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Speculative Attacks and Models of Balance of Payments Crises

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Recent developments in the theoretical and empirical analysis of balance of payments crises are reviewed. A simple analytical model highlighting the process leading to such crises is first developed. The basic framework is then extended to deal with a variety of issues, including alternative post-collapse regimes, uncertainty, real sector effects, external borrowing and capital controls, imperfect asset substitutability, sticky prices, and endogenous policy switches. Empirical evidence on the collapse of exchange rate regimes is also examined, and the major implications of the analysis for macroeconomic policy are discussed. [JEL E42, F31, F41]

THE LITERATURE on balance of payments crises examines the consequences of incompatible monetary, fiscal, and exchange rate policies for the balance of payments of a small open economy. In a seminal paper Krugman (1979) showed that, under a fixed exchange rate regime, domestic credit creation in excess of money demand growth leads to a gradual loss of reserves and, ultimately, to a speculative attack against the currency that forces the abandonment of the fixed exchange rate currency—a phenomenon known as the "peso problem" (Krasker

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and the adoption of a flexible rate regime. This attack always occurs *before* the central bank would have run out of reserves in the absence of speculation.

Krugman's analysis drew on the Salant and Henderson (1978) model of a stabilization scheme in which the government uses a stockpile of an exhaustible resource to stabilize its price—a policy that eventually ends in a speculative attack in which private agents suddenly acquire the entire remaining government stock.[1] Because of the nonlinearities involved in his model, however, Krugman was unable to derive explicitly a solution for the time of collapse in a fixed exchange rate regime. Later work by Flood and Garber (1984b) provided an example of how such a solution can be derived in a linear model, with or without arbitrary speculative behavior.

A considerable literature has developed in recent years that has amended or extended the original Krugman-Flood-Garber insight in various directions: the nature of the postcollapse exchange regime; uncertainty regarding the credit policy rule and the level of reserves that triggers the regime shift; real effects of anticipated crises; external borrowing and capital controls (both temporary and permanent); imperfect asset substitutability and sticky prices; and endogenous policy switches. This paper reviews these extensions and advances, highlights their policy implications, and examines areas that may warrant further attention.

The remainder of the paper is organized as follows.[2] Section I sets out a single good, full-employment, small open economy model that specifies the basic theoretical framework used for this type of analysis. Section II examines various extensions of this framework. Section III reviews empirical work, while Section IV examines some perspectives for future research. Finally, Section V draws together the major policy implications of the existing literature for macroeconomic policy under a fixed exchange rate regime.

I. A Basic Analytical Framework

The basic framework used here to analyze the process leading to a balance of payments crisis consists of a simple continuous time, perfect

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[1] See also Salant (1983) for a discussion and extensions of the Salant-Henderson model. A crucial distinction between attacks in resource markets and the foreign exchange market is the possibility for external borrowing to supplement the central bank's reserves, an issue that is examined below.

[2] A previous version of the paper (available from the authors on request) provides a review of recent experiences of a group of developed and developing countries that faced exchange rate and balance of payments crises.

foresight model.[3] The model is a log-linear formulation that allows us to solve explicitly for the time of occurrence of the crisis, by assuming initially that the exchange rate is allowed to float permanently in the postcollapse regime. This framework allows us to present the basic insights of the literature, which have been shown to carry through in more complex models.[4]

Consider a small open economy whose residents consume a single, tradable good whose domestic supply is exogenously fixed at $\bar{y}$. The good is perishable and its foreign currency price is fixed (at, say, unity). Purchasing power parity holds, so that the domestic price level is equal to the nominal exchange rate. Three assets are available—domestic money (held by domestic residents only), and domestic and foreign bonds, which are perfect substitutes. There are no private banks, so that money supply is equal to the sum of domestic credit issued by the central bank and the domestic currency value of foreign reserves held by the central bank, which earn no interest. Domestic credit is assumed to expand at a constant growth rate. Finally, agents have perfect foresight.

Formally, the model is defined as follows:

$$m_t - p_t = \phi\bar{y} - \alpha i_t, \qquad \phi, \alpha > 0 \tag{1}$$

$$m_t = \gamma D_t + (1 - \gamma)R_t, \qquad 0 < \gamma < 1 \tag{2}$$

$$\dot{D}_t = \mu, \qquad \mu > 0 \tag{3}$$

$$p_t = s_t \tag{4}$$

$$i_t = i^* + E_t\dot{s}_t. \tag{5}$$

All variables, except interest rates, are measured in logarithms; m_t denotes the nominal money stock, D_t is domestic credit, R_t is the book value in domestic currency of foreign reserves held by the central bank, s_t is the spot exchange rate, p_t is the price level, i^* is the foreign interest rate (assumed constant), and i_t is the domestic interest rate;[5] E_t denotes the expectation operator conditional on information available at time t, and a dot over a variable indicates a time derivative.

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[3] The continuous time formulation is particularly convenient in the present context. For some of the complications that arise in a discrete time model of speculative attacks, see Obstfeld (1986a).

[4] The model is not explicitly derived from a choice-theoretic framework with properly defined intertemporal constraints, but its basic behavioral equation (the money demand function) is compatible with such a formulation. Optimizing models have been developed by Bacchetta (1990), Calvo (1987), Claessens (1988, 1991), Obstfeld (1985, 1986a), Penati and Pennachi (1989), and van Wijnbergen (1988, 1991).

[5] For convenience, we initially constrain international reserves to be positive.

Equation (1) defines real money demand as a positive function of income and a negative function of the domestic interest rate. Equation (2) is a log-linear approximation to the identity linking the money stock to reserves and domestic credit, which grows at the rate μ (equation (3)). Purchasing power parity and uncovered interest parity are defined in equations (4) and (5), respectively.

Under perfect foresight, $E_t\dot{s}_t = \dot{s}_t$. Setting $\bar{y} = i^* = 0$ and combining equations (1), (4), and (5) yields

$$m_t = s_t - \alpha\dot{s}_t. \tag{6}$$

When the exchange rate is fixed (at $\bar{s}$), $\dot{s}_t = 0$, and the central bank accommodates any change in domestic money demand through the purchase or sale of international reserves to the public.[6] Using equations (2) and (6) yields

$$R_t = (\bar{s} - \gamma D_t)/(1 - \gamma), \tag{7}$$

and, using (3)

$$\dot{R}_t = -\mu/\Theta, \qquad \Theta \equiv (1 - \gamma)/\gamma. \tag{8}$$

Equation (8) shows that if domestic credit expansion is excessive (that is, if it exceeds the fixed demand for money given in equation (6) with $\dot{s}_t = 0$ and $s_t = \bar{s}$), reserves are run down at a rate proportional to the rate of credit expansion. Any finite stock of foreign reserves will, therefore, be depleted in a finite period of time.

Assume that the central bank announces at time t that it will not continue to defend the current fixed exchange rate after reserves reach a lower bound, $\bar{R}$.[7] After reserves reach the lower bound, the central bank will withdraw from the foreign exchange market and allow the exchange rate to float freely and permanently thereafter. Rational agents will anticipate that without speculation reserves will, at some point, fall to the lower bound and will therefore anticipate the ultimate collapse of the system. To avoid losses at the time of collapse, speculators will force a crisis *before* this point is reached. The problem is to determine the exact moment of the collapse of the fixed exchange rate, or equivalently, the time to transition to a floating rate regime.

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[6] Since capital is perfectly mobile, the stock of foreign reserves can jump discontinuously as private agents readjust their portfolios in response to current or anticipated shocks.

[7] Previously, the public had assumed that the central bank would continue to defend the fixed exchange rate indefinitely, even if reserves became negative. For convenience, we set the lower bound at $\bar{R} = 0$. Recall that R is defined as the logarithm of reserves, so setting $\bar{R} = 0$ as the minimum level of reserves is simply an accounting convention.

To calculate the length of the transition period, we use a process of backward induction, which has been formalized by Flood and Garber (1984b). In equilibrium, under perfect foresight, agents can never expect a discrete jump in the level of the exchange rate, since a jump would provide them with profitable arbitrage opportunities. As a consequence, arbitrage in the foreign exchange market fixes the exchange rate immediately after the attack to equal the fixed rate prevailing at the time of the attack. Formally, the time of the collapse is found at the point where the "shadow floating rate," which reflects market fundamentals, is equal to the prevailing fixed rate. The shadow floating rate is the exchange rate that would prevail if $R_t = 0$ and the exchange rate were allowed to float freely.[8] As long as the fixed exchange rate exceeds (that is, is more depreciated than) the shadow floating rate, the fixed rate regime is safe; beyond that point, the fixed rate is not sustainable.

If the shadow floating rate is below the prevailing fixed rate, speculators would not profit from purchasing the government's entire international reserve stock and precipitating the adoption of a floating rate regime, since these speculators would experience an instantaneous capital loss on their reserve purchases. Symmetrically, if the shadow floating rate is above the fixed rate, then speculators would experience an instantaneous capital gain. Neither anticipated capital gains or losses at an infinite rate are compatible with a perfect foresight equilibrium. Speculators will compete with each other to remove such opportunities. Such opportunities lead to an equilibrium attack, which incorporates the arbitrage condition that the preattack fixed rate should equal the postattack floating rate.

A first step, therefore, is to find the shadow floating rate, which can be expected to take the form[9]

$$s_t = \kappa_0 + \kappa_1 m_t. \tag{9}$$

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[8] Put differently, the shadow rate is the exchange rate that would prevail following a successful attack. It is defined with respect to the underlying model, the minimum size of reserves, and the postcollapse government policy.

[9] In general, the solution can be derived—assuming no bubbles—by using the forward expansion:

$$s_t = \gamma D_t + \alpha E_t \dot{s}_t = (\gamma/\alpha)\int_t^{\infty} e^{(t-k)/\alpha} E_t D_k \, dk,$$

or, using equation (3) and imposing perfect foresight:

$$s_t = (\gamma/\alpha)\int_t^{\infty} e^{(t-k)/\alpha}[D_t + (k-t)\mu]dk,$$

which expresses the shadow floating exchange rate as the "present discounted value" of future expected fundamentals. Integration by parts yields equation (12) below.

