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AN OPTIONS-BASED ANALYSIS OF EMERGING MARKET EXCHANGE RATE EXPECTATIONS: BRAZIL'S REAL PLAN, 1994-1999

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Abstract

This paper uses currency option data from the BMF, the Commodities and Futures exchange in Sao Paulo, Brazil, to investigate market expectations on the Brazilian Real-U.S. dollar exchange rate from October 1994 through March 1999. Using options data, we derive implied probability density functions (PDF) for expected future exchange rates and thus measures of the credibility of the "crawling peg" and target zone ("maxiband") regimes governing the exchange rate. Since we do not impose an exchange rate model, our analysis is based on either the risk-neutral PDF or arbitrage-based tests of target zones. The paper, one of the first to use options data from an emerging market, finds that target zone credibility was poor prior to February 1996, improved afterwards through September 1997 and later started to worsen again. The market anticipated periodic band adjustments, and estimated distributions are very sensitive to political and economic news affecting the credibility of the regime. We also test whether devaluation intensities estimated from these option prices can be explained by standard macroeconomic factors.

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Keywords: Exchange rate credibility, implied distributions, options.

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AN OPTIONS-BASED ANALYSIS OF EMERGING MARKET EXCHANGE RATE EXPECTATIONS: BRAZIL'S REAL PLAN, 1994-1999

This paper uses a new data set of options on the Brazilian Real / US dollar exchange rate to extract market expectations, as embodied in the risk-neutral probability density function (PDF), of Real-dollar exchange rates over horizons of one to three months. Unlike ordinary exchange rate forecasts that provide only a point estimate of the future exchange rate, options-based forecasts, by permitting the derivation of a PDF, describe a range of realizations and the probability attributed to each range.

This PDF-based approach is especially effective for an analysis of the Real/$ exchange rate, which from June 1994 to January 1999, under the Real Plan, was characterized by a combination of a crawling peg and a target zone regime. Over short horizons, the exchange rate followed a crawling peg surrounded by a "miniband," but for long horizons, superimposed on the crawling peg, there was also an official "maxiband" with a fixed (non-crawling) central rate, floor, and ceiling.

The PDFs derived in this paper enable us to compare market expectations embedded in options with these two concurrent regimes. For example, we can identify whether markets in fact anticipated a faster depreciation, and if so, where (relative to the crawling peg) probability was concentrated. Relative to a single-point expectation of the future exchange rate, a great advantage of a full PDF is the ability to disentangle magnitude and probability of expected depreciation. For the longer-horizon fixed target zones, we conduct "arbitrage-based tests" of credibility, developed in Campa and Chang (1996), that are virtually assumption-free. Given these target zones, we are also able to determine both "intensities" and probabilities of realignment, and to investigate possible economic determinants of realignment intensity. Thus, a single approach using dollar-Real options permits us to analyze both facets of the Brazilian exchange rate regime during the Real Plan.

This work contributes to the growing literature on the use of options to characterize expected asset returns, and in particular to predict currency crises. Recent empirical work using options to identify the distribution of expected exchange rates includes Malz (1996b) and Campa, Chang and Reider (1997, 1998). Papers specifically focusing on currency crises, especially the 1992 ERM crisis, include Campa and Chang (1996), Malz (1996a), and Mizrach (1996). These can be contrasted against measures of devaluation risk not based on options, as in Bertola and Svensson (1993), Kaminsky, Lizondo, and Reinhart (1997), and Svensson (1991).

The motivation for this research is two-fold: first, to use options-based estimates of the PDF to compare market expectations with the two concurrent exchange rate regimes in the Brazilian Real Plan; and second, to observe the time path of market perceptions to gauge policy effectiveness over time. Furthermore, this is one of the first options-based tests of exchange rate regime credibility on an emerging market. Within emerging markets, this is also the first paper to deal with the data challenges of exchange-traded options, rather than over-the-counter (OTC) volatility quotes. OTC data, by construction free of arbitrage violations, are normally subject to less observation error and hence easier to interpret empirically. Thus, our technique could potentially be used for other emerging markets including those with only exchange-traded currency options.

The remainder of the paper is structured as follows. Section I describes the theoretical background to deriving risk-neutral probability density functions (PDFs) from options—and for target zone regimes, the derivation of re-alignment intensities and probabilities, as well as arbitrage-based tests of credibility. Section II discusses the Real Plan and pertinent historical background, including the "miniband" and "maxiband" regimes. Section III introduces our option data, provides summary statistics, and conducts a preliminary analysis. Section IV investigates the behavior of the PDF over time, and in the context of a crawling peg, describes the probability and magnitude characterizing expected deviations from this regime. Section V addresses the "maxiband" target zones, estimated realignment intensities and probabilities, and arbitrage-based measures of credibility. Section VI explores the empirical relation between estimated intensities and standard macroeconomic factors. Section VII concludes.

Options-Based Indicators of Devaluation and Tests of Exchange Rate Band Credibility

Options—whose payoff depends on a limited range of future exchange rates rather than an entire distribution—are able to provide more precise information than other financial indicators about expected future exchange rates, and the amount of probability attributed to any given realization. In contrast, the forward rate, for example, can indicate only the mean of this distribution. The advantages of an options-based approach will be discussed further below.

Options and the Risk-Neutral Distribution

We begin with a few brief definitions. A call option gives its holder the right but not the obligation to purchase a fixed amount of foreign currency (in the case of Brazilian Real-US dollar options, \$1000 US) at a pre-determined price (referred to as the *strike* price or *exercise* price) in local currency. A *put* option gives the right but not the obligation to conduct the reverse transaction, i.e., to sell a fixed amount of the foreign currency (\$1000 US) for a given strike price in local currency.

An *American* option may be exercised at any time before its expiration date; a *European* option, only on its expiration date. Because the European option can be exercised only on a single date, an analytical relationship known as *put-call parity* can be established between the price of a European call and European put of the same strike. This relation, derived from arbitrage restrictions, permits the price of a call to be computed from the price of a put with the same strike and expiration date, and vice-versa. The analysis in this paper focuses exclusively on relationships derived from European call options (though some of the call option data were constructed from European put data via put-call parity).

It was first shown in Breeden and Litzenberger (1978) that the decline in the value of a European call option due to an infinitesimal increase in the strike price equals the discounted risk-neutral probability that the option will finish "in-the-money" (spot exceeding the strike on expiration). Accordingly, the value of a call option (under risk-neutrality) at time T with a strike price K is then given by

$$Call_{K,T} = \frac{1}{1+i_T}\int_K^{\infty}(S_T - K)\int(S_T)dS_T \qquad [1]$$

where S_T is the spot exchange rate at time T, $f(S_T)$ is the risk-neutral density function for the spot at time T, and i_T is the domestic risk-free rate for an investment maturing at time T. The partial derivative of equation (1) with respect to strike price K is:

$$\frac{f\,Call_{K,T}}{fK} = -\frac{1}{1+i_T}[1-F(k)] \qquad [2]$$

where F(K) is the risk-neutral cumulative density function of the exchange rate at time T, evaluated at strike price K. Taking the second partial derivative of equation (1) with respect to strike yields:

$$\frac{f^2 Call_{K,T}}{fK^2} = \frac{1}{1+i_T}f(K) \qquad [3]$$

This then provides a direct relationship between observed European call prices and the value of the corresponding risk-neutral probability density function, i.e. the PDF. Note that the call price is based on the payoff (S_T - K) multiplied by its risk-neutral probability $f(S_T)$, which incorporates both the actual probability of that realization of spot and the value the market places on that state of nature. In other words, $f(S_T)$ is not necessarily the actual density function, since—because of risk—a dollar in one state may be valued differently from a dollar in a different state.

Equation [3] is important because it provides the method by which the PDF can be extracted from call prices. If a continuous call price function twice-differentiable in strike exists, then the PDF is uniquely determined. In reality, such a continuous call price function is not available, but will be estimated from discrete point observations using a method described in Section IV of this paper.

"Intensity" of Devaluation or Realignment

When there are specific reference exchange rates in place, as in the case of target zones, a risk-neutral PDF can be used to indicate the perceived probability of devaluations or "re-alignments" of various sizes beyond that specific reference level. By looking at only that part of the PDF representing a deviation from the reference exchange rates, we can isolate the risk of a change in regime. A summary measure incorporating both probability and magnitude of change from given reference rates, over all possible realizations deviating from these reference rates, can be termed an "intensity" measure. Campa and Chang (1996) define such an intensity as:

$$G(T) = \int_{\bar{S}}^{\infty} (S_T - \bar{S}) \int (S_T)\, dS_T \qquad [4]$$

Intuitively, intensity G(T) is a risk-neutral probability-weighted average of all exchange-rate realizations requiring a re-alignment, or under deviation scenarios beyond $\bar{S}$. In other words, the magnitude of realignment is multiplied by the risk-neutral probability of each realization. Comparing equations (4) and (1), the intensity of realignment is simply the future value of a European call with a strike price at the upper-bound. Mathematically,

$$G(T) = Call_{\bar{S},T}(1 + i_T) \qquad [5]$$

Though this call with a strike price at the upper-bound does not exist in most cases, its price (and hence the intensity of realignment) is easily calculated once a risk-neutral PDF has been derived.

