Inside and Outside the Band Exchange Rate Fluctuations for Brazil

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Abstract

This paper analyzes the empirical fit of a new approach to exchange rate target zones. Unlike most of the literature on target zones, we use an estimation procedure that takes explicitly into account the band constraints, and hence their effect on the expectations of agents. Crucially, we do not impose Uncovered Interest Parity to assess realignment expectations. Rather than a point estimate of the future exchange rate, we estimate the entire range of realizations anticipated by the markets, and the probability attributed to each range. We examine high-frequency Brazilian post-stabilization (stable) data in allowing for both realignment jumps and within-the-band jumps. Knowledge of the exchange rate distribution can be relevant not only to the private sector for the management of currency risk, but also to policymakers as a source of prompt market feedback to policy changes or other political and economic shocks.

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1 Introduction

The European Monetary System and its speculative crises spurred motivation for empirical analyses of target zone models. This same motivation waned once empirical failures of those models were documented (see below). However, currency arrangements that resemble informal or formal target zones are naturally advantageous, in particular to countries that are coming out of an inflationary environment. Keynes (1930, pp. 319-331) set up the argument by emphasizing that a nonzero band allows some degree of national monetary independence, so that monetary policy can to some extent be used for domestic stabilization. That is, unlike the standard textbook Mundell-Fleming model, it is possible to have fixed exchange rates *and* monetary independence. The central bank can control the domestic interest rate, albeit temporarily, via control of the expected rate of currency depreciation within the band (in essence, by exploiting the mean reversion regularity of the exchange rate changes within the band). For example, the central bank can dampen the effect of an increase in the domestic interest rate by increasing the exchange rate and creating an expected currency appreciation within the band. Governments and central banks generally prefer to have some monetary independence. Most important, the internationalization of capital has rendered emerging markets particularly prone to capital flows' volatility and inflation concerns.

This paper uses a data set of Brazilian financial and macroeconomic variables for the period after a successful stabilization, to extract the distribution of exchange rate changes when a target zone characterizes the exchange rate regime. By modeling the entire distribution of exchange rates, we are able to isolate the probability of target zone realignments. We therefore do not resort to the popular method of imposing Uncovered Interest Parity to extract the expectations of realignments. Svensson (1990) argued that risk premia in target zones should be small; his work has motivated a large literature that ignores risk premia.

The empirical estimation of the exchange rate model with expectations and a target zone considers not only the possibility of the exchange rate being on the boundary but also that of realignments. The approach is based on Bekaert and Gray (1996) and Jorion (1988). Jumps in general are incorporated by conditioning the distribution of exchange rate changes on a jump variable where the probability and size of a jump vary over time as a function of financial and macroeconomic variables. There are two types of jumps in exchange rates, namely realignment jumps and within-the-band jumps. The latter is associated with a perfectly credible target zone[1]. The conditional distribution of exchange rate changes is thus characterized.

[1] Perfect credibility is defined as probability zero that the bands will be realigned.

We are able to capture features of the 'classical' target zone model, such as reversion towards the mean, and in addition we elaborate on the probability of a jump. In particular, unlike previous studies, our methodology takes explicitly into account the target bands. The use of this information is crucial for our estimation of jumps in the exchange rate. Hence, we make use of a truncated distribution to characterize the behavior of the exchange rate within the band. Our full characterization of the model includes a probabilistic mixed densities structure.

The rest of the chapter is organized as follows. Section 2 describes the theoretical background of exchange rates target zones models. The next section describes the econometric approach and estimation. Data description and implementation are presented in section 4, and section 5 concludes.

2 Theoretical Target Zone Models

Krugman (1987)[1] minimalist monetary model of target zones and exchange rates dynamics derived results which were at first surprising, and spurred a vast amount of literature in the late 1980's and early 1990's, mostly in unpublished form. The Krugman model has two crucial assumptions: (i) *perfect credibility* of the target zone; and (ii) the target zone is defended with *"marginal" interventions only*. Those two assumptions were proved untenable by empirical work (see below). We can characterize Krugman's novel approach by the presence of uncertainty and nonlinearity, the use of stochastic calculus, and the non-specification of the fundamental. Several results on the behavior of exchange rates are derived of this simple specification[2].

We briefly state the well-known results: (i) the so-called *"honeymoon effect"* implies that the exchange rate regime is a stabilizing one; (ii) *mean reversion* toward the central parity imparts a negative correlation of the forward premium or interest rate differential and the exchange rate (under the often used parity condition); (iii) the *"smooth pasting"* conditions make the exchange rate a non-linear function of the underlying fundamentals, described by an S-shaped curve; and (iv) the distribution of the exchange rate within the band is U-shaped/bimodal.

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[1] The research program on target zones was defined during intensive discussions of a crude version of 'Target Zones and Exchange Rate Dynamics' (NBER 1988, and QJE 1991) at a NBER conference on the EMS in December 1987. The field grew rapidly, far outpacing the ability of normal channels of publication to keep up. See Krugman and Miller (1992).

[2] The monetary model set-up was a convenience, as its empirical drawbacks were well-known.

Krugman's model provided a breakthrough in the study of exchange rate target zones. From a simple framework many predictions for the behavior of exchange rates within a target zone were derived. This naturally prompted a large empirical literature. Empirical tests of the Krugman model were however fairly disappointing. We build on these empirical developments by using an econometric approach which takes into account the possibility of an imperfectly credible target zone (allowing for realignments of the band), as well as the existence of intra-marginal interventions.

As we discuss below, there is ample evidence that the central bank intervenes intra-marginally, that is, in the interior of the band. The presence of realignment risk accounts for the rejection of the assumption of perfect credibility. Moreover, we do not impose uncovered interest parity to assess realignment expectations. Although much of the literature has developed around the imposition of this condition, on the grounds that existing risk premia are negligible, in fact there is evidence that uncovered interest parity does not hold empirically.

The basic Krugman model has been tested extensively on data from the ERM, the Scandinavian countries, and as far back to the Bretton Woods system and the gold standard. The U-shape of the exchange rate density, implying that the exchange rate spends most of its time near the edge of the band, is clearly rejected by the data. Instead, the data show that the distribution is hump-shaped, with most of the probability mass in the interior of the band [Bertola and Caballero (1992), Flood, Rose and Mathieson (1991), Lindberg and Soderlind (1994)]. The deterministic relationship between the interest rate differential and the exchange rate (under uncovered interest parity and perfect credibility) is rejected by the data; plots result mostly in wide scatters of observations [Svensson (1991), Flood, Rose and Mathieson (1991), Lindberg and Soderlind (1994)].

The two crucial assumptions of the Krugman model are also rejected by the data. The assumption of perfect credibility is rejected for most target zones and most sample periods [Svensson (1991), Flood, Rose and Mathieson (1991)]. The assumption that the central bank undertakes only marginal interventions is also not satisfied; in fact, interventions that occur in the interior of the band ("intra-marginal" interventions) are abundant [Giavazzi and Giovannini (1989), Dominguez and Kenen (1992), Lindberg and Soderlind (1995)]. Hence, it was only natural that the theoretical literature shifted to accommodate those empirical facts.

To counter the crucial assumptions, the two main extensions involve the incorporation of imperfect credibility and intra-marginal interventions. Bertola and Svensson (1993) pioneered the imperfect credibility assumption, with the modeling of time-varying realignment risk. They also suggested the so-called 'drift-adjustment' method to estimate realignment expectations, via the imposition of the assumption of uncovered interest parity. This method was implemented in Rose and Svensson (1995), Lindberg, Soderlind and Svensson (1993), and Svensson (1993), among others. The importance of the assumption of intra-marginal interventions, to explain the evidence on the hump-shape of the exchange rate distribution, was established primarily by Lindberd and Soderlind (1995). In particular, they find evidence of fairly strong mean reversion, and fail to find evidence of nonlinearities.

This notwithstanding, empirical measurements of risk premia do not seem to validate Svensson's argument for the imposition of the uncovered interest parity condition to extract expectations from the data. Svensson (1990) argued that risk premia in target zones are small and could be made negligible. This argument has motivated a large amount of research, whose empirical papers use the 'drift-adjustment' method. Recently, Bekaert and Gray (1996) showed that for the French Franc/Deutsche Mark rate after 1987, and covering the EMS currency crises of September 1992 and August 1993, risk premia tend to be large prior to realignments[1]. Moreover, in contrast to previous empirical work, they find evidence of nonlinearities. Gourinchas (1995) uses a non-parametric instrumental variables approach to reach similar conclusions. In addition, while the 1987-1991 EMS period has been used to illustrate a credible target zone at work, Bekaert and Gray (1996) do find evidence of substantial realignment probabilities. The important implication is that previous approaches that ignore the potential impact of large foreign exchange risk premia before realignments are likely to incur in unreliable computations of realignment probabilities. We therefore explicitly model the possibility of the existence of risk premia.[2]

The use of options data in the estimation of exchange-rates conditional distributions is yet another alternative empirical approach to the use of the uncovered interest parity condition. This is precisely what Campa, Chang and Reider (1997) implement in recent work. They also find evidence in favor of nonlinearities. A related interesting reference is Lim et al (1998), who use options and combinations of a distributional assumption with conditional variance specifications to capture stylized facts about exchange rate changes and the pricing of currency options.

