Monetary Policy in a Target Zone with Stochastic Capital Flows*

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Abstract

We present a small open economy where utility maximizer investors can invest in domestic (nominal) bonds or foreign (real bonds) which are not assumed to be perfect substitutes besides, investors must hold positive real money balances for transaction purposes. The domestic interest rate and the exchange rate in a stochastic equilibrium model where the driving force is an exogenous stochastic component of the demand of domestic bonds. The central bank is committed to the sustainability of a target zone exchange rate regime. Intervention only takes place at the boundaries of the target zone. As a result of the interaction of the different markets, the exchange rate and the equilibrium interest rate are positively correlated and both depend negatively on the exogenous stochastic stock of foreign lending. We also study the effects on the loss of reserves and equilibrium dynamics of two different types of central bank sterilization intervention-sterilized and non-sterilized-. A straightforward extension allows us to study "speculative attacks" and predict the sustainability of the regime.

1. Introduction

The ability of international investors to transfer large amount of funds across increasingly integrated international capital markets has become an important factor in the determination of exchange rates and interest rates throughout the world. Central banks interested in maintaining a currency peg, either real or nominal, or in keeping the exchange rate within a trading band, now face volatile and sizeable capital flows, capable of compromising the central bank's objectives. Some of these capital flows originate as a reaction of international investors to changes in the economic fundamentals of the host country. However, in many instances capital reacts in response to non-economic variables (e.g. political instability, investment opportunities in other emerging markets, incentive structures to portfolio managers, end-of-year liquidation policies, "herding" behavior on the part of uninformed traders, etc.)

The effects of capital flows on the exchange rate and on the level of interest rates in a small open economy, has not been properly addressed in the literature. In our opinion, this has been a consequence of the (ex-ante) interest rate parity condition that most of the work in international finance invokes. Interest rate parity implies a perfectly elastic supply of capital to the domestic economy at an interest rate equal to the world interest rate plus the expected rate of depreciation of the currency. In other words, domestic and foreign securities become perfect substitutes. Besides the counterfactual microeconomic foundations of this assumption (it essentially requires risk-neutral investors), the infinite elasticity of supply makes the model incapable of studying the effects of exogenous and stochastic capital flows. Some papers have addressed this question by adding a risk premium component to domestic interest rates, which can in principle vary in response to changes in

the non-economic variables mentioned before. However, the precise relation between capital flows and the risk premium remains unclear.

In this paper we assume the point of view that capital flows affect financial markets by altering the supply and demand for the various financial assets traded. To the extent that central banks try to maintain the exchange rate within certain limits, they may be forced to react to capital flows by transacting with a similar array of assets, thus affecting the supply and demand for these instruments and with it their equilibrium prices. Therefore, the study of capital flows cannot ignore the response from the central bank that these flows generate. Our aim in this paper is to study different central bank response policies and explore their impact on the level of interest rates, and on the volatility of the exchange rate and the interest rate. In particular, we study two extreme policies: a sterilized intervention, where the central bank tries to prevent any impact of capital flows on domestic prices by acting as their counterpart in the domestic security market; and a non-sterilized intervention, where capital flows are allowed to affect domestic interest rates but the central bank adjusts the liquidity in the market in order to maintain the value of the currency.

We focus on the so-called target zones, where the exchange rate is allowed to move freely within a band but once the pre-specified limits are reached, the central bank intervenes through one of the two mechanisms previously mentioned. Trading zones, with or without well defined intervention limits, continue to be used in many currency markets. Nevertheless, there is no work in this area trying to address the effect of the central bank policy on financial markets. We find target zones to be a convenient starting point for this analysis. Unlike in a dirty float, in a target zone the intervention policy is preannounced, eliminating any uncertainty derived from central bank actions. At the same time, the flexibility of exchange rates within the target zone allows us to analyze the policy implications on the volatility of

asset prices.

In this model we consider exogenous and stochastic international capital flows (that can be interpreted as transactions originated by noisy traders) to be the only source of uncertainty driving the dynamics of exchange rates and interest rates. The interaction of the security and currency markets resembles the original ideas of Metzler (1951) and Tobin (1969), which generated a large amount of literature which postulated a central role of asset markets on exchange rate determination (see Branson and Henderson (1985) and its references).

From the technical point of view, our paper builds upon the literature of target zones developed after the initial paper of Krugman (1991). Most of these papers assume that the only source of uncertainty, and hence the driving force of the dynamics of asset prices, is a stochastic shock to the demand for real balances. (In principle these models could accommodate any shock to the economic fundamentals to the extent that they influence the demand for money). In these models, once the exchange rate reaches either of the intervention limits, the one dimensional policy of the central bank is to provide the appropriate liquidity to the market in order to maintain the value of the currency. This is achieved by acquiring or selling international reserves in exchange for domestic currency. The simplicity of the model has proven to be a valuable tool for analyzing various policy issues. Miller and Weller (1991), Svensson (1991, 1992), Delgado and Dumas (1992) and Van Wijnbergen (1991) have extended the basic machinery to address several questions, ranging from financial issues, such as the term structure of interest rates, to macroeconomic considerations, like stabilization policies. Nevertheless, we find it difficult to accept that the intraday volatility in currency markets can be solely explained by changes in the local demands for each currency. We consider that the flow of capital from one securities market to another, either in response to fundamentals or to other variables, to be a more appealing cause of financial markets

volatility.

A shortcoming of the basic target zone model is the prediction that, as long as the target zone remains credible, a weak currency must be associated with low domestic interest rates and a strong currency with high interest rates. This counterfactual result follows directly from the one-sided uncertainty that credible bands impose: when the currency is weak, it can only appreciate, thus reducing the inflationary premium required to make domestic securities attractive. Several papers have studied variations to the original model capable of reversing this result. The main line of thought is the lack of credibility on the target zone system, due to a stochastic devaluation risk which increases as the currency weakens (Bertola and Caballero (1992), Bertola and Svensson (1993), Dumas, Jennergren and Näslund (1995), Werner (1995)). Our model delivers the desired correlation between interest rate and exchange rates as a direct consequence of the interaction between the domestic security market and the market for domestic currency. In our model, a weakening of the domestic currency is the result of an outflow of capital, which also forces an increase in domestic interest rates in order to restore the equilibrium in the securities market.