Arbitrage-Based Tests of Target Zone Credibility

Campa and Chang (1996) also develop two tests of band credibility relying solely on arbitrage or convexity arguments, without assumptions about risk preferences. These tests will be used for analysis and comparison in Section V.

The first test (hereafter referred to as "Test 1") is based only on a simple no-arbitrage restriction: the maximum future spot rate cannot exceed any credible upper band. At expiration, the payoff of a European call equals, at most, spot minus strike. Therefore, under credibility, the maximum value of the call cannot exceed the present value of the upper band minus the strike. Thus, credibility can be rejected whenever

$$Call_{K,T} > \frac{\bar{S} - K}{1 + i_T} \qquad [6]$$

Note that this test can be used even when there is only one reference rate.

The second test ("Test 2" from here on) is derived from convexity arguments and also provides an upper bound for the value of a call with a strike between two reference rates, or within the bands of a target zone. The argument is that under credibility, a call with a strike at or below the lower band will always finish in-the-money, and therefore is worth exactly its intrinsic value. This intrinsic value is $S_0/(1 + i_T^*)\text{-}K/(1 + i_T)$, where i_T^* is the foreign risk-free rate and S_0 is the current spot. Furthermore, a call with a strike greater than the upper band will always finish out-of-the-money, and therefore be worthless. Call value, when mapped against strike, is a convex function passing through these two points. Therefore, a straight line—since we do not know the degree of convexity of the call function, but do know that it cannot be less convex than a line—connecting these two points must provide an upper bound on all points in between. Thus, credibility can be rejected whenever the call value exceeds this upper bound, or

$$Call_{K,T} > \frac{S_0}{1+i_T*} - \frac{\underline{S}}{1+i_T} \frac{\overline{S}-K}{\overline{S}-\underline{S}} \quad [7]$$

Notice that by rearranging the terms of Test 2, we can show that the RHS of Test 2 is equal to the RHS of Test 1 times a coefficient less than one, provided the forward rate does not exceed the upper band. Therefore, as long as the forward rate is within the band, Test 2 is always at least as restrictive as Test 1. The one advantage of Test 1 is that it does not require the existence of a credible second reference rate, and provides a valid test even in the absence of a credible lower band. Test 2, in fact, is a test of the joint hypothesis that two reference rates, or the lower and the upper band of a target zone, are credible.

The Real Plan and Relevant History

Brazil had been subject to high levels of inflation since the early 1980s, and had unsuccessfully attempted to rein in inflation several times prior to 1994's Real Plan. Economic problems, in part, date back to 1964 when the military overthrew the civilian government, resulting in military control of the economy until 1985. (It was not until 1990 that the first popularly elected president was inaugurated.) During this military-ruled period, Brazil pursued industrialization policies based on trade protection, import substitution, large state-owned enterprises, and high levels of government spending financed through increases in the amount of money in circulation. By 1990, hyperinflation had been structured into the economy, through both indexation and expectations, with the concomitant debilitating effects.

Prior to the Real Plan, several attempts were made to contain inflation, usually involving combinations of wage and price controls, tightening of the money supply, tax hikes, freezing of bank deposits and the introduction of a new currency. These all failed as the fundamental problem lay in expectations of high inflation and excessive government spending.

The Real Plan, introduced in December 1993 by Finance Minister Fernando Henrique Cardoso, differed from the previous plans in that it directly addressed the problem of inflationary expectations. Cardoso recognized that past inflation was being transmitted into future expectations by indexing and various contract negotiations, as inflation figured into all wage and business contracts. The idea was to break this connection by creating a unit of transactional account in which price and wage contracts would be negotiated and written, and whose value would be kept roughly equal to $1. The official currency, the cruzeiro real, would then be devalued against this unit. The Unit was called the Unit of Real Value (URV), and was introduced in March 1994. At the same time, the constitutional links between revenue and expenditure were circumvented by creating a special fund (Fundo Social de Emergencia - FSE) to eliminate the public sector deficit, thereby addressing a fundamental source of inflationary pressure. (The creation of the FSE was necessary to avoid the structural claims guaranteed by the constitution to the states and to entitlement programs.) Four months after the introduction of the URV, the Real was introduced. The central bank (Banco Central do Brazil) committed not to permit a depreciation beyond 1.00 Real/$, though appreciation would be allowed. Furthermore, a reserve ratio was implemented requiring one American dollar to each Real emitted.

The result of the Real Plan was a reduction in inflation from 50% per month, as of June 1994, to less than 2% per month by the end of the year. Inflation has since then continued to drop, and in May 1998, 12-month inflation was 3.12%, its lowest value since November 1949. The Real Plan also had positive effects on the rate of economic activity during this period. Brazil's real GDP grew at an average annual rate of 4.0% during the four-year period 1994-1997, compared with an average annual growth rate of -0.2% during the four years prior to the implementation of the plan (1).

Exchange rate stabilization was an integral part of the Real Plan. Upper and lower bands ("maxibands")—as indicators of the maximum possible movement up or down—were established in March 1995, at a rate of .93 and .88 Real/$. While announcing these broader "maxibands," the central bank in practice followed a "crawling peg" system, in which the Real gradually depreciated, but remained within a "miniband" surrounding a depreciating central rate . Under this informal system, the Real's central rate was devalued approximately 0.5%-0.6%/month, and central bank intervention assured that at all times, the spot rate would not deviate by more than 0.25% (half the "miniband width") in either direction. In practice, the central rate was devalued discretely by about 0.10% (although sometimes 0.05% or 0.15%) about 5-7 times per month. Starting April 1997, the government started devaluing the central rate by about 0.7% monthly. To discourage speculation against the system, the actual magnitude and timing of these mini-devaluations was kept slightly irregular. Furthermore, the size of the minidevaluation would be smaller than the width of the miniband itself, so the instantaneous direction of the spot rate could not be known with certainty, discouraging "one way" bets.

While this system of a predictable crawling peg surrounded by a miniband provided short-term stability in the spot rate, the government wished to maintain some flexibility over longer periods such as several months. To commit to a very narrow range, even one surrounding a crawling peg, risked tying the government's hands unnecessarily and inviting outside speculation against the currency. Thus, the government remained free to alter either the rate of devaluation or the width of the miniband. At the same time, the government also wished to provide some indicative levels for medium-term forecasting. This dual objective was reached by instituting wider "maxibands." Though the exchange rate never technically violated these bands, the central bank adjusted the maxibands as markets gradually approached the maximum Real/$ exchange rate, an event that has typically occurred every six to twelve months (Figure 1) .

After the original maxibands were implemented in March 1995, the bands were changed on four separate occasions: June 22, 1995; January 30, 1996; February 18, 1997, and January 19,1998. In April of 1998, the government also announced that the lower end of the miniband would depreciate at a rate of 0.65% a month, while the upper band would depreciate at a rate of 0.75%, de facto widening the minibands over time. The Real had been under much pressure to depreciate due to the overall turmoil in international financial markets since the beginning of the Asian crisis in July 1997. This increased volatility, coupled with the inability of the Brazilian government to commit to some of the structural reforms in their fiscal accounts and social security system, led to wide speculation on the viability of the exchange rate system in the fall of 1999. This speculation subsided after the

(1) Other key components of the Plan included: the privatization of state-owned enterprises, the reduction of the fiscal deficit, social security reform, and Constitutional reforms to deregulate the labor market and to relax the excessive protections provided to public workers.

Brazilian government agreed to an IMF-led financial package in November 1998. The government announced another realignment of the maxibands on January 12, 1999 amid intensive turmoil in the financial markets. The day after the Real had depreciated to the upper end of the new band, the government abandoned the system and let the Real float. Given this track record, the following sections will seek to investigate issues of exchange rate regime credibility—both the crawling peg and the maxiband system—and how market perceptions of the distribution of the Real/$ spot rate have changed over time.

Data Description

The data obtained consist of high, low, average, and last transaction prices for every trading day of dollar futures (daily observations of contracts of multiple maturities), calls and puts (daily observations of multiple strikes and expiries), and closing spot rates, from the Commodities & Futures Exchange (Bolsa de Mercadorias & Futuros, known as the BM&F) in Sao Paulo, Brazil. The data cover the period from July 1994, shortly after implementation of the Real Plan, through March 1999. Calls are initially both European and American, until a 1995 shift in convention, making all calls expiring after October 1995 European. All put contracts are European.

The BM&F was formed in July 1985 and began trading in January 1986. Currently, the exchange offers a range of futures and options contracts on the US dollar, the Ibovespa (the Brazilian stock index), sovereign debt instruments, inter-bank deposit rates, US-Brazilian interest rate spreads, gold, cattle, and agricultural commodities. With a total trading volume of 102.3 million contracts and a financial volume of 6.1 trillion US dollars during 1997, BM&F is currently ranked fourth among the world's derivative exchanges (2). In 1997, 39.7 million contracts traded were US dollar futures, 8.1 million contracts were US dollar call options, and 71,820 contracts were US dollar put options (3). Total trading volume in foreign exchange contracts has actually declined since 1985, but this is due primarily to increases in contract size; financial volume has more than doubled from 1996 to 1997. US dollar contracts for both futures and options apply to the “commercial” (as opposed to financial) exchange rate on a notional amount of $100,000.

