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## ABSTRACT

In the literature on speculative attacks on a fixed exchange rate, it is usually assumed that the monetary authority responsible for fixing the exchange rate reacts passively to the monetary disruption caused by the attack. This assumption is grossly at odds with actual experience where monetary-base implications of the attacks are usually sterilized. Such sterilization renders the standard monetary-approach attack model unable to provide intellectual guidance to recent attack episodes. In this paper we describe the problems with the standard model and develop a version of the portfolio-balance exchange rate model that allows the study of episodes with sterilization. Sterilized attacks may be regarded as a laboratory test of the monetary versus portfolio-balance exchange rate models. The monetary model fails the test. These issues are motivated by reference to the December 1994 collapse of the Mexican peso.

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Summary

Speculative attacks on fixed exchange rate regimes were once thought of as market pathologies that would be avoided by well-functioning markets. Recent work by Salant and Henderson (1978) and Krugman (1979), however has developed the idea that speculative attacks are the response of well-functioning markets to government policy inconsistency. The literature often takes as an example a small country that attempts to fix its exchange rate to the currency of a large trading partner even though that partner's long-term inflation rate is well below that of the small country. Clearly the fixed exchange rate is inconsistent, over the long term, with a substantial inflation differential. If governments will not resolve such policy inconsistencies the markets will. The recent speculative attack literature models the markets' competitive response to such inconsistencies.

One of the crucial assumptions in the recent models is at odds with actual experience. In the models it is assumed that the monetary authority in the country whose exchange-rate peg is attacked allows the country's base money growth to be disrupted by the attack. More precisely, in the models it is assumed that base money is allowed to collapse by an amount equal to the size of the attack. In modern experiences the monetary authority actually insulates the monetary base from the attack by sterilizing the reserve outflow. In the standard models, reserve-loss sterilization in an attack implies that no fixed exchange rate regime can survive temporarily. Either it works indefinitely or it collapses at inception.

Since fixed exchange rate regimes, in actual experience, are almost always temporary and reserve losses in an attack are usually sterilized, the current models predictions are grossly at odds with the data they were built to explain. Sterilized attacks provide a near-laboratory setting in which to study the short-run performance of the monetary-approach exchange rate model. In this setting the pure monetary model fails disastrously.

In this paper we resurrect the portfolio-balance model of exchange rates. Using a portfolio-balance model, we are able to track the asset-market implications of a sterilized attack from the money market, where it is neutralized by sterilization, to the bond markets, where the effects of open market operations required for sterilization are felt more strongly. Our modifications allow the attack literature to survive, but in somewhat less robust health.

All of these modifications are motivated by our examination of the Mexican peso crisis of December, 1994.

## I. Introduction

When a country pursues a policy of fixing its exchange rate or controlling its rate of depreciation relative to one or more of its trading partners, it is widely understood that the exchange-rate policy will be maintained as long as it does not conflict with other, more important, economic or political constraints. If investors believe that the exchange-rate policy will be altered eventually, their actions can precipitate a series of events, a speculative attack, that tests the credibility of the commitment and the ability to maintain the exchange rate policy. Speculative attacks on the currency bands in the European Monetary Union in 1992 and the collapse of the Mexican Peso in December, 1994 underscore the relevance of studying such attacks. 1/

The literature modeling speculative attacks as the market response to unsustainable government price-fixing policy began with Salant and Henderson (1978), who developed the main ideas in an application to a government policy to fix the price of gold. The modeling then moved to the foreign exchange market where Krugman (1979) and Flood and Garber (1984a) adapted the Salant and Henderson model for collapsing exchange-rate regimes. In the exchange-rate model, the policy eventually to be attacked is an announced fixed exchange rate. The country responsible for the fixed rate also adopts other high-priority expansionary policies inconsistent with the long-term

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1/ The EMU experience is studied in Goldstein et al. (1993) and the Mexican experience is studied in IMF (1995).

maintenance of the fixed rate. Because of the expansionary, high-priority policy the modeled country slowly depletes its international reserves, which are exhausted in a final discrete speculative attack. Following the attack, the high-priority policies continue unaltered and the exchange-rate policy is switched to a sustainable alternative. 1/