Our results on the implication of central bank policies show that a non-sterilized intervention at the weak-end of the target zone leads to higher interest rates, without affecting the volatility of either the interest rate or the exchange rate. On the other hand a sterilized intervention at the weak-end decreases the level of interest rates (although at the precise moment of intervention no effect takes place), decreases the volatility of the exchange rate and increases the volatility of interest rates. With regards to interventions at the strong end, the non-sterilized lowers interest rates without affecting volatilities, while the sterilized increases domestic interest rates, while reducing their volatility, and increases the volatility of the exchange rate.

Our theoretical results contrast with the empirical analysis of Rogoff (1984). He finds no evidence that sterilized interventions affect the exchange rate premium (interest rate differential between domestic and foreign bonds adjusted for the expected rate of appreciation). The difference may be on the strict intervention rules that target zones impose, as well as their strong implications on exchange rate dynamics.

Regardless of the type of policy adopted, an intervention at the weak-end of the zone aimed at sustaining the value of the currency will imply a loss of reserves for the central bank. In the case of a sterilized intervention, the central bank de facto uses its reserves to purchase the domestic securities dumped by international investors, thus preventing an impact on domestic financial markets. If instead the central bank does not sterilize, the loss of reserves comes as a consequence of the reduction in the quantity of real balances demanded that is the result of the increase in the interest rate. The magnitude of the reserve losses in each case is determined by the elasticity parameters of the demand for the various financial instruments.

A more subtle point is the implication of each policy choice on the dynamics of future interventions. In particular we explore the following question: Suppose the central bank is asked to intervene at the strong end, which leads to a reserve accumulation. How does the intervention choice affect the probability that the central banks loses the recently acquired reserves during a given period into the future? Our model predicts that this likelihood is larger for a sterilized intervention than for a non-sterilized intervention. In other words, reserves accumulated through sterilization tend to be "temporary". Consider now the opposite scenario. The central bank has just lost reserves and we ask how does the policy choice affect the chances of recovering those reserves during a given period. In this case, the likelihood for a sterilized intervention is lower. Thus, reserve losses associated to a sterilized intervention

tend to be "permanent".

The model we develop can be extended to provide an adequate framework for the analysis of speculative attacks. By adding to the demand for domestic securities a risk premium that depends on the level of reserves, our model generates dynamics that seem to replicate some of the episodes observed in currency markets (for a detailed study see Goldberg (1994)). Most of the literature on speculative attacks stems from the original work of Krugman (1979), extended by Flood and Garber (1984), Obstfeld (1984) and Penati and Pennacchi (1989). In these papers an "attack" is a discrete depletion of reserves that matches the adjustment in the quantity of real balances demanded once the exchange rate regime is abandoned. The extension of this analysis to target zones was undertaken by Krugman and Rotemberg (1992). By contrast in our model an attack occurs once reserves fall below a threshold level at which the process generated by loss of reserves, hence an increase in risk premia, hence a lower demand for domestic securities, hence further reserve losses, ceases to converge. We show that the optimal intervention policy choice in terms of maximizing the life expectancy of the regime is linked to the relative elasticities of the demands for money and domestic securities.

Our paper is structured as follows: in Section 2 we introduce the economy; in Section 3 we specify demands for money and domestic security and derive the differential equation that determines equilibrium exchange rates; in Section 4 we introduce the boundary conditions that characterize a target zone and study the qualitative properties of the solution; in Section 5 we develop a numerical example; in Section 6 we study the effects of the different types of intervention; in Section 7 we extend the model in order to study speculative attacks; in Section 8 we offer some concluding remarks.

2. Description of the Economy

We consider a small open exchange economy with a single consumption good. Transactions in the small economy are denominated in the "local" currency. This economy interacts with a large economy (rest of the world) that we do not explicitly model.

Let S denote the spot exchange rate (units of local currency per unit of foreign currency). Let P^* denote the price of the single consumption good in the rest of the world, denominated in units of foreign currency. In order to simplify the analysis we shall consider that P^* remains fixed (i.e. no foreign inflation) and equal to one. Thus we shall refer to foreign assets as "real" assets. By the law of one price, the price of the good denominated in the local currency is simply

$$P = S \cdot P^* = S,$$

therefore, the local inflation is identical to the rate of depreciation of the domestic currency.

The domestic economy is populated by an infinitely lived representative consumer who seeks to maximize expected lifetime utility. In order to accomplish this, the domestic consumer trades two available assets: a nominal bond denominated in local currency and a (real) bond denominated in foreign currency. The domestic security is assumed to be in positive net supply $\bar{B}$. We can think of this security as short term government bonds, and $\bar{B}$ the value of the domestic debt, which is assumed to remain constant. In addition, the domestic consumer demands local currency that provides transaction services. In order to keep the model as simple as possible, we do not impose short sale or borrowing constraints on individual holdings of assets. The representative consumer problem is therefore,

$$\max E[\int_0^\infty \exp(-p\tau)U(C(\tau))d\tau] \tag{2.1}$$

$$\begin{aligned} \text{s.t. } dW &= dI^* + d(\frac{I}{S}) + (Y - C - h(\frac{M}{S}, C))dt \\ W &= I^* + \frac{I}{S} + \frac{M}{S} \end{aligned}$$

where I^* denotes the total investment in the foreign bond, I denotes investment in the domestic nominal bond, M denotes nominal cash balances and W total wealth denominated in units of foreign currency. The function h denotes the transaction technology, which typically would depend on total consumption and holdings of real balances. Finally, Y denotes the endowment flow and C the consumption flow.