In this paper, we only use the European options. Data on dollar call options significantly outnumber dollar put data. Put data were translated using put-call parity and used only to augment the call data if a corresponding call did not exist. The data consist of 7235 observations from the later time period with purely European options, with mixed calls and puts. From this dataset we extracted 6934 usable (about 200 questionable observations were deleted) observations of the options. This revised data set forms the basis for our subsequent analysis.

In deriving the PDF and conducting credibility tests, we use futures prices as an approximation of the forward rate, as in Bodurtha and Courtadon (1987). US interest rate data are daily Eurodollar rates for 1 day, 1 week, 1 month, 3 month, 6 month, and 1 year, obtained through Datastream. Linear interpolation between the two closest maturities along the yield curve is used to obtain the Eurodollar rate corresponding to the options’ maturity. Brazilian interest rate data are computed using covered interest rate parity, using the appropriate futures contract (whose maturity normally coincides with that of the options),

(2) Bolsa de Mercadorias & Futuros 1997 Annual Report.

(3) These figures are for contracts based on commercial US dollar rate. Contracts are also available based on the floating rate; however, these represent less than one percent of total transactions volume.

spot exchange rate (again the mid-point of bid and ask), and computed Eurodollar rate. Since we have closing spot and U.S. interest rate data, we use the last traded futures contract in each day's calculations. Finally, exchange rate band information was obtained from the World Bank.

Macroeconomic indicators used in Section V to determine economic explanatory variables are drawn primarily from International Financial Statistics (IFS) by the International Monetary Fund. The choice of variables follows Rose and Svensson (1994). The "real exchange rate" is constructed from the nominal exchange rate (IFS code ...rf), the US PPI (IFS code 63BB.ZF), and the Brazilian WPI (IFS code 63.Z.CF). "Output" is represented by industrial production (IFS code 66...b). "Inflation" is the percentage change in consumer prices (IFS line 64...x). The "trade balance" is the ratio of exports to imports (IFS line 70 divided by line 71); "Reserves" are foreign exchange excluding gold (IFS code 1l.d) and "Money" is Reserve Money (IFS line 14).

In Table 1a, we report the mean and standard deviation of strike price over three maturity ranges (i.e. 1-30 days, 31-60 days, and 61-90 days) and six time periods corresponding to different exchange rate regimes. Maturities vary because unlike over-the-counter option contracts, which have a fixed time-to-expiration, BM&F standardized options and futures contracts settle on the first business day of the maturity month (4). Note that especially in the first time period (March 10, 1995 – June 22, 1995) even the mean strike price was often outside the band.

In Table 1b, we report the distribution of these strike prices over time relative to the spot, forward, and upper-band. The concentration of strike prices is important for two reasons. First, it indicates in what exchange rate range market liquidity and interest were greatest. Second, it will affect the reliability of the PDF we extract from these data. Generally, the PDF is most reliable in ranges spanned by the observed strikes. Notice in Table 1b that the distribution of strike prices has become more concentrated over time: the percentage of strikes above the spot is increasing over the four initial periods, but the percentage above the upper-band tends to decrease after the second period. To the degree that market activity reflects a concentration of expectations (to be verified more formally later in the paper), this pattern suggests that market expectations are exhibiting less dispersion over time, and that the upper-band is becoming increasingly credible (as indicated by the decline in the percentage of strikes exceeding the upper-band).

The behavior of the underlying Real-dollar exchange rate also appears to have shifted over these periods. Table 2 reports the standard deviation of daily changes in the spot and forward rates. These standard deviations have decreased over the first three periods, a pattern coincident with less dispersed expectations as suggested by the increased concentration in observed strike prices. The standard deviation starts to rise during 1997 in relationship with the start of the Asian crisis and remain relatively high during 1998.

Table 2 also reports, by option maturity and exchange rate regime, the mean and standard deviation of the Black-Scholes implied volatilities extracted from observed option prices. A number of stylized facts are worth noting. First, in all cases, shorter maturities are

(4) The exchange does offer a "flexible" option contract that can be tailored to the issuer's needs including style, maturity, dollar value, etc. However, data on these contracts were not available, and in any event, given the potentially unique structure of each contract, each observation would have to be individually evaluated. Furthermore, low liquidity would reduce the reliability of such data.

associated with high mean volatility. When normally calm markets experience occasional periods of high uncertainty expected to be temporary, implied volatility will increase, and more markedly for short-maturity options than for longer-dated options. Second, by similar reasoning, the standard deviation of short-dated volatility will be the highest, since longer-dated volatility will again reflect an average of high-volatility and low-volatility periods. Third, the mean implied volatility is one to two orders of magnitude greater than realized volatility obtained from the time series of exchange rate changes. This is because implied volatility reflects the presence of the "peso problem"—the risk of a rare but substantial exchange rate shock, in this case a devaluation of the Real. Throughout the periods in question, the Real remained stable, or depreciated only gradually against the dollar until the beginning of 1999 when the Real Plan was abandoned and the exchange rate suffered a large devaluation in January 1999. Of course, in small samples, realized volatility can very easily be substantially below implied volatility in the presence of a "peso problem" if that rare event does not occur in sample. Fourth, the number of long-maturity options (60 to 91 days) traded in the markets significantly dropped after the summer of 1997 when the turmoil in emerging markets started.

The Implied PDF and Expected Deviations from the Crawling Peg

Estimation of the Risk-Neutral PDF (over 15-day periods)

We first use our option data to derive risk-neutral PDFs corresponding to horizons of one, two, and three months. Because of data limitations, this procedure will require certain numerical approximations, but the resulting PDFs provide potentially richer information about expectations than simple point-estimate characterizations of expectations as provided by the forward rate or an econometric model.

A common approach to deriving the PDF from option prices characterizes Black-Scholes volatilities ("vols") implied in option prices as a function of the strike price. For any given date and time horizon, one can interpolate and extrapolate from existing implied vols to express implied vol as a continuous function of only the strike price. This function is commonly known as the "volatility smile" (5). The function is then transformed into a continuous call price function that is twice-differentiable in strike. This approach does not require that the Black-Scholes model hold; indeed, the fact that implied vol varies with strike rather than being constant across all strikes is itself evidence against Black-Scholes assumptions. Note that the numerical technique in this volatility smile-based approach can vary, as discussed in Shimko (1993) and Campa, Chang, and Reider (1997, 1998). In Shimko (1993), the method applied in this paper, the implied volatility smile is fitted as a quadratic function of the strike. In contrast, Campa, Chang, and Reider (1997, 1998) use the method of cubic splines (6).

In our attempt to derive a PDF from the Brazilian options data, a significant empirical problem is that, for any given observation date and maturity date, we observe an

(5) Volatility plotted as a function of the strike price often resembles a "smile" because Black-Scholes implied volatilities tend to increase as the strike price moves away from the forward rate.

(6) For a number of dates, we also fit a cubic spline (as in Campa, Chang, and Reider (1997, 1998)) to the data, and obtain similar results to the quadratic, suggesting that the results are robust to the method used. Since the cubic spline method exactly fits the observed prices, and we were concerned about some measurement error in option premium due to asynchronous prices in the options, we decided to report the estimations using the quadratic approximation instead.

insufficient range of strike prices to trace out a reasonably complete volatility smile. This prevents us from constructing daily estimates of the PDF on all but a few dates. Also, as mentioned previously, options expire on the first business day of every month, reducing the frequency to only monthly if we wish to compare PDFs with the same time horizon. To overcome these data limitations, we make the assumption that the shape of the volatility smile remains constant for a period of 15 days (7). For convenience, we assign the period's midpoint as the "observation date" for each 15-day period. For instance, for 60-day call options, implied volatilities are collected for options ranging from 53 to 67 days to expiration. Each volatility corresponds to a strike/forward ratio for the collection period. We convert each strike/forward ratio to an absolute price by multiplying by the forward rate central to the period. The implicit assumption is that during this period, the relationship between volatility and the strike/forward ratio remains constant.

Aggregating option observations over such 15-day periods, we obtain a monthly series of PDFs for 35, 60, and 91-day call options (the 35-day periodicity captured a greater spectrum of strikes than did a 30-day). Many of these PDFs are estimated using over 20 data points on the volatility smile, and most use over 10 data points. Only in one case do we use as few as five options data points. PDFs are discarded if the associated continuous call price function is non-convex, as occurred in two instances. PDFs were also smoothed using an exponential smoothing technique, which removes non-monotonicities or negative values in the tails of the distribution. When this technique is applied, if a non-monotonicity or negative value is detected, the computed PDF at this point is modified to decline from the previous value towards zero at an exponentially decreasing rate.

Figures 2a-c provide three-dimensional time series of risk-neutral PDFs estimated using numerical derivatives, for 35, 60, and 91-day options respectively. The PDFs are presented as a function of the strike/forward ratio. The first observation in any of the graphs is June 2, 1995. (The dates on the horizontal axes are shown in reverse to facilitate a better view of the fluctuations in the estimated distributions over time.) All time series appear to exhibit increasing skewness over time. Positive skewness in this context indicates that a large depreciation of the Real is more likely than a large appreciation. The increase in skewness largely stems from the disappearance of a downside tail, in the region of Real appreciation. Kurtosis, on the other hand, decreased through the first part of the sample until the fall of 1997 and then started to increase again until the end of the sample. Kurtosis reflects "fatter tails," relative to the lognormal distribution, and denotes a relatively high probability of extreme outcomes—holding volatility constant. These graphical results reinforce our earlier inferences from the distribution of strike prices.