In this attack scenario, base-money and it components, international reserves plus domestic credit, play the leading roles. In addition to fixing the exchange rate, it is assumed that the government finances a fixed real fiscal deficit by expanding domestic credit. Real and nominal money demand are fixed in these models while the exchange rate is fixed so domestic-credit expansion results in exactly equal reserve losses, or to give an opposite spin, reserve losses are perfectly sterilized during the fixed rate regime. 2/ Money financing of the fiscal deficit is the high-priority policy that is inconsistent with the fixed rate. Eventually, the international reserves that serve as a buffer between the fixed-exchange-rate policy and the overly expansionary domestic credit policy are exhausted and the fixed exchange-rate policy is abandoned.

The distinctive feature of the attack models is that foreseen speculative attacks are consistent with private equilibrium. The exchange

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1/ Flood and Garber (1984b) and Obstfeld (1986) investigate the possibility that the attack causes changes in the high-priority policy, which can result in multiple equilibria.

2/ In empirical applications, such as Blanco and Garber (1986), money demand is not fixed. It responds to output changes, terms-of-trade changes and to a disturbance term. In the applications, money demand shifts assume as important a role as does money supply.

rate need not jump at the time of the attack. Instead of having prices jump, the Salant and Henderson insight was the prediction that *the attack would take place at precisely the time prices need not jump* - when the change in money supply due to the attack is exactly balanced by the change in money demand due to the interest-rate effect of the policy change to a sustainable regime.

In the current paper we challenge the applicability of the standard attack scenario and in doing so we challenge the short-run applicability of the monetary model of the exchange market. The standard model requires the supply of base money in the country being attacked to jump downward at the instant of the attack, reflecting the reserve loss during the attack. In recent experiences, that assumption does not fit the facts. Reserve losses before and at the time of the attacks were sterilized in the EMU and over-sterilized in Mexico. With such sterilization, the standard attack model is a nonstarter. In Section II we develop a version of the standard model, demonstrate its main results and illustrate its problems with an example drawn from the Mexican experience in 1994. In Section III we present a portfolio-balance model that allows us to follow the trail of the attack's discrete portfolio adjustment from the money market, where it usually resides, into the bond markets, where it is driven by the sterilization-connected open market operations.

## II. The Simplest Model

The Flood and Garber (1984a) speculative attack model combines a money market equilibrium condition, equation (1), with uncovered interest rate parity, equation (2): 1/

$$M/P = a_0 - a_1 i, \quad a_1 > 0, \tag{1}$$

$$i = i^* + (\dot{S}/S). \tag{2}$$

These equations are presented for a certainty example in continuous time, but the main points carry over to more realistic settings. In equation (1), M is the level of high-power money, $M = R + D$ with R the domestic-currency book value of international reserves and D the domestic credit held by the domestic monetary authority. 2/ P is the domestic price level. The domestic-currency interest rate is i. The foreign-currency interest rate is $i^*$, which is assumed constant. S is the exchange rate quoted as the domestic-currency price of foreign exchange and $\dot{S}$ is the time rate of change

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1/ In section I we copy the Flood and Garber (F&G) model and notation except for the attack time, for which F&G used the notation z and we use T.

2/ For simplicity we assume that interest payments on government holding of foreign securities are either rebated to the foreign government, roughly cancel with domestic interest payments to foreign governments or are part of the fiscal deficit.

of S. 1/ We also assume purchasing power parity so that $P = P^{*}S$ with $P^{*}$ the foreign price level, which is assumed to be constant. Domestic credit grows at the rate $\dot{D} = \mu > 0$, which is used to finance government expenditure.

While the exchange rate is fixed, $S = \bar{S}$ and $\dot{S} = 0$. From equation (1), the demand for domestic nominal money balances is, therefore, constant during the fixed rate regime. Reserve losses by the monetary authority exactly match domestic-credit expansion. Money is constant but reserves are lost unit for unit as domestic credit expands. This process ends in a final discrete reserve loss, a speculative attack, that is foreseen by the private sector and is, in equilibrium, devoid of profit opportunities. We now turn to characterizing the final attack.

