2\frac{dy_2}{dq_1} - m_1\frac{dy_1}{dq_1}$$

7. In constrast, the current account always improves in the Fleming-Mundell model [7, 12] because capital outflows are triggered by lower interest rates, and the exchange rate must depreciate to generate an offsetting current account surplus.

which shows that fiscal expansion in country 1 raises interest rates in country 2 because of the trade linkage effect on country 2's income ; and depreciation of country 1's currency lowers interest rates in country 2 by lowering output there. Since $\dot{e}$ initially equals $dr_1 - dr_2$ from (1), then from (28) and (29)

$$(30)\ \dot{e} = v^* d\mu_1 + w^* de$$

where

$$v^* = -\frac{(\phi_1/\beta_1)(\gamma_2 - 1 - \sigma_2\phi_2/\beta_2)}{Z} - \frac{(\phi_2 m_1/\beta_2)}{Z}$$

and

$$w^* = -\frac{\phi_1}{\beta_1}\frac{\delta(\gamma_2 + m_2 - 1 - \sigma_2\phi_2/\beta_2)}{Z} - \frac{\phi_2}{\beta_2}\frac{[\delta(\gamma_1 + m_1 - 1 - \sigma_1\phi_1/\beta_1)]}{Z}$$

Then substituting $\dot{e}$ from (30) into the expectations scheme (8) yields

$$(31)\ \theta_1(\bar{e} - e) + \theta_2(\bar{p}_1 - p_1) = v^* d\mu_1 + w^* de$$

Since initially $\bar{e} - e$ is given by $d\bar{e} - de$ and $\bar{p}_1 - p_1$ is given by $d\bar{p}_1$, (31) yields

$$(32)\ \frac{de}{d\mu_1} = \left(\frac{\theta_1}{\theta_1 + w^*}\right)\frac{d\bar{e}}{d\mu_1} + \left(\frac{\theta_2}{\theta_1 + w^*}\right)\frac{d\bar{p}_1}{d\mu_1} - \frac{v^*}{\theta_1 + w^*}$$

According to (32), it is necessary to derive the long-run effect on e and p_1 to determine $\frac{de}{d\mu_1}$. Therefore, consider the following long-run equilibrium of the model from equations (2), (4), (5), and (7) :

$$(33)\ \beta_1 r - p_1 = \phi_1\bar{y}_1 - q_1$$

$$(34)\ -\sigma_1 r - \delta p_1 + \delta p_2 + \delta e = -\mu_1 - (\gamma_1 - 1)\bar{y}_1 - m_2\bar{y}_2$$

$$(35)\ \beta_2 r - p_2 = \phi_2\bar{y}_2 - q_2$$

$$(36)\ -\sigma_2 r + \delta p_1 - \delta p_2 - \delta e = -\mu_2 - (\gamma_2 - 1)\bar{y}_2 - m_1\bar{y}_1$$

where in the long run $r_1 = r_2 = r$, and incomes are at their natural levels, $\bar{y}_1$ and $\bar{y}_2$. Solving these equations yields

$$(37)\ d\bar{r} = \frac{1}{\sigma_1 + \sigma_2} d\mu_1$$

$$(38)\ d\bar{p}_1 = \frac{\beta_1}{\sigma_1 + \sigma_2} d\mu_1$$

$$(39)\ d\bar{p}_2 = \frac{\beta_2}{\sigma_1\,\sigma_2} d\mu_1$$

and

$$(40)\ d\overline{e} = \frac{\delta(\beta_1-\beta_2)-\sigma_2}{\delta(\sigma_1+\sigma_2)}\,d\mu_1.$$