Towards the middle of the sample, it is striking how the part of the distribution below the forward rate is extremely concentrated in values very close to (but below) the forward rate (i.e. small Real appreciation). In contrast, for values above the forward rate, the distribution quickly drops to zero for points beyond a 2% depreciation from the forward rate. This is consistent with the government's stated policy of constant depreciation over time. This pattern started to change in the fall of 1997 when large hikes in domestic interest rates by the Brazilian government to support the exchange rate caused the forward rate to significantly increase relative to the spot rate. As the interval between the spot and forward rates widened. the amount of implied probability became more evenly distributed throughout that interval.

(7) Starting in October 1997, due to the drop in the number of 91-day options traded, we expanded the window for 91-day options to 21 days.

Deviations from the Crawling Peg (Miniband) Regime

We now use these PDFs to identify potential divergences between market expectations and the existing crawling peg regime of 0.5%-0.6% per month. We focus on possible Real depreciations of a larger magnitude than the crawling peg, namely 2% and 5% over horizons of 35, 60, and 91 days (approximately 1, 2, and 3 months). All these combinations of depreciations and time horizons represent a rate of Real depreciation at least as fast as under the crawling peg, and usually more so. For example, the existing crawling peg would imply about a 1.8% depreciation over three months.

For each devaluation size (x%) and horizon, we calculate the "probability" of devaluations of at least x%. "Probability" denotes the total amount of probability, not weighted by distance, representing devaluations of at least x% from the current spot. Graphically, this corresponds to the area under the curve in the right-hand tail of the risk-neutral PDF beyond an x% devaluation. In contrast, "intensity" denotes the total probability, *weighted by the amount of depreciation beyond x%*, of all devaluations of at least x%.

Table 3 depicts the probability, at the start of each month, of a depreciation of at least 2% or 5% over horizons of 35, 60, and 91 days. A number of points are striking in this table. First, the credibility of the crawling peg improved consistently over time during the period February of 1996 to October 1997. During this sample period median probabilities of a 5% depreciation at all horizons are less than 1%. After October 1997 the depreciation probabilities significantly increased and became more volatile. For instance the 0.93% median probability of a 2% depreciation, at the 35-day horizon, during the 21 months to prior to October 1997 was lower than any other estimated probability after that. After October 1997 this median probability rose to 6.05%.

Second, within any of the four exchange rate regimes, the probability of a 2% or 5% depreciation does not change markedly in the months just prior to the maxiband realignment. Depreciation probabilities remain high throughout the first regime (August 1995, when our data begin, to January 1996), then drop significantly beginning in February 1996, remaining low even up to the February 1997 realignment. Depreciation probabilities behave similarly for the following regime, changing only in the last two months of the last regime prior to system's abandonment. This does not imply that markets expected no maxiband realignment, as we will see in the following section. Yet, the options data indicate that any anticipated maxiband realignment was not expected to be accompanied by a large spot depreciation.

Third, around times of realignments (the months preceding January 1996 and January 1997) the probability of a 5% depreciation is usually far smaller than that of a 2% depreciation. This indicates that the probability mass of a depreciation of 2% or more arises primarily from expected small depreciations –i.e. between 2% and 5%– rather than expected large depreciations of 5% or more. Thus, even when the crawling peg regime is not perceived as fully credible by the market –i.e. some depreciation beyond the usual 0.5%-0.6% per month is expected– much of the market's "doubt" surrounding the crawling peg regime is in the form of minor rather than major expected depreciations beyond the crawl.

Fourth, our estimates of depreciation risk prove extremely sensitive to news affecting the Brazilian economic and political situation. Probabilities of large depreciations increased considerably in April and May of 1996. This coincided with a humiliating defeat suffered in Congress by the Brazilian government on Social Security Reform, a key part of the structural reforms under the Real Plan. Likewise, in May 1997, bribery accusations against some Congress members resulted in a sharp temporary rise in depreciation probabilities. From summer 1997 onwards, fluctuations in monthly probabilities depend on the news surrounding not only Brazil but also other emerging economies. Depreciation probabilities substantially increased around November and December 1997 when the Brazilian government was forced to introduce an emergency fiscal package to reduce speculation on the sustainability of the Real plan. In June 1998 depreciation probabilities significantly increased again, this time in reaction to the spillovers from the Asian crisis and the resignation of President Suharto in Indonesia, which reportedly also affected other emerging economies such as Russia and Mexico.

Empirical Findings: Tests of Exchange Rate "Maxi-Band" Credibility

Arbitrage-Based Tests (Daily Observations)

We now focus on Brazil's "maxibands" and perform a number of tests, including the arbitrage-based tests of band credibility using Tests 1 and 2 (equations [7] and [8] respectively) discussed in Section I of this paper. We start by focusing simply on the behavior of the spot and three ranges of forward rates (1-30 days, 31-60 days, and 61-90 days) against the band. We see in Figure 1a that there is no violation of the upper-band by the spot. In Figure 1b, for 1-30 day data, an ongoing violation of the upper-band by the forward occurs only in the first target zone regime, although the longer-dated forward prices (Figures 1c-d) do approach and at times cross the upper-band in other regimes just prior to subsequent adjustments.

The options-based test results are graphed in Figures 3a-f. Figures 3a-c report the results from Test 1 for options in three different maturity ranges (1-30 days, 31-60 days, and 61-90 days), while Figures 3d-f report the results of Test 2 for the same maturity ranges. We report, for each maturity, the observed price of the call option on a given date minus the corresponding "maximum" consistent with credibility from all the options with the relevant maturity range observed that day. Positive values for Tests 1 and 2 constitute a violation of upper-band credibility. If there are multiple call options observed on a given date, then only the maximum such statistic for each date is reported. On some days, these maxima include some calls whose strikes exceed the upper-band, i.e. automatic violations of the target zone. Recall that since these are arbitrage-based tests, a single option can be sufficient to reject credibility. This approach does not mix calls with different expiration dates, as these arbitrage-based tests specifically refer to a given band width and time horizon.

Credibility of the exchange rate band is consistently rejected for the initial months of the exchange rate band. During all of 1995 and until the exchange rate realignment of January 30, 1996, options with maturities beyond 30 days were consistently priced higher than their maximum value consistent with credibility. During this period, many options traded with strike prices larger than the existing upper band, i.e. automatic violations of credibility. Using options with maturities less than 60 days, we find credibility harder to reject from February 1996 until about November 1996, with the exception of a few days around August 1996 coinciding with the turmoil caused by the resignation of the Argentinean Finance Minister. Options with longer maturities (more than 60 days) rejected the credibility of this exchange rate band slightly earlier, starting around mid-summer 1996.

After the realignments of January 1997 and January 1998, credibility of the exchange rate band could still be rejected. Yet, the percentage of traded options whose price was inconsistent with credibility of the new band declined significantly, at around 20% of the traded options, and in both cases started to rise again towards the fall of that year.

Probability and Realignment Intensities of the Maxibands

As we did with the minibands above, we compute the estimated monthly probabilities and intensities of devaluation (reported in Table 4) implied by the estimated PDFs at the three different horizons. Devaluation probabilities were consistently large at all horizons during the first part of the sample ("Regime II"), until the realignment of January 30, 1996. After that devaluation, probabilities were very close to zero until about November 1996, four months prior to the February 18, 1997 realignment, when the probabilities of devaluation began to steadily increase again. For the next two regimes the probabilities of devaluation started to increase earlier, at around September and October of the previous year.

Realignment intensities in Table 4 are expressed on an annualized basis as a percentage of the existing upper band. These numbers refer the product of the probability of a devaluation and the expected size of the devaluation (measured from the upper band). At the beginning of January 1996, the estimated 35-day devaluation intensity was slightly higher than 34% annually. This suggests, for instance, a 50% probability of a 70% annual depreciation rate of the spot rate beyond the upper band over a 35-day horizon. This number seems high given the government's policy at the time of aiming for a steady monthly nominal devaluation of the Real of about 0.5-0.6%. The low realignment intensities observed prior to the following realignment on February 19, 1997 corroborates the increased credibility of the stated government policy during this period. Estimated three-month realignment intensities at the beginning of February 1997 are 2.58% while the estimated probability of the devaluation was over 98 percent. This again indicates that, although a realignment was widely expected, the expected devaluation of the spot rate from such a realignment was very small and of the same order as the observed depreciations in the previous months.

Like our estimates of expected depreciations beyond the crawling peg, probabilities and intensities of realignments (devaluations beyond the maxibands) also prove sensitive to news affecting the Brazilian economic and political situation. For example, the failure to pass Social Security Reform legislation (April-May 1996), the Congressional bribery scandal (May 1997), and the financial turmoil in emerging markets (Oct. 97 and May 1998) increased both realignment intensity and realignment probability, especially at the 91-day horizons.

Economic Determinants of Realignment Intensity

To ascertain whether variation in realignment intensity can be explained by common macroeconomic variables, we perform regressions whose dependent variables are the monthly estimates of devaluation intensity and its lower bound, as estimated in Section V. The macroeconomic variables used are similar to those in Rose and Svensson (1994). No lagged right-hand-side variables were included, however, because of the limited number of left-hand-side observations available.