Following the final speculative attack, reserves are exhausted so that $M = D$, the exchange rate is allowed to float freely and will take on the value consistent with:

$$D/P^{*}\tilde{S} = a_0 - a_1(i^{*} + (\dot{\tilde{S}}/\tilde{S})), \tag{3}$$

where $\tilde{S}$ is the post-attack flexible exchange rate termed the *shadow flexible exchange rate*. We simplify notation by rewriting (3) as:

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1/ A dot over a variable, e.g. x vs $\dot{x}$, signifies the right-hand time derivative.

$$D = \beta\dot{\tilde{S}} - \alpha\tilde{S}, \tag{3a}$$

where $\beta = P^{*}(a_0 - a_1 i^{*}) > 0$ and $\alpha = a_1 P^{*}$. The solution to this equation is:

$$\tilde{S} = \lambda_0 + \lambda_1 D, \tag{4}$$

where $\lambda_0 = [\alpha\mu/\beta^2]$ and $\lambda_1 = 1/\beta$. Notice that the shadow freely-floating rate does not depend on reserves, which we assume would have hit their minimum level, set at zero for simplicity.

Speculators profit in an attack by purchasing foreign exchange from the monetary authority at the fixed price $\bar{S}$ and reselling at the market-determined price $S$. While $S < \bar{S}$, speculators would be unable to profit by attacking the fixed rate so the regime survives. If speculators wait until $S > \bar{S}$, then the lucky speculators who purchase the monetary authority's reserves will reap a capital gain. In this perfect foresight example, however, luck has no role. The speculators understand the situation and compete against each other so that $S$ never gets a chance to exceed $\bar{S}$. Competition ensures that the foreseen attack takes place at the instant when there are no profits or losses, which requires $S = \bar{S}$. To determine the date of the attack, set $S = \bar{S}$. 1/ It follows that the attack takes place at time T, where

$$T = \frac{R_0 - (\alpha\mu/\beta)}{\mu}, \tag{5}$$

with $R_0$ the level of reserves at some arbitrary time 0, which is the time the model is started. 2/ These results duplicate those presented in Flood and Garber (1984a).

Crucial to the above logic is the assumption that the monetary authority does not sterilize the reserve loss at the time of the attack. The implication of this assumption is displayed in Figure 1, which tracks base-money and its components before and after the attack at time T. Prior to the attack, base money is constant with reserve losses exactly sterilized by increases in domestic credit. At the time of the attack, T, base money jumps downward by the size of the reserve loss at the attack. This is a striking aspect of this model, which is not usually a good match for the data in actual attack episodes.

Figure 2 plots Mexican base money and its components from January 1992 through December 1994, the month of the collapse of the (sliding) Mexican

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1/ This happens when the decrease in money demand stemming from the increase in the domestic interest rate, is equal to the decrease in base money from the loss of the final reserve stock.

2/ We time-subscript variables, e.g. $R_0$, only when necessary.

peso peg to the U.S. dollar. From the figure, it is clear that during the fixed rate period large reserve movements were normally sterilized so that base-money growth is smoother than either of its components. This agrees with the model presented above. What does not agree with the model, however, is the behavior of the components of the base during the attack period. At the attack, reserve losses were sterilized fully so that the attack did not accompany a discrete reduction in base money. Such sterilization is clearly a relevant policy option and is probably the option most relevant to current policy modeling and discussions. When reserve losses at the time of the attack are sterilized fully, the standard model is inconsistent with a foreseen attack. In this model, when the authorities fully sterilize the reserve losses during an attack, the attack takes place at the inception of the fixed rate regime and speculators reap a capital gain.