Each bond provides a riskless nominal return in units of its own denomination.

$$\frac{dI^*}{I^*} = r^* dt \qquad , \qquad \frac{dI}{I} = r dt$$

The only stochastic element in the consumer problem is the dynamic behavior of the exchange rate. The randomness in the price of local currency will be a consequence of an exogenous and stochastic component of the demand for domestic bonds, originated from noisy traders (to be introduced below).

In a model with either a fixed exchange or a target zone regime, the exchange rate may also exhibit randomness due to the possibility of a regime collapse. In such case, the demand for domestic bonds would typically depend on a risk premium, which itself would be a function of other endogenous, and hence stochastic, variables in the model. As we explain below, due to the complexity of the model, we shall abstract from this effect.

Let N denote an exogenous demand for domestic nominal securities by noisy traders, denominated in real terms. We shall assume that

$$dN = \eta dt + \sigma dz \tag{2.2}$$

where η and σ are exogenously given and z is a one-dimensional Brownian motion. The introduction of noisy traders tries to capture the behavior of non-specialized investors or mutual funds, whose allocation of funds to emerging markets may be affected by variables not explicitly modelled here, such as the political climate, the return of alternative investment opportunities, etc. Holdings of the domestic securities by noisy traders in units of domestic currency will be given by SN.

All equilibrium variables in the economy will be function of the exogenous and stochastic variable N. In particular, if g denotes the equilibrium relationship between N and S, $S = g(N)$, Ito's lemma provides an explicit formula for the devaluation rate

$$\frac{dS}{S} = \gamma dt + \nu dz \tag{2.3}$$

with

$$\gamma = \frac{g'}{g}\eta + \frac{1}{2}\frac{g''}{g}\sigma^2 \tag{2.4}$$

$$\nu = \frac{g'}{g}\sigma \tag{2.5}$$

Applying Itô's lemma once more, we can write the equilibrium process of the real return of the domestic bond as

$$\frac{d(\frac{I}{S})}{\frac{I}{S}} = (r - \gamma + \nu^2)dt - \nu dz \tag{2.6}$$

The equilibrium in the domestic bond market, and in the local currency market will be determined by the supply of domestic bonds, the supply of local currency, the exogenous demand for domestic bonds by noisy traders and the demand for domestic bonds and for local currency by expected utility maximizing investors. In addition, the exchange rate regime that determines the evolution of S and of the money supply has to be specified. Finally, other aspects of the monetary policy such as open-market transactions that affect the relative supplies of domestic bonds and local currency, have to be considered.

The equilibrium condition in the market for domestic securities will be given by

$$\bar{B} - B^C = I + S \cdot N \tag{2.7}$$

where B^C denotes the stock of securities held by the central bank, and I the demand for domestic securities by utility maximizing investors.

In addition to holding domestic securities and issuing money, the central bank in the home country accumulates interest bearing foreign assets, which we will refer to as international reserves R. We shall assume that the central bank is subject to the following constraint

$$M^S = B^C + S \cdot R + D \tag{2.8}$$

where D stands for the stock of domestic credit, that will remain constant in our analysis and for simplicity we set to zero.

3. Equilibrium

The optimizing model described above is in general not tractable. The optimal values of the choice variables that result from the consumer problem (2.1) are functions of all future

state contingent equilibrium values of interest and exchange rates. In order to produce some intuition about the equilibrium determination of asset prices, we shall introduce specific functional forms for the demands for assets. This procedure, although ad hoc as it deviates from the optimizing framework just presented, will allow us to develop a better understanding of the equilibrium dynamics. As we shall see, even for a very simple specification of asset demands, the equilibrium pricing formulas are highly non-linear stochastic differential equations. The virtue of this simplified approach is that it allows us to solve the equilibrium numerically and provide a qualitative analysis of the effects of different types of central bank intervention on endogenous variables.

We shall assume the following functional forms for the demand of real balances and the demand for domestic securities

$$\frac{M^d}{S} = a_0 - a_1 r \qquad a_0, a_1 > 0 \tag{3.1}$$

$$\frac{I}{S} = \theta\omega \qquad \omega > 0 \tag{3.2}$$

with

$$\theta = \frac{r - \gamma + \nu^2 - r^* - \lambda}{\nu^2 + \lambda} \qquad \lambda > 0 \tag{3.3}$$

The demand for real balances is relatively standard in the literature. On the other hand, the specification that we have assumed for the demand of domestic securities deserves some comments.

The parameter θ is a relative measure of the mean/variance real return of the domestic asset. In fact this measurement is exact when $\lambda = 0$. This fraction appears explicitly in the optimal asset demands for a logarithmic utility investor (Merton 1971) and for a constant

absolute risk averse investor. For the latter specification of preferences the optimal asset demand is in fact identical to ours (for $\lambda = 0$). Notice that if the rational investor exhibits a logarithmic utility, the optimal asset demand would also resemble our specification, except that the constant ω would be replaced by the present value of life-time wealth, which is a time-varying and state dependent construct.

The parameter λ is introduced for technical reasons. It is meant to measure a sort of risk premium attached to the collapse of a target zone or a fixed exchange rate regime which would trigger a discrete devaluation. Notice that either in a fixed exchange regime or at the edges of the band in a target zone (where the exchange rate is locally fixed due to smooth pasting conditions), both the drift and the variance of the equilibrium exchange rate would be zero. Hence, if $\lambda = 0$ (perfectly credible regime) domestic and foreign securities would become perfect substitutes (at least locally). Thus $r = r^*$ and the demand for domestic assets would not be well defined.

We would expect that under a non perfectly credible regime, domestic and foreign securities would cease to be perfect substitutes even if the instantaneous expected rate of depreciation is zero. If that is the case, which in our model would be captured with $\lambda > 0$, θ would be well defined. We chose to introduce λ into the definition of θ in a rather simple way. In essence we assume agents perceived λ as a reduction in the expected real return and at the same time an increase in its variance (by the same amount).