The estimated equation is:

$$\text{Intensity}_t = \alpha + \beta_1(\text{RER})_t + \beta_2\,(\text{Infl})_t + \beta_3(\text{Output})_t + b4(\text{Trade})t + b5(\text{FRES})t + b6(\text{Money})t + et \qquad (9)$$

The explanatory variables on the RHS are: the real exchange rate (RER), determined using the nominal monthly average exchange rate, the US PPI, and the Brazilian WPI, defined as Real/US$; inflation (Infl), which is the difference between the Brazilian and US inflation rates; Brazilian index of industrial production (Output); Brazilian trade balance divided by GDP (Trade); Brazilian foreign reserves (FRES); and, the value of Brazilian high-powered money (Money).

All variables except inflation are expressed in logs. On the left-hand-side, we use the monthly probabilities of a 2% depreciation from the spot rate, derived from the full estimated PDF.

Results from OLS regressions using equation [9] for the 35-day, 60-day, and 91-day probability data are reported in Table 5 (8). We should first note the low power of these regressions owing to the small number of observations in our sample. The regression results clearly indicate the low explanatory power of these macroeconomic variables. For the specification using the 60-day realignment intensity, we cannot reject the hypothesis that all the coefficients equal zero. None of the indicators is significant in all three regressions. Foreign reserves are the only variable that has a significant coefficient in more than one regression—with higher reserves associated with lower depreciation probability. The coefficients on Money and on the real exchange rate do have the expected sign and Money has a significant coefficient in the regression of the 90-day intensity. Increases in the Brazilian money supply and real exchange rate appreciations appear to increase the probability of depreciation. For the other economic fundamentals the estimated coefficients are insignificant and usually have the opposite sign that one would expect (9). Given the small number of observations, it is not appropriate to draw general conclusions from these estimates. Nevertheless, the results are consistent with the general conclusions of Svensson and Rose (1994) and Campa and Chang (1998): that macroeconomic variables are largely unable to explain intertemporal movements in realignment risk.

VII. Conclusion

This paper has used a new data set of exchange-traded options from March 1995 through January 1999 to derive risk-neutral probability density functions for the Real/Dollar exchange rate over horizons ranging from one to three months. The PDF is a superior indicator to a single point estimate of exchange rate expectations, such as a forward rate or survey-based forecast, in that it assigns varying amounts of probability to different possible outcomes. Although we introduce some approximations to compensate for sparse data, we make no assumptions about exchange rate dynamics. The PDF then can be used to analyze both the crawling peg and the maxiband exchange rate regimes. These two overlapping systems operated in Brazil since early 1995, several months after the June 1994 introduction of the Real Plan, designed to combat inflation and currency depreciation.

In assessing market expectations under the crawling peg, we use the risk-neutral PDF to calculate both the intensity and probability of depreciation beyond the crawling peg.

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(8) The results reported here do not change qualitatively if one replaces the dependent variable (depreciation probabilities) with either the probabilities of depreciations reported in Table 4b or the probabilities or intensities of devaluations reported in Table 6

(9) We performed similar regressions using the average monthly minimum intensity of realignment computed according to equation (6) and the results were equally unsuccessful.

A high probability accompanied by a relatively low intensity, for example, indicates that the market anticipates depreciation beyond the peg, but most of this depreciation is concentrated just outside the peg. Empirically, we find that the credibility of the peg increased over time during 1996 and the first half of 1997 and started to deteriorate again after the start of the Asian crisis in July 1997. The occasional spikes in depreciation intensity and probability can usually be explained by identifiable political or economic news in Brazil.

Our evaluation of the maxiband regime consists of two arbitrage-based tests of target zone credibility, as well as a measure of devaluation intensity outside the band. Tests based on arbitrage reject credibility whenever observed option prices are inconsistent with zero probability lying outside the band. When this occurs, devaluation intensity outside the band is positive. The numerical value of this intensity then provides a quantitative indicator of markets' questioning the maxiband regime. Empirically, we are usually able to reject credibility, but find that through our sample ending in July 1997, the intensity of devaluation has fallen over time as the regime became increasingly credible.

This paper also provides a more general methodology for extracting the risk-neutral PDF even when data are limited. In particular, we aggregate observations over several days, normalizing the option price by the contemporaneous forward rate. Our method involves fitting a single volatility smile to these multi-day observation periods. Assuming stationarity of the distribution over each period, this approach results in more precision when relatively few options are observed, a common difficulty with many emerging markets (10).

Analysis of the shape of the PDFs over time also provides insight into market perceptions. In general, the PDFs appear to exhibit a greater degree of kurtosis and skewness (towards Real devaluation) with time. Increased kurtosis, i.e. fatter tails for a given level of volatility, suggests that increasingly markets believed that if a depreciation were to occur, it would be a large depreciation. Holding volatility constant, an increase in kurtosis implies less probability of a devaluation outside the target zone, but a larger expected devaluation if devaluation occurs.

We also run regressions seeking to identify macroeconomic determinants of realignment risk. We find little evidence that standard macroeconomic indicators can explain observed realignment risk, consistent with Rose and Svensson (1994) and Campa and Chang (1998). Our observation of increasing kurtosis over time suggests that devaluation outside the band is increasingly perceived as a rare large event, rather than a more likely but not necessarily large event.

Overall, the paper's findings reinforce earlier work on options' superior ability, relative to macroeconomic or interest-rate based indicators, to anticipate the periodic realignments of the exchange rate bands. By providing a more sensitive indicator of exchange rate risk—either in the form of depreciation beyond the crawling peg or a realignment of the maxibands—we have also documented the fluctuations in the degree of exchange rate credibility during the years of Brazil's Real Plan.

(10) Since the Real Plan implied a clear break in the process driving the Brazilian exchange rate, we have ignored in our estimation of the expected exchange rate distribution all the historical information from the time series process of the spot rate. In general, one can think of using both the information in option prices, and spot movements in the computation of the expected distribution. Pan (1999) provides an application of such approach to the S&P500 index.

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Table 1a: Mean and Standard Deviation of Strikes

This table reports the mean and standard deviation (in parentheses) of strikes for European call data in three maturity ranges (1-30 days, 31-60 days, and 61-90 days) for the period 3/95 to 7/97. The four periods over which these statistics are computed correspond to different exchange rate band regimes: March 10, 1995 through June 22, 1995 (.88-.93 R/$); June 23, 1995 through Jan 30, 1996 (.91-.99 R/$): Jan 31, 1996 through February 18, 1997 (.97-1.06 R/$); February 19, 1997 through January 18, 1998 (1.05-1.14 R/$); January 19, 1998 through January 12, 1999 (1.12-1.22 R/$); and from January 13, 1999 through the end of the data (no bands). The number of observations is listed below each statistic.

Band Period	3/10/95 6/22/95	6/23/95 1/30/96	1/31/96 2/18/97	2/19/97 1/18/98	1/19/98 1/12/99	1/13/99
R/$ Band	.88-.93	.91-.99	.97-1.06	1.05-1.14	1.12-1.22	n.a.
1-30 Days, Mean	1.027	1.010	1.040	1.126	1.197	1.793
Std.Dev.	(.227)	(.138)	(.051)	(.055)	(.043)	(.248)
# obs.	11	158	563	930	1096	24
31-60 Days, Mean	.854	.985	1.047	1.125	1.202	1.938
Std. Dev.	(.066)	(.040)	(.050)	(.043)	(.051)	(.273)
# obs.	14	204	740	920	900	19
61-90 Days, Mean	.956	.991	1.046	1.119	1.208	.
Std. Dev.	(.172)	(.019)	(.050)	(.030)	(.070)	.
# obs.	20	203	608	520	183	0

Table 1b: Percentage of Strikes Above the Spot, Forward, and Upper-Band

This table reports the percentage of strike prices above the spot rate, forward rate and upper-bands, for European call data in three maturity ranges (1-30 days, 31-60 days, and 61-90 days), for the period 3/95 to 7/97. The four periods over which these statistics are computed correspond to different exchange rate band regimes: March 10, 1995 through June 22, 1995 (.88-.93 R/$); June 23, 1995 through Jan 30, 1996 (.91-.99 R/$); Jan 31, 1996 through February 18, 1997 (.97-1.06 R/$); February 19, 1997 through January 18, 1998 (1.05-1.14 R/$); January 19, 1998 through January 12, 1999 (1.12-1.22 R/$); and from January 13, 1999 through the end of the data (no bands).

	3/10/95 6/22/95	6/23/95 1/30/96	1/31/96 2/18/97	2/19/97 1/18/98	1/19/98 1/12/99	1/13/99
R/$ Band	.88-.93	.91-.99	.97-1.06	1.05-1.14	1.12-1.22	n.a.
1-30 Days						
Spot	.64	.85	.94	.99	.94	.71
Forward	.55	.80	.82	.95	.83	.67
Upper-Band	.55	.41	.28	.33	.28	n.a.
31-60 Days						
Spot	.43	.95	.97	1.00	.98	.421
Forward	.21	.76	.76	.87	.78	.421
Upper-Band	.21	.47	.33	.37	.35	n.a.
61-90 Days						
Spot	.40	.995	.997	1.00	1.00	.
Forward	.15	.78	.77	.83	.72	.
Upper-Band	.30	.65	.36	.34	.31	n.a.