Equation (37) shows that fiscal expansion in country 1 raises the world interest rate in the long run. This is the mechanism that crowds out investment spending and helps restore incomes to their natural level. Equations (38) and (39) indicate that the long-run price levels will rise, since higher prices are necessary to generate higher interest rates by contracting real money supplies. Equation (40) shows that fiscal expansion in country 1 has an uncertain effect on the long-run equilibrum exchange rate. If the semi-interest elasticities of money demand were identical in the two countries or lower in country 1, the domestic currency would appreciate in the long run in reaction to fiscal expansion in country 1, just as it does in the Fleming-Mundell model and the Dornbusch model. But if the semi-interest elasticity of money demand were sufficiently high in country 1, fiscal expansion in country 1 would cause the long-run price level to rise there sufficiently that the home currency would have to depreciate to restore equilibrium in the two countries' goods markets. Finally, it is of interest to calculate the effect of fiscal expansion in country 1 on the terms of trade. Using (38)−(40) we get

$$(41)\ \frac{d(\overline{p}_1-\overline{p}_2-\overline{e})}{d\mu_1} = \frac{\sigma_2}{\delta(\sigma_1+\sigma_2)},$$

which shows that country 1's terms of trade improve. The reason is that higher interest rates in country 2 require country 2's terms of trade to deteriorate to restore output at its natural level.

Equations (26), (27), (32), (38), and (40) along with information on θ_1, θ_2, v^*, and w^* now yield the desired results about the effects of fiscal expansion. Using the parameter values in *Table 1*, one obtains the following results shown in *Table 3*.

Table 3

Effects of Fiscal Expansion in Country 1

TRIALS = 8192	$(dy_2/du_1 > 0) = 7721$
STABLE =8192	$(dy_1/du_1+dy_2/du_1 > 0) = 8192$
$(de/dq_1 < 0) = 7360$	$(dCA/du_1 < 0) = 7721$
$(dy_1/du_1 > 0) = 7724$	

Observe first that the domestic currency appreciates in most, although not all, cases. The possibility of *depreciation* of the domestic currency arises when, as shown above, fiscal expansion causes the long-run equilibrium exchange rate on the domestic currency to depreciate. One would then expect the domestic currency to depreciate immediately to maintain asset market equilibruim. Recall from equation (40), however, that this will happen only when the semi-interest elasticity of the demand for money in country 1 in sufficiently greater than in country 2.

In most cases the effect on domestic output is expansionary. But this does not always happen. The reason is that in some cases the appreciation of the domestic currency is sufficiently strong to cause domestic output to actually decline! However, this unusual event clearly would not occur if trade flows responded to the exchange rate with a lag. In that case, the fiscal expansion would have the only direct immediate effect on aggregate demand, and domestic output would expand.

Similarly, the effect on foreign output in most cases is also expansionary. If the domestic currency appreciates, this will have an expansionary impact overseas which will be supplemented with a positive trade linkage effect coming from the domestic country. However, if the domestic currency depreciates, this will have a contractionary effect overseas, which dominates the trade linkage effect in 471 of 832 cases.

Finally, notice that world output always expands, a sensible result given that output normally expands in both countries. Also, country 1's current account deteriorates in most cases, necessarily matching the number of cases in which country 2's output expands.

Ⅳ. Summary

The model developed in this paper is a two-country extension of the variable output model constructed by Dornbusch for the case of floating exchange rates and perfect asset substitutability. The two-country version permits one to analyze the short-run effects of monetary and fiscal policy on the home country and the outside world. Numerical simulations of the model produce the following results. Monetary expansion in the home country causes the home currency to depreciate to help restore asset market equilibrium, as in Dornbusch's model. Economic activity expands in the home country because of the internal effect of monetary expansion and because of the depreciation of the currency. However, in country 2 economic activity may either rise or fall because the trade linkage effect operating there is accompanied by the contractionary effect of the foreign currency appreciation. Finally, the current account may either improve or deteriorate because the direct effect of the depreciation on the trade balance occurs along with increased imports by the home country due to income expansion.