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[1] This does not go without a proviso. Bekaert and Gray's (1996) empirical estimates come from a reduced-form estimation that is likely to be subject to small sample problems. This is however minimized given their care in carrying out an out-of-sample analysis which instill confidence in their estimates of the risk premium.

[2] In fact, empirical testing of uncovered interest parity per se strongly rejects the null hypothesis of a coefficient on the interest rate differential equal to one in a regression on the exchange rate change. Froot and Thaler (1990) report that the average coefficient across some 75 published estimates is -0.88. One of the explanations for the deviations of uncovered interest parity is the existence of risk premia.

Other papers have attempted to investigate the relationship between expected devaluation/realignment of the exchange rate in a target zone and economic fundamentals beyond the EMS countries. However, work like Thomas (1994) and Werner (1995), still use a 'drift-adjustment-method-type' approach which may potentially lead to unreliable estimation. This is even more so the more unstable the data being used.

We use an approach close to Bekaert and Gray (1996) to estimate the conditional distribution of exchange rate changes for an emerging market country. We explicitly take into account the upper and lower bands of the target zone, and parameterize the distribution as a function of financial and macroeconomic variables. In addition, we expand the empirical research on target zones beyond the EMS experience, and use high-frequency data from Brazil. Our choice of Brazil is driven by its remarkable stabilization experience of 1994: data has since been relatively more stable and informative. The stabilization program included from the outset an 'implicit' target zone for the Brazilian currency vis-a-vis the US dollar, which later on became the official exchange rate regime[1].

Like any empirical work with a finite data set, we are also faced with the possibility of peso problems. We try to mitigate this effect with the inclusion of forward-looking conditioning variables. Nevertheless, our choice set is inherently more limited, given the more difficult nature of emerging market data.

3 Econometric Model

Contributors to the target zone literature were soon aware of the need to include intra-marginal interventions and realignments at a theoretical level. Empirical estimation has lagged behind. The problem is clearly not whether realignments take place or not but rather whether the information with regard to future movements of the band is contained in the information set of agents. Empirical estimation of an exchange rate model with expectations and a target zone is non-trivial since expectation formation will have to take account not only of the possibility of the exchange rate being on the boundary, i.e. intra-marginal and marginal interventions, but also that of realignments. The actual distribution is unknown, and realignments indicate that the system is not perfectly credible.

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[1] See Ribeiro (1998) for a historical perspective on the Brazilian *Real* experience.

In this spirit, we explicitly model the possibility that the exchange rate may occasionally jump, taking it outside the band. We have therefore two kinds of jumps: *within-the-band jumps* and *realignment jumps*. To this end, we make use of a jump indicator variable, which will define the two pieces of the distribution of exchange rate changes, conditional on available information[1].

It is crucial to note that we do not identify jumps to realignments; instead jumps within the band and realignment jumps are modeled as one process. This makes sense as economic agents are not concerned with movements in the central parity, but rather with movements in exchange rates. In addition, there are relatively few realignment jumps, so including jumps within the band helps to identify our jump parameters. Table one illustrates the largest increases and decreases in the Real/Dollar bilateral rate. Indeed, while large jumps are associated with realignments, there are many jumps within the band which are of the same order of magnitude as the realignment jumps. There are eight realignments over the sample period, and two of them drive the fourth and fifth largest increases, i.e. depreciation, in the exchange rate. Several jumps that are within the band are higher than realignment jumps.

Formally, we are interested in $f(\Delta S_t \mid I_{t-1})$. $f(\cdot|\cdot)$ denotes a conditional density; ΔS_t represents log exchange rate changes, I_{t-1} the information set. We illustrate via the indicator variable J_t, where

$$J_t = \begin{cases} 1 & \text{if the exchange rate jumps at time t} \\ 0 & \text{otherwise} \end{cases}$$

Trivially, the conditional distribution can then be written as

$$f(\Delta S_t \mid I_{t-1}) = f(\Delta S_t \mid I_{t-1}, J_t = 0)\Pr(J_t = 0 \mid I_{t-1}) + f(\Delta S_t \mid I_{t-1}, J_t = 1)\Pr(J_t = 1 \mid I_{t-1}).$$

Our purpose is to characterize the distribution of exchange rate changes. Given our distributional assumption, we then parameterize the unknowns as a function of the composite fundamental, i.e. our conditioning variables. Finally, to close the model, we specify the probabilistic environment.

It is convenient to consider separately the two pieces of the density, namely first the conditional distribution in the absence of jumps, and second, the conditional distribution with jumps in the exchange rate. We therefore aim at a mixed-distribution structure.

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[1] This section draws upon Bekaert and Gray (1996). In turn, their model draws upon Ball and Torous (1985) and Jorion (1988) jump-diffusion models.

3.1 The Credible Regime

We first consider $f(\Delta S_t \mid I_{t-1}, J_t = 0)$, the distribution of exchange rate changes when the target zone is perfectly credible. In this case, the density is bounded, defined only on the range between the upper and lower bounds.

To proceed, we need to be more specific about which distribution of exchange rate changes. The actual distribution is unknown, but we have some useful pieces of information. First, most theoretical models consider exchange rate changes to be normally distributed --an increment from a Brownian motion-- in the absence of a target zone[1] [2]. Secondly, Lindberg and Soderlind (1995) have shown that in a target zone with (mean-reverting) interventions, the unconditional distribution of the (composite) fundamental is a truncated normal distribution. In addition, in a credible target zone, there is zero credibility of the exchange rate moving outside the band: we therefore truncate that part of the density.

Hence, for the credible regime, we use a truncated normal density which has few parameters to estimate and is defined on [L, U], respectively the lower boundary and the upper boundary of the band. The truncated normal depends on four parameters, the mean and the variance of the underlying normal distribution, and the truncation points. In a target zone model, the truncation points are predetermined, and the mean and the variance have particular characteristics. Formally, ΔS_t is modeled as being normally distributed with conditional mean m_{t-1} and variance s^2_{t-1}, functions of the information set I_{t-1}, with any probability mass falling outside the range [Δ_L, Δ_U] being truncated.

We proceed with the specification of the truncated normal density parameters. The conditional mean m_{t-1} is parameterized to incorporate the mean reversion characteristic of a target zone model. Hence, exchange rate changes depend on the position in the band, PB_{t-1}, which takes a value on

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1 The normality assumption has in fact been shown to fail to capture stylized features of (the unconditional distribution of) exchange rate changes, namely leptokurtosis, skewness, and volatility clustering. See Lim et al (1998). This notwithstanding, the normal distribution has often been used on account of its tractability and asymptotic properties. Bekaert and Gray (1996) and this author are not exceptions.

2 The Handbook of International Economics (1995, p.1873) has a practical footnote on ‘all you need to know about Brownian motion for its present discussion [the Krugman model]’. For a variable that follow an increment from a Brownian motion, its sample path is almost everywhere continuous, exchange rate changes are independent, and its distribution is normal with variance equal to the time difference, hence stationary.

[-1, 1] indicating the relative position of the exchange rate within the target zone. (When PB_{t-1}=0, the exchange rate is at the center of the target zone.)
Let

$$m_{t-1} = b_9 + b_{10} PB_{t-1}; \qquad \text{<1>}$$

the expected change toward the center of the target zone is stronger when the exchange rate is near the boundary of the band.

The conditional variance s^2_{t-1} follows a process which allows for the dependence on the position within the band and the occurrence of realignments. This specification captures the importance of the eventual corrosion of the band, as well as the position within the band, which is the sole determinant of conditional volatility in standard target zone models (e.g. Krugman (1991)). Let

$$s^2_{t-1} = b_{11} + b_{12} RD_{t-1} + b_{13} \left| PB_{t-1} \right|. \qquad \text{<2>}$$

The realignment dummy RD_t takes the value of 1 when there is a realignment of the target zone in week t and zero otherwise. The position within the band, PB_t, tells us whether the conditional volatility decreases as the exchange rate approaches the bounds of the band. This is indeed the result in the Krugman model.