Table 2: Standard Deviation of Changes in the Spot, Forward Rates and Implied Volatilities

This table reports the standard deviation of daily percent changes in the spot rate, three forward rates relative, and the mean and standard deviations of implied volatilities from the options over the four Real/Dollar maxiband regimes during the sample period, 3/95 to 7/97. Observations on the forward rates and implied volatilities are separated in three maturity ranges (1-30 days, 31-60 days, and 61-90 days). The four regimes are: March 10, 1995 through June 22, 1995 (.88-.93 R/$), June 23, 1995 through Jan 30, 1996 (.91-.99 R/$), Jan 31, 1996 through February 18, 1997 (.97-1.06 R/$), February 19, 1997 through January 18, 1998 (1.05-1.14 R/$), January 19, 1998 through January 12, 1999 (1.12-1.22 R/$) and from January 13, 1999 through the end of the data (no bands). Number of observations is provided below each statistic.

	3/10/95 6/22/95	6/23/95 1/30/96	1/31/96 2/18/97	2/19/97 1/18/98	1/19/98 1/12/99	1/13/99
R/$ Band	.88-.93	.91-.99	.97-1.06	1.05-1.14	1.12-1.22	n.a.
Spot Std. Dev.	0.0046	0.0010	0.00073	0.0010	0.0009	0.0644
# obs.	69	149	259	218	229	35
1-30 Day						
Forward Std. Dev.	.0065	.0026	.0015	.0025	.0026	.0582
# obs.	67	146	247	217	228	33
Implied Volatility						
Mean	46.64	13.65	5.06	8.13	7.91	42.10
Std. Dev.	29.20	19.85	6.68	7.83	7.60	17.64
# obs.	11	151	528	927	1062	24
31-60 Day						
Forward Std. Dev.	.0071	.0024	.0016	.0029	.0029	.0615
# obs.	67	147	251	220	229	35
Implied Volatility						
Mean	18.74	4.57	4.13	6.12	7.12	34.89
Std. Dev.	7.83	5.96	4.48	5.00	5.89	6.70
# obs.	14	202	702	914	883	16
61-90 Day						
Forward Std. Dev.	.0079	.0026	.0018	.0032	.0033	.0756
# obs.	67	146	240	219	219	34
Implied Volatility						
Mean	19.85	4.37	3.48	4.31	6.90	.
Std. Dev.	11.74	2.32	4.19	2.81	5.64	.
# obs.	20	201	581	516	182	0

Table 3: Probabilities of a 2% and of a 5% depreciation over 35, 60, and 91-day horizons, 8/95-1/99

This table reports the probability that the expected exchange rate will depreciate by more than 2% and 5% over a given horizon. These probabilities are estimated monthly from implied PDFs at three different horizons (35, 60 and 91 days).

Date	35 Day 2 %	5%	60 Day 2 %	5%	91 Day 2 %	5%
Regime II: [.91-.99]						
Aug-95	13.32	10.51	12.38	2.98	88.03	37.61
Sep-95	36.53	22.05	66.21	9.03	81.35	15.34
Oct-95	35.45	19.75	39.01	29.65	61.61	6.58
Nov-95	15.25	11.07	50.54	28.27	58.79	6.37
Dec-95	29.80	21.12	14.17	6.49	16.34	0.78
Jan-96	34.37	25.69	15.45	1.54	26.79	1.92
Regime III: [.97-1.06]						
Feb-96	1.09	0.03	11.79	0.52	13.62	1.43
Mar-96	2.67	1.48	11.67	1.80	14.56	9.03
Apr-96	0.47	0.01	0.35	0.00	25.06	8.68
May-96	1.25	0.16	3.14	0.12	44.20	22.80
Jun-96	0.57	0.00	10.56	4.00	25.07	0.75
Jul-96	0.50	0.00	1.49	0.00	22.88	0.72
Aug-96	0.66	0.00	4.12	0.00	–	–
Sep-96	1.50	0.07	12.01	0.59	31.55	1.21
Oct-96	0.00	0.00	.	.	5.18	0.00
Nov-96	0.08	0.00	4.11	0.00	22.77	0.33
Dec-96	3.81	0.17	3.19	0.00	18.31	0.00
Jan-97	1.31	0.00	23.95	4.52	38.19	1.65
Feb-97	1.17	0.01	11.53	0.08	32.74	0.00
Regime IV: [1.05-1.14]						
Mar-97	0.93	0.00	2.55	0.00	37.44	0.88
Apr-97	2.23	0.00	6.14	0.00	27.02	0.00
May-97	0.21	0.00	16.52	2.48	83.80	61.61
Jun-97	0.73	0.00	9.24	0.07	49.91	1.13
Jul-97	0.90	0.00	3.51	0.00	34.21	0.01
Aug-97	3.96	0.23	8.48	0.06	55.44	0.20
Sep-97	1.76	0.00	11.56	0.07	53.34	0.33
Oct-97	18.38	3.45	12.39	0.17	37.77	1.03
Nov-97	13.45	0.99	70.01	30.41	–	–
Dec-97	12.30	1.55	57.35	24.02	83.60	41.30
Jan-98	15.57	1.98	5.90	0.00	–	–
Regime V: [1.12-1.22]						
Feb98	4.49	0.10	33.11	3.55	–	–
Mar-98	1.30	0.00	14.36	0.87	–	–
Apr-98	1.64	0.00	16.09	0.73	–	–
May-98	5.73	0.03	10.01	0.00	–	–
Jun-98	6.05	0.34	72.24	54.31	–	–
Jul-98	1.36	0.00	20.49	1.95	–	–
Aug-98	4.94	0.23	7.13	0.00	36.90	3.42
Sep-98	5.36	0.21	8.50	0.02	–	–
Oct-98	8.73	0.68	10.89	0.00	–	–
Nov-98	6.56	0.15	0.15	0.00	–	–
Dec-98	13.90	1.32	0.01	0.00	–	–
Jan-99	14.62	3.56	59.03	0.03	–	–

Table 4: Probabilities of Realizations outside the Maxiband and Intensities of Maxiband Realignment, 8/95-1/99

This table reports the total probability of the expected exchange rate realizations outside the maxiband and the annualized expected intensities of realignment (as a % of the upper end of the band) from the estimated PDFs at three different horizons (35, 60 and 91 days).

Date: (start of Month)	Probability (in %) outside the Upper Band			Intensity of Realignment		
	35-Day	60-day	91-Day	35-Day	60-day	91-Day
Regime II: [.91-.99]						
Aug-95	2.01	7.12	26.03	1.16	1.76	3.69
Sep-95	24.97	14.60	32.41	22.12	1.88	2.14
Oct-95	25.62	32.35	25.91	20.41	17.19	1.44
Nov-95	13.79	38.17	31.62	12.08	14.40	1.82
Dec-95	30.32	10.95	9.51	24.42	3.57	0.37
Jan-96	44.91	23.51	33.77	34.58	1.36	1.46
Regime III: [.97-1.06]						
Feb-96	0.00	0.04	0.00	0.00	0.00	0.00
Mar-96	1.09	0.88	0.00	0.65	0.17	0.00
Apr-96	0.00	0.00	7.28	0.00	0.00	1.90
May-96	0.08	0.03	16.92	0.02	0.00	3.14
Jun-96	0.00	3.52	0.32	0.00	1.18	0.02
Jul-96	0.00	0.00	0.47	0.00	0.00	0.02
Aug-96	0.00	0.00	.	0.00	0.00	.
Sep-96	0.19	1.12	2.23	0.03	0.09	0.11
Oct-96	0.00	.	0.01	0.00	.	0.00
Nov-96	0.00	0.39	4.01	0.00	0.01	0.12
Dec-96	3.81	1.29	3.21	0.42	0.03	0.04
Jan-97	4.96	26.85	38.19	0.23	2.97	1.48
Feb-97	0.00	50.18	98.12	0.00	1.56	2.58
Regime IV: [1.05-1.14]						
Mar-97	0.00	0.00	0.07	0.00	0.00	0.00
Apr-97	0.00	0.00	0.00	0.00	0.00	0.00
May-97	0.00	0.06	52.37	0.00	0.00	16.44
Jun-97	0.00	0.00	0.29	0.00	0.00	0.01
Jul-97	0.00	0.00	0.00	0.00	0.00	0.00
Aug-97	0.38	0.04	0.13	0.06	0.00	0.00
Sep-97	0.00	0.26	0.83	0.00	0.01	0.02
Oct-97	7.17	0.82	3.64	2.02	0.04	0.14
Nov-97	6.23	48.81	.	1.00	13.33	.
Dec-97	10.42	47.11	73.54	1.98	11.78	8.92
Jan-98	20.41	4.39	.	3.77	0.08.	.
Regime V: [1.12-1.22]						
Feb98	0.00	54.03	.	0.00	4.57	.
Mar-98	0.00	0.10	.	0.00	0.01	.
Apr-98	0.00	0.09	.	0.00	0.01	.
May-98	0.00	0.00	.	0.00	0.00	.
Jun-98	0.23	50.85	.	0.04	26.49	.
Jul-98	0.00	1.53	.	0.00	0.18	.
Aug-98	0.57	0.00	3.65	0.08	0.00	0.29
Sep-98	2.16	1.24	.	0.28	0.04	.
Oct-98	6.65	1.75	.	1.08	0.05	.
Nov-98	4.67	0.04	.	1.16	0.00	.
Dec-98	10.73	5.48	.	1.30	0.12	.
Jan-99	36.93	12.65	.	6.16	7.10	.