If the authorities fully sterilize reserve losses, equation (4) becomes:

$$\tilde{S} = \lambda_0 + \lambda_1 D^+ \qquad (4a)$$

where $\lambda_0$ and $\lambda_1$ are given above and the forcing variable is now denoted $D^+$ to indicate that it measures domestic credit just after the attack, $D^+ = \beta\bar{S}$. This distinction is significant because D jumps upward at the time of the attack to exactly sterilize reserve losses in the attack. *It follows that*

*$D^+$ is always equal to the pre-attack base money supply. It follows further that $S$ is always greater than $\bar{S}$.* In other words, a fixed rate with full sterilization of reserve losses in an attack would be attacked immediately. Subtracting $\bar{S}$ from $S$ in equation (5) results in:

$$\tilde{S} - \bar{S} = \alpha\mu/\beta^2 . \tag{6}$$

The shadow flexible rate is always above the fixed rate when the attack reserve loss is sterilized. 1/ This model is, therefore, incapable of producing an anticipated future attack on a fixed exchange rate regime when the attack reserve loss is sterilized. 2/ What is happening technically is that sterilization of reserve losses in the attack removes the discrete adjustment from the money supply but does not remove the discrete adjustment from money demand. It is impossible to balance the jumps and the fixed rate can not survive, even temporarily.

The pure monetary-approach model of a speculative attack is, therefore, inconsistent with the data it was intended to explain. In the next section we propose a portfolio-balance alternative.

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1/ The shadow rate would always be above the fixed rate for stochastic growth in D or if the minimum level of R were not known for certain by the private sector in this simple model with full sterilization. We thus ignore these complications.

2/ This is not a multiple equilibrium issue. There is one equilibrium and it is to attack at inception of the fixed rate.

## III. A Bond-Market Modification

Since attacks have been observed on fixed rate regimes that fully sterilize final reserve losses, with the attacks occurring long after the inception of the fixed rate regime, it is clear that the model needs modification. The policy action of reserve loss sterilization is a conscious effort to remove the discrete adjustments attached to an attack from the money market. When the monetary authority sterilizes reserve losses, it expands domestic credit by the size of the reserve loss so that the attack does not influence the base-money supply. Domestic credit is normally expanded by the monetary authority using base money to purchase domestic-government securities from the private sector. Thus sterilization involves discrete bond-market shifts.

Our approach to modeling anticipated, sterilized attacks is to add a specific model of the bond markets to our monetary-approach model. Modeling so far required only an explicit money market. Bond market considerations were handled by two assumptions: (A) perfect substitutability between domestic and foreign bonds, which is the certainty version of risk neutrality, and produces equation (2), and (B) the exogenity of $i^*$, the foreign interest rate. With $i^*$ exogenous and equation (2) determining $i$, the model did not need to confront domestic bond-market repercussions of reserve-interest-paying reserves released by the domestic monetary authority. 1/ We relax our model by dropping the perfect substitutability assumption, but we retain the exogenity of $i^*$. This is the certainty version of adding a risk premium to equation (2). 2/

The perfect substitutes assumption is replaced by a bond-market model based on a convenient version of Tobin's (1971) portfolio-balance model. We retain equation (1) but we drop equation (2) replacing it with:

$$B - SB^* = \theta^{-1}(i - i^* - (\dot{S}/S))SP^*w, \tag{7}$$

where B is the stock of domestic-currency denominated interest-paying debt issued by the domestic government and held in the private sector at home and abroad and $B^*$ is the analogous foreign magnitude. w is world-wide liquid real wealth, which is constant, so $SP^*w$ is the domestic-currency value of world wealth. Equation (7) may be a bit unfamiliar; it results from placing symmetry restrictions on domestic and foreign tastes for government

1/ Any modification of the model that allows something to jump in addition to the expected rate of exchange rate change can serve in theory as the relevant modification. Since previous work has usually ignored the bond market we choose to bring this back to center stage.