Fiscal expansion in the home country may cause the home currency to either appreciate or depreciate, depending on the size of the semi-interest elasticity of money demand in the country.[8] Domestic output expands in most cases because of the internal effect of fiscal expansion ; although if the domestic currency appreciates, there will be a crowding-out effect on aggregate demand. Similarly, in country 2 output will rise in most cases because the trade linkage effect operating there will be accompanied by an expansionary effect if the foreign currency depreciates.[9] Finally, the current account may either improve or deteriorate (but most likely the latter). If the home currency appreciates, the negative direct effect on the trade balance will be sufficient to cause the current account to deteriorate. However, if the home currency depreciates, there will be a positive direct effect on the trade balance that may outweigh the rise in imports due to income expansion at home.

Sources for Estimated Parameters

Goldfeld, Stephen M. and Daniel E. Sichel, "The Demand for Money", in B. M. Friedman and F.H. Hahn, *Handbook of Monetary Economics*, Vol. 1. (Elsevier Science Publishers, 1990). (for β_1, β_2, ϕ_1, and ϕ_2)

OECD Economic Outlook, Occasional Studies, "Fiscal Policy Simulations with the OECD International Linkage Model," July 1980. (for m_1 and m_2)

Artus, Jacques R. and Malcom D. Knight, *Issues in the Assessment of the Exchange Rates of Industrial Countries*, Occasional Paper 29 (International Monetary Fund, July 1984). (for δ)

Mauskopf, Eileen, "The Transmission Channels of Monetary Policy : How Have They Changed?", *Federal Reserve Bulletin* (December, 1990). (for σ_1, and σ_2)

8. Note that when one imposes symmetry, as in Turnovsky's model [16], the domestic currency must appreciate, and foreign output necessarily rises, in contrast to the results in this paper.
9. In practice, the evidence suggests that fiscal expansion can lead to home currency depreciation, but cross-country fiscal policy multipliers are almost always positive. See Edison, *et. al.* [6, pp.55-60], Frankel [8, pp.20-23], and Oudiz and Sachs [15, pp.19-23].

Appendix
The Exchange Rate Expectations Scheme

Consider the following exchange rate expectations scheme, which assumes perfect foresight. We wish to show that this scheme is consistent with the model.

$$(A1)\ \dot{e} = \theta_1(\bar{e}-e) + \theta_2(\bar{p}_1-p_1)$$

Using equation (1) and differentiating yields

$$(A2)\ \dot{e} = (1/\theta_1)\dot{r}_2 - (1/\theta_1)\dot{r}_1 - (\theta_2/\theta_1)\dot{p}_1$$

Solving for $\dot{r}_1$, $\dot{r}_2$, and $\dot{p}_1$ using equations (2), (3), (5) and (6), one obtains

$$(A3)\ \dot{e} = A_1(y_1-\bar{y}_1) + A_2(y_2-\bar{y}_2)+A_3\dot{y}_1+A_4\dot{y}_2$$

Differentiating equations (2), (4), (5), and (7) and using (3) and (6) yields

$$(A4)\ \dot{y}_1 = B_1\dot{e}+B_2(y_1-\bar{y}_1) + B_3(y_2-\bar{y}_2)$$

and

$$(A5)\ \dot{y}_2 = C_1\dot{e} + C_2(y_1-\bar{y}_1) + C_3(y_2-\bar{y}_2)$$

Linearizing equations (1), (2), (4), (5), and (7) around long-run equilibrium levels yields

$$(A6)\ y_1 - \bar{y}_1 = D_1(\bar{e}-e) + D_2(\bar{p}_1-p_1) + D_3\dot{e}$$

and

$$(A7)\ y_2 - \bar{y}_2 = D_4(\bar{e}-e) + D_5(\bar{p}_1-p_1) + D_6\dot{e}$$

Finally, combining (A3)−(A7) yields an equation of the form

$$(A8)\ \dot{e} = K_1(\bar{e}-e) + K_2(\bar{p}_1-p_1).$$

Thus, $\theta_1 = K_1$ and $\theta_2 = K_2$. However, since K_1 and K_2 are non-linear functions of θ_1 and θ_2, θ_1 and θ_2 are not unique. Nevertheless, one θ_1, θ_2 set will satisfy the system's stability conditions, and this set can be obtained using the procedure discussed in the text.

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