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SPECULATIVE ATTACKS: FUNDAMENTALS AND SELF-FULFILLING PROPHECIES

Robert P. Flood
Nancy P. Marion

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ABSTRACT

We develop a modified "first-generation model" in order to understand better the 1994 Mexican peso crisis as well as aspects of the European currency crises in 1992-93. We introduce the assumption that the speculative attack is sterilized by the domestic monetary authority, we incorporate a stochastic risk premium, and we allow for some price stickiness. The modified model shows that macroeconomic policies inconsistent in the longer run with a fixed exchange rate can push the economy inevitably towards a currency crisis, but it also demonstrates how a government currently following consistent macroeconomic policies can suddenly face a speculative attack triggered by a large shift in speculative opinion. However, the ability of a sudden shift in speculative opinion to trigger an attack is bounded by the position of fundamentals. Thus an attack does not require a later change in policies to make it profitable.

Robert P. Flood
Research Department
International Monetary Fund
700 19th Street, NW
Washington, DC 20431
and NBER
rflood@imf.org

Nancy P. Marion
Department of Economics
Dartmouth College
Hanover, NH 03755
nancy.marion@dartmouth.edu

I. INTRODUCTION

The recent currency crises in Europe and in Mexico have renewed efforts to understand and control the forces underlying speculative attacks on fixed exchange rates. Until the European crises in 1992-93, there was agreement that speculative attacks occur because governments run macroeconomic policies inconsistent in the longer term with the fixed exchange rate. For example, a government might monetize a large fiscal deficit. Over time, excessive money growth leads to reduced international reserve holdings and eventually triggers an attack by speculators. The government abandons the fixed exchange rate and the currency depreciates.

The European experience and the 1994 Mexican peso crisis forced economists to rethink the cause of speculative attacks. Many of the European countries, and later Mexico, were running disciplined macroeconomic policies when their currencies were attacked. If inconsistent macroeconomic policies are not in place to push an economy towards a currency crisis, what causes an attack? Some economists now believe that a currency crisis can be an unpredictable event, not forced by movements in past or current fundamentals. Instead, a spontaneous attack may pull the country off a fixed exchange rate if it brings about a future change in macroeconomic policies.

Models that assume inconsistent government policies *push* the economy towards a currency crisis are called "first-generation models." Developed in the 1980s, these models have represented the mainstream view about currency crises for more than a decade.[1] Models that assume a currency crisis can arise even when macroeconomic policies are consistent with the fixed exchange-rate policy, and that the attack itself *pulls* the economy toward adopting more expansionary policies that validate it are called "second-generation"

[1]The first-generation models are surveyed by Agenor, Bhandari and Flood (1992). A notable example is Krugman (1979), which was inspired by Salant and Henderson (1978) and simplified by Flood and Garber (1984a).

models. These models are being used to interpret the European and Mexican currency crises of the 1990s.[2]

One important feature of the second-generation models is the role for self-fulfilling expectations. For example, if speculators suddenly and arbitrarily expect a currency to depreciate, a government must mount a costly defense of the fixed exchange rate. This defense may push the costs of fixing the exchange rate above the benefits, especially if a country is at the bottom of the business cycle, faces election pressures, has a fragile banking sector, or is otherwise constrained. Because a change in private-sector expectations alters the cost-benefit calculation and may lead the government to abandon the fixed exchange rate, the crisis is arbitrary in its timing. Even governments with disciplined stabilization policies may be susceptible to successful attacks.

However, as pointed out by Krugman (1996, p. 27), the multiplicity of possible attack times in these stories arises "precisely because a speculative attack may induce a government to change its policy," thereby justifying the attack *ex post*. In the absence of an attack, the fixed exchange rate can be sustained indefinitely. The post-attack depreciation represents a move to a new equilibrium only if other nominal values also adjust subsequently. The problem is that empirical support for such behavior is far from overwhelming, since expansionary policies often fail to materialize after speculative attacks (Eichengreen, Rose and Wyplosz, 1995).

The second-generation models are to be credited for focusing attention on two previously neglected points: (1) political, business-cycle and banking considerations may make it impossible to mount a traditional market-oriented defense of a fixed exchange rate; and (2) highly volatile shifts in speculative opinion might bring down an otherwise viable fixed exchange rate. Yet their requirement that post-attack policies become more

[2]See, for example, Obstfeld (1986, 1991, 1994), Calvo (1995), Jeanne (1995), Bensaid and Jeanne (1995) and Sachs, Tornell, Velasco (1995). These models built on early work done by Flood and Garber (1984b).

expansionary, thereby validating speculators prior beliefs that the currency will depreciate, is problematic.[3]

Ideally, a model of speculative attacks should capture several empirical features. It should recognize a role for domestic considerations, since these often constrain the authorities from undertaking a strong defense of the fixed exchange rate. It should incorporate realistic macroeconomic policies. Expansionary macroeconomic policies inconsistent in the longer run with a fixed exchange rate may be in place to push the economy towards a currency crisis, but they need not be operating currently to trigger an attack, nor must they necessarily follow an attack. In addition, the model should permit large shifts in speculative opinion to trigger a speculative attack.

The model we develop below is a modified first-generation model. We believe that it is a useful framework for understanding the 1994 Mexican peso crisis as well as aspects of the European crises. We adopt the first-generation model's focus on speculators and the profits available to them. If there is no profit for speculators, there is no attack. Once profit is available, the speculators pounce. The model shows how macroeconomic policies inconsistent in the longer run with a fixed exchange rate can push the economy inevitably towards a currency crisis. It also demonstrates how a government currently following consistent macroeconomic policies can suddenly face a speculative attack triggered by a large shift in speculative opinion. The ability of a sudden shift in speculative opinion to trigger an attack is bounded by the position of fundamentals, however. For an attack to succeed, it must be the case that historical or current macroeconomic policies have made the exchange rate vulnerable to an attack. Consequently, an attack does not require a later change in policies to make it profitable.

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[3]It might be argued that the post-attack depreciation itself is the relevant expansionary policy. That argument requires either that the real exchange rate be misaligned prior to the depreciation, which would be a fundamentals problem, or that domestic prices be increased after the depreciation, which would show up as a post-attack policy validation.

Our modified first-generation model recognizes the constraints imposed by domestic considerations by assuming that the authorities sterilize continually to keep the monetary base on the desired growth path. Such sterilization accords well with actual events in Europe and Mexico.[4] The monetary effects of a speculative attack are also sterilized fully. To contrast our story with the second-generation models and to conform more closely to actual events, government stabilization policies are not made more expansionary after the attack. Indeed, we assume government policies are invariant to speculative attacks.

While second-generation models suggest that the attack time is not uniquely pinned down because of the interaction of policymakers and the private sector, we attribute the non-uniqueness of attack time ("multiple equilibria") entirely to private speculative behavior. Thus we move the focus away from policy-induced multiple equilibria and toward private sector-induced multiple equilibria. In our modified model, there can be a broad range of parameters and fundamentals over which currency crises can, but need not, occur, and this range is determined, in part, by agents' perceptions of risk. If agents suddenly perceive their environment to be riskier, that will condition their behavior and will influence the time when a speculative attack can be successful. Political or economic events or even sunspots can trigger this revision in perceptions about risk. If conditions are right, the increased perception of risk can result in a matching increase in observed risk. We model this behavior by incorporating a stochastic risk premium into relative asset returns. The stochastic risk premium introduces a nonlinearity into the money market and leads to multiple equilibria.

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[4]When sterilization operations are incorporated into existing first-generation models, it makes a fixed exchange rate extremely precarious regardless of the amount of international reserves available to the authorities or the behavior of other economic fundamentals. For example, Flood, Garber and Kramer (1996) show that in the traditional first-generation model, if the public knows an attack on the fixed exchange rate regime will be sterilized completely, the fixed rate regime will be stillborn regardless of the exchange rate chosen for fixing and the size of the finite reserve stock committed to preserving the fixed exchange rate.

II. THE MODEL

We study a stochastic, discrete-time model of an open economy with a fixed exchange rate. Agents have rational expectations and know the fixed exchange rate will be abandoned should the central bank run out of reserves.[5] There is uncertainty about fundamentals, and this uncertainty influences asset returns and price-setting behavior. There is a time-varying risk premium attached by the marginal investor to domestic-currency assets. There is also some price stickiness in the market for domestic goods. The monetary authority conducts sterilization operations in order to keep the monetary base on its desired growth path regardless of what happens to the exchange-rate regime. In the benchmark case, growth of the monetary base is zero.

The model we present departs from the standard first-generation models, such as Krugman (1979) and Flood and Garber (1984a), in three important ways. The first departure is that the speculative attack is fully sterilized by the domestic monetary authority's purchase of domestic bonds. Consequently the monetary base does not drop when speculators purchase the monetary authority's international reserves in a speculative attack. Since sterilization moves the attack from the money market into the bond market, we introduce a conveniently-specified bond market by means of a bond-based risk premium.

The second departure is that we introduce a nonlinearity into the model through our specification of the risk premium. This nonlinearity generates multiple attack equilibria that can be influenced by speculative opinion.

The third departure is that we decompose the consumption bundle into home goods and internationally-traded goods and allow for price stickiness in home goods. The decomposition allows real exchange rates to change during a currency crisis and the

[5]With a bit more structure we could have the attack end in devaluation.

stickiness helps the model mimic actual real exchange rate and interest rate movements in the period leading up to an attack.

We now describe the model in detail.