Taking the rate of change of equation (9) and noting from equation (2) that under floating $\dot{m}_t = \gamma \dot{D}_t$ yields

$$\dot{s}_t = \kappa_1 \gamma \mu. \tag{10}$$

In the postcollapse regime, therefore, the exchange rate depreciates steadily and proportionally to the rate of growth of domestic credit. Substituting (10) in (6) yields

$$s_t = m_t + \alpha \kappa_1 \gamma \mu. \tag{11}$$

Comparing equations (11) and (9) yields

$$\kappa_0 = \alpha \gamma \mu, \qquad \kappa_1 = 1.$$

Noting that $D_t = D_0 + \mu t = m_t / \gamma$, we obtain

$$s_t = \gamma(D_0 + \alpha \mu) + \gamma \mu t. \tag{12}$$

The fixed exchange rate regime collapses when the prevailing exchange rate, $\bar{s}$, equals the shadow floating rate, s_t.[10] From (12) the exact time of collapse, t_c, is obtained by setting $\bar{s} = s_t$, so that

$$t_c = (\bar{s} - \gamma D_0) / \gamma \mu - \alpha,$$

or, since, from equation (2), $\bar{s} = \gamma D_0 + (1 - \gamma) R_0$,

$$t_c = \theta R_0 / \mu - \alpha, \tag{13}$$

where R_0 denotes the initial stock of reserves.

Equation (13) indicates that the higher the initial stock of reserves, or the lower the rate of credit expansion, the longer it will take before the collapse occurs. Without speculation, $\alpha = 0$, and the collapse occurs when reserves are run down to zero.[11] The (semi-)interest rate elasticity of money demand determines the size of the downward shift in money demand and reserves when the fixed exchange rate regime collapses and the nominal interest rate jumps to reflect an expected depreciation of the domestic currency. The larger α is, the earlier the crisis. Finally, the larger the initial proportion of domestic credit in the money stock (the higher γ), the sooner the collapse.[12]

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[10] After the transition, the money supply consists only of the domestic credit component (as reserves have fallen to, and remain at, zero) and has to be equal to money demand, given by equation (1). For simplicity, we treat γ as given in both regimes.

[11] Following Grilli (1986, p. 154), the point in time where $\alpha = 0$ in equation (13) can be defined as the point of "natural collapse."

[12] Note, again, that in our reduced form, γ appears as an artifact of log-linearization, and is used in the model to convert the exogenous credit growth rate to a money supply growth rate.

The analysis implies therefore that the speculative attack always occurs *before* the central bank would have run out of reserves in the absence of speculation. To determine the stock of reserves just before the attack (that is, at t_c^-) use equation (7) to obtain[13]

$$R_{t_c^-} \equiv \lim_{t \to t_c^-} R_t = (\bar{s} - \gamma D_{t_c^-})/(1 - \gamma),$$

where $D_{t_c^-} = D_0 + \mu(t_c^-)$, so that

$$R_{t_c^-} = [\bar{s} - \gamma(D_0 + \mu(t_c^-))]/(1 - \gamma). \tag{14}$$

Using equation (13) yields

$$\bar{s} - \gamma D_0 = \gamma\mu(t_c^- + \alpha). \tag{15}$$

Combining (14) and (15) finally yields

$$R_{t_c^-} = \mu\alpha/\Theta. \tag{16}$$

The top panel of Figure 1 portrays the behavior of reserves, domestic credit, and the money stock during the period surrounding the regime shift, while the bottom panel displays the behavior of the exchange rate, which is also the price level in this model. Prior to the collapse at t_c, the money stock is constant, but its composition varies, since domestic credit rises (at the rate μ) and reserves decline at the rate μ/Θ. An instant before the regime shift, a speculative attack occurs and both reserves and the money stock fall by $\mu\alpha/\Theta$. Since reserves are exhausted by the attack, the money stock is equal to domestic credit in the postcollapse regime. In the bottom panel of Figure 1, the exchange rate remains at $\bar{s}$ during the precollapse regime. The path continuing through *AB* followed by a discrete exchange rate jump, *BC*, corresponds to the natural collapse scenario. With speculation, the transition occurs earlier at *A*, and no discrete change in the exchange rate occurs. Speculators, who foresee reserves running down to zero, avoid the loss from the discrete exchange rate change by attacking the currency at the point where the transition to the float is smooth—that is, where the shadow floating exchange rate equals the prevailing fixed rate.

II. Extensions to the Basic Framework

The basic theory of balance of payments crises presented above has been refined and extended in several directions. We examine, in this section, major areas in which the analytical literature has developed. We first

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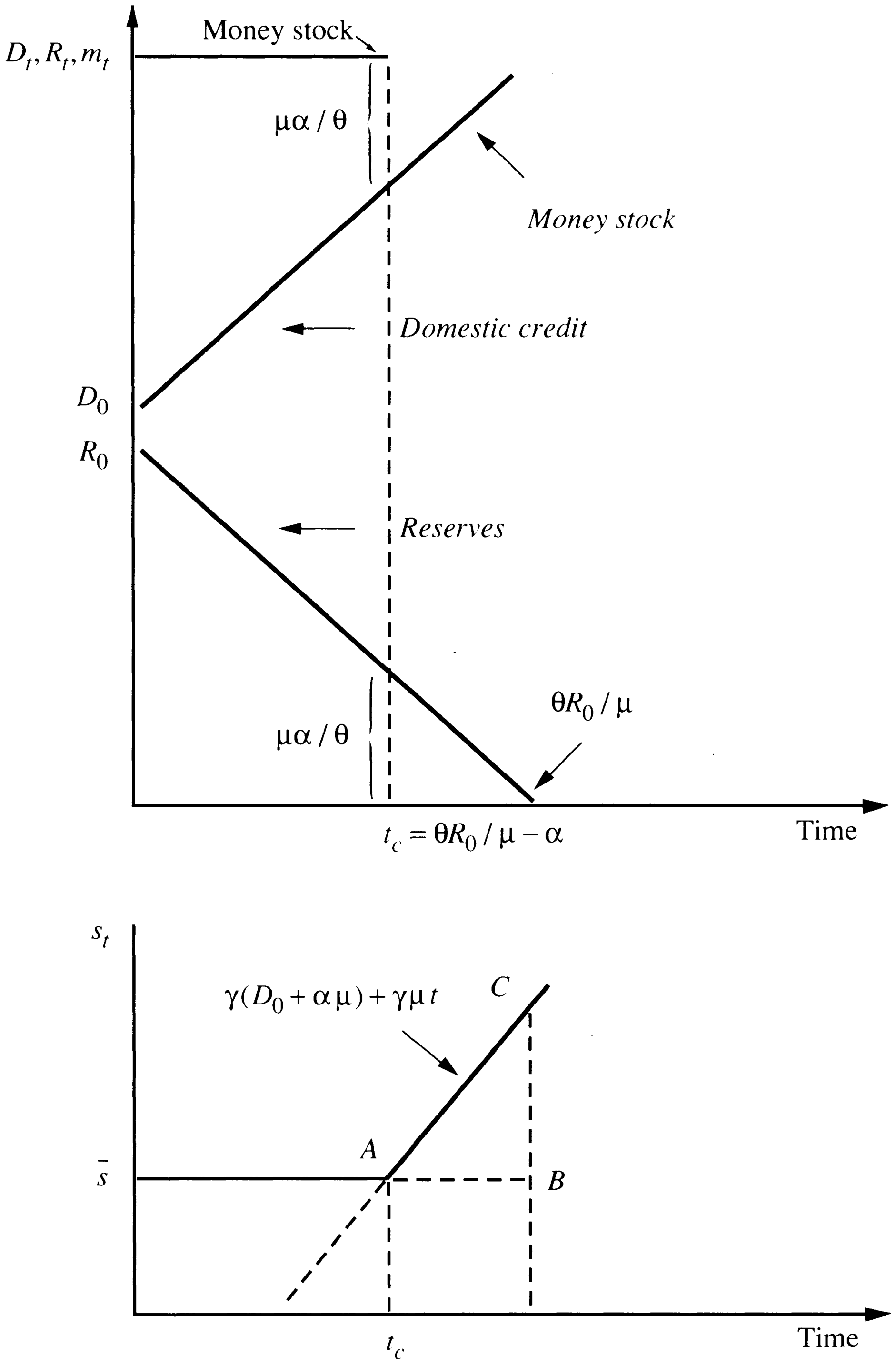
[13] R_t is discontinuous at time t_c. It is positive as approached from below and jumps to zero at t_c; see top panel of Figure 1.

Figure 1. *Reserves, Credit, Money, and the Exchange Rate*



consider alternative assumptions regarding the postcollapse exchange rate regime. Second, we consider the introduction of uncertainty in the above framework. The role of perfect asset substitutability and sticky prices is then assessed. The real effects of an (anticipated) exchange rate crisis are subsequently examined in a model with endogenous output, sticky forward-looking wages, and external trade, with particular attention being devoted to the effect of a potential crisis on the behavior of the real exchange rate. The focus then switches to the role of foreign borrowing and the imposition of controls as policy measures undertaken to postpone the occurrence of a balance of payments crisis. Finally, the issue of policy switches (that is, changes in the macroeconomic policy mix) as a means of avoiding a collapse is examined.

Alternative Postcollapse Regimes

It has been assumed in the foregoing discussion that the exchange rate regime that follows the collapse of the fixed rate is a permanent float.[14] Although the focus of the early theoretical literature has been on the transition from a fixed exchange rate to a postcollapse floating exchange rate, various alternative scenarios are suggested by actual experience. For instance, the central bank can devalue the currency (Blanco and Garber (1986)) or can decide to adopt a crawling peg regime following the breakdown of the fixed rate system (Dornbusch (1987)).[15] A particularly interesting case—often observed in practice—corresponds to a situation in which after allowing the currency to float for a certain period of time, the central bank once again returns to the foreign exchange market with the objective of fixing—at a depreciated level—the exchange rate. As a rule, one would expect the timing of a crisis to depend on the particular exchange arrangement agents expect the central bank to follow after a run on its reserve stock.