Ideally, λ should depend on future values of equilibrium variables. However the process of establishing numerically such a relationship in computationally unfeasible. For the purposes of the analysis we will consider λ constant.

In the last section of the paper we will allow λ to be a function of endogenous variables. This approach, although heuristic, gives some light with regards to the dynamics of a regime

collapse and the effectiveness of alternative measures of monetary policy.

From (2.7), (3.2) and (3.3) the nominal interest rate r that clears the bond market, is

$$r = \left(\frac{\nu^2 + \lambda}{\omega}\right)\left(\frac{\bar{B} - B^C}{S} - N\right) + \gamma - \nu^2 + \lambda + r^* \tag{3.4}$$

Also, from equations (2.8) and (3.1), equilibrium in the money market implies

$$r = \frac{a_0}{a_1} - \frac{1}{a_1}(\frac{B^C}{S} + R) \tag{3.5}$$

Together, these two expressions determine the equilibrium exchange rate in terms of other variables. If B^C and R are assumed to be locally constant, as will be the case inside the target zones that we study, equations (3.4) and (3.5) determine the equilibrium exchange rate as a function of the exogenous stock of holdings of domestic assets by noisy traders, N and its parameters. As mentioned in the previous section, let $S = g(N)$ denote such equilibrium relationship between these two variables.

By Itô's lemma

$$\frac{dS}{S} = \frac{dg}{g} = \gamma dt + \nu dz$$

where the undetermined drift and volatility parameters of the exchange rate process, are given by equations (2.4), (2.5)

$$\begin{aligned} \gamma &= \frac{g'}{g}\eta + \frac{1}{2}\frac{g''}{g}\sigma^2 \\ \nu &= \frac{g'}{g}\sigma \end{aligned}$$

Replacing these values into equations (3.4) and (3.5) the following nonlinear second order

differential equation obtains,

$$\begin{aligned}\alpha[gR + B^C] &= g - \beta\eta g' - \frac{\beta}{2}\sigma^2 g'' + \beta\sigma^2\frac{(g')^2}{g} - \beta\lambda g \\ &\quad -\mu\left(\sigma^2\frac{(g')^2}{g} + \lambda g\right)\left(\frac{\bar{B} - B^C}{g} - N\right) \qquad (3.6)\end{aligned}$$

where

$$\begin{aligned}\alpha &= (a_0 - a_1 r^*)^{-1} \\ \beta &= \alpha a_1 \\ \mu &= \frac{\beta}{\omega}\end{aligned}$$

The solution to this differential equation (subject to appropriate boundary conditions) defines the equilibrium relationship between the stock of noisy traders' holdings and the nominal exchange rate. The appropriate boundary conditions are given by the specific exchange rate regime. Our main interest lies in target zone regimes, which we shall analyze in detail in the next section. Unlike a free float or a fixed exchange regime, a target zone system is such that the exchange rate is allowed to float freely within a range $[S_0, S_1]$, where no form of central bank intervention occurs (B^C and R remain constant). As it has been pointed out in the target zones literature, the fact that rational investors anticipate the intervention at the edges of the band implies that the dynamics of the exchange rate within the band would nevertheless differ from a free float.

4. Target Zones

In order to obtain the particular solution to the differential equation (3.6) for a target zone regime with predefined bounds, $[S_0, S_1]$, we must define the exact form of central bank intervention that is supposed to occur once the exchange rate reaches either end of the band. We can classify central bank interventions on the basis of two criteria. The first, which is essentially technical, is whether interventions occur in discrete or infinitesimal amounts. The second, which we will analyze in detail in the next section, is based on the asset (high powered money or bonds), that the central bank uses to purchase or sell the required amounts of foreign currency.

With regard to the first point, we shall assume as is customary in the literature, that interventions occur only in infinitesimal amounts at the edge of the band. This assumption yields the so-called smooth pasting conditions

$$g'(N_0) = g'(N_1) = 0 \tag{4.1}$$

where N_0 and N_1 are determined implicitly by $S_0 = g(N_0)$ and $S_1 = g(N_1)$.

For this set of initial conditions, the particular solution takes the form of an inverted S (see figure 1). As the figure shows, $N_1 < N_0$, which supports the intuition that a large level of foreign lending is associated with a strong currency. The smoothness of the equilibrium relationship is a consequence of the differentiability equation (3.6) and the smooth pasting conditions. In figure 1 we also show the equilibrium interest rate as a function of the exogenous stock of lending N. An important feature of our results is the positive correlation between S and r. This feature, which is typically present in the data, contrasts with what was predicted by the original theoretical models of target zones (Krugman 1991, Svensson

1992). The difference lies in the so-called ex-ante interest rate parity condition which most of the work in this area invokes (i.e. the perfect sustitutability between domestic and foreign bonds). Recall that in these original models once the exchange rate has been driven to its upper limit (usually as a consequence of exogenous increases in the money supply or reductions in the velocity), additional shocks that would tend to weaken the currency need to be accommodated through the appropriate monetary policy. A cap on the exchange rate is synonymous to a cap on domestic prices. Hence, a weak exchange rate leads to low (or negative) expected inflation. By assumption, the expected real return of domestic securities is set equal to the foreign interest rate (which is kept constant). Thus the domestic nominal interest rate must fall.

It should be mentioned though, that a large amount of literature has been devoted to introducing additional elements into the original model capable of generating a positive correlation between interest and exchange rates. Some of the most successful explanations revolve around the lack of credibility of the regime measured through a risk premium associated to an abandonment of the regime, and which increases as the domestic currency depreciates (see Bertola and Caballero (1992), Bertola and Svensson (1993) and Svensson (1991)).