A. Asset Market Structure

The principal equations of the model are:

$$(1)\quad m_t - q_t = -\alpha i_t + \delta\varepsilon_t; \qquad \alpha > 0,\ \delta \gtreqless 0$$

$$(2)\quad i_t = i^* + E_t(s_{t+1} - s_t) + \theta_t(c + b_t - b_t^* - s_t)$$

Equation (1) describes the domestic money market, where m_t is the log of the domestic high-powered money supply, q_t is the log of the domestic price level, and the demand for real money balances depends negatively on the domestic interest rate, i_t. Money demand is also influenced by a real shock, ε_t.

Equation (2) is the interest parity condition. Let s_t be the log of the exchange rate, quoted as the domestic-currency price of foreign exchange. Then the domestic interest rate deviates from the foreign interest rate, i_t^*, by the expected rate of change of the exchange rate, $E_t(s_{t+1} - s_t)$, plus a time-varying risk premium, $\theta_t(\ldots)$.

The risk premium is influenced by several factors---the relative private holdings of domestic and foreign government securities, agents' attitudes towards risk, and uncertainty about the future exchange rate.[6] The term $(b_t - b^*_t - s)$ describes the world-wide relative private holdings of government securities, where b_t is the log of world-wide private

[6] The assumption that the risk premium depends on relative supplies of government debt is familiar from the portfolio-balance models of Tobin (1969) and Branson (1968) and tested by Frankel (1984) and others. The assumption has not found much empirical support using data on developed countries. Werner (1996), however, has found such a risk premium works well for Mexico during the 1992-94 period.

holdings of domestic government securities and $b_t^* + s_t$ is the log of world-wide private holdings of foreign government securities expressed in domestic-currency terms.

The term θ_t summarizes how desired asset holdings are influenced by tastes toward risk and uncertainty about returns. In the example we develop below, we set $\theta_t = zV_t(s_{t+1})$. In this expression for θ_t, z is a measure of risk aversion, such that if investors are risk neutral, z = 0, and V_t is the variance operator conditional on information available at time t.

θ_t(....) is a tractable log-linearization of elements that may influence attitudes toward asset risk. It has the following properties: (1) in a world of certainty ($V_t(.) = 0$) or risk neutrality (z = 0), the risk premium is zero; (2) the constant c is sufficiently large to ensure that a bigger θ increases the risk premium; and (3) neither aggregate world wealth nor country shares in world wealth are important determinants of the risk premium.[7] The functional form for the risk premium is adopted primarily for tractability.[8]

B. Goods Market Structure

The log of the domestic price level q_t is a weighted average of the domestic price of domestically-produced goods, p_t, and the domestic-currency price of imported goods, $p_t^* + s_t$, where p_t^* is the log of the foreign price level:

$$(3)\quad q_t = \eta\, p_t + (1 - \eta)(p_t^* + s_t)\,.$$

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[7]The third property is simply required for tractability. It holds only if agents residing in different countries hold proportionately identical portfolios. In reality, agents hold portfolios heavily biased towards domestic assets.

[8]Our risk premium results from the maximization of $E_tW_{t+1} - gV_t[W_{t+1}/W_t]$, where E_t is the expectations operator and W_t is real wealth. Goods prices are sticky. We log-linearize the resulting asset demand function by setting $S_tB_t^* / W_t = \alpha_0 + \alpha_1(s_t + b_t^* - b_t)$, where upper-case letters represent variables in levels, lower-case letters represent variables in logs, and $\alpha_1 = 1$ for simplicity.

We build in some price stickiness by assuming p_t is set at time t-1 at a value that is expected to clear the market for home goods at time t. If the excess demand for home goods depends on relative prices, $p_t - p^*_t - s_t$, and p^*_t and other influences on excess demand are normalized to zero in logs, the expected market clearing price for home goods is:

$$(4)\quad p_t = E_{t-1}\, s_t.$$

The price of domestically-produced goods will change only if agents anticipate a change in the exchange rate. The price of imported goods may change unexpectedly, however, due to exchange-rate surprises.

C. Asset Accounting

It is useful to specify government balance sheets first in levels of the variables and then move to the appropriate log-linearizations. In levels, the domestic high-powered money supply, M_t, is equal to the level of domestic credit held by the central bank, D_t, plus the book value of international reserves held by the central bank, R_t. In logs, we let $m_t = \omega d_t + (1-\omega)r_t$, where $d_t = \log D_t$, $r_t = \log R_t$, and ω is the share of domestic credit in the money supply at the point of linearization, $\omega = D/M$.

The outstanding supply of domestic-currency government bonds is denoted by H_t. World-wide private holdings of these bonds are B_t and the domestic monetary authority's holdings of these bonds are denoted as domestic credit, D_t. Letting $h_t = \log H_t$ and $b_t = \log B_t$, we log-linearize the bond market as: $b_t = \gamma h_t - (1-\gamma)d_t$, where $\gamma>1$ is the ratio H_t/B_t at the point of linearization.

One final piece of structure involves the underlying exogenous process driving the economy. We assume that real government expenditure is financed partly by issuing nominal government bonds and partly by levying taxes. Taxes increase with the stock of outstanding government bonds so that the deficit does not grow without bound and transversality conditions apply.

Recalling that h_t is the log of outstanding interest-paying nominal claims on the domestic government, let these bonds follow the process:

$$(5)\quad h_t = \mu + \rho h_{t-1} + \varepsilon_t; \quad u > 0, \quad 0 < \rho < 1,$$

where $\mu/(1-\rho)$ is the steady-state log-level of domestic bonds, ρ is the degree of autocorrelation in the bond process, and ε_t is the shock to the bond process. For example, a negative productivity shock that reduces tax revenues will cause bond financing to increase unexpectedly, and this disturbance permanently feeds into the bond process to cover next period's unexpectedly higher interest payments. The negative productivity shock also reduces the demand for money, so in this example the parameter δ in the money demand function is negative. The shock to the bond process can also arise from an unexpected increase in government expenditures that is financed in part by bond sales. In this case, the disturbance increases the demand for money, so the parameter δ in the money demand function is positive.

We assume that the monetary authority purchases government securities to keep the domestic high-powered money supply constant, $m = \overline{m}$. This policy requires full sterilization of international reserves.

Notice that ε_t is the only stochastic element in the model.[9] The precise distribution of ε_t will turn out to be crucial, but we will turn to that later.

[9]We could incorporate many different types of shocks, but doing so would increase the dimensionality of the problem and make it impossible to graph our results.

III. Policy

We postulate lexicographic government preferences concerning the fiscal deficit, monetary policy and the fixed exchange rate. The fixed rate, $\bar{s}$, gets the lowest priority. When international reserves hit some lower limit, the government decides against borrowing reserves or changing domestic interest rates. Instead, the fixed rate is abandoned and the exchange rate is allowed to float freely thereafter.[10]

Recall that the government operates in asset markets so as to keep the domestic high-powered money supply constant. This monetary policy will be maintained even if there is a speculative attack. Although having policy change with a speculative attack is an essential feature of second-generation models, Eichengreen, Rose and Wyplosz (1994, 1995) find that "government budgets and the growth rate of domestic credit are essentially unrelated to exchange-rate episodes." (1995, p.293) Consequently, while the government lets the exchange rate float freely after a successful attack, we assume other government policies are invariant to the attack.

IV. What Triggers An Attack?

If domestic bond expansion exceeds foreign bond expansion, then over the longer run it will become increasingly difficult to maintain a fixed exchange rate since portfolio reallocation by the private sector will drain international reserves.[11] The crucial question, of course, is when will the fixed exchange rate break down?

The simple answer is that it will break down whenever it is worthwhile for speculators to attack the currency, and that will happen when speculators believe the foreign exchange they buy from the central bank at a fixed price can immediately be resold

[10]We set the lower limit on the reserve level at zero. Endogenizing the lower limit does not affect the main results.

[11]This condition is specific to our assumed functional forms.

at a higher price. In other words, the attack will take place when the attack causes the currency to depreciate.

Following Flood-Garber (1984a), we define the shadow exchange rate, $\tilde{s}$, to be the rate that would prevail at time t if the fixed exchange rate were attacked, international reserves were driven to their lower bound, and the exchange rate were allowed to float freely thereafter. The condition for an attack is that the shadow rate exceed the fixed rate ($\tilde{s}_t > \bar{s}$).

In order to determine the time of attack and to analyze behavior prior to the attack, we must solve the model for the shadow exchange rate and determine when it exceeds the fixed rate. It turns out that the shadow rate is very simple to solve when prices are set internationally ($\eta = 0$) and more complicated to solve when prices of domestically-produced goods are sticky. The reason for the difference is that with internationally set prices, the shadow rate does not incorporate any elements of the fixed-rate system. All variables used to determine the shadow rate at time t are known at time t-1 based on forward-looking prospects. When some prices are sticky, elements of past beliefs enter into the solution for the shadow rate. While price stickiness complicates the solution for the shadow rate, it also allows the model to mimic two feature of many attack episodes, namely the rise in domestic interest rates and the appreciation of the real exchange rate prior to the attack. When all prices are set internationally, the domestic interest rate can never rise prior to the attack in the absence of foreign price increases since the interest rate must equate the demand for real money balances with the supply, and the supply of real money balances is fixed when the central bank fully sterilizes and the exchange rate is fixed. Internationally set prices also rule out real appreciation since purchasing power parity must hold. We therefore incorporate sticky prices. Since the model's main results obtain in the special case where nominal money balances are deflated by the price of home goods ($\eta = 1$), we present this case below. This case corresponds to the one used by Dornbusch (1976). We record in the appendix the shadow rate solution for the case $0 \leq \eta \leq 1$.