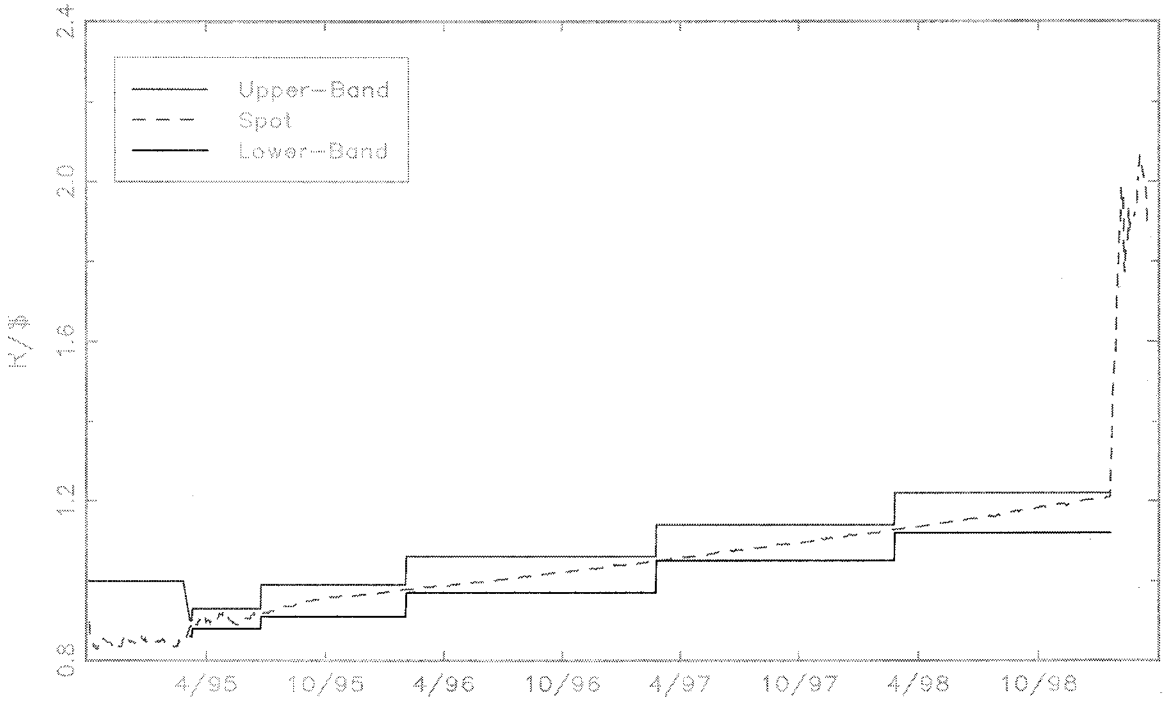
Table 5: Relationship between Realignment Intensities and Fundamentals, 8/95-1/99

This table reports the estimated coefficients from OLS regressions of the estimated monthly probabilities of a 5% real depreciation on a set of macroeconomic indicators. The indicators are: RER – US$/Real real exchange rate, INFL – Brazilian inflation rate, OUTPUT – index of industrial production, TRADE – trade balance, FRES – Brazilian foreign reserves, and MONEY – high-powered money. All variables except INFL are expressed in logarithms. Standard errors appear in italics below each reported coefficient.

	35-Day	60-Day	91-Day
RER	-1.39	-2.96	-2.88 *
	1.02	2.42	-0.73
INFL	-0.76	-2.23	-3.81
	3.58	8.69	8.44
OUTPUT	-0.50	0.56	1.82
	0.62	1.46	1.65
TRADE	0.18	0.41	0.26
	0.15	0.35	0.33
FRES	-0.30 *	-0.40*	-1.75 *
	0.12	0.15	0.73
MONEY	0.06	0.20	0.51 *
	0.07	0.17	0.26
Adj. R2	0.27	0.15	0.44
N. Obs.	42	41	28

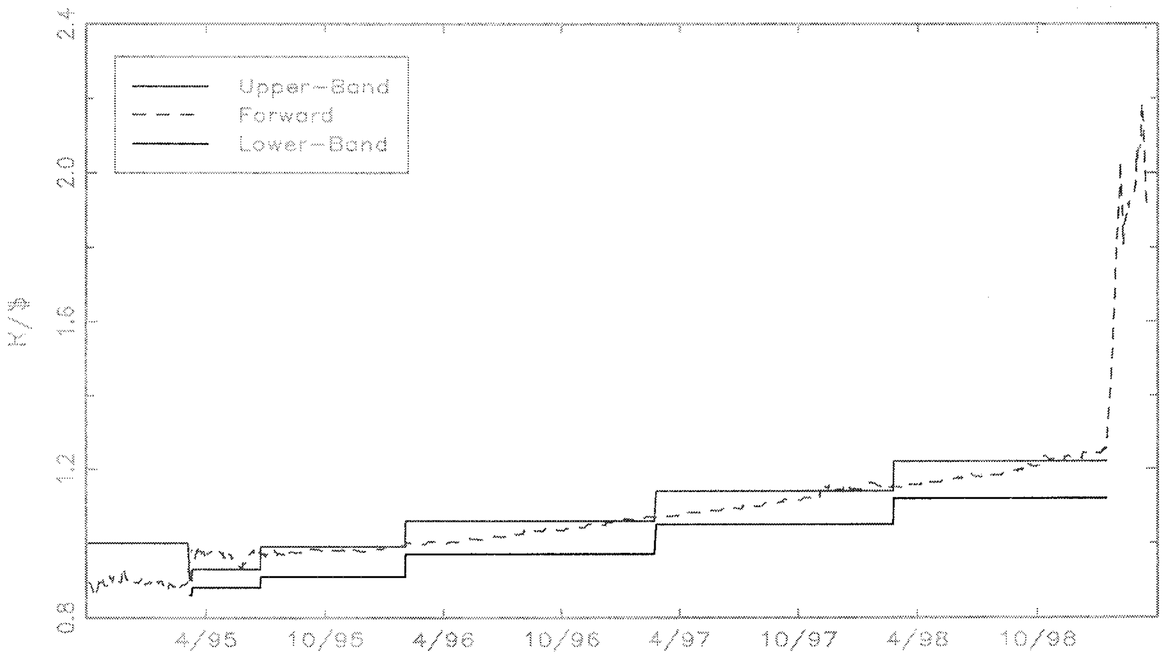
Figures 1a-1b: Real/Dollar Spot Rate and 90-day Forward Rates

Spot vs Maxi-bands, 10/94-4/99



Observation date

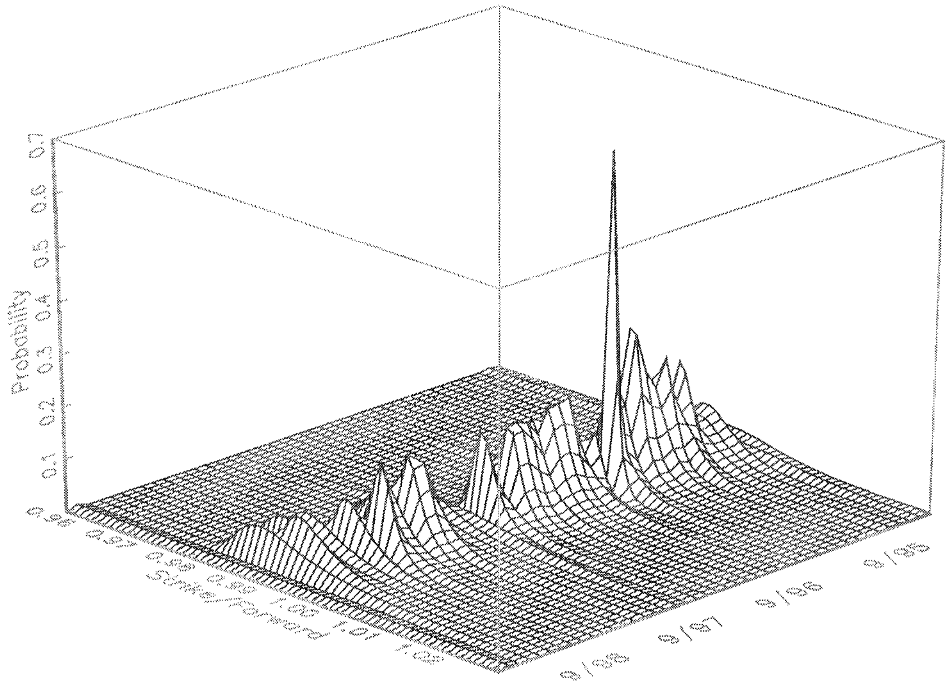
61-90 Day Forward vs Maxi-bands, 10/94-4/99