The model developed above can be modified to consider the case, as in Obstfeld (1984), of a (perfectly anticipated) temporary postcollapse period of floating followed by a new peg, and to study the effect of the

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[14] The analysis above has been extended to consider the case where the precollapse regime is a crawling peg arrangement, and the case where speculative runs occur as buying rather than selling attacks. See Connolly and Taylor (1984) and Grilli (1986).

[15] For other models in which a reserves crisis is followed by a devaluation, see Grilli (1986) who also considered the case where a speculative attack forces a revaluation of the domestic currency. See also Otani (1989), Rodriguez (1978), and Wyplosz (1986).

length of this period on the time of occurrence of the crisis.[16] In what follows, we study this case as an illustration of the type of modifications of the basic structure needed for an analysis of alternative postcollapse regimes. Suppose that the length of the transition period of floating, denoted by τ, and the level $\bar{s}_1 > \bar{s}_0$ to which the exchange rate will be pegged at the end of transition are known with certainty.[17] The time, t_c, at which the speculative attack occurs is calculated, as before, by a process of backward induction. However, this principle now imposes two restrictions rather than one. First, at time $t_c + \tau$ the preannounced new fixed rate, $\bar{s}_1$, must coincide with the interim floating rate, $\bar{s}_1 = s_{t_c+\tau}$. Second, the initial fixed rate, $\bar{s}_0$, must also coincide with the relevant shadow floating rate—that is, $\bar{s}_0 = s_{t_c}$. The condition $\bar{s}_1 = s_{t_c+\tau}$ acts as a terminal condition on the exchange rate differential equation. Imposing this terminal condition requires use of the homogeneous part of the exchange rate solution.

Recall that in the last section, when the central bank's policy was assumed to involve abandonment of the fixed rate and floating indefinitely thereafter, the shadow floating rate was given by equation (11). Now, under a transitory floating regime, the shadow rate is given by

$$s_t = \kappa_0 + \kappa_1 m_t + Ae^{t/\alpha}, \qquad t_c \leq t \leq t_c + \tau, \tag{17}$$

where A is a constant to be determined. The complete solution must, therefore, specify values for both t_c and A. These solutions are obtained by imposing $\bar{s}_0 = s_{t_c}$ and $\bar{s}_1 = s_{t_c+\tau}$ on equation (17).[18] The solutions for t_c and A are

$$t_c = (\bar{s}_0 - \kappa_0 - \kappa_1 \gamma D_0 - \Omega)/\kappa_0 \gamma \mu \tag{18a}$$

$$A = \Omega e^{-(t_c/\alpha)}, \tag{18b}$$

where $\Omega = [(\bar{s}_1 - \bar{s}_0) - \kappa_1 \gamma \mu \tau]/(e^{\tau/\alpha} - 1)$.

Equation (18a) indicates that the collapse time is linked to the magnitude of the expected devaluation, $(\bar{s}_1 - \bar{s}_0)$, and the duration of the transi-

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[16] Such a transitory floating rate regime has also been studied by Djajic (1989).

[17] The new fixed exchange rate, to be viable, must be greater (that is, more depreciated) than or equal to the rate that would have prevailed had there been a permanent postcrisis float.

[18] Formally, these restrictions are given by

$$\bar{s}_0 = \kappa_0 + \kappa_1 \gamma (D_0 + \mu t_c) + Ae^{(t_c/\alpha)}$$

and

$$\bar{s}_1 = \kappa_0 + \kappa_1 \gamma [D_0 + \mu (t_c + \tau)] + Ae^{(t_c + \tau)/\alpha}.$$

Direct manipulations of these equations yield the solutions for A and t_c given in equations (18a) and (18b).

tional float.[19] Crises occur earlier the greater the anticipated devaluation: equation (18a) shows that the higher the anticipated postdevaluation exchange rate, the sooner the speculative attack occurs ($\partial t_c / \partial \bar{s}_1 < 0$).[20] The relationship between timing and the length of the floating rate interval depends, in general, on the parameters of the model; $\partial t_c / \partial \tau < 0$ for a small τ and $\partial t_c / \partial \tau > 0$ for a large τ. If the transitional float is sufficiently brief, however, a speculative attack on the domestic currency will occur as soon as the market realizes that the current exchange rate cannot be enforced indefinitely.

Uncertainty and the Timing of a Collapse

In the basic model developed above, it has been assumed that there is some binding threshold level, known by all agents, below which foreign reserves are not allowed to be depleted. The attainment of this critical level implies a permanent shift from a fixed exchange rate regime to a floating rate regime. In practice, however, agents are only imperfectly informed of central bank policies. They may not perfectly know the threshold level of reserves that triggers the regime shift. If uncertainty about current and future government policy is prevalent, the assumption of perfect foresight may be inappropriate.

An implication of the perfect foresight model developed above, which is contradicted by experience, concerns the behavior of the domestic nominal interest rate. In the model the nominal interest rate stays constant until the moment the attack occurs—at which point it jumps to a new level consistent with the postcollapse regime. Uncertainty over the depreciation rate, as modeled below, may help to account for a rising interest rate in the transition period. Indeed, while specific results are sensitive to arbitrary specifications regarding distributional assumptions of random terms, only stochastic models are consistent with the large interest rate fluctuations observed in actual crises.

Uncertainty in the theory of balance of payments crises has been introduced in various forms but has focused on two aspects: first, uncertainty regarding the reserve limit that triggers the crisis; and second, uncertainty regarding domestic credit growth.

In practice, investors are uncertain about how much of its potential

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[19] Note that equations (18a) and (18b) yield a solution for the collapse time that is equivalent to (13) for $\tau \rightarrow \infty$, since $(1 - \gamma)R_0 = \bar{s} - \gamma D_0$.

[20] If s_1 is high enough, it is possible that $t_c \leq 0$. In this case, the speculative attack occurs at the moment investors learn that the fixed exchange rate cannot be maintained forever.

reserves the central bank is willing to use to defend its fixed exchange rate target. Uncertainty about the reserve level that a policymaker is willing to use to defend the exchange rate was first examined by Krugman (1979), who emphasized the possibility of alternating periods of crises and recoveries of confidence entailed by such uncertainty.[21] A general result, however, seems to be that speculative behavior is quite sensitive to the specification of the process that produces the critical level of foreign reserves. Depending on whether the threshold level is stochastic or fixed but unknown to agents, currency speculation reveals itself as, respectively, a speculative outflow distributed over several periods of time, or a sudden speculative attack on the currency (Willman (1989)).

Uncertainty about domestic credit growth was first introduced by Flood and Garber (1984b) in a discrete time stochastic model. In their framework, credit is assumed to depend on a random component.[22] In each period, the probability of collapse in the next period is found by evaluating the probability that domestic credit in the next period will be sufficiently large to result in a discrete depreciation, should a speculative attack occur. In the Flood-Garber framework a fixed rate regime will collapse whenever it is profitable to attack it. The condition for a profitable attack is, as in the model developed above, that the postcollapse exchange rate, s_t, be larger than the prevailing fixed rate, $\bar{s}$. Profits of speculators are equal to the exchange rate differential multiplied by the reserve stock used to defend the fixed rate regime. Since these are risk-free profits earned at an infinite rate (speculators could always sell foreign exchange back to the central bank at the fixed rate if the attack is unsuccessful), the system will be attacked if $s_t > \bar{s}$. Therefore, the probability at time t of an attack at time $t + 1$, denoted ${}_t\pi_{t+1}$, is given by

$$ {}_t\pi_{t+1} = \mathrm{prob}_t(s_{t+1} > \bar{s}). \tag{19} $$

The specific form of the process driving s_t will determine the exact form of ${}_t\pi_{t+1}$.[23] From equation (19), the expected rate of depreciation of the exchange rate is given as

$$ E_t s_{t+1} - s_t = {}_t\pi_{t+1}[E_t(s_{t+1} | s_{t+1} > \bar{s}) - \bar{s}], \tag{20} $$

where $E_t(s_{t+1} | s_{t+1} > \bar{s})$ denotes the conditional expectation of s_{t+1}.

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[21] The issue has also been examined by Cumby and van Wijnbergen (1989), Otani (1989), and Willman (1989). Uncertainty about the policy regime itself is examined below.

[22] The reason why the government might want to execute "surprise" injections of domestic credit has not been thoroughly examined in the literature. Penati and Pennachi (1989) suggested a possible link between the timing of a surge in domestic credit and seigniorage considerations.

[23] The analysis could be extended to calculate the complete term structure of agents' beliefs about an attack—that is, the probabilities ${}_t\pi_{t+2}$, ${}_t\pi_{t+3}$, and so on. See Blanco (1986) and Agénor (1990).

The expected rate of exchange rate depreciation given by equation (20) will change as the value of the variables forcing s_t change. The expected rate of change of the exchange rate increases prior to the collapse, because both ${}_t\pi_{t+1}$ and $E_t(s_{t+1} | s_{t+1} > \bar{s})$ rise with the approach of the crisis.[24] The probability of an attack next period, ${}_t\pi_{t+1}$, rises because the increasing value of the state variable (domestic credit) makes it increasingly likely that an attack will take place at $t + 1$. The quantity $E_t(s_{t+1} | s_{t+1} > \bar{s})$ gives the value agents expect the exchange rate to be next period, given that there will be a speculative attack at $t + 1$. In turn, that value depends on the value agents expect for the state variable next period, given that an attack will occur at $t + 1$. As the value of the state variable rises from period to period, its conditional expectation also rises, as well as the conditional expected rate of change of the exchange rate. As a result, the domestic nominal interest rate rises with the approach of the crisis.