In the case where $\eta = 1$, we can use (3) and (4) to obtain:

$$(6)\quad q_t = p_t = E_{t-1}s_t.$$

The domestic price level is tied to beliefs about the exchange rate that were formed in the previous period. Formally, we have:

$$(7)\quad p_t = (1-\pi_{t-1})\bar{s} + \pi_{t-1}E_{t-1}(\tilde{s}_t \mid \tilde{s}_t > \bar{s}),$$

where π_{t-1} is the probability at time t-1 that an attack will take place at time t and $E_{t-1}(\tilde{s}_t \mid \tilde{s}_t > \bar{s})$ is the t-1 expectation of next period's (flexible) exchange rate, conditional on the exchange rate exceeding $\bar{s}$ so the attack occurs. The probability estimate and the conditional expectation of the exchange rate will change with the state of the economy.

To aid in solution of the shadow rate, we linearize the cumulative distribution for the stochastic variable ε by assuming ε has a uniform distribution centered on zero with upper bound w and lower bound -w. Formally, if $f(\varepsilon)$ is the probability density associated with the outcome ε, then

$$(8)\quad f(\varepsilon) = 0 \;;\quad \varepsilon < -w$$

$$f(\varepsilon) = 1/(2w) \;;\quad -w \leq \varepsilon \leq w$$

$$f(\varepsilon) = 0; \quad \varepsilon > w$$

V. Solving for the Shadow Rate

The model is linear, so we propose a linear solution for the shadow exchange rate of the form:

$$(9)\quad \tilde{s}_t = \lambda_0 + \lambda_1 h_{t-1} + \lambda_2 \varepsilon_t.$$

The solution method is described in the appendix. It exploits the assumption that the stochastic variable ε has a uniform distribution. In the solution for the shadow rate in (9),

$$(10)\quad \lambda_0 = \text{a constant term} \quad \text{(see appendix)}$$

$$(11)\quad \lambda_1 = \frac{\alpha\gamma\rho\theta}{[\alpha(1+\theta)+\frac{\overline{\pi}}{2}+\frac{1}{4}-\alpha\rho]} \geq 0$$

and λ_2 satisfies the fifth-order polynomial:

$$(12)\quad c_0 + c_1\lambda_2 + c_2\lambda_2^2 + c_3\lambda_2^3 + c_4\lambda_2^4 + c_5\lambda_2^5 = 0$$

where the values of the c_i coefficients are given in the appendix.

Equation (12) is consistent with five different values of λ_2, but some of these values are not economically sensible. Excluding solutions that have imaginary values leaves us with the possibility of three solutions for a range of parameter configurations. Nothing seems to preclude any of these solutions. We thus have the potential for multiple equilibria even though government macroeconomic policies remain invariant to the speculative attack.

In the special case where the disturbance to the bond process is uncorrelated with money demand ($\delta=0$), one of the feasible roots for λ_2 is zero. When λ_2 is zero, the risk premium term θ and the coefficient λ_1 also become zero , so that one of the shadow-rate solutions is deterministic. We shall call this solution the "fundamentals solution," since it is just a constant influenced by the value of the nominal money stock, the level of the fixed exchange rate, the foreign interest rate, and the model parameters. The other two shadow-rate solutions can be classified as "second-moment bubbles." They exist because the variance of the exchange rate today depends on the expected variance of the exchange rate in the future. These bubbles are not to be confused with the more familiar first-moment bubbles that come about when the exchange rate today depends on the expected future exchange rate. In contrast to first-moment bubbles, these second-moment bubbles have no intertemporal dimension and do not violate transversality conditions.

A. Two Examples

Solutions for the shadow rate involve finding economically sensible values of λ_2 that obey the fifth-order polynomial (12). It is well known that constant coefficient polynomials beyond order three generally do not have explicit reduced-form solutions for the roots in terms of the constant coefficients. We therefore resort to numerical methods. We consider two examples to correspond to the cases where the shocks to money demand and the bond supply process are negatively correlated ($\delta<0$) and where they are positively correlated ($\delta>0$).

In the first example, we let $\delta=-0.025$ and we set [12]

$\alpha = 1$ (the semi-elasticity of money demand with respect to the interest rate)

$\mu = 1$ (the annual growth rate of domestic government bonds)

$\rho = .9$ (autoregressive coefficient in the bond supply process)

[12]In addition to the parameters listed below, we need to set variables such as i^*, $\bar{s}$, b^* and $\overline{m}$ in order to determine the constant term (λ_0) in the shadow rate equation (9). The Gauss program used to extract the roots and draw the subsequent polynominal figures is available from the authors.

$\gamma = 1.1$ (implying that domestic credit held by the central bank accounts for about 10 percent of the debt issued by the domestic government)

$z = 2$ (risk aversion parameter)

$w = 1$ (the distribution of the shock)

$\sigma_\varepsilon^2 = \frac{w^2}{3}$ (the variance of the shock ε that is uniform on $(-w, w)$).

The example is pictured in Figures 1-3. Figure 1 shows the fifth-order polynomial and Figure 2 zooms in on the left-hand part of Figure 1 to confirm pictorially that there are, in fact, three real roots. Figure 3 summarizes the most important aspects of some three-dimensional figure drawn in $(\tilde{s}_t, h_{t-1}, \varepsilon_t)$ space, where we can plot versions of equation (9). The three-dimensional picture (not drawn) consists of four planes. With $\tilde{s}_t$ as the vertical axis, the first plane is flat at the height $\tilde{s}_t = \bar{s}$. Call this the $\bar{s}$ plane. The other three planes are found by plotting equation (9) for the three different real values of the λ_2's. These planes are upward-sloping with respect to both h_{t-1} and ε_t. Call these planes the $\tilde{s}_t$ planes. Figure 3 is the view obtained from looking down on the three-dimensional figure.

The lines drawn on the $\bar{s}$ plane in Figure 3 represent where the three $\tilde{s}$ planes cut through the $\bar{s}$ plane; that is, the points in (h_{t-1}, e_t) space above which the shadow exchange rate exceeds the fixed exchange rate, triggering an attack.

Since on the lines

$$\bar{s} = \tilde{s} = \lambda_0 + \lambda_1 h_{t-1} + \lambda_2 \varepsilon_t,$$

we plot the lines as:

$$h_{t-1} = ((\bar{s} - \lambda_0)/\lambda_1) - (\lambda_2/\lambda_1)\varepsilon_t$$

where the horizontal axis on the $\bar{s}$ plane is centered on zero and measures 2w in length to conform with the uniform distribution of ε and the vertical axis on the $\bar{s}$ plane is positioned by the constant term, λ_0.

In the second example, we change δ to a positive value, setting δ=0.1. This example is pictured in Figures 4 and 5. Figure 4 shows the three real roots of the fifth-order polynomial and Figure 5, like Figure 3, is the view obtained from looking down on the three-dimensional figure. Note that when $\delta<0$, all three lines on the $\bar{s}$ plane have a negative slope, but when $\delta>0$, one line has a positive slope.

The key point illustrated by Figures 3 and 5 is that a $\tilde{s}$ plane can cut the $\bar{s}$ plane in one of three places. There are three lines drawn on the $\bar{s}$ plane that illustrate the three economically sensible solutions for the shadow rate such that the shadow exchange rate equals the fixed exchange rate. The speculative attack will take place when the state moves the $\tilde{s}$ plane above the relevant line drawn on the $\bar{s}$ plane. But which is the relevant line?

The model does not distinguish among them. Nevertheless, it is clear that line (a) requires a greater stock of outstanding domestic government debt (h) or a bigger shock (ε) or both to bring on the attack. If the economy's state (determined by h and ε) is below all three lines, then there can be no attack because the $\tilde{s}$ plane has not yet cut through the $\bar{s}$ plane. If the state is above all three lines, then there must be an attack because the $\tilde{s}$ plane is above the $\bar{s}$ plane regardless of whether it cut through at line (a), (b) or (c).

What about if the economy's state is somewhere above line (c) but not yet above line (b) or line (a)? Here we have the possibility of multiple equilibria. If agents expect the shadow rate to conform with the solution represented by line (c), the high-variance shadow-rate solution, then the attack will take place as soon as the $\tilde{s}$ plane cuts through the $\bar{s}$ plane at line (c). If, however, agents adopt a lower-variance shadow-rate solution, such as that represented by line (a), for example, there is no reason to attack the fixed exchange rate when the economy's state causes the $\tilde{s}$ plane to cut through the $\bar{s}$ plane at line (c).

Suppose that agents have in mind the low-variance shadow-rate solution represented by line (a) and that the state is on the $\tilde{s}$ plane somewhere above the region bordered by lines (a) and (c), having cut through the $\bar{s}$ plane at line (c). The economy is in a fragile position. The economy can maintain the fixed exchange rate as long as agents continue to expect a low-variance shadow rate. But if agents suddenly come to expect the high-variance shadow rate (line (c)), then the shadow exchange rate determined by the economy's state would exceed the fixed exchange rate and there would be an immediate and successful attack.