3.2 The Jump Process

Next, we specify the possibility that the exchange rate may jump, in which case the relevant part of the density is $f(\Delta S_t | I_{t-1}, J_t = 1)$. As mentioned, the jump may take the exchange rate outside the current target zone *or* within the target zone. Realignment jumps may cause a jump in the exchange rate (a discontinuity will occur if the new target zone and the old target zone do not overlap). Within-the-band jumps may also occur, say because of a change in the fundamental value of the currency due to announcements of changes in central bank policy[1]. Incidentally, the literature on speculative attacks is closely linked to that of target zone models; hence we consider the case of a speculative attack on the currency. Suppose the exchange rate is in the lower (stronger) edge of the band when the speculative attack begins. It is plausible that there is enough room for a large and sudden depreciation of the currency to be accommodated within the band. On the other hand, a prolonged attack may

[1] In fact, the Brownian motion characterization of the exchange rate in target zone models is consistent with the random walk behavior of floating exchange rates (Meese and Rogoff (1983)).

or may not lead to a realignment of the target zone. Consequently, we look at predictability of all jumps.

Jumps in the exchange rate are specified as being drawn from a normal distribution, as there is no a priori reason to impose limits on the magnitude of a jump. Moments of the jump distribution are dependent on the information set, in such a form that the conditional standard deviation is proportional to the conditional mean. This is a most natural way of imposing a constraint on our model, to keep it computationally economical. Indeed, when large jumps are expected, it is natural that the expected standard deviation will be large as well.

Specifically, to anticipate the discussion below, when the exchange rate jumps, changes in exchange rates ΔS_t are conditionally normally distributed with conditional mean r_{t-1} and conditional variance $r_{t-1}^2 d^2 + a$. The variance is thus an affine function of the mean, where d^2 is a scaling parameter[1]. The fixed term is not linked to the mean, while the variable term is driven by the mean, on account of mean reversion.

The conditioning variables, drawn from the information set, are thought of as financial and macroeconomic variables, although the latter are not only hard to obtain at a high frequency but also may create tensions between exchange rate and other macroeconomic policy concerns. On account of notation, we precede the variable by 'd' whenever a first differencing operation is made, while we write 'Δ' to indicate percentage change. Both operations are used to take into account the time series properties of the variables, in particular nonstationarity[2].

Therefore, we write the conditional mean

$$r_{t-1} = b_6 + b_7 \Delta L_{t-1} + b_8 dID_{t-1}. \qquad \text{<3>}$$

where *DL* measures the change in the spot rate necessary for it to reach the lower bound, a measure related to the position in the band, and *ID* is the interest differential.

The position of the exchange rate within the band is unlikely to be a sufficient statistic to gauge the strength of the currency. It is informative as larger jumps are expected near the edges of the band: at the lower edge a larger jump can be accommodated within the band, and at the upper edge the only possible type of jump is a realignment jump, which tend to be relatively large.

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[1] The scaling factor and the additive term are parameters to be estimated. Their workings play somewhat of a role in the specification of the likelihood function (see below).

[2] Statistical tests available upon request.

The interest differential ID_t reflects speculative tensions and actions of monetary authorities to defend the currency, which are quickly captured in interest rates. However, movements in the interest differential between Brazil and the United States are entirely driven by the Brazilian rate. The series has a high magnitude, in the order of 30 percent per month, and may not be reflecting only market expectations. Indeed, we unusually find that the variable in levels is nonstationary. Nevertheless, the interest differential is too important an indicator to be ruled out of our model.

Both the slope of the yield curve and the interest differential can be used as jump indicators, and they are highly correlated. We use the interest differential as a jump size indicator. Given its forward-looking nature, we would have liked to use the slope of the yield curve to model the jump probability. However, the nature of the Brazilian data for the period under consideration is such that the term structure of interest rates is ill-defined, particularly in the period following the onset of the stabilization program as contracts resisted longer maturiries. This may also be a cause for our finding of nonstationarity of the interest differential. For European (EMS and Nordic countries) data, the slope of the yield curve is shown to be a better jump probability predictor, as in Bekaert and Gray (1996).

Given our restrictions in the use and interpretation of series constructed with local interest rates, we naturally look for other asset prices that are forward-looking and presumed to capture expectations, hence providing another measure of fundamentals. Other natural asset prices are bonds and stocks, used in the specification of the jump probability (below).

3.3 The Probabilistic Environment

The last two conditioning variables are, respectively, the price of Brazilian Brady bonds and a local Brazilian stock market index[1]. Both variables are presumed to reflect market expectations in foreign and local markets. Brazil's stock market BOVESPA index is often used as a forward looking variable that reflects market expectations. On a recent speculative attack on the currency, the *real*, and its policy response, it was said "[...] this nerve-racking wait-and-see approach was given a small breathing space this week. Brazil's beleaguered stockmarket surged on rumours that a rescue was in the offing."[2]

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[1] We would have liked to include other variables in our conditioning set, such as the level of reserves or the inflation differential. Unavailability of the series at the required frequency prevents their inclusion.

[2] The Economist, September 19th 1998, p. 24.

However, the specification of the variables in levels BRY and BOV, respectively the yield on Brazilian Brady bonds and the stock market index, were dropped from the original model specification. BRY did not seem to add much information, and yet the model was likely to be overfit by the larger set of parameters to be estimated. The variable BOV is nonstationary, hence we use its first difference and the first lag –these are significant, therefore included in our information set.

The conditional probability of jumps, l_{t-1}, is thus modeled as a function of the slope of the local (Sao Paulo) stock market index, ΔBOV, as well as the position in the band

$$l_{t-1} = \Pr(J_t = 1 | I_{t-1}) ;$$

$$l_{t-1} = \Phi (b_1 + b_2 |dPB_{t-1}| + b_3 |dPB_{t-2}| + b_4 |\Delta BOV_{t-1}| + b_5 |\Delta BOV_{t-2}|) \text{ [1]}, \qquad \text{<4>}$$

where $l_{t-1} \in [0,1]$ using the normal cumulative distribution function. First lags have been tested by the likelihood ratio statistic. Inclusion of lags provides the process with longer memory.

Table 1 documents the largest increases and decreases in the exchange rate over the sample period, as well as realignments of the target zone central parity. Table 2 specifies the raw conditioning variables and their transformations, where appropriate.

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[1] Note that the coefficient for PB_{t-1} is β_2, and the coefficient for PB_{t-2} is $\beta'=-\beta_2+\beta_3$. In this specification, we treat movements in the regressors as having a symmetric impact on the jump probability, albeit there may be arguments for an asymmetric treatment not captured here. Both increases and decreases in the local stock market index impact the jump probability via the distribution function, which is an increasing function.

Table 1: **Largest Changes in the Real/Dollar Exchange Rate**

Largest increases in the Real/dollar exchange rate over the period 25 July 94 to 2 May 96

rank	date	percentage change	position in the band	days until next realignment	days since last realignment
1	03/07/95	3.43	-0.47	3	105
2	04/25/96	2.90	0.78	--	51
3	10/18/94	2.33	-0.73	95	13
4	09/26/94	2.22	-0.20	0	0
5	03/20/95	2.20	3.00	0	0
6	11/16/94	1.18	-1.00	76	32
7	11/24/94	1.17	-0.87	70	38

Largest decreases in the Real/dollar exchange rate over the period 25 July 94 to 2 May 96

rank	date	percentage change	position in the band	days until next realignment	days since last realignment
1	04/29/96	-2.87	0.33	--	53
2	09/20/94	-2.22	-1.92	3	--
3	01/06/95	-1.74	-0.93	40	68
4	01/02/95	-1.73	-0.87	44	64
5	11/08/94	-1.20	-1.27	81	27
6	11/07/94	-1.18	-1.13	82	26
7	11/17/94	-1.18	-1.13	75	33

Table 2: **Data Variables**

Data Variables[1]
Exchange Rate Changes ΔS_t:
$\Delta S_t=(\ln(S_t/S_{t-1})*100$, the continuously compounded percentage exchange rate change. S_t represents the Real per Dollar sell rate at the parallel market (Sao Paulo) nominal daily exchange rate at time *t* [2].
Position in the Band PB_t:
$PB_t=(S_t-c_t)/[(U_t-L_t)/2]$, where c_t is the center of the band, U_t the upper band, and L_t the lower band. Hence PB_t represents the relative position of the exchange rate within the band, with $\{1<PB_t<1$, and $PB_t>0$ of the Real is in the weak half of the band [3].
Local Stock Market Index BOV_t:
BOV_t represents the Sao Paulo BOVESPA index at the market close at time *t*, scaled by 1000.
Interest Differential ID_t:
The interest differential between Brazil and the United States, i_t^{BM}- i_t^{USM}. The Brazilian rate is the overnight rate at the interbank market (CDI-over), expressed in percent per month. The U.S. rate is the US federal funds middle rate, expressed in percent p.a. and compounded to an effective monthly rate[4].
Realignment Dummy Variable RD_t:
This dummy variable takes the value of unity when a realignment of the bands occurred in week of day *t*, and 0 otherwise.