2/ If we were to model imperfect substitutability as resulting explicitly from risk, the parameters in the behavior functions below would include moments from the distribution of returns, taste parameters concerning risk and transactions cost technology parameters that help characterize the demand for money. In a stochastic version of this model, as conditional return moments change surrounding an attack, the linearized model's parameters would change also.

bonds. Rearranging equation (7) gives a revised version of equation (2) augmented by the bond-market model, equation (7):

$$i = i^* + (\dot{S}/S) + \frac{\theta(B - SB^*)}{SP^*w}, \quad \theta \geq 0 \tag{8}$$

where $\theta(B - SB^*)/SP^*w$ is compensation required due to imperfect substitutability in perfect foresight. 1/

We retain the assumption that domestic credit rises at the rate $\mu$ in order to finance government expenditure, but now we need to be explicit about the bond-market implications of interventions to fix the exchange rate and to sterilize reserve losses during an attack, when applicable. When the exchange rate is fixed, we rewrite equation (1) using other assumptions as:

$$R + D = P^*\bar{S}(a_0 - a_1(i^* + [\theta(B - SB^*)/\bar{S}P^*w])). \tag{9}$$

$P^*$ and $i^*$ are constant. S is constant while the exchange rate is fixed, so $\dot{S} = 0$. For now it is also assumed that B is constant. $B^*$, however, is not constant. The reserves that are drained from the monetary authority are

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1/ Alternatively, the last term in equation (2a) is recognized as a potential model of the risk premium in which the quantities of domestic and foreign government bonds outstanding in the private sector are crucial to the interest-rate differential.

As in Calvo (1995) domestic and foreign bonds play an important role although in Calvo that role is due to bond-financing of fiscal deficits.

interest-paying foreign-government foreign-currency assets and the sum of all reserve losses is added to the initial $B^*$ available to the private sector. We assume that $B^*$ is constant at $B^*_0$ except for reserve movements so that: 1/

$$B^*_t = B^*_0 + \frac{(R_0 - R_t)}{\bar{S}} \tag{10}$$

We find the rate of reserve loss during the fixed rate regime by taking the time derivative of each side of equation (9) after substituting from equation (10):

$$\dot{R} = -\mu/(1 + [a_1\theta/w]) \equiv -\rho \tag{11}$$

This rate of reserve loss applies regardless of reserve sterilization during the inevitable attack. We next analyze the entire dynamic attack process using the new asset-market structure under two options: (1) reserve losses in the attack are not sterilized, and (2) reserve losses in the attack are sterilized fully. 2/

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1/ Because R is denominated in domestic-currency units it must be converted to foreign currency units by dividing reserve losses by the exchange rate.

2/ In the appendix we present the results for the model modified for partial sterilization.

1. <u>Option 1 - No Sterilization</u>

This option replicates the policy studied in the first section, but now the bond-market implications must be studied also. Following a successful attack, asset market equilibrium requires:

$$D = c_1 + \beta_1 \tilde{S} - \alpha \dot{\tilde{S}}, \tag{12}$$

where $c_1 = -w^{-1}a_1\theta B_0$; $\beta_1 = P^*(a_0 - a_1 i^*) + w^{-1}a_1\theta(B^*_0 + [R_0/\bar{S}])$ and $B_0$ and $B^*_0$ are initial levels of B and $B^*$ at the time the model is started. In the event of an attack, all remaining international reserves are purchased from the monetary authority, so the money supply falls at the attack from M = R + D to M = D. These reserves reappear now in the bond market, increasing the aggregate privately-held stock of foreign bonds by the size of the remaining reserve stock. The solution to equation (6) is:

$$\tilde{S} = \lambda_{20} + \lambda_{21} D \tag{13}$$

where $\lambda_{21} = 1/\beta_1$ , $\lambda_{20} = (\alpha_1 \lambda_{21} \mu - c_1)/\beta_1$. Until the time of the attack, S is below $\bar{S}$. The attack occurs when S reaches $\bar{S}$ at time $T_1$, where:

$$T_1 = \frac{R_0 - \frac{\alpha\rho}{\beta}}{\rho} . \tag{14}$$

In equation (14) $\rho$ replaces $\mu$. Notice that $\rho \to \mu$ as $(\theta/w) \to 0$, which is this model's way of portraying a large bond market that can absorb shocks with little or no effect on interest rates.

2. Option 2 - Sterilization at Attack

When the monetary authority sterilizes the attack on reserves it expands domestic credit, D, by precisely the size of the attack. This increase in domestic credit is accomplished by the monetary authority's open market purchase of B from the private sector in an amount equal to the size of the final attack. The sterilization operation, therefore, has additional bond market consequences.