Thus if agents suddenly revise their expectations because they believe the foreign-exchange market has become riskier, the fixed exchange rate can collapse, producing the risk anticipated by the agents. It should be clear, however, that this possibility of a self-fulfilling collapse can only occur for certain states of the economy. For instance, if the economy's fundamentals are very sound, so that the state is in the "no-attack zone" below line (c), then even if agents suddenly come to believe the world is riskier (jumping from the low-variance shadow rate solution of line (a) to the high-variance shadow rate solution of line (c), for example), the fixed exchange rate will not collapse. Only if the economy's fundamentals deteriorate sufficiently to put the state in the "possible attack zone" (above line (c) but not yet above lines (a) and (b)) could a sudden adverse shift in expectations about risk trigger an attack. Note also that in this "possible attack zone" the collapse is initiated by a change in agents' beliefs about risk and does not require an *ex-post* change in government stabilization policies.

To summarize, the existence and relevance of multiple equilibria depend on (1) having the appropriate parameter values to give three real values for λ_2, (2) having agents adopt the low-variance shadow rate solution at the start, and (3) having the state take on a value such that the economy finds itself in the "possible attack" zone.

Multiple equilibria can be excluded if (1) the parameters of the model do not give multiple relevant solutions for the shadow rate, or (2) if the pre-attack state is not in the "possible attack zone." For example, in this model if θ is constant, then there are no multiple equilibria.

In this framework, a speculative attack can be caused by poor fundamentals because the state puts the economy into the "attack zone." Alternatively, the attack can be caused by a self-fulfilling shift in expectations because the state puts the economy into the fragile "possible attack" zone and agents suddenly shift from the low-variance shadow rate solution to a higher-variance one. It is not the case that any fixed exchange rate regime is subject to successful attack. Fundamentals must change enough to put the economy in the fragile zone.[13]

VI. The Mexican Experience

In this section, we consider how well key aspects of the Mexican experience are captured by our model. We focus on four areas: sterilization policy, interest rates, real exchange rates and international reserves.[14]

A. Sterilization Policy

The early first-generation models assume that the net domestic credit component of the monetary base is exogenous and unaffected by activity in the foreign-exchange market. International reserves are merely the residual that balances the domestic money market at the fixed exchange rate. At the time of the attack, there is a discrete drop in the money supply that reflects the sudden depletion of reserves.

The Mexican story was different in the 1992-1994 period. Both before and during the exchange-rate crisis, the authorities sterilized reserve losses, keeping the monetary base on a relatively smooth trend. (See Figure 6.) Our model captures this policy stance by assuming the monetary authority sterilizes fully to keep the monetary base at the desired level before, during and after the speculative attack.

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[13]In principle, the framework sometimes permits one to distinguish between an actual attack caused by fundamentals and one caused by a self-fulfilling shift in expectations. If one uses data to estimate the lambdas and finds that the economy was at the low-variance shadow-rate solution at the attack time, then the speculative attack was due to fundamentals. If the estimated lambdas indicate that the economy was at the high-variance shadow-rate solution, then the attack could have been brought on by fundamentals or by a sudden shift from the low-variance shadow-rate solution.

[14]Our description of the stylized facts draws heavily on IMF (1995).

The sterilization policy also sets the stage for the attack by tying the hands of the policymaker. After the Colosio assassination, the Mexican authorities could have defended the peso by tightening monetary policy or passively allowing the loss of international reserves to contract the monetary base. The government resisted monetary contraction in part because higher interest rates would have strained an already vulnerable banking system and conflicted with the goal of promoting economic activity in an election year. We capture these domestic constraints in a general way by requiring the central bank to keep the monetary base constant even as reserves decline.

B. Interest Rates

In the traditional speculative attack literature with perfect foresight, the nominal domestic interest rate is constant until the moment of attack. With uncertainty, the domestic interest rate rises with the approach of the attack because the conditional expected rate of change of the exchange rate rises as reserves are depleted.

The behavior of Mexican interest rates prior to the attack follows an interesting pattern. Figure 7 presents three-month rates on cetes, Tesobonos, and U.S. treasury bills. Cetes are peso-denominated government securities, while Tesobonos are peso-denominated government securities with the principal indexed to the U.S. dollar exchange rate. The spread between the interest rates on cetes and Tesobonos is an indicator of exchange-rate risk, while the spread between the rates on Tesobonos and U.S. treasury bills measures the risk premium. In early 1994, cetes interest rates were around 10 percent. They moved up to the 14-17 percent range in April, increasing the spread over Tesobono rates and U.S. treasury bill rates. However, these interest differentials narrowed somewhat in the second half of 1994 before shooting up at the time of the attack in December. The interest-rate differential between Tesobonos and U.S. treasury bills also widened after the Colosio assassination in March, 1994, narrowed after Zedillo was elected president in August, and shot up again at the attack time in December. The interesting feature of interest-rate behavior is that the market did not demand a very large premium for peso lending in the second half of 1994. Some observers have taken this pattern to mean that the currency crisis was unexpected by the markets.

In our model, the spread between the interest rate on domestic-currency assets and the risk-free foreign interest rate is accounted for not only by the expected rate of depreciation of the exchange rate, but by a time-varying stochastic risk premium. The risk premium depends in part on the relative supplies of interest-bearing domestic and foreign securities in the portfolios of the private sector. Suppose that in the period leading up to the speculative attack, private investors come to expect a depreciation of the domestic currency. By itself, that will raise domestic interest rates above the risk-free foreign interest rate as private investors sell domestic securities and purchase foreign securities. But since this portfolio reallocation entails a loss of international reserves, the central bank sterilizes the reserve loss by purchasing domestic securities. Consequently, the outstanding stock of domestic securities held by the private sector declines and one component of the risk premium falls. Thus, on net, the interest rate on domestic-currency assets might rise very little. Private investors also seemed to moderate their views about an expected depreciation of the peso in the summer of 1994, as evidenced by the narrowing spread between rates on cetes and Tesobonos in July. Since the model incorporates a time-varying probability of collapse that is influenced by investors' perceptions of risk, it can allow for an adjustment in expectations that gives lesser weight to the chance of a devaluation.

C. The real exchange rate

In the early first-generation attack models, the country experiencing an attack is a price taker and its real exchange rate, the domestic price level divided by the product of its trading partner's price level and the fixed exchange rate, is presumed to be fixed.

In Mexico, a large movement occurred in the real exchange rate after fixing the nominal rate because domestic inflation, while declining, exceeded inflation in its major trading partner(s). Figure 8 shows that Mexico's real effective exchange rate appreciated quite significantly after the peso was controlled in 1988. Our model gets the real appreciation in the pre-attack period, but not through the inflation channel. By allowing home-goods prices to be set a period in advance, domestic prices can rise prior to the attack if agents come to expect a depreciation of the home currency. We can get real exchange-rate appreciation via domestic inflation if we abandon our assumption of a constant monetary base and allow the monetary base to grow faster than its foreign counterpart. Such a modification is a straightforward extension, but we forego it here in order to keep the model as simple as possible.

D. International reserves.

First-generation attack models all show that international reserves decline in the period leading up to the currency crisis and fall precipitously at the time of attack as the central bank makes a last-ditch effort to defend the fixed exchange rate. The underlying reason for the reserve loss is the excess supply of money produced by monetization of the fiscal deficit.

Figure 9 shows gross and net Mexican international reserves since 1990. Net reserves built up over the 1990-93 period, reaching a peak of $25 billion in February, 1994. Subsequently, there was a dramatic decline. More than $3 billion in reserves was lost in March; more than $8 billion in April. After a lull, $4.5 billion was lost in November and finally $6.5 billion in December.

Our model captures the decline in reserves in the period leading up to the attack even though there is no monetization of the fiscal deficit. Instead, the government's bond-financing leads private investors to reallocate their portfolios. When private investors sell domestic securities for foreign securities, the central bank must exchange reserves for domestic currency at the fixed exchange rate. Consequently, the central bank's inventory of international reserves declines. If the central bank also sterilizes this reserve loss, the domestic interest rate may not rise sufficiently to coax private investors to hold the outstanding stock of domestic securities. As a result, portfolio reallocation efforts may continue, further draining reserves. The government's debt financing also generates expectations of a future currency depreciation that stimulates portfolio reallocation and drains reserves. If speculative opinion suddenly shifts, with investors perceiving more risk, there will be a massive portfolio reallocation that exhausts reserves and ends the central bank's ability or desire to defend the fixed exchange rate.

VII. Conclusion

The first-generation model of currency crises relies on deteriorating fundamentals as the underlying cause of speculative attacks. It also emphasizes that speculators trigger the attack in anticipation of large capital gains. We have modified the standard first-generation model under uncertainty to take into account the monetary authority's practice of sterilizing the effects of reserve changes on the monetary base. We have also modeled some stickiness in price-setting behavior that allows the real exchange rate to appreciate and the domestic interest rate to rise in the period leading up to the attack. Finally, we have included a time-varying stochastic risk premium that introduces a nonlinearity into the money market. This nonlinearity gives rise to self-fulfilling multiple equilibria *for some range of the fundamentals*. Multiple equilibria are generated solely by private sector behavior and do not require a change in government policy *ex post* to validate the attack. If private investors suddenly come to believe there is increased risk, that alone can lead to a self-fulfilling speculative attack if the economy's fundamentals have deteriorated to the point of putting the economy in a fragile state. While the risk-premium channel need not be the only source of nonlinearities, it is a sensible and convenient way to focus on self-fulfilling speculative attacks arising solely from private-sector behavior.

We close by making some comparisons of first-generation and second-generation models of currency crises. We try to be reasonably even-handed in our choice of comparisons but make no pretense of being fully objective.