1 Excluded from this table are variables that were either unavailable at given frequency, or that were subsequently dropped from the model due to lack of informativeness. These variables were the cumulative interest differential, the level of reserves, the slope of the yield curve, and the return on Brady bonds.

2 Note that the formal band started on the 13th of March 1995. The prior `implicit` band was estimated by using a ceiling of 1:1 and a floor from the announced spread between the buy and sell rates.

3 ΔL_t and ΔU_t are respectively $[(S_t-L_t)/S_t]*100$ and $[(U_t-S_t)/S_t]*100$.

4 The choice of true market rates is limited. In fact, while one may argue about the choice of the interbank and federal funds rate, the magnitudes are such that their difference is well representative of the spread.

The entire econometric model is thus specified, and the two components of the conditional density follow. The truncated density has as truncation points the change on the exchange rate necessary for it to arrive at either edge of the band, since we seek to estimate the change in the exchange rate.

Model Specification

$$f\left(\Delta S_t \middle| I_{t-1}\right) = \begin{cases} TN\left(m_{t-1}, s^2_{t-1}, \Delta_{L_{t-1}}, \Delta_{U_{t-1}}\right) & with \Pr\left(1 - l_{t-1}\right) \\ N\left(r_{t-1}, r^2_{t-1} d^2 + a\right) & with \Pr\ l_{t-1} \end{cases}$$

where

$$\begin{aligned} l_{t-1} &= \Phi\left(b_1 + b_2\left|dPB_{t-1}\right| + b_3\left|dPB_{t-2}\right| + b_4\left|\Delta BOV_{t-1}\right| + b_5\left|\Delta BOV_{t-2}\right|\right) \\ r_{t-1} &= b_6 + b_7 \Delta L_{t-1} + b_8 dID_{t-1} \\ m_{t-1} &= b_9 + b_{10} PB_{t-1} \\ s^2_{t-1} &= b_{11} + b_{12} RD_{t-1} + b_{13}\left|PB_{t-1}\right| \\ d^2 &= b_{14} \\ a &= b_{15} \end{aligned}$$

4 Estimation

The econometric model that is described incorporates the target zone upper and lower bounds. Ordinary Least Squares estimation is not feasible, as it is not robust to the distributional assumptions[1]. Maximum Likelihood estimation is required. The model of the conditional distribution of exchange rate changes amounts to a reduced-form model. Full Information Maximum

[1] In particular, it is easy to show that in this case the error term is correlated with the regressor. Let the regression equation be $n_t = b'x_t + e_t$, where for OLS estimation, as usual, it is assumed that e_t is i.i.d. and uncorrelated with x_t. Call n_t the deviation from central parity, and a target zone restricts it to lie between the floor and the ceiling of the band, such that $-B \le n_t \le B$. Trivially, $-B - b'x_t \le e_t \le B - b'x_t$, with the error term being regulated by the bounds of this last inequality. For more on this, see Chen and Giovannini (1992), as well as Pesaran and Samiei (1992).

Likelihood requires the specification of the joint density of exchange rate changes and the conditioning variables, which is beyond the scope of this paper. Instead, we maximize the conditional likelihood function $\prod_{t=2}^{T} L\left(\Delta S_t \middle| I_{t-1}\right)$.

The log-likelihood function Λ is given by

$$\Lambda(\Delta S_T ; q) = \sum_{t=2}^{T} \ln\left[\sum_{i=1}^{2} f(\Delta S_t \middle| J_t = i, I_{t-1}; q)\, \Pr(J_t = i \middle| I_{t-1})\right]$$

<5>

where q is the vector of parameters affecting the conditional distribution of exchange rate changes

As argued above, we parameterize only the second piece of the log-likelihood function, leaving aside the distribution of the conditioning variables; although some degree of efficiency is sacrificed, the second piece alone allows identification of q, hence the maximum likelihood estimators are consistent. In essence, this amounts to using maximum likelihood to estimate the parameters of a reduced-form model[1].

The nonlinear problem must be solved iteratively, and it is notoriously difficult to estimate. It comprises the combination of two densities and a conditional variance specification, a reasonable-sized data matrix of 433x11, and a parameter vector to be estimated of minimum dimension 15x1. Several initial values, algorithms, and specifications were used. In particular, the vector of initial values was chosen given the feedback from different simulations. Various implementation issues are worth commenting on.

The log-likelihood is specified in terms of the truncated normal (TN) and the normal (N) density functions. A closer look at the form of the two components of the log-likelihood function is warranted:

$$\Lambda = (1 - l)\frac{f((\Delta S - m)/\sqrt{s^2})/\sqrt{s^2}}{\Phi((\Delta U - m)/\sqrt{s^2}) - \Phi((\Delta L - m)/\sqrt{s^2})} + l \; f((\Delta S - r)/\sqrt{r^2 d^2 + a})/\sqrt{r^2 d^2 + a}$$

<5a>

where f (Φ) denotes the standard normal density (probability) function. Note that the TN is only defined within its range, and we do explicitly take into account its support. We purposedly use a combination of the two densities to account for the large observations. Intuitively, we do not want to restrict the actual observations as long as there is a non-zero probability of a jump, even when a jump has actually not occurred.

[1] The econometric model is estimated by maximum likelihood using the GAUSS MAXLIK module.

The conditional variance specification merits some discussion as well. Exchange rate changes exhibit temporal dependencies as a result of volatility clustering. Specifically, in periods of turbulence large changes are followed by large changes, and analogously for periods of tranquility. This occurrence is an important contributing factor to leptokurtosis in the unconditional distribution. Essentially, peakedness in the distribution reflects periods of tranquility when there is little movement in the exchange rate, whereas the fatness in tails is associated with periods of turbulence when the exchange rate exhibits large movements. ARCH-like conditional variance structures help to capture some of the leptokurtosis, albeit not all of it[1]. Nonetheless, we have tried several GARCH specifications, where the initial values were set at zero for the first 'news' term (the ARCH term), and at the mean of the squared residual vector for the first forecast variance term. While this exercise added much computational cost, results were not improved (via likelihood ratio tests), and subsequently we dropped the ARCH and the GARCH terms. Our conditional variance specification depends linearly on the information set.

Indeed, the combination of the two densities has implications regarding the moments of the actual data. Higher first and second moments of the normal density compared to the truncated normal density are likely to account for the leptokurtosis in the data, thereby diminishing the significance of an ARCH-type specification.

5 Data

The data were obtained from the Getulio Vargas Foundation in Brazil, FGV/EPGE-RJ, Datastream, and The Economist Intelligence Unit Business Latin America report.

The sample consists of daily macroeconomic and financial variables for the Brazilian economy, from July 25th, 1994 to May 2nd, 1996, a total of 433 observations adjusted for holidays. The start of our sample is marked by the full implementation of the stabilization plan that brought a new currency into circulation, the Real, on July 1st, 1994. We do not start our sample then, on account of conversion and accounting issues. Our data collection ends in May 1996[2].

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1 See Lim et al (1998).

2 For details on data issues, see Ribeiro (1998).

Figure 1 plots the Real/Dollar exchange rate and the target zone bounds over the sample period. Figure 2 has time-series charts of the variables in the model, namely the position in the band, the interest differential, and the Sao Paulo BOVESPA stock market index.