In our model, the positive correlation is a mere consequence of the equilibrium conditions in the asset market. A negative shock on N (an outflow of noisy trader capital) calls for an increase in the domestic interest rate that would provide incentives to rational investors to hold those securities previously held by noisy traders. The increase in the domestic interest rate causes a reduction in the demand for real balances which forces domestic prices up (i.e. a depreciation of the currency). We consider that the transmission mechanism of our model is more closely related to how financial markets actually operate. Indeed, our story fits fairly well to the sequence of events in Mexico during 1994. From March to November

of 1994, the outflow of financial capital caused either by political instability or by rapidly increasing interest rates in the US led to higher domestic interest rates and a depreciation of the currency (within the limits of intervention).

Our argument would not hold if the central bank took the active role of purchasing these securities being sold by noisy investors. In such a case, neither the exchange rate nor the interest rate would vary. However, we have assumed and will continue to do so throughout the paper that no form of intervention occurs in the interior of the band. (As we shall see, such a bond repurchase is one of the two forms of intervention that the central bank must choose from when the weak-end of the band is reached).

By assumption, within the band, the level of reserves and the stock of domestic securities held by the central bank remain constant. Notice, however, that equation (2.8) implies that the nominal supply of money would expand or contract as the market value of reserves, expressed in units of domestic currency, varies. This particular modelling decision will have a role in our simulations (we will discuss the implication of keeping the nominal money supply constant within the band and reflecting profits from the revaluation of foreign assets through a corresponding decrease in $\bar{B}$).

When the exogenous stock of lending reaches either limit, N_1 or N_0, the central bank is forced to intervene in order to prevent a further depreciation or appreciation, respectively. Consider, for expositionary purposes what happens at the weak-end of the band (the other case is a mirror image). Suppose $N = N_1$. A further decrease in N, $dN < 0$, would lead in the absence of intervention, to an increase in the interest rate. Such increase would cause a reduction in the demand for real money balances which would force a depreciation of the currency beyond S_1. To prevent this from happening, the central bank must take action in either of two ways: it can use some of its international reserves R to repurchase from noisy

traders the securities dumped into the market (dN), thus preventing any impact on the interest rate and the corresponding efforts on the demand for real balances; or it can allow the initial effects on the bond market and the demand for money to take place and use its international reserves to purchase the excedents or real balances, preventing an adjustment via prices. We call the first alternative a "sterilized" intervention, as the effects from the capital outflows are offest by the central bank action, eliminating any impact on the interest rate or the demand for money. The second alternative is a "non-sterilized" intervention, where the capital outflow leads ultimately to a higher level of interest rates. In the next section, we shall study the dynamics of the equilibrium variables under both types of central bank policies.

The previous discussion suggests that stocks of bonds and money matter. As a consequence, open market operations, where the central bank decreases the supply of money through an increase in the outstanding supply of bonds, or viceversa, will not be innocuous. Without considering for the moment what happens to the entire equilibrium relationship between S and N, an open market operation designed to contract the money supply must increase domestic interest rates, otherwise rational investors would not willingly hold the securities previously held by the central bank. Notice that the increase in domestic rates would also lead to a reduction in the real money demand. We cannot expect in general, that such a reduction in the demand for money would match exactly the initial reduction in the money supply. For this to happen the interest rate elasticities of the demands for domestic assets and for real balances must be equal in absolute value. Otherwise, the equilibrium in the money market would only be restored by a discrete change in the exchange rate (the direction would depend on the relative ordering of these elasticities). For example, if the real money demand is less elastic with respect to the interest rate than the demand for domestic

securities, an expansion of the money supply through an open market transaction (a central bank repurchase of bonds) would decrease the domestic interest rate and increase the demand for real balances. However the increase in demand would be smaller than the expansion in the money supply, forcing an increase in domestic prices (i.e. a discrete depreciation of the domestic currency). Naturally, for the central bank to be able to implement such a transaction in our model, it would have to be non anticipated by rational investors, who otherwise would incorporate the probability of such movements in the equilibrium dynamics of the exchange rate.

Before proceeding with the numerical solution of the model it is worth reviewing the mechanics of the solution once the exogenous stock of lending has fallen outside of the range $[N_1, N_0]$. The reader familiar with this literature may want to skip directly to the next section. Consider again the case of a drop in N below N_1. The central bank is forced to intervene according to either of the two policies described above (or a combination of both). As a consequence, R or B^C (or both) would change. Suppose that at the next instant N increases ($dN > 0$). At this moment, the exchange rate would appreciate along the *new* equilibrium S-shaped curve (i.e. along the solution to equation (3.6)) for the *new* values or R and B^C, and subject to conditions (4.1) for some *new* values of N_0 and N_1. It so happens that the new value of N_1 is exactly the last value of N at which the government intervened. Later in the paper we will show how the entire equilibrium relationship evolves after a "sterilized" and a "non-sterilized" intervention, both at the weak and the strong ends of the band.

5. Numerical Example

In the absence of closed form solutions to equation (3.6) with boundary conditions (4.1) we present a numerical example that will help to develop some insight of the model. We assume the following parameter values:

$$\begin{array}{rclrcl} \eta & = & 0 & \mu & = & 0.4 \\ \alpha & = & 0.625 & \bar{B} & = & 4.0 \\ \sigma & = & 0.20 & B^C & = & 0.5 \\ \beta & = & 1.0 & R & = & 1.0 \\ r^* & = & 0.05 & \lambda & = & 0.05 \\ S_0 & = & 0.95 & S_1 & = & 1.05 \end{array}$$

There is nothing particularly relevant with regard to this choice of parameter values other than the fact that they provide solutions where the relative values of foreign lending, domestic holdings of domestic bonds and reserves seem reasonable as compared to real data.

Before analyzing the effects of government intervention, we examine the effects of changes in the parameters of the stochastic process governing capital flows on the equilibrium relations between S, r and N.