1. Policy response to the crisis. This is perhaps the weakest point of the second-generation models. In order to generate interesting multiple equilibria, the second-generation models require either the expectation of a relaxation of some government policy in response to the attack, or a devaluation when none is called for by the fundamentals. Unless there are unmodeled nonlinearities in private behavior, an unwarranted devaluation necessitates later expansion of domestic nominal variables either by the government or by the private sector. Empirical evidence suggests that stabilization policies do not become more expansionary after speculative attacks. Certainly an expected expansion may not materialize in a few cases, but the lack of expansion when one is expected should not be the norm. The first-generation model, with and without modifications, assumes a constant government policy around the attack epoch.

2. Domestic constraints on policy actions. A fixed exchange rate is credible as long as markets believe that the authorities will do whatever is required to maintain it, regardless of the consequences. In the first-generation models, the size of the international reserve stock is the precise measure of this commitment. In reality, however, it is the strength of the commitment and not just the size of the reserve stock that determines a fixed exchange rate's viability. The second-generation attack models are strongest in this dimension. The essence of these models is to bring to the forefront the continual balancing of the benefits of the fixed exchange rate with other domestic objectives, such as high employment or the continued solvency of the banking system.

In the current paper, we pay some attention to domestic objectives by requiring the monetary base be invariant to foreign-exchange market events. This policy goes part way toward bringing domestic conditions into the determination of how long to maintain the fixed exchange rate, but their role is considerably understated.

3. Interest rates. Both first- and second-generation models do well at capturing the rise in domestic nominal interest rates as the attack approaches. The second-generation models show how a sudden change in speculative opinion can increase domestic interest rates so that the costs of maintaining the fixed rate exceeds the benefits. The modified first-generation model in this paper shows how the nominal domestic interest rate is influenced by two components, the conditional expected rate of change of the exchange rate and a time-varying stochastic risk premium. Depending on how these two components behave, the domestic interest rate can rise considerably or very little with the approach of the attack.

4. International reserves. The first-generation models come out better here. The Mexican reserve experience shown in Figure 9 shows reserves falling during 1994 and approaching a dangerously low level at year's end. According to the first-generation model, this type of reserve behavior is entirely expected. According to the second-generation models, the timing of this reserve behavior is either a coincidence or an inessential add-on. For the Mexican case, reserve movements clearly deserve to be center stage.

In the 1992 European case, reserves were also crucial, but in a different way from the prediction of the simplest models. As discussed in IMF (1992), German attempts to defend DM parities substantially increased their international reserve holdings. Sterilizing those reserve purchases put pressure on German interest rates and monetary targets. German reserve purchases were crucial to maintaining the parities, so when these purchases conflicted with other higher-priority policies, the parities were adjusted.