Following a successful attack that is sterilized the asset markets are in equilibrium when:

$$D^{+} = P^{*} \tilde{S}(a_0 - a_1(i^* + \frac{\dot{\tilde{S}}}{\tilde{S}} + \frac{\theta(B_0 - R_t - \tilde{S}(B_0 + \frac{R_0}{\bar{S}}))}{P^{*} \tilde{S} w})), \qquad (15)$$

where $D^{+}$ is the level of domestic credit immediately following the attack and is increased over pre-attack D by precisely the amount of reserve losses - $D^{+}$ is equal to the pre-attack monetary base. $R_t$ is the level of international reserves held by the domestic monetary authority at time t. We rewrite equation (11) as:

$$D^{+} = c_{2t} + \beta_2 \tilde{S} - \alpha \dot{\tilde{S}}, \tag{16}$$

where $c_{2t} = c_1 + (R_0 - R_t)/w$; $\beta_2 = \beta_1$. Note that $c_{2t}$ is fixed from the attack time forward, but is variable until a successful attack.

The solution to equation (16) is:

$$\tilde{S} = \lambda_{30t} + \lambda_{31} D^{+}, \tag{17}$$

where $\lambda_{31} = 1/\beta_1$ and $\lambda_{30t} = (\alpha\lambda_{31}\mu - c_{2t})/\beta_1$. 1/

In equation (17), the variable $R_t$ enters the solution through $c_{2t}$, but does not enter the forward-looking derivative of the solution with respect to time. $R_t$ is the magnitude of the once-and-for-all open-market purchase of domestic-currency securities that is required to sterilize the attack. This variable now enters the expression for $S_t$ because of the bond-market implications of the sterilization operation. The time derivative of S that is relevant to asset holders is the partial derivative with respect to $D^+$. Although D jumps at the time of attack, its forward-looking derivative remains $\mu$.

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1/ Expressions for $R_t$ and $D^+$ in terms of the model's state variables are given in the appendix.

If the fixed exchange rate regime is viable at its inception, S approaches $\bar{S}$ from below reaching $\bar{S}$ at time $T_2$, where

$$T_2 = \frac{R_0 - (\mu P^* w/2\theta\beta_1)}{\rho} .$$

For this special case of 100% sterilization, the fixed rate is viable temporarily for sufficiently high initial reserves. In general, reserve losses in the final attack may be sterilized in any percentage, with 0% and 100% analyzed in the text. 1/

## IV. Tentative Conclusions

The standard pure monetary-approach speculative attack model is incapable of representing a situation where it is expected that the policy authority will fully sterilize reserve losses in an attack. Since such reserve sterilization is widespread in fixed or controlled exchange rate regimes, a modification of the standard model is required. We have proposed one simple modification. We added the certainty analog of bond-based foreign exchange risk premium, a portfolio-balance exchange-rate model, which responds appropriately to the open market operation required for sterilization.

1/ Such possibilities are studied in the Appendix, where it is shown that partial sterilization delays an attack relative to full sterilization.

While intended as a note in the speculative attack literature, the present contribution points out the fragility of a fixed exchange rate policy when the monetary authorities also target the base money supply. Without sterilization, the fixed rate is as robust as is short-run money demand combined appropriately with the stock of international reserves. With complete sterilization, the fixed rate is only as robust, reliable and well understood as is imperfect bond-market substitutability.

APPENDIX I

Representations of $R_t$, $D^+$

$$R_t = (1/(1 + (a_1\theta/w)))(-D_t + \beta\bar{S} - \frac{a_1\theta}{W}(B_0 - \bar{S}B_0^*))$$

$$D^+ = P^*\bar{S}(a_0 - a_1(\tilde{i}^* + \frac{\theta(B_0 - \bar{S}(B_0^* + \frac{R_0 - R_t}{\bar{S}})}{P^*\bar{S}w}))$$

APPENDIX II

## Partial Sterilization

The monetary authority may choose any degree of sterilization of the final attack. To reflect this possibility we rewrite the relevant text equations as:

$$D^{+} = D_0 + \mu t + \gamma R_t,$$

where $\gamma$ is the degree of sterilization. For $\gamma = 0$ there is no sterilization. For $\gamma = 1$ sterilization exactly offsets reserve losses in the attack. In principle $\gamma$ can be any real number. 1/ For sterilization governed by equation (A1) the attack time is:

$$T_g = \frac{R_0 - \dfrac{\alpha_1 \mu}{\beta_2 (1-\gamma + (\alpha_1 \theta (\gamma+1)/P^{*} w)}}{\rho},$$

where $T_g$ is the generalized attack time.