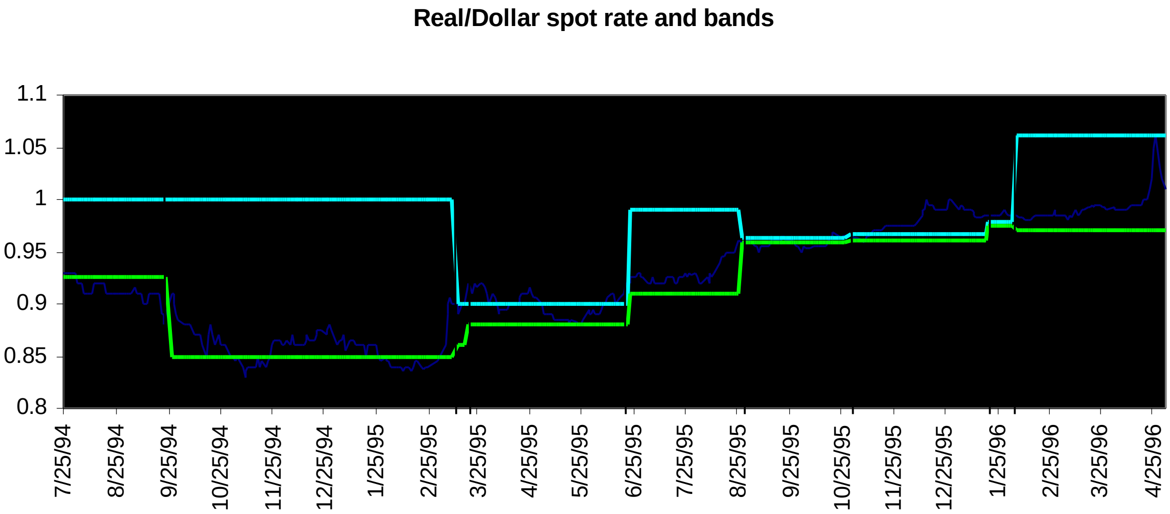
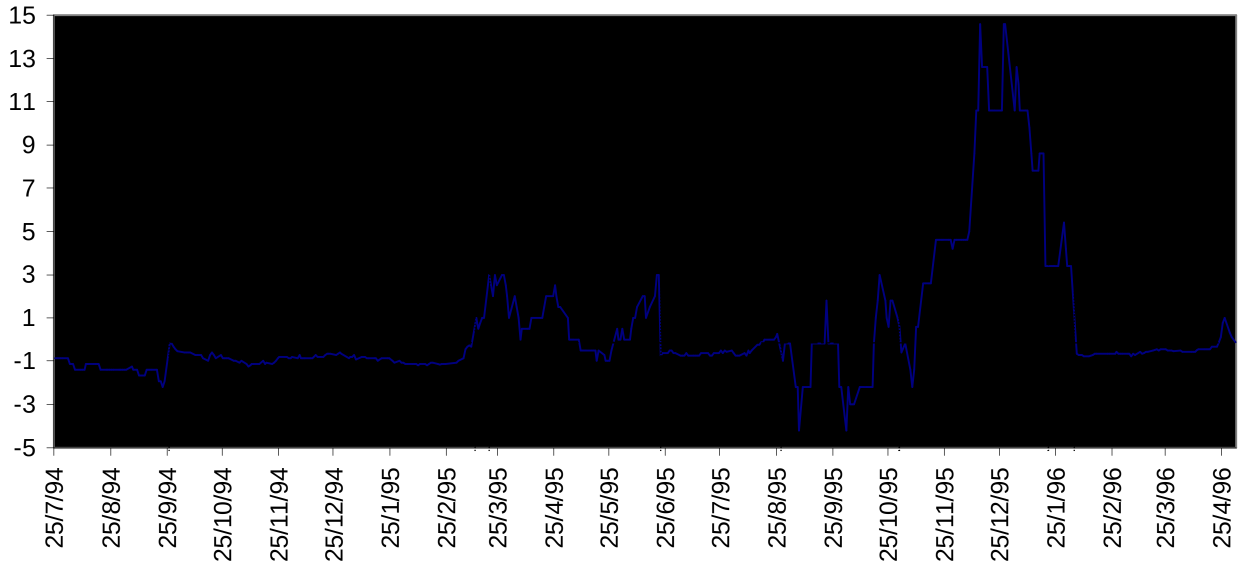


Figure 1: **The Real/Dollar Exchange Rate and Its Fluctuation Bands.**

Position in the Band (PB)



Log Changes in the Exchange Rate

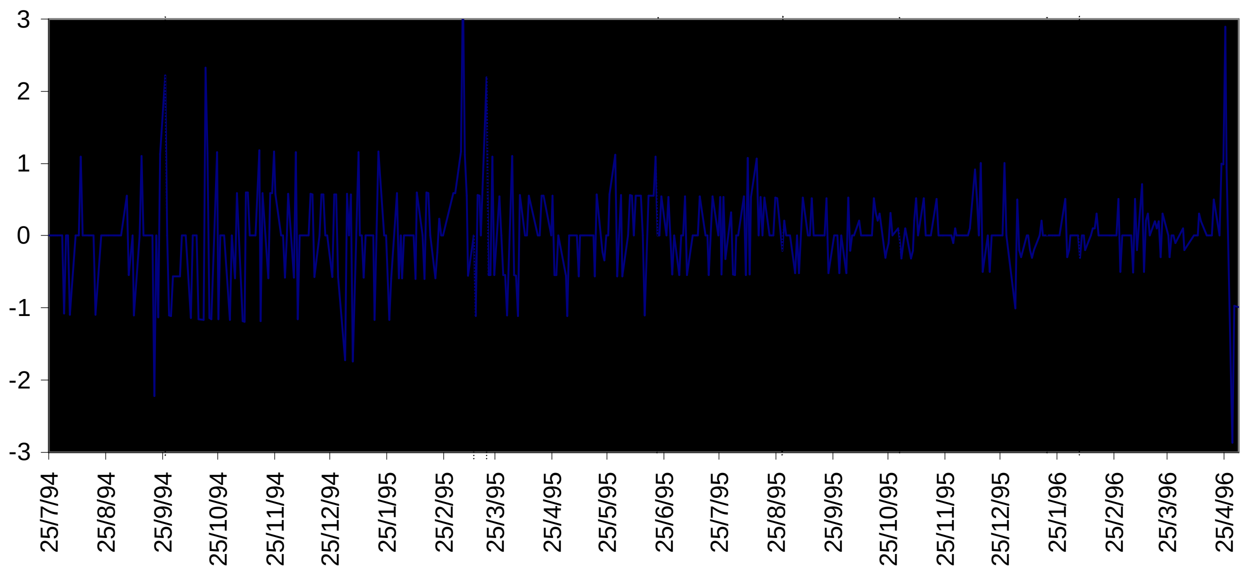
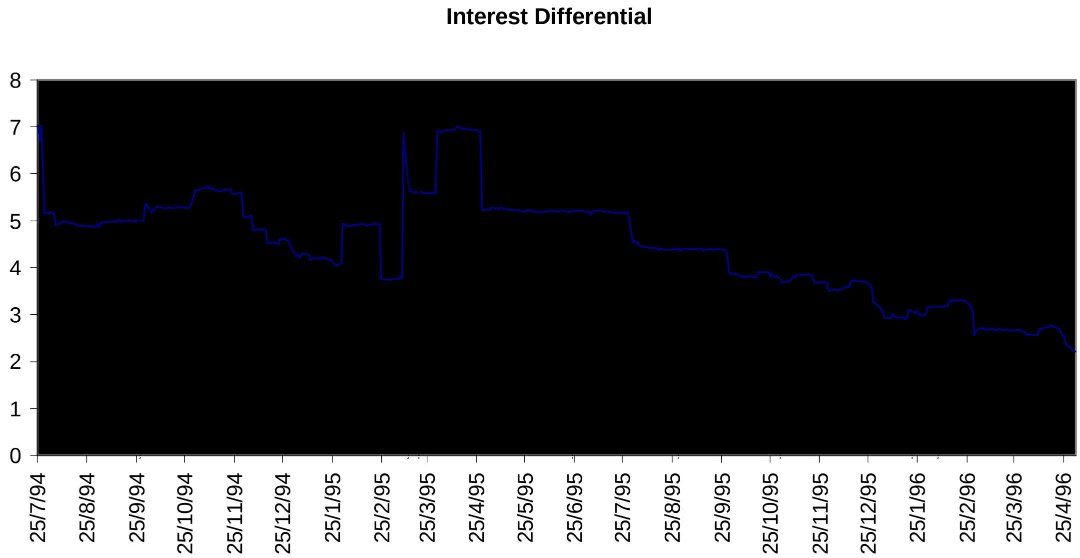
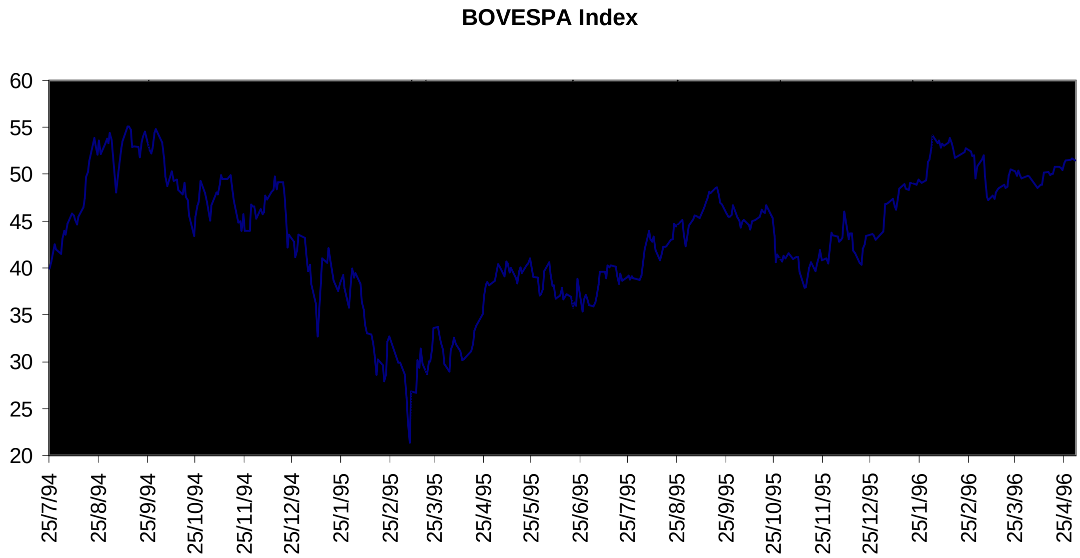