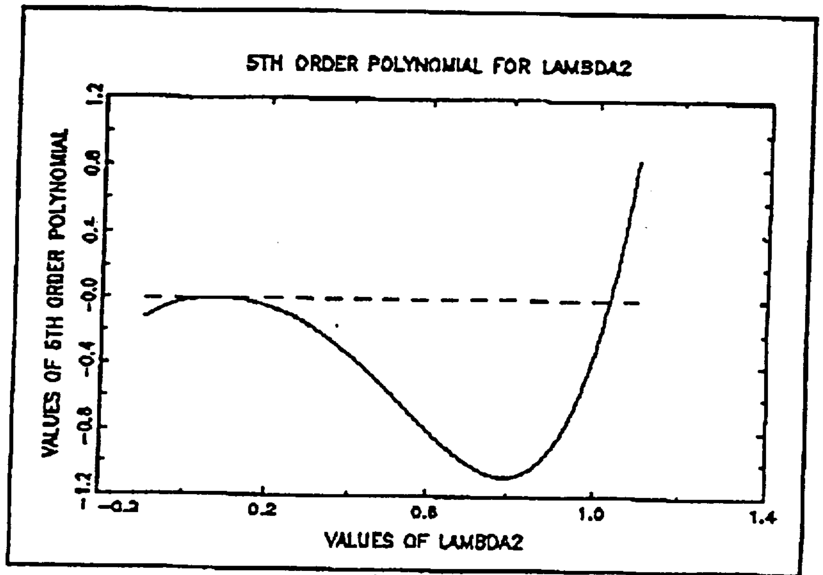


Figure 1
5th-Order Polynomial
Delta = -.025

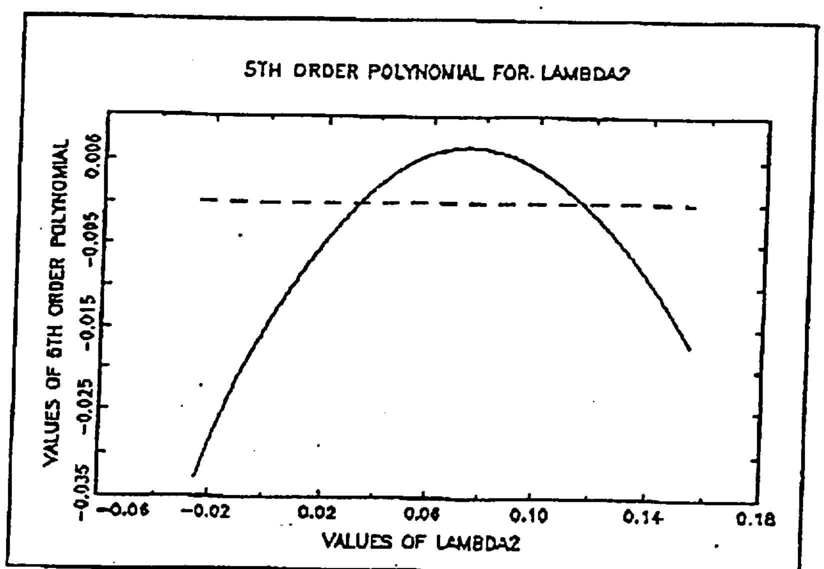


Figure 2
Zoom Check on Roots

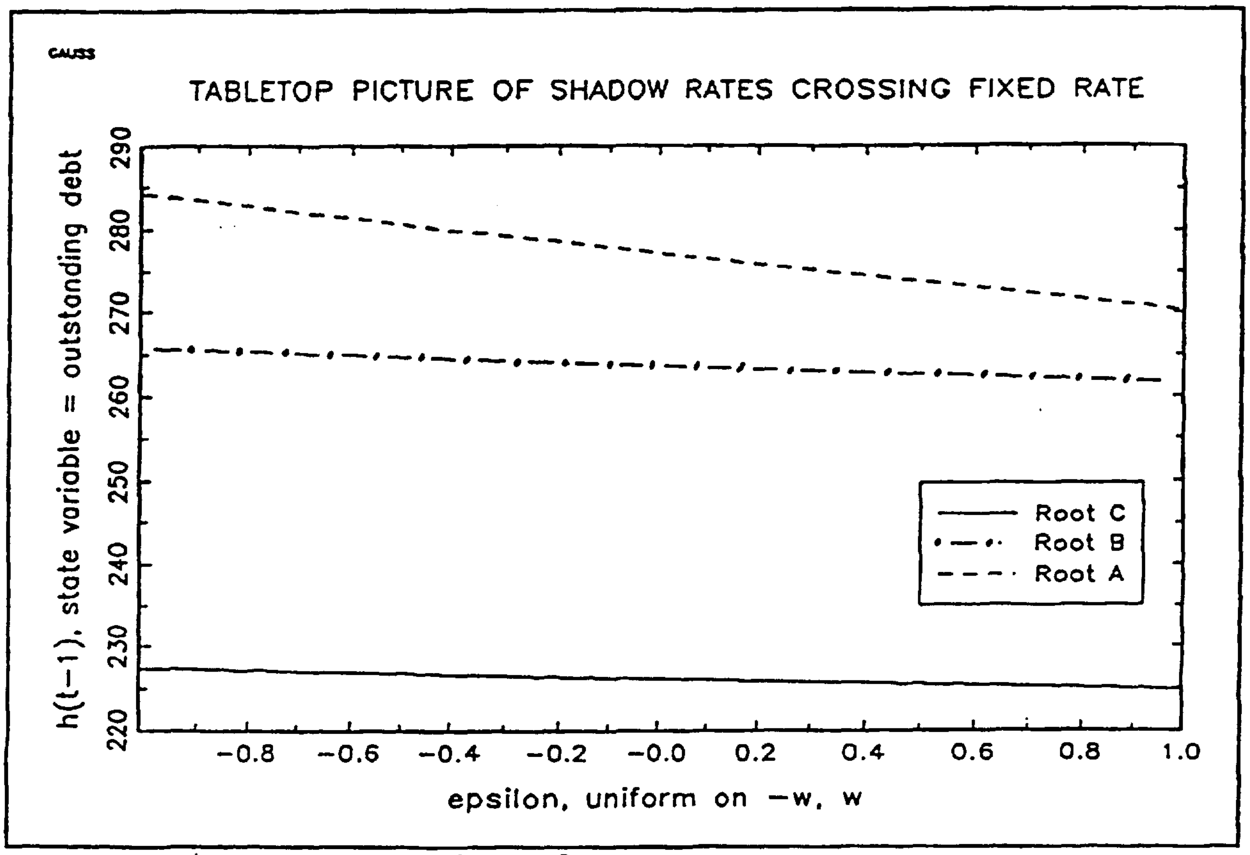


Figure 3
Delta = -.025

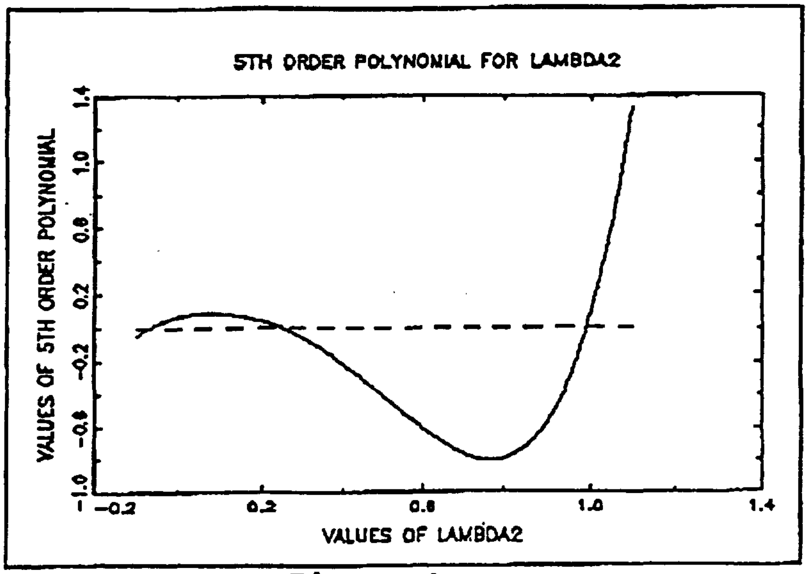


Figure 4
5th-Order Polynomial
Delta = .1

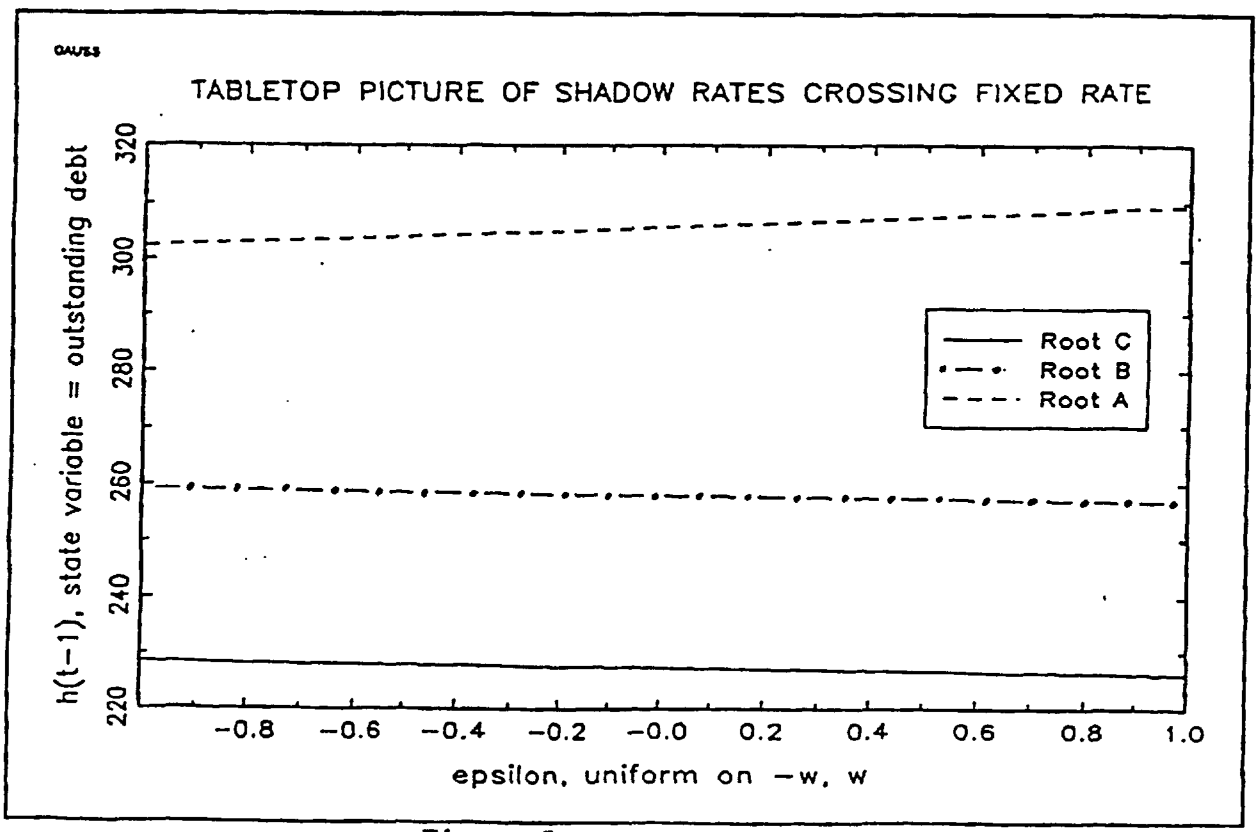
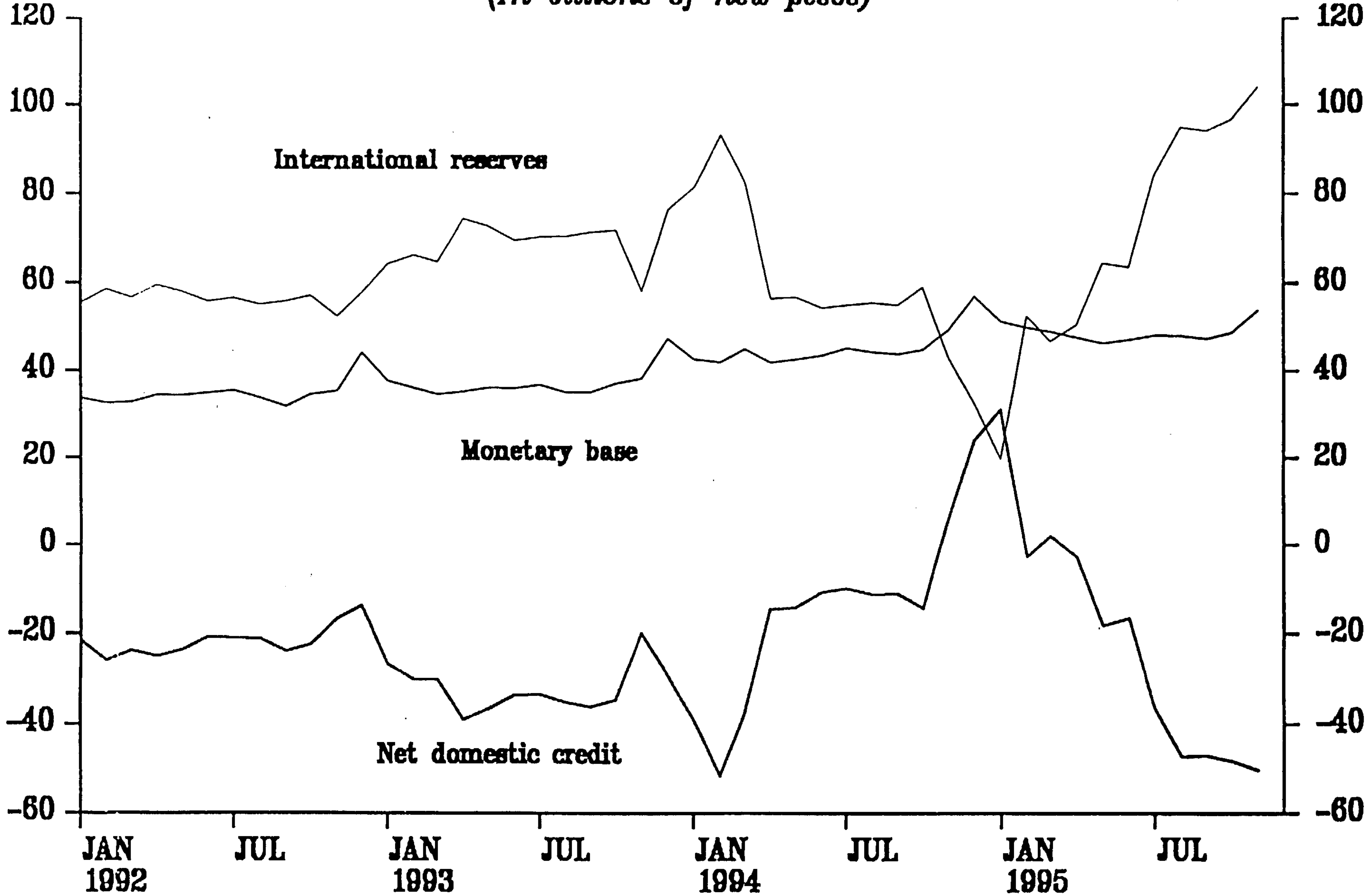