Consider the effect of a change in the drift parameter of capital flows η. The results are exhibited in Figure 2. As the graph suggests a fall in η causes a discrete depreciation of the domestic currency.

Insert Figure 2

The intuition behind this result is as follows. A drop in η implies a lower expected value of future capital flows. This in turn implies a smaller expected appreciation (or a larger depreciation) of the domestic currency (recall that $\gamma = \eta g'/g + \pi^2 g''/2g$, with $g' < 0$). In order to restore the expected real return of domestic bonds the domestic nominal interest rate must increase. The corresponding decrease in the demand for real balances forces a discrete increase in the exchange rate.

Consider now a change in the variance of capital flows σ^2. The effect, which is shown in figure 3, is less obvious at a first glance. An increase in σ^2 causes a counter clockwise rotation of the equilibrium exchange rate schedule. In other words, at the weak-end of the band an increase in the volatility of capital flows causes an exchange rate *appreciation.* Similarly, at the strong end of the band, an increase in the volatility of capital flows leads to *depreciation* of the domestic currency.

Insert Figure 3

In order to understand this effect, let's consider an initial point close to the weak-end of band where, as the graph suggests, the magnitude of this effect is larger. Recall that σ^2 affects both parameters of the equilibrium exchange rate: the drift γ and the variance ν^2. More precisely, σ^2 enters into γ through the second order term (quadratic error from Itô's formula) and into ν^2 directly, as a first order effect (equations (2.4), (2.5)). At the weak-end of the band these two terms have opposite signs, however the smooth pasting conditions (g' approaching zero near the ends of the band) imply that the former is larger in absolute value.

The concavity of g at the weak-end implies that γ is negative, i.e. at the weak-end, the exchange rate is more likely to appreciate than to depreciate provided the band is credible. An increase in σ^2 causes an increase in the absolute value of γ. A more negative γ makes the domestic bond more attractive, which leads to a combination of a drop in S and a drop in r. A smaller r is also related to a flatter g curve. Notice that the effect of an increase in the volatility parameter resembles that of an increase in volatility of the underlying asset on the price of a financial option. Due to the one-sided uncertainty of the option, an increase in volatility makes the option more valuable: losses remain bounded while higher returns become more likely.

At the strong end of the band the effect is exactly the opposite. An increase in the volatility of capital flows increases the expected losses from a depreciation. At the new equilibrium the domestic interest rate is larger and so is S.

In summary, an unexpected increase in volatility causes a once and for all jump in the exchange rate towards the central parity. Also, the range of N over which no intervention occurs is expanded. This does not mean, however, that interventions are less likely, since the expanded range is confronted with a larger volatility. In Table 1 we compare the increase in the range of N with the likelihood that the limiting values of N might be reached over some finite period τ starting from the central parity. It turns out that the increase in the measure of $[N_1, N_0]$ after an increase in the volatility is not enough to compensate for the dispersion of future values of N. As the table shows, starting from the central parity, the expected time to intervention sharply shrinks as σ^2 increases.

Table 1

Expected time to intervention (τ)

σ	N_1	N_0	τ
0.08	1.87	3.96	81.30
0.20	1.73	4.10	17.46
0.50	1.39	4.46	4.62

6. Central Bank Intervention

In this section we study the impact that the two types of central bank interventions defined previously have on the equilibrium relationship between the stock of exogenous lending and the exchange rate. Recall that the two elementary forms of interventions were defined as a "sterilized" intervention (where the central bank uses its international reserves to repurchase government bonds at the weak-end of the band and sells government bonds for reserves at the strong end); and a "non-sterilized" intervention (where the central bank uses reserves to buy excedents of real balances at the weak-end and sells additional real balances in exchange of reserve currency at the strong end). In essence, in a sterilized intervention the outstanding supply of bonds is accommodated so that the initial variation in the foreign lending does not pass through the interest rate and domestic prices. In contrast, in a non-sterilized intervention these effects are allowed to take place and the adjustment is made through the nominal supply of money in order to prevent changes in the price level.

We are interested in two implications from each sort of intervention. First, the amount of reserves required to support the regime. In the case of a sterilized intervention this is straightforward as $dR = dN$. However in a non-sterilized intervention dR depends on the magnitude of the impact of the capital flow on the interest rate and hence on the demand for real balances. In general, the more inelastic the demand for bonds or the more elastic the demand for money, the larger the amount of reserves involved in a non-sterilized intervention.

This argument is applicable to real world episodes. For example, our argument supports the view that if in the months preceding the Mexican crisis the Banco de México had not sterilized capital outflows, the impact on interest rates and the demand from money would have been substantial, and could have led to a dollarization of the economy and a larger reserve loss.

The second implication we study is somewhat more subtle, and it has to do with the post-intervention mix of foreign and domestic assets in the monetary base, and its implications on the entire equilibrium schedule. As we will explain later, the two types of interventions have different effects on the volatility of prices and the likelihood of further interventions in the future. We should mention that this implication is linked to our specification of the monetary base where reserves are marked to market and the money supply varies accordingly. To the extent that the central bank does not reflect capital gains or losses into the monetary base, the effects on asset price volatility that we report would vanish. Our assumption as to how the central bank conducts monetary policy within the band may seen unrealistic. However, if we had considered instead a broader monetary aggregate composed by financial assets denominated both in local and foreign currency, our results most likely would continue to hold as intervention would tend to alter the mix of these assets.

Regardless of the type of intervention, the central bank uses its international reserves to support the exchange rate regime. The parameter λ that we introduced in the demand for domestic bonds by rational investors was meant to reflect some sort of lack of credibility on the regime. Intuitively, such a risk parameter should be related, among other things, to the level of international reserves held by the central bank. Hence, a detailed study should account for these indirect effects of reserves on the demand for assets and hence the equilibrium. Computer simulations show that in the short run different specifications of the

risk premium have little effect on the equilibrium. For this reason we have chosen not to complicate the analysis any further at this stage and keep λ constant. This would be the case, for example, if intervention were sporadic. A comprehensive study of this issue where risk premia are endogenous is beyond the scope of this paper. Nevertheless, in the next section we will investigate the long run effects of the two types of interventions once we allow for a specific functional relationship between R and λ.