The Flood-Garber stochastic approach has given rise to a number of empirical applications, which are examined below.[25] The introduction of uncertainty in collapse models has several implications for the predictions of these models, beyond being consistent with a rising interest rate differential prior to the crisis. First, the transition to a floating regime is stochastic, rather than certain. The collapse time becomes a random variable and cannot as before be determined explicitly, since the timing of a potential future speculative attack is unknown. Second, there is always a nonzero probability of a speculative attack in the next period,[26] a possibility which, in turn, produces a forward discount on the domestic

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[24] If the probability density function of s_{t+1}, viewed at time t, is denoted $g_t(s_{t+1})$, then

$$ {}_t\pi_{t+1} = \int_{\bar{s}}^{\infty} g_t(s_{t+1}) ds_{t+1} $$

and

$$ E_t(s_{t+1} | s_{t+1} > \bar{s}) = \int_{\bar{s}}^{\infty} g_t(s_{t+1}) s_{t+1} ds_{t+1}. $$

[25] Uncertainty on domestic credit growth has also been introduced by, among others, Blanco and Garber (1986), Dornbusch (1987), Grilli (1986), and Obstfeld (1986b), who show that as a result of uncertainty there may be circumstances when a system may be attacked even though it is fundamentally viable. See the discussion below.

[26] In the Flood-Garber model increments to credit follow an exponential distribution (so that $g_t(s_{t+1})$ defined above is an exponential function)—an assumption that implies that a particularly large increment to credit may cause such a large loss in reserves that a transition to floating occurs immediately. This may happen even if reserves are large. By contrast, Dornbusch (1987) used a uniform distribution for credit growth with an upper limit. The existence of a maximum rate of increase implies that, if reserves are large, there will be no immediate possibility of a regime shift.

(1980)). Available evidence suggests indeed that the forward premium—or, as an alternative indicator of exchange rate expectations in developing countries, the parallel market premium—in foreign exchange markets tends to increase well before the regime collapse. Third, the degree of uncertainty about the central bank's credit policy plays an important role in the speed at which reserves of the central bank are depleted (Claessens (1991)). In a stochastic setting, reserve losses exceed increases in domestic credit because of a rising probability of regime shift, so that reserve depletion accelerates on the way to the regime change—a pattern that has often been observed in actual crises.

Asset Substitutability and Sticky Prices

Extensions of the theory of balance of payments crises to a world of sticky prices and imperfect asset substitutability have been discussed by Flood and Hodrick (1986), Blackburn (1988), and Willman (1988).[27] A simple way to introduce sluggish price adjustment in the basic framework developed above requires dropping the assumption of perfect substitutability between domestic and foreign goods (which yields the purchasing power parity condition (4) and implicitly implies an instantaneously cleared goods market) and specifying a Dornbusch-type price equation of the form[28]

$$\dot{p}_t = \lambda[\delta(s_t - p_t) - \Psi(i_t - \dot{p}_t) - \bar{y}], \qquad \lambda, \delta, \Psi > 0, \tag{21}$$

in which aggregate demand is inversely related to the real exchange rate and the real interest rate. The parameter λ measures the speed of adjustment of prices to excess demand. Using equations (1)–(3) and (21) and (5) and setting, as before, $i^* = \bar{y} = 0$ yields, under floating exchange rates and perfect foresight, a nonhomogeneous differential equation system in s_t and p_t:

$$\begin{bmatrix} \dot{s}_t \\ \dot{p}_t \end{bmatrix} = \begin{bmatrix} 0 & 1/\alpha \\ \dfrac{\lambda\delta}{1 - \lambda\Psi} & -\dfrac{\lambda}{\alpha}\left(\dfrac{\alpha\delta + \Psi}{1 - \lambda\Psi}\right) \end{bmatrix} \begin{bmatrix} s_t \\ p_t \end{bmatrix} + \begin{bmatrix} -\gamma(D_0 + \mu t)/\alpha \\ \dfrac{\lambda\Psi\gamma}{\alpha(1 - \lambda\Psi)}(D_0 + \mu t) \end{bmatrix}. \tag{22}$$

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[27] See also Goldberg (1988) who relaxed the assumptions of purchasing power parity and interest rate parity used in the Flood-Garber model.

[28] The analysis could easily be extended to consider some alternative price adjustment rules discussed in Obstfeld and Rogoff (1984).

The two eigenvalues of this system are given by

$$[-\lambda(\alpha\delta + \Psi) \pm \{[\lambda(\alpha\delta + \Psi)]^2 + 4\alpha\lambda\delta(1 - \lambda\Psi)\}^{1/2}]/2\alpha(1 - \lambda\Psi).$$

Provided that $(1 - \lambda\Psi) > 0$, the system (22) is saddlepoint stable, with one negative root (denoted by ρ) and one positive root.[29] Solving for the particular solutions yields

$$s_t = \gamma\left[D_0 + \mu\left(\alpha + \frac{1}{\lambda\delta}\right)\right] + \gamma\mu t + Ae^{\rho t} \tag{23a}$$

$$p_t = \gamma(D_0 + \alpha\mu) + \gamma\mu t + \alpha\rho Ae^{\rho t}, \tag{23b}$$

where A is an arbitrary constant that can be determined by imposing an initial condition on the predetermined output price.[30]

The solution value for s_t can be used to determine the timing of the crisis, which occurs, as before, at the point where the shadow exchange rate equals the prevailing fixed rate. Although an explicit solution cannot be derived analytically here, the collapse time can be determined graphically at the intersection of the curve, $Ae^{\rho t}$, and the straight line, $\bar{s} - \gamma D_0 - \gamma\mu(\alpha + 1/\lambda\delta) - \gamma\mu t$. Moreover, it can also be established that under fairly general conditions, the higher the degree of price flexibility, the earlier the crisis occurs ($\partial t_c/\partial\lambda < 0$). Essentially, this result derives from the anticipatory component that movements in prices reflect in the sticky-price regime. Under perfect substitutability between domestic and foreign goods, the output price remains constant (at the prevailing fixed exchange rate) until the crisis occurs, at which point it rises by the amount of exchange rate depreciation. By contrast, when the speed of adjustment to aggregate excess demand is less than infinite, a perfectly anticipated future collapse of the exchange rate regime has an immediate effect on the behavior of domestic prices. Specifically, prices begin rising gradually (as soon as agents become aware that the exchange rate is not viable indefinitely), so as to prevent any jump when the regime switch occurs. The higher the degree of price inertia, the longer it will take for

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[29] The condition $1 - \lambda\Psi > 0$ is actually a necessary one for stability under the fixed exchange-rate regime. Solving the model as before and setting $\bar{s} = \dot{s}_t = 0$ yields $\dot{p}_t = -\lambda\delta p_t/(1 - \lambda\Psi)$, which gives an unstable solution for $1 - \lambda\Psi < 0$.

[30] To see the relationship between equations (23a) and (23b) and the floating exchange rate solution obtained under perfect substitution between domestic and foreign goods, set $\lambda \rightarrow \infty$ in (23a). Then $\rho \rightarrow \delta/\Psi > 0$, which requires, for stability, to set $A = 0$. The resulting solution is then equivalent to (12) and implies, from (23b), that $s_t = p_t$.

Alternatively, setting $\lambda \rightarrow \infty$ in equation (22) yields a system with roots given by δ/Ψ and $1/\alpha$, implying that the model is globally unstable. Imposing stability leaves us with only the particular solution, which is of the form (12).

prices to adjust and ensure a "smooth" transition—and, therefore, the longer will be the time elapsed before the collapse.[31]

The effect of price flexibility on the collapse time derived above has also been highlighted by Blackburn (1988). In addition, Blackburn also examined the role of imperfect asset substitutability in the collapse process. His analysis showed that the higher the degree of capital mobility, the earlier the crisis occurs. As in Willman's (1988) model, imperfect substitutability between domestic and foreign bonds implies that it is essentially the accumulating trade balance deficit that leads to depletion of foreign reserves and eventually causes the balance of payments crisis. Because of the potential impact of government spending on external deficits, it is therefore not just monetary policy, but rather the fiscal-monetary mix that is of importance in the analysis of the collapse process.

Output, the Real Exchange Rate, and the Current Account

The early literature on balance of payments crises focused on the financial aspects of such crises and ignored the real events that were occurring simultaneously. Available evidence suggests, however, that balance of payments crises are often associated with large trade balance and current account movements during the periods preceding, as well as during the periods following, such crises. Typically, large current account deficits tend to emerge as agents adjust their consumption behavior (and not only the composition of their holdings of financial assets) in anticipation of a crisis. As suggested by the experience of Argentina (see Connolly (1986)), movements in the real exchange rate and the current account can be quite dramatic in the periods preceding exchange rate crises. Such movements may provide an additional argument to explain why (in addition to uncertainty, discussed above) runs on reserves rarely occur abruptly but are generally preceded by a period during which official foreign reserves are lost at increasing rates.[32]

The real effects of a potential exchange rate crisis have been inves-

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[31] The assumptions of sticky prices and disequilibrium in the domestic goods market have also implications for the behavior of the real exchange rate, aggregate demand, and the trade balance, which are examined in a more general setting below.

[32] The period of reserves losses in excess of domestic credit creation that typically precedes a speculative attack may result solely because private agents hedge against the risk of an exchange crisis by accumulating foreign currency-denominated assets (Penati and Pennachi (1989)). The possibility of a collapse, which leads to a depreciation and a jump in the price level, implies a positive level of expected inflation, pushes up the nominal interest rate, and reduces domestic money demand. If domestic credit continues to expand, the nominal interest rate will continue to increase, and reserves will continue to decline.

tigated by Flood and Hodrick (1986) in economies with sticky prices and contractually predetermined wages, and by Willman (1988) in the context of a model with endogenous output and foreign trade.[33] Following Willman, we can assume—as in equation (21)—that domestic output is demand determined, positively related to the real exchange rate, and inversely related to the real interest rate. The trade balance also depends positively on the real exchange rate, but is negatively related to domestic output. A crucial feature of Willman's model is the existence of forward-looking wage contracts, as in Calvo (1983). Under perfect foresight, an anticipated future collapse will affect wages, which, in turn, will influence prices, the real exchange rate, and, therefore, output and the trade balance. At the moment the collapse occurs, the real interest rate falls because of the jump in the rate of depreciation of the exchange rate. Output therefore increases, while the trade balance deteriorates. But since wage contracts are forward looking, anticipated future increases in prices are discounted back to the present and affect current wages. As a result, prices start adjusting before the collapse occurs. The real interest rate falls gradually, and experiences a downward jump at the moment the collapse takes place, resulting from the upward jump in the rate of inflation. The decline in the (ex post) real interest rate has an expansionary effect on domestic activity before the collapse occurs. However, output also depends on the real exchange rate. The steady rise in domestic prices is associated with an appreciation of the domestic currency and a negative impact on economic activity that may outweigh the positive output effect resulting from a lower real interest rate. The net impact of an anticipated collapse on output may well be negative, if relative price effects are strong. The continuous loss of competitiveness, unless it is associated with a fall in output, implies that the trade balance deteriorates in the period before the collapse of the fixed exchange rate regime. The trade deficit increases further at the moment the crisis occurs and returns gradually afterwards to its steady-state level.