Fig 2: **Time-series charts of the variables in the model.**





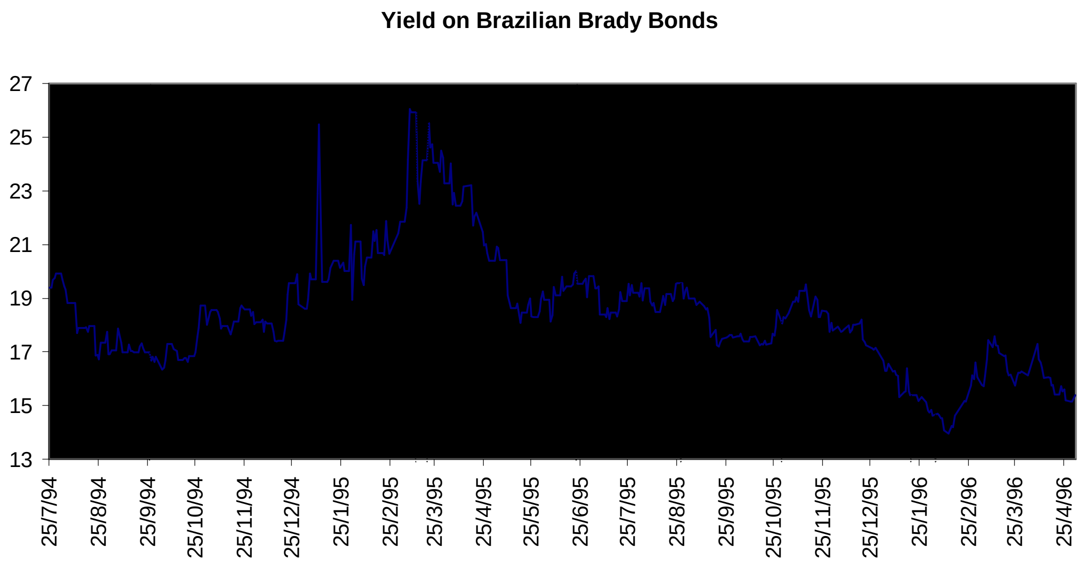


Figure 2 (cont.): **Time-series charts of the variables in the model.**

6 Results

Maximum likelihood parameter estimates are presented in Table 3. Our parameter estimates confirm most of the intuition reviewed above. We review these in turn below.

The mixed distribution we estimate for changes in exchange rates is characterized by four parameters, namely the two first moments for the truncated normal 'inside-the-band' distribution and those for the normal distribution. At first, one might expect that volatility for the normal representation would be higher than that for the truncated normal, restricted by its lower and upper bounds. However, our estimation indicates that the variance of the truncated normal distribution is higher than that for the normal one, 0.37 compared to 0.08. On the other hand, first moments for the truncated normal and the normal are close to each other, -0.09 relative to -0.03, as we might have expected. Figure 3 illustrates the two densities and their respective parameters.

Several tests of restricted models are reported in Table 4. The test on the mean reversion equation examines the significance of the dependence of the conditional mean on the position in the band in the absence of jumps. The volatility test examines the significance of GARCH effects in the conditional volatility. The test on the jump size equation examines the joint significance of the conditioning variables in predicting jump size. The next test examines time variation in the jump size and jump probability. Finally, the last test examines the existence of jumps. Likelihood ratio test statistics (LRT) and their associated critical values are presented.

Table 3: **Maximum Likelihood Parameter Estimates**

PARAMETERS	ESTIMATES		STD.ERR	EST/S.E.	P-VALUE
jump probability: $l_{t-1} = \Phi(b_1 + b_2 \lvert dPB_{t-1} \rvert + b_3 \lvert dPB_{t-2} \rvert + b_4 \lvert \Delta BOV_{t-1} \rvert + b_5 \lvert \Delta BOV_{t-2} \rvert)$					
β_1	0.2279		0.2810	0.811	0.2086
β_2	-0.3799		0.3506	-1.084	0.1393
β_3	3.5926	***	1.4018	2.563	0.0052
β_4	0.1877	**	0.0890	2.110	0.0174
β_5	0.1775	**	0.0929	1.911	0.0280
jump size equation: $r_{t-1} = b_6 + b_7 \Delta L_{t-1} + b_8 dID_{t-1}$					
β_6	0.0806	***	0.0246	3.273	0.0005
β_7	-0.0169	***	0.0050	-3.405	0.0003
β_8	0.0033		0.0239	0.136	0.4458
mean reversion equation: $m_{t-1} = b_9 + b_{10} PB_{t-1}$					
β_9	-0.2339	***	0.0885	-2.642	0.0041
β_{10}	-0.5466	***	0.1247	-4.385	0.0000
volatility equation: $s^2_{t-1} = b_{11} + b_{12} RD_{t-1} + b_{13} \lvert PB_{t-1} \rvert$					
β_{11}	0.8564	***	0.3478	2.462	0.0069
β_{12}	4.8923		8.0495	0.608	0.2717
β_{13}	-0.7512	**	0.3516	-2.136	0.0163
$d^2 = b_{14}$					
β_{14}	15.0701	*	9.9209	1.519	0.0644
$a = b_{15}$					
β_{15}	0.0685	***	0.0188	3.649	0.0001

The sample consists of daily data from 25 July 1994 to 2 May 1996, a total of 433 observations. The model assumes exchange rate changes to be conditionally distributed as a truncated normal, with conditionally normal jumps:

$$f(\Delta S_t \lvert I_{t-1}) = \begin{cases} TN\ (m_{t-1}, s^2_{t-1}, \Delta L_{t-1}, \Delta U_{t-1}) & w\ /\ \Pr(1 - l_{t-1}) \\ N\ (r_{t-1}, r^2_{t-1} d^2 + a) & w\ /\ \Pr\ l_{t-1} \end{cases}$$

*** denotes significance at 99 percent, ** =significance at 95 percent, * =significance at 90 percent.

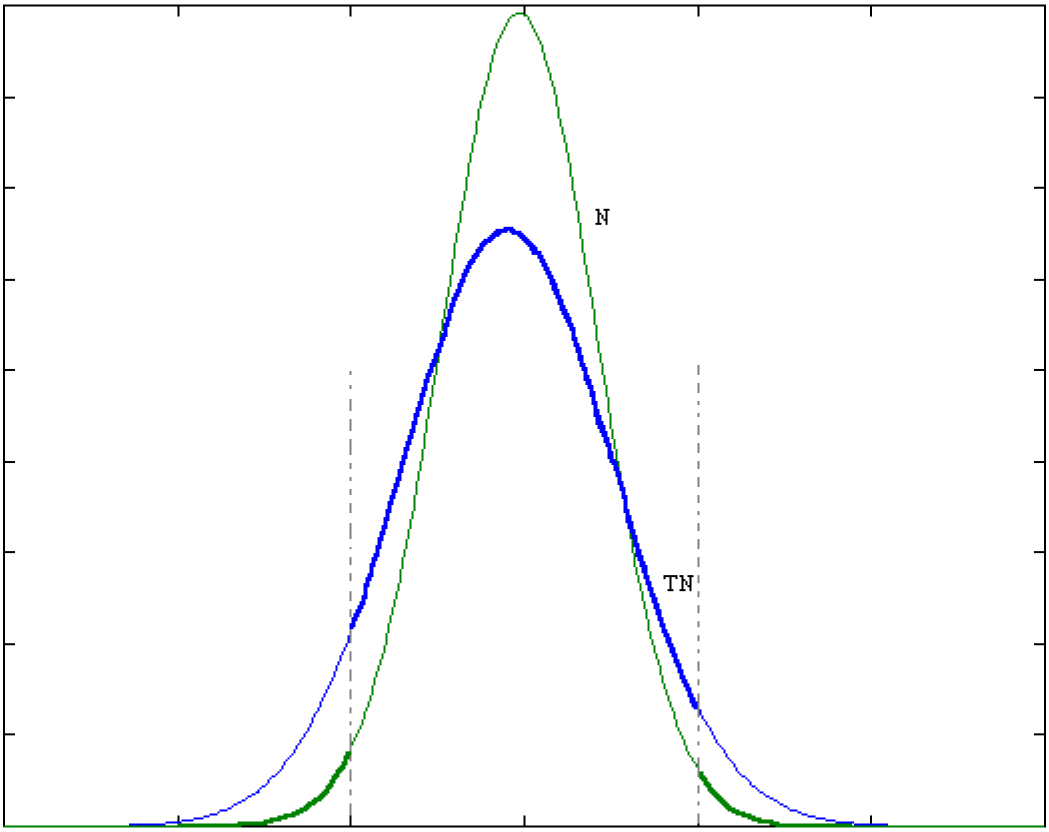


Figure 3: **The truncated normal (TN) and normal (N) densities.** Parameter values are –0.09 and –0.03 for the means, respectively, and 0.37 and 0.08 for the variances.