Consider first the case of a "non-sterilized" intervention. The effects on the exchange rate and the interest rate are displayed in figures 4 and 5. There are two features worth pointing out. The first one is the nearly parallel shifts in the equilibrium exchange rate and interest rate schedules. The second is the increase in the level of interest rates after a loss of reserves. This latter effect is a direct consequence of the drop in foreign lending which requires investors to hold a larger share of domestic securities. With regards to the parallel shift of the equilibrium schedule, recall that in a non-sterilized intervention the bond holdings of the central bank remain unaltered. As a consequence, changes in the real money supply after changes in the exchange rate are of the same magnitude before and after the intervention. Since the demand for real balances has been assumed to be linear, the slope of the equilibrium relationship between the exchange rate and the domestic interest rate remains unaltered.

Consider now a "sterilized" intervention. As we shall see, the consequences are different if the intervention occurs at the weak or at the strong end of the band. The effects from intervention at the weak-end are shown in figures 6 and 7. Unlike a non-sterilized intervention, sterilization by definition prevents any immediate effects on interest rates. Notice however that a sterilized intervention flattens out the equilibrium exchange rate schedule while making the interest rate schedule steeper. In other words, a given capital inflow $dN > 0$ would

have smaller effects on the exchange rate after the intervention but a larger effect on the interest rate that it would have before the central bank had been forced to take action.

The effect on the exchange rate schedule stems from the assumed evolution of the money supply inside the target zone. Recall that by assumption in the absence of any intervention, the money supply is adjusted continuously in order to reflect the market value of the central bank assets.

$$M^S = B^C + S \cdot R$$

A sterilized intervention leaves constant the money supply at the weak-end ($dB^C = S \cdot dR$). However, by increasing the fraction of domestic assets, the real money supply becomes more elastic to changes in the exchange rate.

$$\frac{\partial(M^S/S)}{\partial S} = -\frac{B^C}{S^2} \tag{6.1}$$

In order to explain the effect of a weak-end sterilized intervention on the exchange rate, we will analyze the magnitude of the capital flows required to observe a hypothetical appreciation from S_1 to an arbitrary $S \in (S_0, S_1)$ before and after the intervention takes place. Equation 6.1 implies that the appreciation will lead to a larger expansion of the money supply after the intervention (larger B^C). In order to balance the money market, the reduction in domestic interest rates after the intervention has to be larger. For this to happen the capital flow causing the given appreciation has to be larger after the intervention.

The effect on the equilibrium interest rate schedule is in turn a consequence of what happens to the exchange rate. Consider a given $dN > 0$ before and after the reallocation of the central bank portfolio. As we just argued, the appreciation after the intervention is

smaller. Therefore, the exchange rate has a lower chance of experiencing a devaluation in the future if the intervention has occurred. Thus after the intervention at a given nominal interest rate, the expected real return would be larger. Equilibrium in the domestic security market implies, therefore, a lower interest rate after the recomposition of the central bank assets.

Even though our model does not allow us to analyze any welfare implications from the two types of interventions, the previous discussion suggests two "favorable" aspects of a sterilized intervention. By making the exchange rate less responsive to capital flows, the currency market becomes less volatile. The volatility of the exchange rate is often consider to be a source of higher risk premia which undermines the performance of an economy. The second aspect is the general reduction in the level of interest rates. Notice that near the weak-end of the zone, the effect on the equilibrium exchange rate schedule implies that real interest rates would be lower after an intervention. Thus, our model predicts a favorable impact of a weak-end sterilization on economic activity. In return to lower level of interest rates, the central bank has to accept a larger volatility of this variable. This is reflected in a steeper equilibrium interest rate schedule.

In addition to these effects, there is a negative effect of a sterilized intervention on the life expectancy of the regime. After a sterilized intervention at the weak-end, the measure of the interval $[N_1, N_0]$ increases. The example depicted in the graph is more extreme as $N_0' > N_0$ (although this fact depends on parameters values). In any case, the increase in the size of the interval (which is robust to parameter values) implies that after an intervention, the capital inflows that would allow the central bank to build back its reserves have to be larger. Loosely speaking, reserve losses associated to sterilizations are somewhat "permanent".

Consider now a sterilized intervention at the strong end of the band. In this case, the

central bank must accumulate reserves in order to prevent a further appreciation, and does so by selling some of its own holdings of government bonds. Figure 8 depicts the effects of a strong end sterilized intervention on the exchange rate. Contrary to what happens when the sterilization occurs at the weak-end, this intervention produces a steeper schedule, therefore increasing the volatility of the exchange rate. The driving force is, once again, the recomposition of central bank assets. In this case, the sterilization increases holdings of foreign assets. As a consequence, the real money supply becomes less elastic to changes in the exchange rate. Thus, post intervention, an equilibrium depreciation is associated with a milder reduction in the quantity of real balances supplied. The equilibrium in the money market is restored with a smaller increase in the interest rate, which would be caused by a modest capital outflow.

The effects of a strong end sterilization on domestic interest rate are shown in Figure 9. The results are not the mirror image of the weak-end sterilization. The intervention at the strong end also causes a general reduction on interest rates. That is to say, the interest rate that would be observed if the currency were to depreciate from S_0 to S would be lower once the sterilized intervention takes place. The intuition is as follows. A given capital outflow $dN < 0$ causes a larger depreciation after a sterilization. At such moment, given a nominal return, the real return for domestic assets increases, as the likelihood of a sizeable appreciation is enhanced. To restore the equilibrium in the domestic security market, the nominal interest rate must decrease. As can be seen in the figure, the volatility of the interest rate also goes down in this case.