In the model described above, the real exchange rate appreciates until the time of collapse, at which point it starts depreciating smoothly. This feature of the model seems to account fairly well for the steady real ap-

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[33] The Appendix shows how the basic framework developed above can be extended so as to endogenize output, the real exchange rate, and the trade balance. For an alternative formulation that also shows a large and increasing current account deficit in the periods leading to a balance of payments crisis and a reversal immediately following the crisis, see Claessens (1991). Other models focusing on real exchange rate effects of an anticipated collapse include Connolly and Taylor (1984) and Calvo (1987). Frenkel and Klein (1989) also analyzed the real effects of alternative macroeconomic adjustment policies that aim at preventing a balance of payments crisis.

preciation and subsequent depreciation observed during crisis episodes in countries such as Argentina in 1980–81. By contrast, in the models developed by Calvo (1987) and Connolly and Taylor (1984), the real exchange rate experiences a downward jump at the time of the crisis—a feature of the collapse process that is difficult to rationalize under perfect foresight. In Connolly and Taylor's model for instance, the price of traded goods is fixed at the time of a speculative attack. It cannot jump because the exchange rate is continuous (as a result of the asset-price continuity assumption) and the world price of traded goods is assumed constant. Consequently, a sharp real depreciation at the time of the crisis must be attributed, under perfect foresight, to a substantial *fall* in the nominal price of nontraded goods—an assumption that implies an implausible degree of downward price flexibility for most economies.

Borrowing, Controls, and Postponement of a Crisis

A common feature in countries experiencing balance of payments difficulties has often been recourse to external borrowing to supplement the available amount of reserves, or the imposition of restrictions on capital outflows to limit losses of foreign exchange reserves. In the basic model developed above, it has been assumed that there is a critical level, known by everyone, below which foreign reserves are not allowed to be depleted. In practice, however, it is doubtful whether any such binding threshold exists. A central bank facing a perfect capital market can—at least in principle—create foreign reserves by borrowing. Thus, negative (net) reserves are also feasible.[34]

Pressing the argument a little further, perfect access to international capital markets implies that, at any given point in time, central bank reserves can become (infinitely) negative without violating the government's intertemporal budget constraint. Such access to unlimited borrowing could, in principle, avoid a regime collapse indefinitely. The rate of growth of domestic credit cannot, however, be permanently maintained above the world interest rate, because it would lead to a violation of the budget constraint (Obstfeld (1986a)). In this sense, an overexpansionary credit policy still leads to the collapse of a fixed exchange rate regime. A similar point has been emphasized by van Wijnbergen (1988, 1991).[35]

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[34] In terms of Figure 1 (top panel), official borrowing would shift the curve showing the behavior of reserves upwards at the moment it occurs (before t_c), and would increase the steepness of the negatively sloped path after its occurrence—because of the implied increase in debt-service payments. See Buiter (1987).

[35] The relation between speculative attacks and the solvency of the public sector in an economy with interest-bearing debt has also been examined by Ize and Ortiz (1987).

Moreover, even with perfect capital markets, the timing of borrowing matters considerably for the nature of speculative attacks. Suppose that the interest cost of servicing foreign debt exceeds the interest rate paid on reserves. If borrowing occurs just before the exchange rate regime would have collapsed absent borrowing, the crisis is likely to be postponed. If borrowing occurs long enough before the exchange rate regime would have collapsed in the absence of borrowing, the crisis would occur earlier. The reason why the collapse is brought forward is, of course, related to the servicing cost of foreign indebtedness on the fiscal deficit, which raises the rate of growth of domestic credit (Buiter (1987)).

In practice, most countries face borrowing constraints on international capital markets. The existence of such constraints has important implications for the behavior of inflation in an economy where the government—like private agents—is subject to an intertemporal budget constraint. Consider, for instance, a country that has no access to external borrowing and in which the central bank transfers its net profits to the government. If a speculative attack occurs, the central bank will lose its reserves, and its postcollapse profits from interest earnings on foreign assets will drop to zero. As a consequence, net income of the government falls and the budget deficit deteriorates. If the deficit is financed by increased domestic credit (a typical situation if access to external borrowing is limited) the postcollapse inflation rate will exceed the rate that prevailed in the precollapse fixed exchange rate regime, raising inflation tax revenue so as to compensate for the fall in interest income (van Wijnbergen (1988, 1991)).

Another policy measure aimed at postponing a regime collapse that has been used to limit losses of foreign exchange reserves relates to capital controls. Restrictions of this type have been imposed either *permanently* or *temporarily* after significant losses.[36] A simple way to introduce permanent controls in the above setting is to rewrite equation (5) as

$$i_t = (1 - \rho)(i^* + E_t \dot{s}_t), \qquad 0 < \rho < 1. \tag{24}$$

This equation states that deviations from the domestic interest rate from uncovered interest parity are accounted for by the existence of capital controls, which are modeled here as a proportional tax on foreign interest earnings.[37] Using (24) and solving the model as before, the collapse time is now given by

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[36] Edwards (1989) documented the use of controls in several Latin American countries. Temporary controls have typically been used in advanced countries—notably in Europe—at times where the domestic currency came under heavy pressure on foreign exchange markets.

[37] The tax is assumed set at a level that is low enough so that some degree of capital mobility remains.

$$t_c = \Theta R_0/\mu - (1 - \rho)\alpha. \tag{25}$$

Equation (25) indicates that the higher the degree of capital controls (the higher ρ), the longer it will take for the regime shift to occur.

The impact of temporary capital controls on the timing of a balance of payments crisis has been studied by Bacchetta (1990), Dellas and Stockman (1988), and Wyplosz (1986). In Wyplosz's model the domestic country expands credit excessively. Capital controls are in force, and residents are not allowed to hold foreign currency assets (or to lend to nonresidents), but nonresidents are free from restrictions. There are only two assets, domestic money and foreign money. Nonresidents monitor reserve levels, provoking a "crisis" when reserve levels equal nonresident holdings of domestic currency. The currency is then devalued, setting off a new cycle. The analysis shows that in the absence of capital controls, a fixed rate regime would be viable only if the monetary authorities maintain a sufficient degree of uncertainty so as to force risk-averse speculators to commit only limited amounts of funds in anticipation of a crisis.[38]

However, even with perfect foresight the fixed rate regime might still be viable if interest rates are endogenous—a feature that is absent in Wyplosz's model. Interest rates have an equilibrating role that eliminates the incentive for a run on reserves. For instance, if the public anticipates a devaluation, it will shift out of domestic money. The authorities may accommodate the public, say, by bond sales at interest rates that reflect these expectations; such bond sales avert the need to shift into foreign assets. The implication of the analysis, nevertheless, is that without capital controls interest rates are likely to display substantial variability.[39]

Restrictions on foreign transactions also have real effects, as shown by Bacchetta (1990), who examined the effect of anticipated temporary capital controls in the process of a balance of payments crisis. The anticipation of controls affects the behavior of agents as soon as they are announced—or as soon as agents realize the inconsistency between the fiscal policy and the fixed exchange rate—and usually translates into a current account deficit, as capital outflows are substituted by increased imports. A speculative attack may, however, occur just *before* the con-

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[38] In Wyplosz's model, therefore, exchange controls succeed in salvaging the fixed exchange rate regime by imposing a ceiling on the potential volume of speculative transactions. By contrast, Dellas and Stockman showed that the threat of capital controls may generate (self-fulfilling) speculative attacks instead of serving to deter them.

[39] Repeated imposition of temporary controls may well lead to a risk premium in domestic interest rates that would reflect the risk to investors that capital controls would be reimposed in the future.

trols are imposed. Such an attack may therefore well defeat the very purpose of capital controls.

Policy Switches and Avoidance of a Collapse

Early models of balance of payments crises have been generally limited to the consideration of an "excessive" rate of credit creation.[40] The apparently inevitable character of a regime collapse that such an assumption entails runs into a conceptual difficulty—namely, why is it that the authorities do not attempt to prevent the crisis by adjusting their fiscal and credit policies?[41] Moreover, there is nothing in the model that requires the central bank to float the currency and abandon the prevailing fixed exchange rate at the moment reserves hit their critical lower bound; instead, the monetary authority could as well change its monetary policy rule to make it consistent with the fixed exchange rate target. Some recent models of balance of payments crises have considered this type of endogenous change in monetary policy. For instance, in Drazen and Helpman (1988) the assumption that the authorities choose to adjust the exchange rate instead of altering underlying macroeconomic policy that is inconsistent with the existing exchange parity can only provide a temporary solution. But ultimately, if the new exchange rate regime is inconsistent with the underlying fiscal policy process, there will be a need for a new policy regime. A similar argument has been made in the context of developing countries (Edwards and Montiel (1989)).

In the context of a model of the gold standard, Flood and Garber (1984b) showed that an attack on a price-fixing scheme can be self-fulfilling. This self-fulfilling aspect was applied to exchange rate fixing by Obstfeld (1986b). A collapse, in these models, results from an indeterminacy of equilibrium that may arise when agents expect a speculative attack to cause an abrupt change in government macroeconomic policies. Suppose, for instance, that a country fixes its exchange rate and maintains a stable credit policy in "normal times." In the event of a speculative attack, however, the country will cease fixing the exchange rate and will

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[40] The exogeneity of the rate of growth of domestic credit is usually taken to reflect fiscal "constraints." In optimizing models where—as, for instance, in Claessens (1991) and Obstfeld (1986a)—the government makes lump-sum transfers to domestic agents, domestic credit is endogenous.