Figure 5
Delta = .1

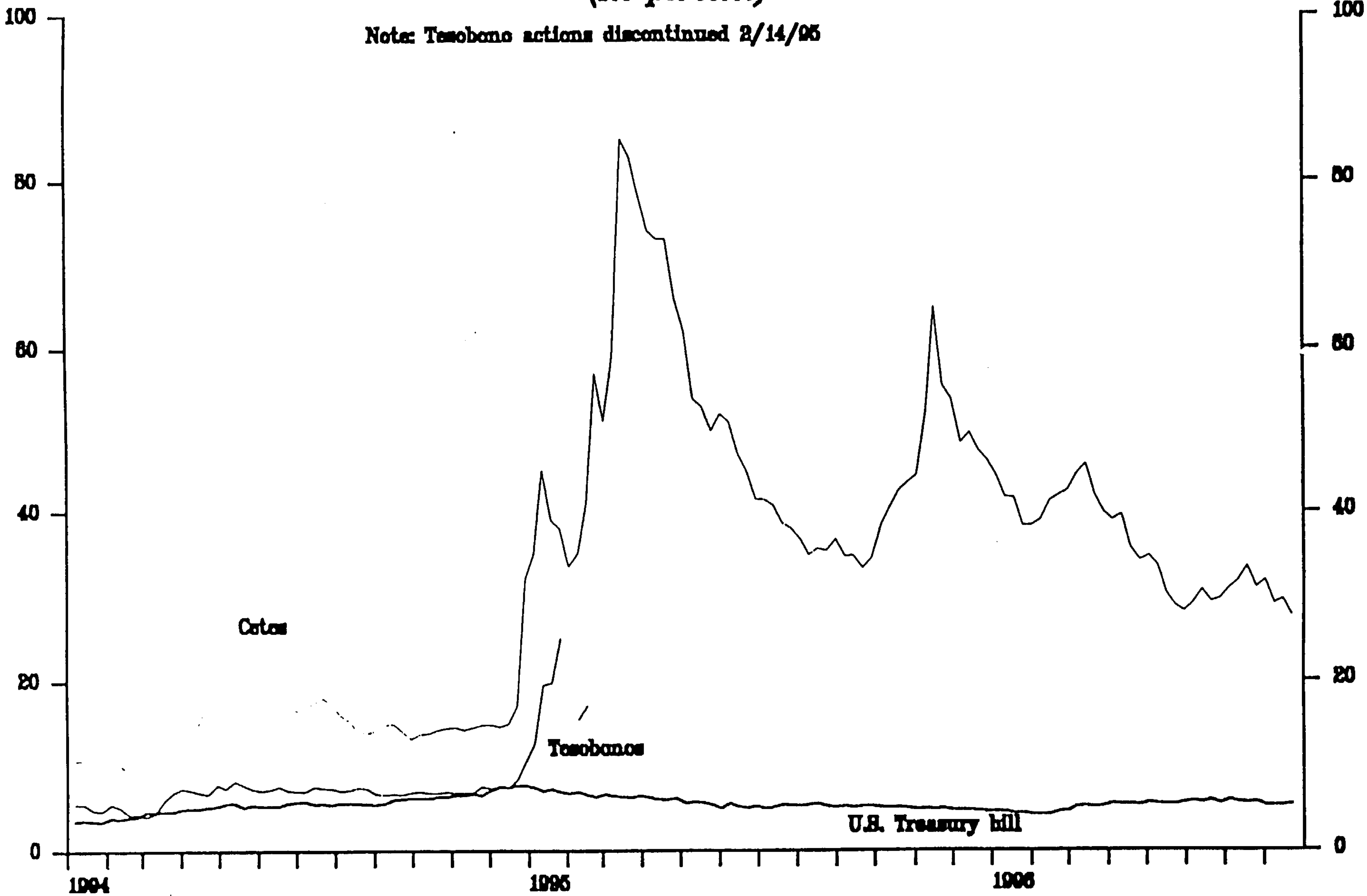
Figure 6. Mexico: Base Money by Component, January 1992–November 1995

(In billions of new pesos)



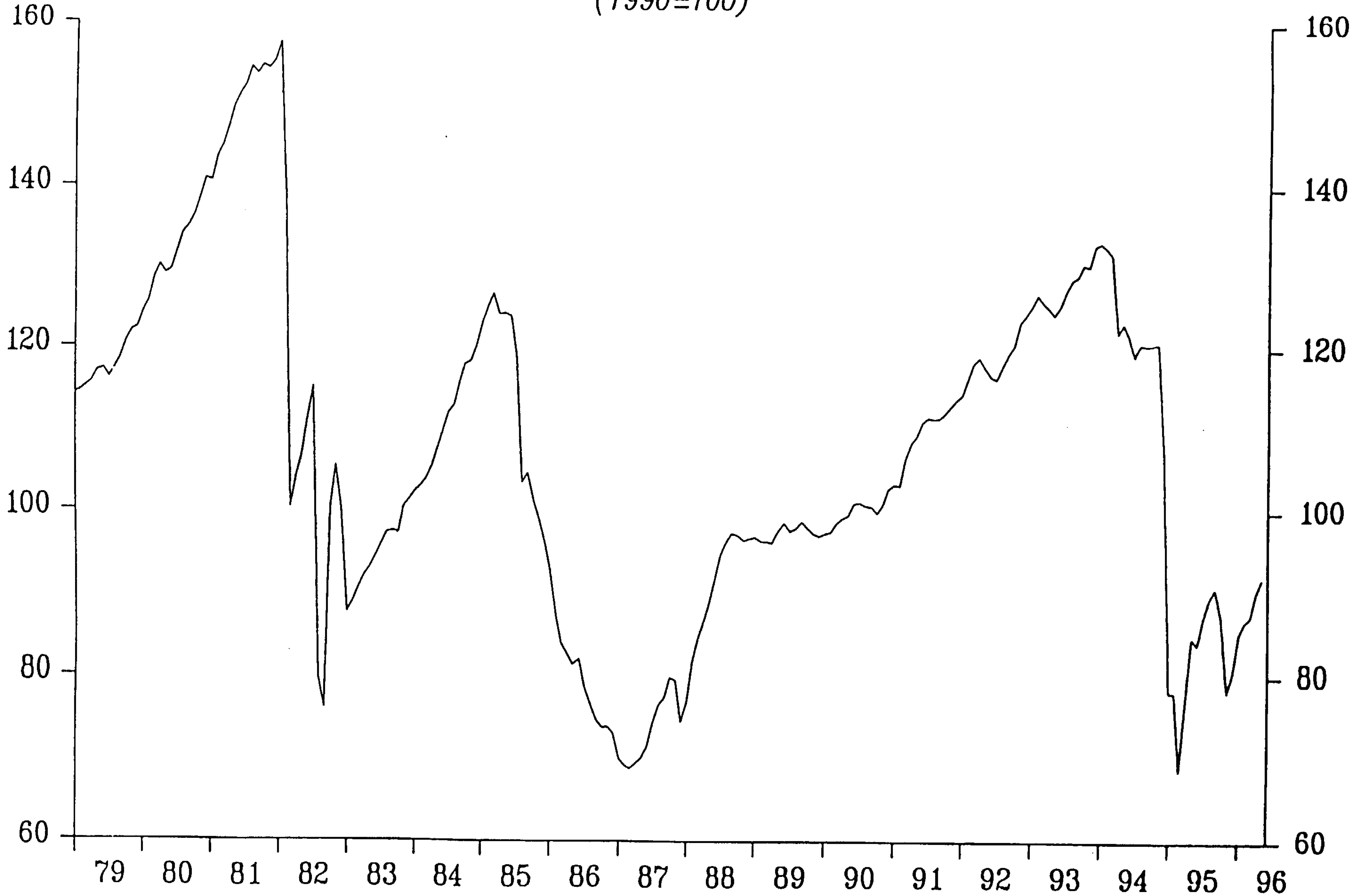
Source: Banco de Mexico, Indicadores Economico, Feb & Dec. 1995.

Figure 7. Yields on Mexican and U.S. Government Securities
(In percent)