1/ It appears from Figure 2 that $\gamma > 1$ for Mexico in 1994.

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Figure 1. Base Money in Theory I

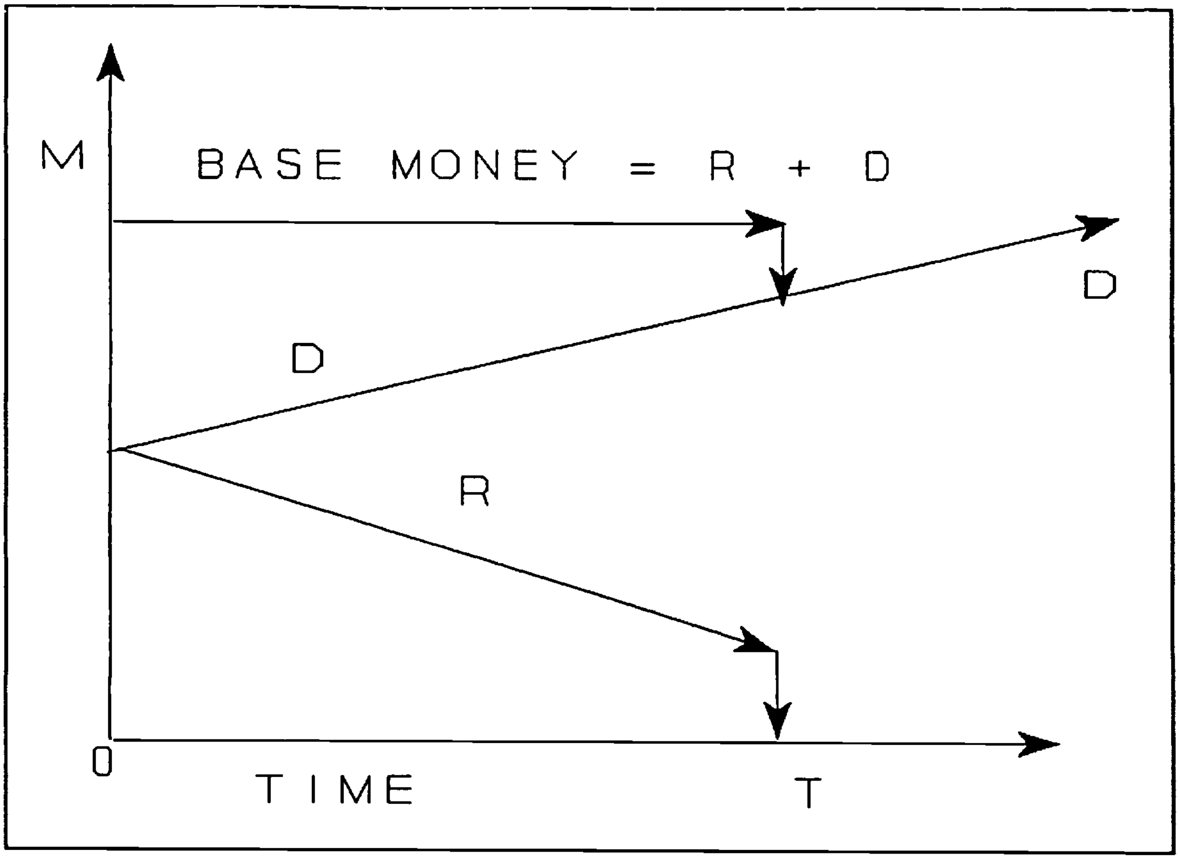

Figure 2. Base Money in Mexico