[41] In the basic framework presented above, the rate of credit creation is exogenous and unrelated to objectives such as deficit finance. In a more complicated model, it is possible that rather than shifting to a floating regime, the authorities may alter the sources of deficit finance and reduce the rate of domestic credit creation.

increase the rate of growth of domestic credit. Evidently, the private sector can be in equilibrium with either policy. If an attack never occurs, the fixed exchange rate will survive indefinitely. If there is an attack, the system may collapse. The indeterminacy arises because the authorities' credit policy is *not* exogenous to the collapse.

Uncertainty about the postcollapse credit rule can also cause a fixed exchange rate regime to collapse—just as arbitrary speculative behavior (or noneconomic extrinsic factors that private agents may believe will trigger a crisis) would. Formally, a simple way to introduce policy uncertainty in the basic model developed above is to allow two possibilities with respect to the credit policy rule (Willman (1987)): there is a probability, q, that the monetary authority will maintain the existing rule given by equation (3) and float the currency from the moment the stock of foreign exchange reserves has been depleted to zero, and a probability, $(1 - q)$, that the authorities will adopt a zero-growth rule consistent with the fixed rate regime; that is

$$\dot{D}_t = 0. \tag{26}$$

Using equation (26) and solving as before, the collapse time can be shown to be now equal to

$$t_c = \theta R_0/\mu - \alpha q. \tag{27}$$

The earlier result (equation (13)) corresponds to a probability equal to unity. If the probability is zero, a speculative attack never occurs and the system collapses "naturally." The smaller q—the greater the probability that the monetary authorities alter the credit policy rule (3)—the longer it takes before the collapse occurs.

An alternative way to formalize the effect of a possible future policy switch is as follows. Suppose that, instead of equation (3), the process driving domestic credit is given by

$$dD_t = \mu dt + \sigma dz_t, \tag{28}$$

where dz_t is a standard Wiener process, and σ is a constant.[42] To derive the solution for the flexible exchange rate in the postcollapse regime, set $R_t = 0$ in equation (2) and use equations (4) and (5) in (1) to get

$$s_t = \gamma D_t + \alpha E_t \dot{s}_t. \tag{29}$$

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[42] Equation (28) is the continuous-time analog of a random walk with trend. Note also that when the variance of domestic credit is zero—that is, $\alpha = 0$—the model reduces to the perfect foresight case.

Suppose that speculators expect the central bank to alter its credit rule (28) in the future—even while allowing the exchange rate to float initially. More precisely, the central bank may decide to again fix the exchange rate, if a higher limit on domestic credit $\bar{D}$ is reached.[43] Such anticipated behavior will affect the behavior of the floating exchange rate. The shadow rate is now given by[44]

$$s_t = \gamma D_t + \gamma\alpha\mu[1 - e^{\tilde{\lambda}(D_t - \bar{D})}], \tag{30}$$

where $\tilde{\lambda}$ is the positive root of the quadratic equation in λ

$$\lambda^2 \alpha\sigma^2/2 + \lambda\gamma\alpha\mu - 1 = 0. \tag{31}$$

The collapse date, t_c, is now a stochastic variable that can be determined by using the "first-passage" probability density function, given, for instance, in Feller (1966, pp. 174–75).

III. Models of Exchange Rate Crises: Empirical Evidence

Speculative attacks and devaluation crises have come to be associated with developing countries and historical applications to now-developed countries. In this section we examine some formal econometric applications of the speculative attack model to such foreign exchange crises. Specifically, we focus on three cases: Mexico (1973–82), Argentina (1978–81), and the United States (1894–96).[45]

In the preceding sections explaining the theory of speculative attacks, arbitrary assumptions needed to be made concerning the policy to which a government would switch following a speculative attack. The assumption that the government allows its foreign exchange reserves to be exhausted and then switches to a floating exchange rate is often made for analytical convenience and needs to be modified for empirical application. Precise modifications depend on the particular application, since government policies differ. The analytical literature does, however, offer a basic lesson: the shadow exchange rate, as derived in the early theoret-

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[43] Such a policy stance may not, of course, be credible. We abstract from this complication here.

[44] For details about the solution procedure, see Froot and Obstfeld (1991). Note that for $\bar{D} \to \infty$, equation (30) yields solution (12).

[45] Our review is not exhaustive. We do not, for instance, discuss the econometric evidence presented by Edwards (1989), which is based on an analysis of 39 devaluation episodes that took place in developing countries between 1962 and 1982. His analysis shows that the probability of a devaluation is strongly affected by the evolution of foreign assets of the central bank, the real exchange rate, and fiscal policy—a result that extends those discussed below.

ical models, allows the development of a lower bound on the probability of a policy switch. The reason is simple—any exchange rate that does not equal or exceed the shadow rate will be profitably attacked by speculators. This lesson is robust to a wide variety of policies followed by the government.

Blanco and Garber (1986), in their study of recurrent devaluations of the Mexican peso, offered the first empirical application of the speculative attack model.[46] The Mexican authorities did not follow the theoretical scenario outlined in Section I and completely abandoned the fixed rate policy. Instead, in the midst of a speculative attack, they devalued the peso against the U.S. dollar. Although such a policy switch does not exactly match the switch to a floating exchange rate usually posited in the theoretical literature, a devaluation that terminates a speculative attack must move the exchange rate to a position where it equals or exceeds the shadow floating rate—which is again defined as the exchange rate that would prevail if the foreign exchange authority had exhausted its stock of international reserves and allowed the exchange rate to float freely. Indeed, a successful devaluation must take the shadow floating rate as a lower bound, since any fixed rate below it would be instantly and profitably attacked.

The development of the shadow floating rate is thus important in empirical applications, and this development requires a model of a flexible exchange rate. Blanco and Garber centered their exchange market model on the domestic money market and augmented that market with uncovered interest rate parity and a relation between Mexican-peso goods prices and U.S.-dollar goods prices. In their model, if international reserves were exhausted and if the exchange rate were allowed to float freely afterwards, then the following equilibrium condition would follow:

$$h_t = -\alpha E_t s_{t+1} + (1 + \alpha) s_t, \tag{32}$$

where h_t is the exchange market forcing variable that would prevail if the switch were made to a floating rate after the exchange authority had exhausted its international reserves, and s is the shadow floating exchange rate. In Blanco and Garber's analysis, h_t is assumed to be exogenous to the exchange rate, and it is assumed to follow a particular linear stochastic process that is invariant to the exchange rate regime. Thus, one can solve in the usual way for the reduced-form function relating s_t to h_t.

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[46] The Mexican experience with exchange rate crises in the early 1980s has also been examined by Connolly and Fernandéz (1987) and Goldberg (1990); the latter explicitly accounted for foreign shocks in the determination of collapse probabilities.

The shadow exchange rate is assumed to play a role in the devaluation rule. In particular, Blanco and Garber assumed that a devaluation will occur if, and only if

$$s_t > \bar{s}, \tag{33}$$

where $\bar{s}$ is the fixed rate prevailing before devaluation. The second part of the devaluation mechanism specifies the postdevaluation fixed rate, $\tilde{s}_t$, to be

$$\tilde{s}_t = s_t + \delta \nu_t, \tag{34}$$

where δ is a fixed positive parameter, and ν_t is a disturbance, which must be positive in the Blanco-Garber framework if condition (33) holds.

Condition (33) determines the devaluation. Indeed, the probability that the currency will be devalued next period, ${}_t\pi_{t+1}$, is the probability based on time t information that condition (33) will hold at $t + 1$; ${}_t\pi_{t+1} = pr(s_{t+1} > \bar{s})$. The alternative to devaluation is no devaluation, so that the exchange rate remains at $\bar{s}$. It follows that the expected exchange rate next period is

$$E_t s_{t+1} = {}_t\pi_{t+1} E_t(s_{t+1} | s_{t+1} > \bar{s}) + (1 - {}_t\pi_{t+1})\bar{s}. \tag{35}$$

Blanco and Garber assume $f_t = Es_{t+1} + \epsilon_t$, where f_t is the forward exchange rate, and ϵ_t is a shock (forecast error), allowing them to turn equation (35) into an estimating equation.

The empirical strategy of Blanco and Garber is built around the fact that neither s_t nor h_t is directly observable. According to the theory, however, h_t is a linear function of observable money market variables, and $\bar{R}$ is the level of international reserves at which the monetary authority would abandon the fixed rate regime if attacked. Blanco and Garber treat $\bar{R}$ as a parameter to be estimated.

Estimation proceeds in several stages. In the first stage, they estimate parameters from the money market. In the second stage they use an initial guess of $\bar{R}$, along with the money market elements to construct an initial h_t series. The initial h_t series is used to estimate the parameters of the h_t process and the other parameters appearing in equation (35), the estimating equation. These parameters are $\bar{R}$, δ, the parameters of the h_t process, and the parameters specific to the cumulative distribution function generating ${}_t\pi_{t+1}$. Since the second stage was initiated by a guessed $\bar{R}^{(1)}$ and produces an estimate $\bar{R}^{(2)}$, the estimate from the second stage is taken as the initial guess for a third stage. The iterative process is continued until the guess, $\bar{R}^{(n)}$, and the revised estimate, $\bar{R}^{(n+1)}$, converge. The estimation uses quarterly data from the fourth quarter of 1973 to the fourth quarter 1981.

The output of the estimation is a set of structural parameter estimates and a constructed time series for s_t and ${}_t\pi_{t+1}$. These time series are generated by combining the mean values of the estimated parameters with the time series for the state variable, h_t. The striking feature of their work is that the estimated probabilities of devaluation in the next quarter, which range from highs of more than 20 percent in late 1976 and late 1981, to lows of less than 5 percent in early 1974 and late 1977, reach local peaks in the periods of devaluation and reach local minima in the periods following devaluation as predicted by the theory.