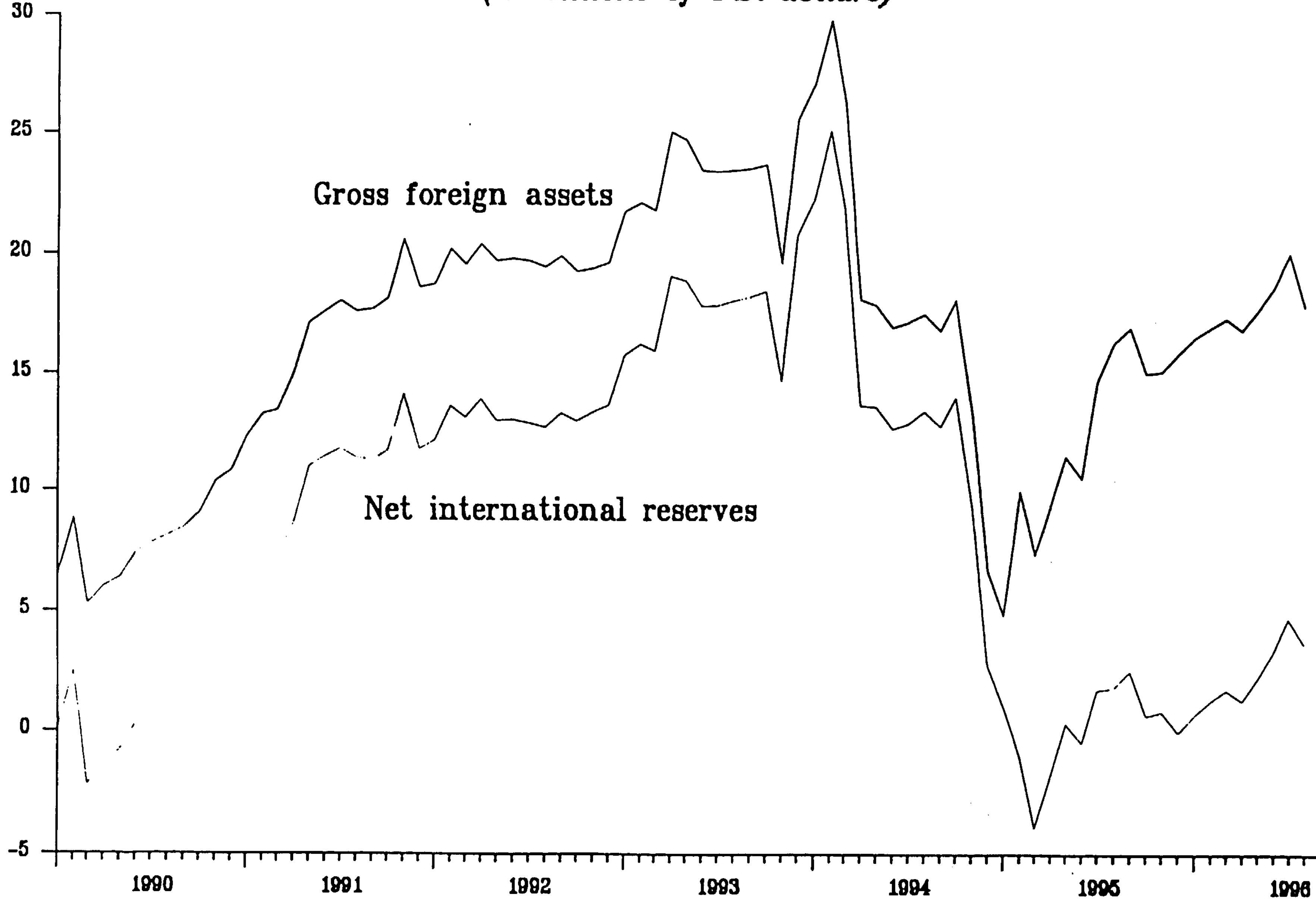
Source: Bloomberg Financial Markets

Figure 8. Mexico: Real Effective Exchange Rate, January 1979-May 1996
(1990=100)



Source: International Monetary Fund, Effective Exchange Rates data base.

Figure 9. Mexico: International Reserves
(In billions of U.S. dollars)



Source: Banco de Mexico.

Appendix

AI. Solving for the shadow exchange rate

The solution for $\tilde{s}_t$ is obtained from the money-market equilibrium, equation (1) in the text. We first make some substitutions. We substitute in for the domestic interest rate using equation (2). We substitute in for the domestic price level using equations (6) and (7), which rely on the assumptions that home-goods prices are set a period in advance at a value expected to clear the market for home goods and that nominal money balances are deflated by home-goods prices. We linearize the product of the probability of attack π_{t-1} and the expected future exchange rate conditional on an attack $E_{t-1}(\tilde{s}_t|\tilde{s}_t > \bar{s})$ as:

(A.1) $\pi_{t-1}E_{t-1}(\tilde{s}_t|\tilde{s}_t > \bar{s}) = -\bar{\pi}\hat{s} + \bar{\pi}E_{t-1}(\tilde{s}_t|\tilde{s}_t > \bar{s}) + \hat{s}\pi_{t-1}$,

where $\hat{\pi}$ is the average probability of attack next period and $\hat{s}$ is the average expectation of next period's exchange rate, conditional on an attack next period.

Since the model is linear, we use the method of undetermined coefficients to obtain linear solutions for the shadow exchange rate of the form:

(A.2) $\tilde{s}_t = \lambda_0 + \lambda_1 h_{t-1} + \lambda_2 \varepsilon_t$

Before solving for the model, we would like an expression for π_{t-1} in terms of the state. Recall that π_{t-1} is the probability of an attack in period t based on time t-1 information:

(A.3) $\pi_{t-1} = pr\{ \tilde{s}_t - \bar{s} > 0\}$

Given the expression for the shadow exchange rate in (A.2), (A.3) can be rewritten as:

(A.4) $\pi_{t-1} = pr\{\lambda_0 + \lambda_1 h_{t-1} + \lambda_2 \varepsilon_t - \bar{s} > 0\}$

$= pr\{ \varepsilon_t > k_{t-1}\}$

where $k_{t-1} = (\bar{s} - (\lambda_0 + \lambda_1 h_{t-1})) / \lambda_2 > 0$.

Since the shock is assumed to have a uniform distribution (-w, w) centered on zero, (A.5) $pr\{ \varepsilon_t > k_{t-1} \} = (w - k_{t-1})/2w$.

Substituting into (A.5) our expression for k_{t-1} gives:

(A.6) $\pi_{t-1} = e_0 + e_1 h_{t-1}$,

where $e_0 = (w\lambda_2+\lambda_0- \bar{s})/2w\lambda_2$ and $e_1 = \lambda_1/2w\lambda_2$.

We also need an expression for $(E_{t-1}(\tilde{s}_t \mid \tilde{s}_t > \bar{s})$ before solving the model. Given our expression for the shadow rate in (A.2), this means we need an expression for $E_{t-1}(\varepsilon_t \mid \tilde{s}_t > \bar{s})$.

Since the distribution of ε_t is uniform, the time t-1 expected value of the shock at time t, conditional on being in the post-attack regime at t, is

(A.7) $E_{t-1}(\varepsilon_t \mid \tilde{s}_t > \bar{s}) = k_{t-1} + (w-k_{t-1})/2$.

Substituting into (A.7) the expression for k_{t-1} yields:

(A.8) $E_{t-1}(\varepsilon_t \mid \tilde{s}_t > \bar{s}) = f_0 + f_1 h_{t-1}$

where $f_0 = (\bar{s} - \lambda_0 + w\lambda_2)/2\lambda_2$ and $f_1 = -\lambda_1/2\lambda_2$.

It is also useful to have an expression for $V_t(s_{t+1})$, which is part of the risk premium. Given our expression for the shadow rate in (A.2), the variance of the shadow rate is

(A.9) $V_t(s_{t+1}) = (s_{t+1} - E_t s_{t+1})^2 = \lambda_2^2 \sigma_\varepsilon^2$

where σ_ε^2 is the variance of the stochastic element ε. Since ε is assumed to have a uniform distribution,

$$\text{(A.10)} \quad \sigma_\varepsilon^2 = \int_{-w}^{w} \frac{1}{2w}(\varepsilon)^2 d\varepsilon = \frac{w^2}{3}$$

Thus

$$\text{(A.11)} \quad V_t(s_{t+1}) = \lambda_2^2 \frac{w^2}{3}.$$

We are now ready to solve the model for the shadow rate. Substituting (2), (6), (7), (A.1), (A.2), (A.6), (A.8) and (A.11) into (1) and using the method of undetermined coefficients gives the shadow rate solution described in the text by equations (9)-(12), where the actual expression for the constant term in (10) is:

(A.12) $\lambda_0 = [(\bar{\pi}/2) + (1/4) + \alpha\theta]^{-1} [\bar{m} - (3\bar{s}/4) - (w\lambda_2/4) + \alpha i^* + \alpha\mu\lambda_1 + \frac{\overline{\pi s}}{2} +$

$\{\alpha\theta\}\{c + \gamma\mu + (1-\gamma)\bar{m} - b^*\}]$,

and the coefficients on the fifth-order polynomial λ_2 are:

$$c_0 = \frac{\beta_0\delta}{\alpha}$$

$$c_1 = \beta_0$$

$$c_2 = \beta_1[\delta - (\beta_0 + \alpha\rho)\gamma]$$

$$c_3 = (\beta_0 + \alpha)\beta_1$$

$$c_4 = -\alpha\gamma\beta_1^2$$

$$c_5 = \alpha\beta_1^2$$

where

$$\beta_0 = \alpha(1-\rho) + \frac{1}{4} + \frac{\bar{\pi}}{2} \ ; \ \beta_1 = z\frac{w^2}{3}$$

In solving for the shadow rate, we are able to simplify the expressions for the λ_i by recognizing that $\hat{s} = \bar{s} + \frac{\lambda_2 w}{2}$.

A.II Model solution when $0 \le \eta \le 1$.

When the domestic price level is a weighted average of home-goods prices and foreign prices and home-goods prices are set one period in advance at a value expected to clear the market, the shadow exchange-rate solution is:

(A.2) $\tilde{s}_t = \lambda_0 + \lambda_1 h_{t-1} + \lambda_2 \varepsilon_t$

where

$$\lambda_0 = \left[\frac{\eta\bar{\pi}}{2} + (1 - \frac{3}{4}\eta) + \alpha\theta\right]^{-1} \{\bar{m} - \frac{3}{4}\eta\bar{s} + \frac{\eta\overline{\pi s}}{2} - \frac{\eta w\lambda_2}{4} - (1-\eta)p^* + \alpha i^* + \alpha\theta[c + \gamma\mu + (1-\gamma)\bar{m} - b^*\} + \alpha\mu\lambda_1\}$$

$$\lambda_1 = \frac{\alpha\gamma\rho\theta}{\alpha(1+\theta)+1-\frac{3}{4}\eta+\frac{\eta\bar{\pi}}{2}-\alpha\rho} \geq 0$$

and

λ_2 is the solution to the fifth-order polynomial:

$$c_0 + c_1\lambda_2 + c_2\lambda_2^2 + c_3\lambda_2^3 + c_4\lambda_2^4 + c_5\lambda_2^5 = 0$$

where

$$c_0 = \frac{\beta_0\delta}{\alpha}$$

$$c_1 = \beta_0[1+\frac{(1-\eta)}{\alpha}]$$

$$c_2 = \beta_1[\delta-(\beta_0+\alpha\rho)\gamma]$$

$$c_3 = [\beta_0 + \alpha + (1-\eta)]\beta_1$$

$$c_4 = -\alpha\gamma\beta_1^2$$

$$c_5 = \alpha\beta_1^2$$

and

$$\beta_0 = \alpha(1-\rho)+1-\frac{3}{4}\eta+\frac{\eta}{2}\bar{\pi} \ ; \ \beta_1 = z\frac{w^2}{3}$$

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