Summarizing, sterilization either at the weak-end or the strong-end of the target zone is an effective policy to reduce the general level of interest rates. At the exact moment of the intervention no effect on interest rates takes place. Effects are felt as the exchange rate

moves toward the opposite end of the target zone. In the case of a weak-end intervention, this reduction in the interest rate schedule is associated with a lower exchange rate volatility but a larger interest rate volatility. At the strong end the opposite result holds: the volatility of the exchange rate increases while the volatility of the interest rate decreases.

We argued that a sterilized intervention at the weak-end has a perverse effect on the life expectancy of the regime. By flattening out the exchange rate schedule, an intervention would make increasingly harder to recover lost reserves. The accumulation of reserves at the strong end does not seem capable of compensating such effect. The steeper exchange rate schedule (larger volatility of exchange rates) increases the likelihood of loosing the recently acquired reserves. Roughly speaking, the reserve accumulation through sterilization is rather temporary, while reserve losses through the same policy are somewhat permanent.

7. Implications for the Collapse of a Target Zone

The model discussed so far can be easily extended to analyze the impact of each type of intervention on the eventual collapse of the regime.

Recall that we assumed a constant parameter λ that we linked to the probability of a discrete devaluation. Presumably, this parameter ought to be a function, among other things, of the level of reserves. More precisely, of the distance between the actual level of reserves and a threshold level $\bar{R}$, that once reached would trigger a discrete devaluation.

A loss of reserves (either through a sterilized or a non-sterilized intervention) would generate a leftwards shift of the demand for domestic securities. This effect on the choice function of rational investors would force the central bank to further intervene in order to support the weak-end of the band. To see this, suppose that the central bank is engaged in sterilization trying to prevent any impact on interest rates and on the demand for money

from an exogenous capital outflow. The initial loss of reserves would make domestic bonds less attractive as the collapse of the target zone becomes more likely. The possibility of capital losses generates additional sales of bonds, in this case by rational investors, that the central bank must absorb. On the other hand if the central bank is not sterilizing, the additional increase in interest rate caused by the reduction in the rational demand for domestic assets would lead to a further reduction in the demand for real balances.

Suppose, as it would probably be the case in a model capable of generating endogenous risk premia, that λ is a decreasing and convex function of the level of reserves.

For example, assume λ is given by

$$\lambda(R) = k(R - \bar{R})^{-\psi} \qquad \psi > 0 \tag{7.1}$$

Under such a specification, the lower R the larger the effect of a reserve loss on the demand of rational investors. The assumed functional form implies that the initial reserve loss is magnified in an increasing fashion as R drops. Figures 10 and 11 show the behavior of reserves under each type of intervention when we apply a monotone sequence of capital outflows, assuming the relationship 7.1 with $\bar{R} = 0$. The vertical segments in each figure correspond to a sufficiently low level of reserves, for which the convexity of $\lambda(R)$ kicks in. At such point, a small outflow generates an explosive path on λ, triggering a "speculative attack" on the currency.

Notice that the speculative attacks that we just described are of a different nature than those in Krugman (1979), Flood and Garber (1984) and Obstfeld (1984). In their case the "speculative" attack comes from a once and for all reduction in the demand for money, consistent with the adoption of a free float after the collapse of a fixed regime. In our case, the attack is a run against domestic securities as a regime collapse, and hence and infinitely

negative real return on domestic assets, becomes imminent.

There is a final point we want to discuss, which is related to the influence of each type of intervention on the life expectancy of the regime. The key issue is the loss in reserves associated with each type of weak-end intervention. As mentioned before in the case of a sterilized intervention, the initial effect (not considering the later impact on rational demand) is $dR = dN$. However, for a non-sterilized intervention, the reserves required to support the regime are given by the interaction of the rational demand for domestic assets and the demand for real balances. Since the central bank is not sterilizing dN forces an initial $dI = -dN$ which can only occur through an increase in r. The exact amount of such effect on interest rates is given by ω in (3.2) and the drift and variance parameters of the exchange rate process. The increase in the interest rate leads to a reduction in the demand for money which has to be accommodated through a loss of reserves. Although we have not included in this discussion the secondary effect on reserves from the increase in λ, it should be clear that this effect would only magnify the reserve losses from both types of intervention, without altering the ranking.

The adequacy of each type of intervention depends, therefore, on the relative elasticities of the demands for domestic securities and real balances. The parameter values in figure 10 correspond to a relatively elastic demand for money and a relatively inelastic demand for securities. The lack of intervention causes a large increase in the interest rate, which in turn causes a large reduction in the demand for money. Figure 11 is based on a different set of parameter values that reverses the order of the elasticities. If the demand for money is inelastic or the demand for assets elastic a non-sterilized intervention that allows capital outflows to impact the interest rate would minimize the loss of reserves.

8. Conclusions

Central banks committed to sustain a target zone can do so either through sterilization (keeping the mix of assets constant) or through non-sterilization (purchasing bonds dumped by foreign investors). Previous works do not allow to study the effect on both exchange rates dynamics and equilibrium interest rates of these policies. Besides, unlike it usually seems to be the case, previous models either predict a negative correlation between exchange rates and interest rates or the positive correlation is the result of the exogenous possibility of abandonment of the target zone regime. We introduce a money market and a bond market. Also, the driving force of our model is an exogenous component of the bonds demand. We study effects of both types of intervention In particular, and more important for economic policy purposes, sterilized intervention in the weak-end of the band seems to yield lower interest rates (but more volatile) and less volatile exchange rates. Also, the loss of reserves due to either type of intervention is the result of the relative values of the elasticities of the money and bond markets. By a straightforward extension of the models we can study the dynamics of "speculative attacks" and predict the sustainability of the regime depending on the parameters of the model.

Our model provides an structure reach enough to study further problems of economic relevance. For example, it can be easily studied the term structure of interest rates and the effects of different types of intervention on the term structure.

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