Cumby and van Wijnbergen (1989) applied a similar speculative attack model to the stabilization program in Argentina, which included the period from December 1978 to April 1981. Exchange market aspects of the program were built around a preannounced table of daily exchange rates (the "tablita"). The speculative attack model is relevant here because tension may arise between government financing needs and the tablita. For example, if government finance should demand more revenue from money creation than would be consistent with the tablita, then agents may conjecture that the tablita would collapse.

The predetermined tablita exchange rate acts like the fixed exchange rate in the previous literature. Cumby and van Wijnbergen used the same model as Blanco and Garber, but they implemented it somewhat differently. Whereas Blanco and Garber aggregated all money market influences into one variable and then fitted a stochastic process for that variable, Cumby and van Wijnbergen assumed that the forcing variables in the money market were appropriately modeled in a disaggregated way with different time series processes appropriate for the money demand disturbance, foreign interest rates, and domestic credit growth, and were unable to reject simple stochastic processes in place in Argentina from January 1979 through December 1980.

The distribution function appropriate to increments of the shadow exchange rate is thus more complex than in Blanco and Garber's study because of the disaggregation of the forcing variable. More important, it is more complex because Cumby and van Wijnbergen treated the minimum level of reserves as a stochastic variable, unknown to agents in the model, which has its own distribution and is independent of other variables in the forcing process. Blanco and Garber treated the minimum quantity of reserves as a variable that is known to agents but is unknown to the researcher. Thus, in deriving the probabilities of devaluation, they did not include a model of agents' uncertainty about minimum reserves.

The econometric estimates of the collapse probabilities by Cumby and van Wijnbergen indicate that the sharp increase in domestic credit growth in the second quarter of 1980 undermined agents' confidence in the crawling peg regime. Credibility of the exchange rate regime fell gradually in the ensuing periods. The one-month-ahead collapse probability rose to nearly 80 percent immediately prior to the abandonment of the crawling peg arrangement in June 1981.

Grilli (1990) applied the speculative attack model to the episode of foreign exchange market pressure on the U.S. dollar from 1894 through 1896.[47] The distinguishing contribution of Grilli's study is the implementation of a model of government reserve borrowing, which ties the speculative attack literature to the optimal contracting literature (see, for instance, Harris and Raviv (1989)). In the framework used by Grilli, the probability of speculative attack is measured in the standard way, but the government is assumed to structure borrowing contracts in order to minimize this probability subject to a set of constraints.

The constraints proxy the government's degree of commitment to the fixed exchange rate system and lead to the development of an optimal government borrowing contract, which is compared in a case study manner with aspects of the Belmont-Morgan contract.[48] The previous literature postulated an exogenous and possibly unknown minimum level of reserves; an important contribution of Grilli's study was to begin to endogenize this variable and thus take more seriously the degree of the government's commitment to the fixed exchange rate regime.

IV. Some Research Perspectives

The literature on speculative attacks has been growing steadily. There is, undoubtedly, a risk in trying to identify areas that may prove fruitful for future developments. We believe, however, that attention might be focused on the following topics: the analysis of speculative attacks in a target zone, the resolution of the "gold standard paradox," the role of reputational factors as a deterrent to speculative attacks, and the testing of collapse models—particularly in the context of developing countries.

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[47] This period was also studied, with less formal econometric techniques, by Garber and Grilli (1986).

[48] The Belmont-Morgan contract refers to the bond issue of February 1895, in which the U.S. Treasury used the services of a syndicate of private bankers, represented by J.P. Morgan and A. Belmont. The contract stipulated the purchase of gold coins by the Treasury, in exchange for long-term bonds. What the syndicate did, in fact, was to grant the Treasury a line of credit (in gold) for the duration of the contract; this line of credit was de facto equivalent to a bond issue. The contract enabled the Treasury to secure short-term financing without the explicit approval of the Congress.

Speculative Attacks on a Target Zone

The literature on fixed exchange rates has usually modeled the policy of fixing the exchange rate by having the policy authority adopt a particular parity for the exchange rate and by standing willing to buy or sell foreign exchange to maintain this price. In actual practice, such as in the Bretton Woods system or the exchange rate mechanism in the European Monetary System, the parity commitment involves announcing a range for the exchange rate and intervening to preserve this range. Such a policy has been termed a target zone for the exchange rate, and a large literature has grown up recently studying the behavior of the exchange rate in such regimes.

One of the important insights of the target zone literature has been that a credible target zone would stabilize exchange rate movements within the zone—a phenomenon described by Krugman (1991) as the "honeymoon effect." In subsequent work, Krugman and Rotemberg (1990) studied target zones that were less than perfectly credible, because the reserves committed to the defense of the zone were limited. In the Krugman-Rotemberg scenario an exchange rate target zone might collapse exactly as the theoretical fixed rate regime collapses in a final speculative attack and a return to a flexible exchange rate (see Flood and Garber (1991)).

In their example, Krugman and Rotemberg showed that limited reserves and the possibility of a speculative attack weaken the honeymoon effect. With the possibility of a speculative attack, agents are not certain of an effective forthcoming intervention to preserve the zone. Therefore, agents' expectations are less "dogmatic" than in a zone of certain permanence. In a permanent zone, agents always expect the exchange rate to be moved back toward the center of the zone when the rate drifts toward the edges. Such rationally regressive expectations are responsible for the honeymoon effect—a shock that in the absence of the credible zone would move the exchange rate up by (say) 10 percent has a smaller effect on the exchange rate in a credible zone because the shock sets into motion the expectation of the return of the exchange rate toward its initial level. Once the zone is not perfectly credible, however, the expected return of the exchange rate is dampened, and so the honeymoon effect is less powerful. The conditions under which credibility of the zone can be enhanced remain an important issue.

The Gold Standard Paradox

Suppose that a small country is operating under a fixed exchange rate and the country's demand for money is rising secularly faster than the domestic credit component of its money supply. The country can expect to gain international reserves over time and it might expect its fixed rate to be indefinitely viable. But suppose also that the country experiences a temporary downward disturbance in money demand that is large enough to exhaust its stock of reserves. In the long run the country's fixed rate is still viable, but in the short run, since reserves are exhausted, the country may have to abandon the fixed rate regime. When the country switches to a flexible exchange rate, the long-term expected increase in the excess demand for money implies that the currency will be stronger in the forward market than in the spot market, or that domestic interest rates will fall below world interest rates. The reduction in domestic interest rates following the abandonment of the parity will therefore increase money demand and appreciate the domestic currency relative to the fixed rate. The gold standard paradox refers to a situation where the fixed rate system would collapse and, following the collapse, the domestic currency would become more valuable.

Two "resolutions" to this paradox have been offered in the literature. The first is the Buiter-Grilli (1991) solution, which works only in a zero-interest environment. The second type of solution is the Salant (1983) price-fixing rule as applied by Krugman and Rotemberg (1990). This solution consists in a change in the rules of the game—that is, the implementation of a rule that sets a floor on the domestic currency price of reserves and ensures the impossibility of a speculative attack when the price of reserves falls at the instant of an attack. However, analytical solutions have so far been obtained only in cases where fundamentals follow some simple stochastic processes.

Reputation as a Deterrent to Speculative Attacks

In line with recent developments in the macroeconomic policy game literature, another potentially fruitful line of enquiry could be to examine the effect of exchange rate credibility on balance of payments crises.[49] A fixed exchange rate regime will, in general, never carry full credibility. Official pronouncements notwithstanding, there is always a risk that when official reserves are being run down, a country will opt to alter its exchange rate rather than its monetary and/or fiscal policy. When agents perceive that the authorities' commitment—and ability—to maintain a fixed exchange rate is weak, speculative attacks may occur. Such attacks

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[49] See Blackburn and Christensen (1989) for a general review of these issues, and Andersen and Risager (1991) for an analysis of credibility factors in the context of exchange rate management.

may take place, in particular, when the competitiveness of a high-inflation country has been eroded by adherence to the nominal exchange rate parity. This will typically reduce the degree of confidence in the existing exchange rate and will raise expectations that the currency will be devalued. A speculative attack can therefore be self-fulfilling because it may lead to an eventual exhaustion of the authorities' foreign exchange reserves, leaving them with little choice but to devalue (see Wood (1991)). Such a situation may be exacerbated if price setters incorporate the possibility of a devaluation in their pricing procedures, thereby adding further inflationary pressure. An important issue in this context is the extent to which reputational factors (such as membership in a currency union, or the appointment of a "conservative" central banker, as suggested by Rogoff (1985)) may mitigate the credibility problem and ensure the viability of a fixed rate regime.

Econometric Testing of Collapse Models

As discussed in the previous section, most empirical studies on balance of payments crises have been conducted in a developing country context. The existing literature has, however, typically ignored the critical role often played in these countries by the parallel market for foreign exchange in diffusing speculative pressures on the official parity—a mechanism that has been formally examined by Agénor and Delbecque (1991).[50] If foreign exchange is rationed in the official market, an expansionary credit policy will depreciate the parallel exchange rate. The resulting increase in the premium will raise prices, appreciate the real exchange rate, and encourage diversion of export proceeds from the official to the parallel market—consequently accelerating the rate of reserves loss and precipitating the collapse of the official exchange rate. A devaluation entails a fall in the premium in the short-run,[51] but the parallel rate will continue to depreciate—and reserves will continue to fall—if credit policy remains expansionary. As in the standard model of balance of payments crises, a fixed exchange rate system is viable only if the authorities are able to maintain fiscal and monetary discipline. This analysis suggests that future empirical research on balance of payments

[50] The model developed by Agénor (1990) treated reserves as exogenous and focused on the behavior of the exchange rate spread. In Agénor and Delbecque's (1991) model, the premium and net foreign assets of the central bank were simultaneously determined, by explicitly considering fraudulent trade transactions.