Table 4: **Likelihood Ratio Tests of Restricted Models**

TEST	RESTRICTION	LRT STATISTIC	CRITICAL VALUE AT 5%
Mean Reversion Equation	$\beta_9=\beta_{10}=0$	7.59	5.99
Volatility Equation	$\beta_{12}=\beta_{13}=0$	19.19	5.99
Jump Size Equation	$\beta_6=\beta_7=\beta_8=0$	36.38	7.82
Time-Varying Jump Size and Probability	$\beta_2=\beta_3=\beta_4=\beta_5=\beta_7=\beta_8=0$	42.90	12.59
Existence of Jumps	$\beta_1=\beta_2=\beta_3=\beta_4=\beta_5=\beta_6=\beta_7=\beta_8=0$	3271.74	18.31

6.1 Mean Reversion

We now turn to the discussion on the parameters of the four equations that characterize the empirical model. The mean reversion equation is given by the mean parameter of the truncated normal density, *m*. To find evidence of mean reversion, we expect that the coefficient on the position within the band variable, PB, be negative. Expected change toward the center of the target zone is stronger when the exchange rate is near the edge.

We find evidence of mean reversion, as the coefficient β_{10} is negative and highly significant. However, in the truncated normal distribution, $m_{t-1} = b_9 + b_{10} PB_{t-1}$, characterize the conditional mean of the underlying normal distribution which is truncated –as opposed to the conditional mean of the truncated distribution. That is, m_{t-1} is bound to denote the peak of a skewed distribution. For, when the exchange rate is near the upper (lower) bound, the right (left) half of the distribution is truncated more than the left (right), resulting in a negatively (positively) skewed distribution. For the case of negative skewness, the mean of the distribution will be lower, further towards the center of the band. Hence, in the absence of jumps, the shape of the truncated normal itself can impart some reversion towards the center of the band.

Thus, we look at the conditional mean of exchange rate changes, cm, cm= $(1-l)\, m + l\, r$. Figure 4 plots the expected change in the Real/Dollar exchange rate, conditional on available information, and the position of the exchange rate within the band. The mean reversion is evident from the fact that when the exchange rate is close to the bounds (or beyond), movements of over 0.2 percent are expected relative to the lower bound, and movements of over 0.6 percent are expected relative to the upper band. These results are consistent with intramarginal central bank intervention, and inconsistent with the Brownian motion assumption of the Krugman model where interventions occur only at the edges of the band. But the nonlinear nature of the mean reversion is consistent with the Krugman model.

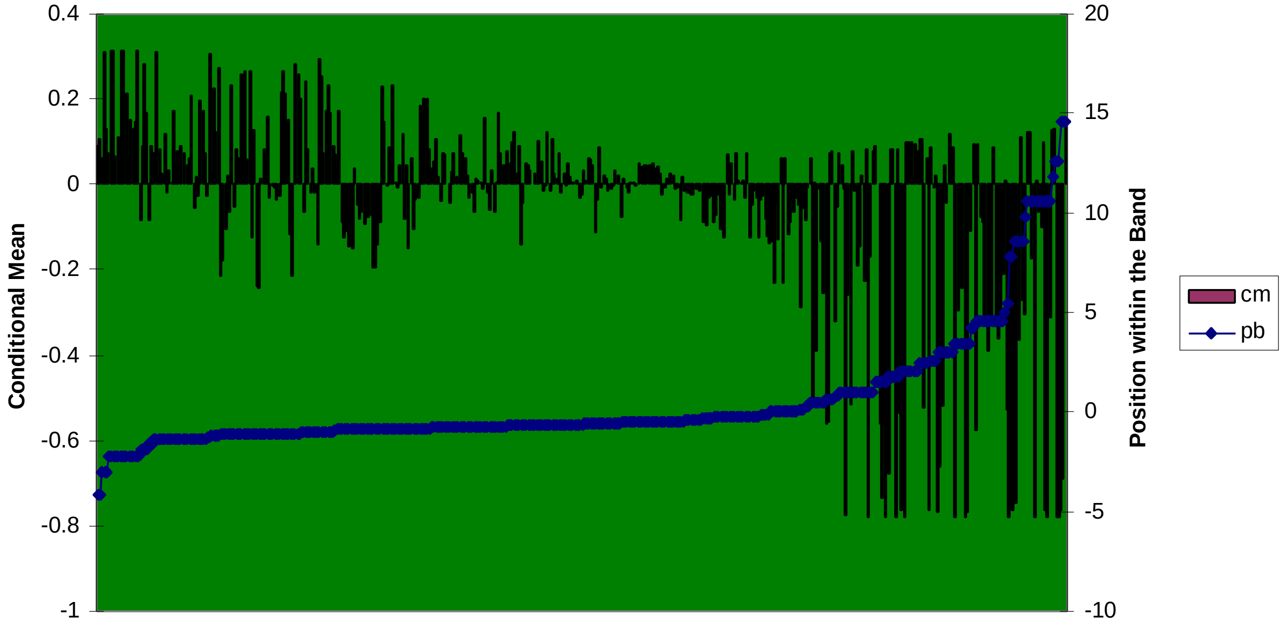


Figure 4: **Expected change in the Real/Dollar exchange rate as a function of theposition of the exchange rate within the bands.** This is a measure of reversion towards the center of the band.

6.2 Conditional Volatility

The volatility equation is represented by the specification for the variance of the truncated normal, s^2. Volatility is captured by information on the position within the band, and a negative coefficient would imply that volatility is lower near the edges. A standard target zone model uses only the latter to infer on the conditional volatility. Additionally, this equation captures available information on realignments, via the realignment dummy variable, RD. Realignments cause a large one-time shock to the exchange rate that usually drives the forecast error to be very large. That is, we are likely to get high volatility when a realignment occurs.

Somewhat surprisingly, our results indicate lower volatility near the edges of the band, as represented by our maximum likelihood estimate of the coefficient β_{13}. This result is consistent with the predictions of Krugman-type models, and inconsistent with the result in Bekaert and Gray (1996). The latter models conditional volatility as an augmented GARCH (1,1) process, which is found to capture well the properties of their data set. The effect of realignments on volatility is not statistically significant.

6.3 Jumps

We want to look at the impact of jumps on the conditional distribution of exchange rates. Although we cannot test for the absence of jumps, we can still look at the jump probability, l, and at the expected mean jump size, r. Precisely, a novelty in this approach is that we are able to disentangle the size and the probability of jumps. This requires that they do not depend on the same set of instruments, hence our specifications.

We have some confidence that the algorithm which solves the nonlinear problem is not on a flat section of the likelihood function, as it has no difficulty in converging to the parameter estimates and the linear equations are unlikely to be collinear. The model is thus identified by the available information set. In addition, while the likelihood function is nonlinear and may admit several local optima, using different optimization algorithms and different sets of initial values gives us confidence that the parameter estimates are at the global maximum. It is also critical the use of a more turbulent period as well to identify the jump parameters; had we used only the post-Mexico crisis sample, we would have found lower jump parameters.

The jump probability equation is characterized by the jump probability parameter, l, which is made a function of the change in (the absolute value of) a forward-looking information variable that is consistent with the prediction of exchange rate movements. We use the stock market variable to this effect; a positive coefficient would signify that the jump probability increases. We infer here that when there is a near crash in the stock market, the probability of a jump is very high, as there is less confidence in exchange rates, consistent with the prediction of large movements in the exchange rate. Extreme upswings can also signal non-sustainability and hence a higher jump probability. We also use the position within the band to estimate the jump probability.

The jump probability is positively related to changes in the stock market and in the position within the band. What is important is the ability of those variables to predict large movements in exchange rates. For the majority of our sample, the fitted jump probability actually shows much variation, as there is much variation in the conditioning variables of the λ equation which helps with the identification of the coefficients. Our results indicate that big fluctuations in the stock market are accompanied by a higher probability of a jump, given that the coefficient β_4 is positive, as we expected. Figure 3.5 plots the jump probabilities. The jump probability experiences dramatic changes prior to realignments (the vertical dashed lines), and it increases at other times as well to reflect the probability of non-realignment jumps.

Although the expected size of a jump also varies substantially over time, the picture is clearer. The jump size equation is given by the parameters of the normal distribution, not restricted to the target zone bands. We would expect that the interest differential is informative as we would expect a larger jump when the differential increases. The intuition here is the weak currency restoring its competitiveness through realignments. At the same time, the coefficient on the position within the band variable should reflect larger jumps expected near the edges of the band. In particular, in the vicinity of the lower band, a larger jump can still be accommodated inside the target zone, whereas near the upper band the only kind of jump, usually large, takes the exchange rate outside the target zone.