[51] Empirical evidence that the parallel market premium falls following an official devaluation in developing countries has been provided by Edwards and Montiel (1989).

crises in developing countries should aim at explaining simultaneously the behavior of the parallel market premium and foreign exchange reserves.

V. Concluding Comments

This paper has provided an overview of recent theoretical and empirical developments in the literature on speculative attacks in foreign exchange markets and balance of payments crises. A simple analytical model was developed to describe the process leading to such crises. The analysis showed that under perfect foresight about the policy rule pursued by the monetary authorities, an exchange rate regime shift from a fixed to a floating regime is preceded by a speculative attack on the currency. Moreover, the timing of such attacks is entirely predictable; intertemporal arbitrage ensures that the regime shift occurs "smoothly." Its timing was shown to depend on the stock of foreign reserves committed by the central bank to the defense of the fixed exchange rate regime.

The second part of the paper dealt with various extensions to the basic analytical model. The third part focused on empirical evidence on the collapse of exchange rate regimes, while the fourth part discussed various perspectives for future research, notably the role of reputational factors as a deterrent to speculative attacks, and the link between models of balance of payments crises and the recent literature on target zones.

The analysis revealed some major policy implications for macroeconomic policy under a fixed exchange rate regime. Balance of payments crises may be the equilibrium outcome of maximizing behavior by rational agents faced with inconsistent monetary and exchange rate policies, rather than the result of exogenous shocks. Measures such as foreign borrowing and capital controls may temporarily enhance the viability of a fixed exchange rate, but will not prevent the ultimate collapse of the system if fundamental policy changes are not implemented.[52] In the process leading to an eventual collapse, speculative runs are likely to occur recurrently, reflecting alternative periods of confidence and distrust in the ability of the central bank to defend the official parity. The more delayed fundamental policy measures are, the higher will be the potential costs (in terms of lost output, for instance) of a regime collapse. Moreover, viability of a fixed exchange rate regime does not only depend on credit growth but will more generally be affected by the overall consistency and sustainability of the macroeconomic policy mix, which

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[52] The imposition of capital controls may even backfire—that is, bring forward the collapse of the regime—if the measure is anticipated well in advance.

in turn will depend on the nature of the intertemporal budget constraints faced by the government and private agents.

An important aspect of the recent literature on balance of payments crises is the emphasis on real effects of an anticipated collapse. Such effects can be quite pronounced, and may imply dramatic fluctuations in real interest rates and the real exchange rate. Such features have often been observed in high-inflation economies implementing stabilization programs based on an exchange rate freeze—such as the Cruzado plan implemented in Brazil in 1986–87. Collapse models may therefore provide important insights in understanding why some exchange rate based stabilization programs have failed in their objectives.[53]

APPENDIX

Real Effects of an Anticipated Regime Collapse

This Appendix shows briefly how the model presented in Section I can be extended so as to endogenize output, the real exchange rate, and the trade balance. Two important assumptions are introduced in the extended model. First, private agents are now assumed to hold domestic long-term and short-term bonds, which are imperfect substitutes. Long-term bonds are not traded, while short-term bonds are perfectly substitutable to foreign (short-term) bonds.[54] Second, nominal wage contracts are assumed to be forward looking. This assumption implies that wages are allowed to jump in anticipation of future movements in prices.[55]

Formally, the equations of the model are given by

$$y_t = c_0 + c_1(s_t - p_t) - c_2(r_t - \dot{p}_t), \qquad c_1, c_2 > 0 \tag{36}$$

$$p_t = \eta\omega_t + (1 - \eta)s_t, \qquad 0 < \eta < 1 \tag{37}$$

$$\omega_t = \lambda \int_t^\infty e^{\lambda(t - k)} E_t p_k \, dk, \qquad \lambda > 0 \tag{38a}$$

$$\dot{\omega}_t = \Psi(\omega_t - s_t), \qquad \Psi \equiv \lambda(1 - \eta) \tag{38b}$$

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[53] See Agénor and Bhandari (1991), Auernheimer (1987), and van Wijnbergen (1988, 1991) for recent attempts to discuss exchange regime collapse and stabilization issues.

[54] This specification implies that the nominal long-term interest rate is determined by the equilibrium condition of the domestic money market. For a model that also distinguishes between short- and long-term interest rates in a somewhat related context, see Turnovsky (1986).

[55] The wage-contracting formula is similar to that used in Willman (1988). The dynamics of Willman's model—which are discussed in the text—are, however, different from those described here.

$$\dot{R}_t \equiv T_t = b_0 + b_1(s_t - p_t) - b_2 y_t, \qquad b_1, b_2 > 0 \tag{39}$$

$$m_t - p_t = \phi y_t - \alpha i_t - \nu r_t, \qquad \phi, \alpha, \nu > 0 \tag{40}$$

$$m_t = \gamma D_t + (1 - \gamma) R_t, \qquad 0 < \gamma < 1 \tag{41}$$

$$\dot{D}_t = \mu, \qquad \mu > 0 \tag{42}$$

$$i_t = i^* + E_t \dot{s}_t, \tag{43}$$

where, in addition to the variables defined in the text, ω_t denotes (the log of) the nominal wage; r_t is the nominal long-term interest rate; and T_t is the trade balance (or net exports), expressed in foreign currency terms; i_t now denotes the short-term interest rate.

Equation (36) is similar to (21) in the text and relates aggregate demand to the real exchange rate and the real long-term interest rate. Equation (37) is a price-setting equation that relates domestic goods prices to a weighted average of wages and the price of imported inputs (with a foreign currency price set to zero, for simplicity). Equation (38a) defines forward-looking wage contracts as in Calvo (1983); equation (38b) results from differentiating (38a) with respect to time and substituting (37) in (38a). Equation (39) relates net exports negatively with economic activity and positively with the real exchange rate. Finally, equations (40) to (43) are similar to equations (1), (2), (3), and (5) in the text, respectively. However, equation (40) now indicates that the demand for money is inversely related to both short- and long-term interest rates, while equation (43) assumes perfect substitutability only between domestic short-term bonds and foreign bonds.

Solving for r_t from (40), substituting the result in (36), and using (37)–(39) with all constant terms set to zero yields

$$\begin{aligned}\dot{R}_t \equiv T_t = {} & \beta_1(s_t - \omega_t) - \beta_2[((1 - \eta) + \alpha/\nu)\dot{s}_t \\ & + \eta\dot{\omega}_t + \{\gamma(D_0 + \mu t) + (1 - \gamma)R_t - \eta\omega_t - (1 - \eta)s_t\}/\nu],\end{aligned} \tag{44}$$

where

$$\beta_1 = \eta[b_1 - c_1 b_2/(1 + \phi c_2/\nu)]$$

and

$$\beta_2 = c_2 b_2/(1 + \phi c_2/\nu).$$

Assuming the conventional Marshall-Lerner condition to hold implies that β_1 is positive. Equation (44) determines the behavior of the trade balance as well as the change in reserves under fixed exchange rates. Setting $\dot{s}_t = 0$ and $s_t = \bar{s}$ yields from (38b) $\omega_t = (\omega_0 - \bar{s})e^{\Psi t} + \bar{s}$, which can be used to substitute out for $\dot{\omega}_t$ in (44), so as to give a differential equation in R_t.

To determine the time of regime collapse, we first calculate as before the shadow floating exchange rate. Under floating, the change in reserves is zero. Setting $\dot{R}_t = R_t = \overline{R} = 0$ in (44) yields

$$\Omega s_t + (1 - \Omega)\omega_t - \nu[(1 - \eta) + \alpha/\nu]\dot{s}_t = \gamma(D_0 + \mu t), \tag{45}$$

where

$$\Omega \equiv \nu(\eta\Psi + \beta_1/\beta_2) + (1 - \eta).$$

Equations (38b) and (45) define the dynamics of wages and the exchange rate. Setting $\delta = \nu[(1 - \eta) + \alpha/\nu]$, the dynamic system can be written as

$$\begin{bmatrix} \dot{\omega}_t \\ \dot{s}_t \end{bmatrix} = \begin{bmatrix} \Psi & -\Psi \\ (1 - \Omega)/\delta & \Omega/\delta \end{bmatrix} \begin{bmatrix} \omega_t \\ s_t \end{bmatrix} + \begin{bmatrix} 0 \\ -\gamma(D_0 + \mu t)/\delta \end{bmatrix}. \tag{46}$$

This system is globally unstable, since both variables are forward looking. Imposing stability yields the solutions

$$s_t = \gamma D_0 + \gamma\mu[\delta - (1 - \Omega)/\Psi] + \gamma\mu t \tag{47a}$$

and

$$\omega_t = \gamma D_0 + \gamma\mu(\delta + \Omega/\Psi) + \gamma\mu t. \tag{47b}$$

The solution for s_t can be used to calculate, as before, the collapse time. From equations (37) and (47a)–(47b), the behavior of prices and the real exchange rate, $(s_t - p_t)$, can also be determined.

Assume now that wages are backward looking, so that equation (38a) is replaced by

$$\omega_t = \lambda \int_{-\infty}^{t} e^{\lambda(k - t)} E_t p_k \, dk, \tag{48a}$$

which yields, under perfect foresight

$$\dot{\omega}_t = \Psi(s_t - \omega_t), \qquad \Psi \equiv \lambda(1 - \eta). \tag{48b}$$

The dynamic system can be written in a form similar to equation (45), but the coefficients in the first line of the general matrix are now given by $(-\Psi, \Psi)$. The system is now saddlepoint stable. Denoting by ρ the negative root, the solution for the exchange rate is now given by

$$s_t = [(\Psi + \rho)/\Psi]Ae^{\rho t} + \gamma D_0 + \gamma\mu(\delta - \Omega/\Psi) + \gamma\mu t, \tag{49}$$

where A is an arbitrary constant, which can be determined by imposing an initial condition on wages. An explicit solution for the collapse time cannot be derived analytically but can be determined graphically at the intersection of the curve $[(\Psi + \rho)/\Psi]Ae^{\rho t}$ and the straight line, $\bar{s} - \gamma D_0 - \gamma\mu(\delta - \Omega/\Psi) - \gamma\mu t$.

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