Indeed, we find that there are larger jumps near the edges of the band. If the distance for the exchange rate to reach the lower band becomes higher, the expected jump size diminishes ($\beta_7<0$). However, the interest differential (in first differences) is not significant for predicting jump size, although its coefficient is of the right sign[1]. A one percent increase in the change of the spread would increase the jump size by 0.3 percent.

It is quite interesting to note that the most informative variable appears to be the local stock market. Notably, the coefficient on the interest differential variable is not significant. Given the magnitude of the Brazilian rate vis-à-vis the U.S. rate, the differential is practically driven by the local rate, which may not be truly reflecting market forces. The yield on Brady bonds was

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[1] The specification of first differences for the interest differential rules out an effect on the jump size of constant spreads.

dropped from the model altogether, as it added much in computational cost and did not appear as informative either. In fact, being dollar-denominated bonds, the only type of risk associated with them is government repayment risk. Insignificance of this variable suggests that this source of variation is not quite important to explain variation in short-term exchange rates.

Figure 6 shows the time variation of the jump size. The size of jumps is somewhat predictable, as realignments are preceded by large movements in the expected mean jump size. Non-realignment jumps are expected to be of relatively smaller magnitude, except perhaps in the period around December 1994 at the onset of the Mexican currency crisis.

We remark here that our analysis is within-sample, and predictability can be potentially deceptive. In particular, structural changes can have affected the structural parameters (of the unspecified underlying model) in such a way that our reduced-form parameter estimates would be unstable. For example, changes in capital controls can protect domestic interest rates from the large fluctuations associated with expectations of exchange rate changes.

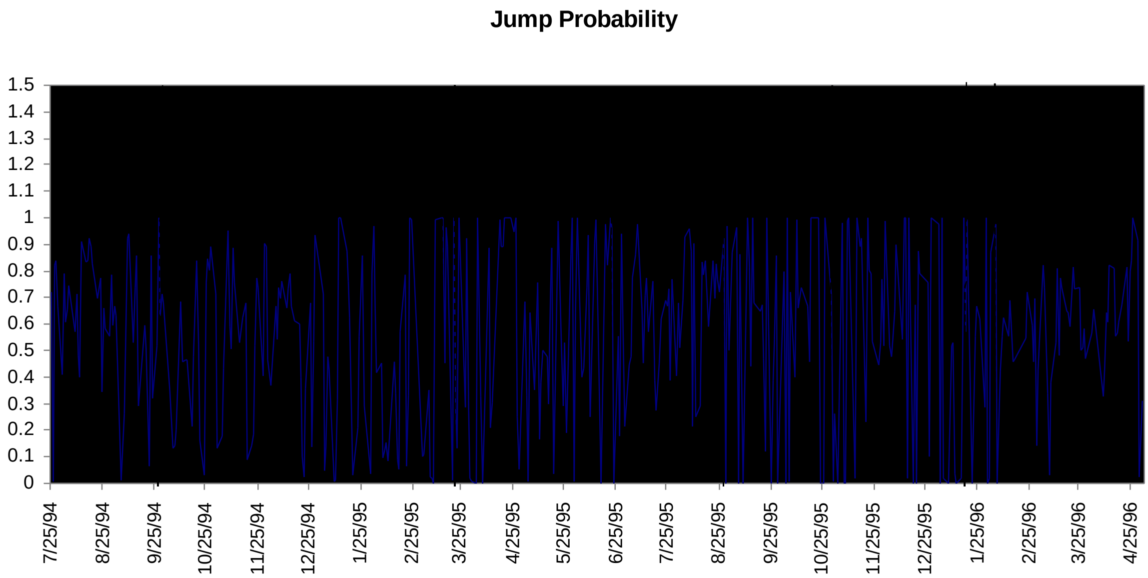

Figure 5: **Probability, conditional on available information, of a jump in the Real/Dollar exchange rate.** Dashed lines indicate realignments.

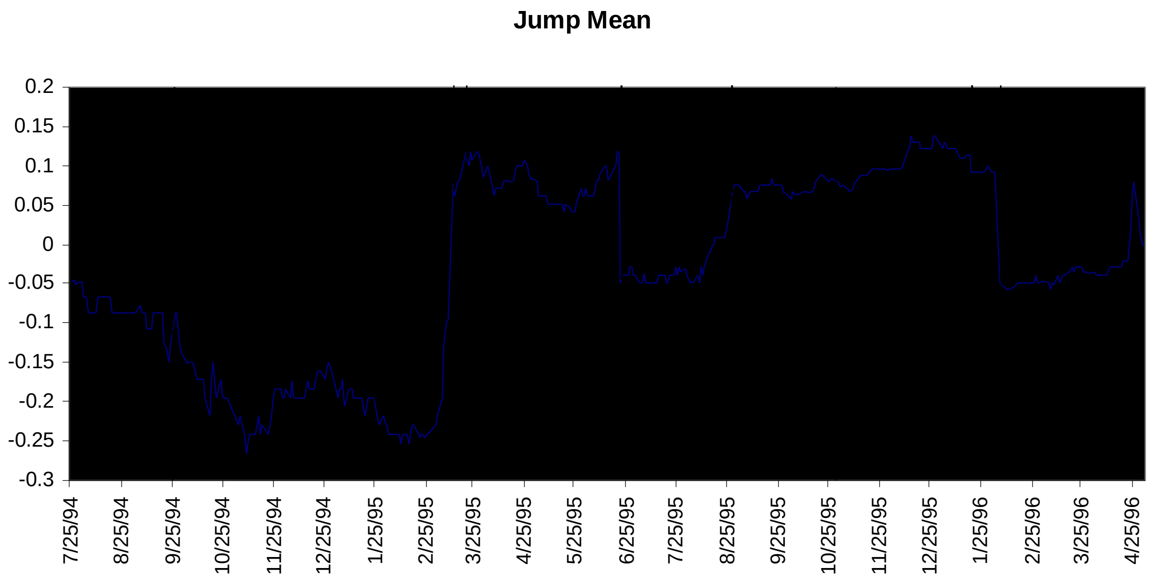

Figure 6: **Expected size of a jump in the Real/Dollar exchange rate.** Dashed lines indicate realignments.

7 Conclusion

Within our framework, we can look at the jump process to assess whether extreme currency movements are associated to phenomena which characterize macroeconomic and political events. However, our model is specified as high frequency, and will not capture low frequency occurrences. We are naturally interested in the question whether currency movements are anticipated by the markets.

Large currency movements are associated with increases in both the expected rate of devaluation, i.e. within the band, and in the uncertainty about future exchange rate movements, or currency risk. We find that exchange rates tend to jump inside the band in addition to realignments of the bands, and jump risk can be characterized. Our model predicts the likelihood and the size of these jumps. We also detect nonlinearities in exchange rate behavior, in contrast to other studies.

From the perspective of costs of exchange rate uncertainty and the exchange rate regime, we can say that when bands are imperfectly credible, exchange rate variability can remain substantial because of the presence of jump risk. It can be argued that the risk coming out of the jump process is more difficult to hedge than that from overall volatility.

The estimation approach we use to estimate changes in an exchange rate that is governed by a regime of bands is novel in two ways. The methodology takes account explicitly for the bands, and it does not make use of the uncovered interest parity assumption -- both carry non-trivial information on the expectations of agents. Additionally, the econometric model is applied to high-frequency data for an emerging market country coming out of a stabilization program, namely Brazil in mid-1994.

We allow for jumps both within the bands and outside the bands: this is modeled via a mixed distributional structure, carrying respective probabilities. We use maximum likelihood estimation to assess the likelihood function composed of a truncated normal density for the credible regime (within the band), and a normal density. The truncation points are data, the lower and the upper edges of the exchange rate band. We parameterize the densities using an information set that includes macroeconomic and financial variables.

For the data used here, and the way the exchange rate regime is managed, the variance for the truncated density is actually higher –a somewhat surprising result. We find evidence for reversion towards the mean, lower volatility the closer to the edges of the band, and increasing jump sizes near the edges. Of the variables in our information set, we find that the local stock market is more informative than the interest differential itself, as well as the yield on government (Brady) bonds. This may reflect the high placement of investors in the local economy, who are mostly risk-loving, alongside a large magnitude of capital flows.

The analysis presented here can potentially be interesting to the peso problem, as data provide a laboratory with the possibility of infrequent but large realignments. It is also likely to be fruitful for the modeling of the behavior of exchange rates and interest rates to examine uncovered interest parity. Finally, the econometric framework could be used to apply truncations and the mixed distribution framework to bounds and constraints more generally, for example restrictions in fiscal spending.

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