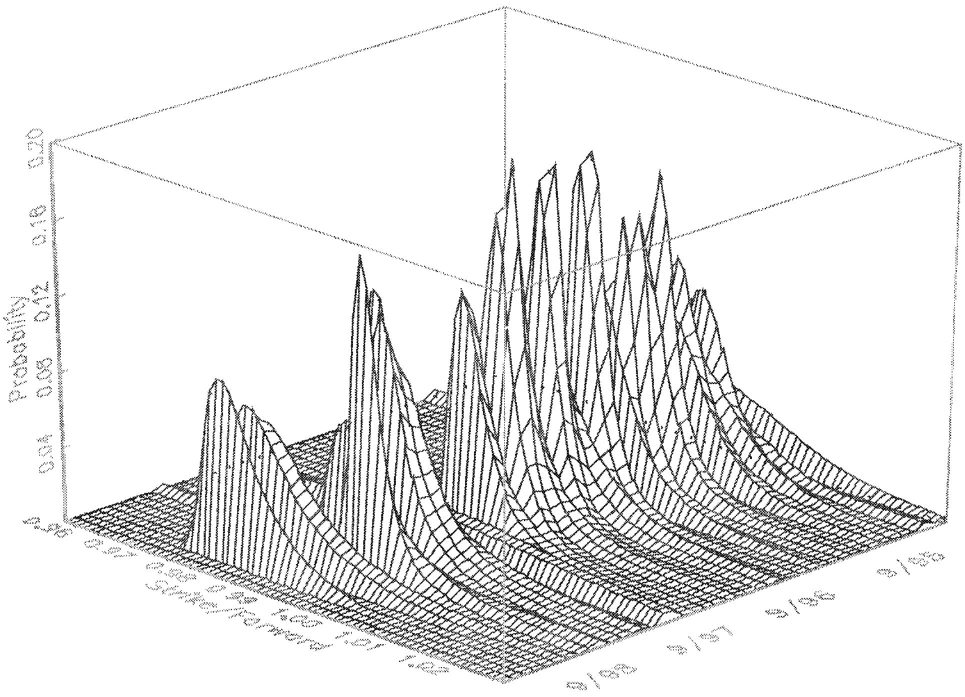
Observation date

Figures 2a-2c: Implied Exchange Rate Probability Distributions 10/94-1/99, 35, 60 and 91 days

35 day PDFS

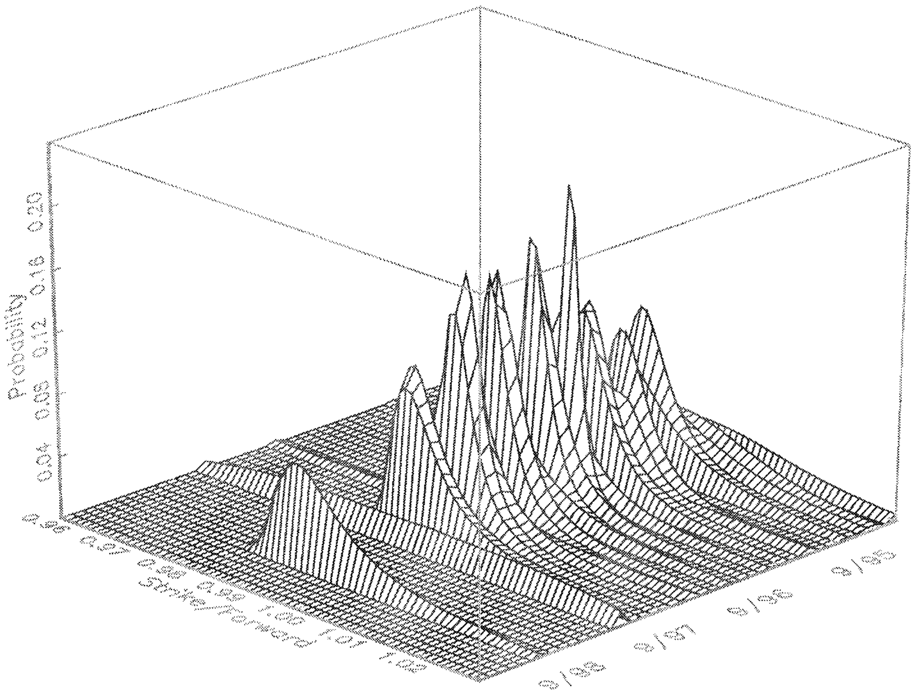


60 day PDFS



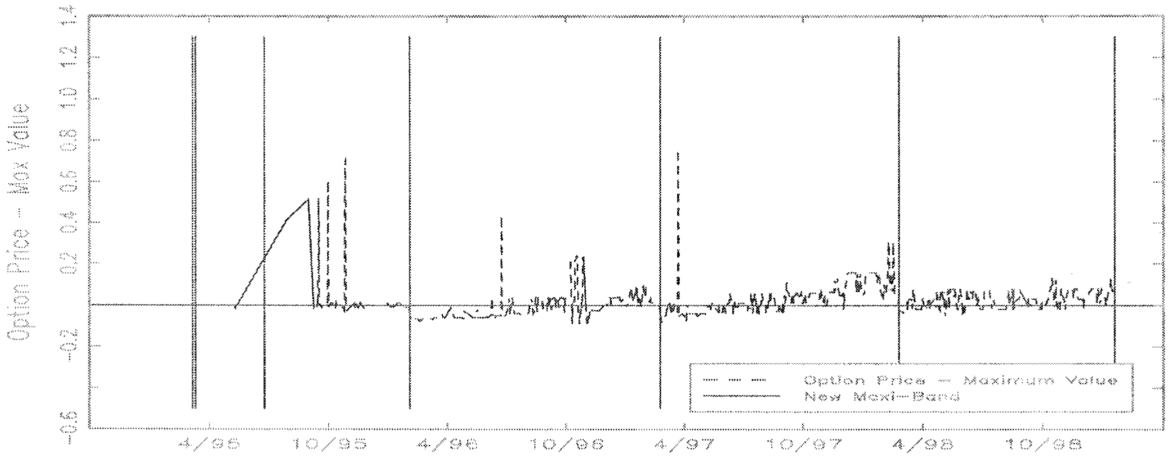
(continued)

91 day PDFS



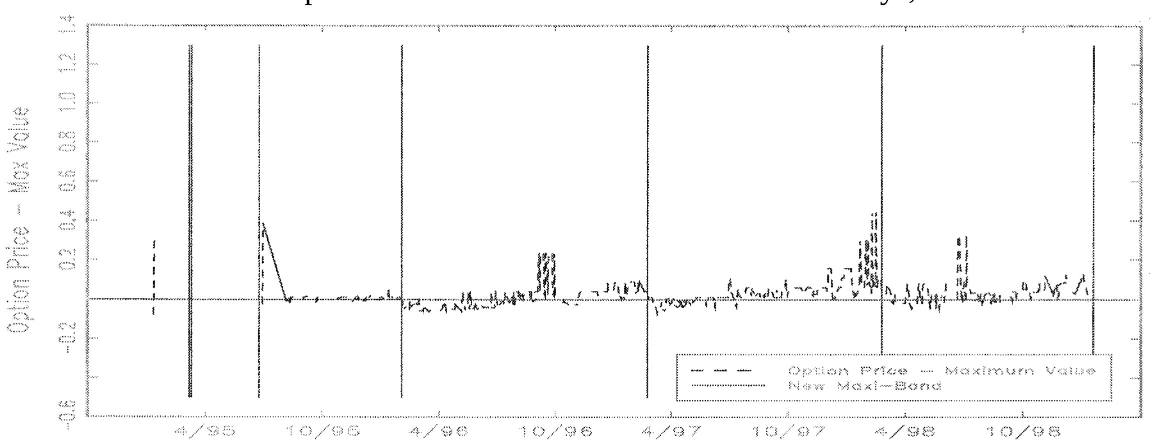
Figures 3a-3f: Arbitrage-Based Tests of Exchange Rate Credibility

Test 1. Options with Maturities between 1 and 30 days, 10/94-1/99



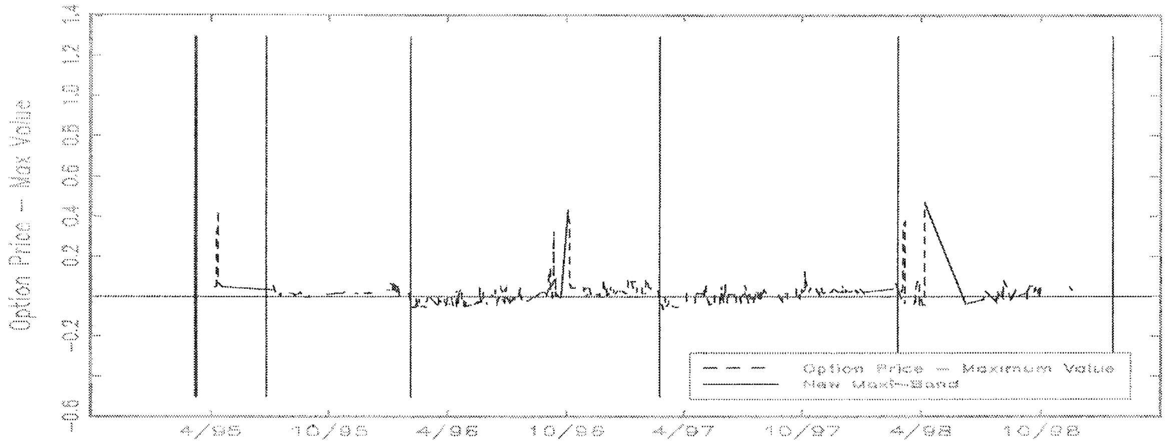
Observation date

Test 1. Options with Maturities between 31 and 60 days, 10/94-1/99



Observation date

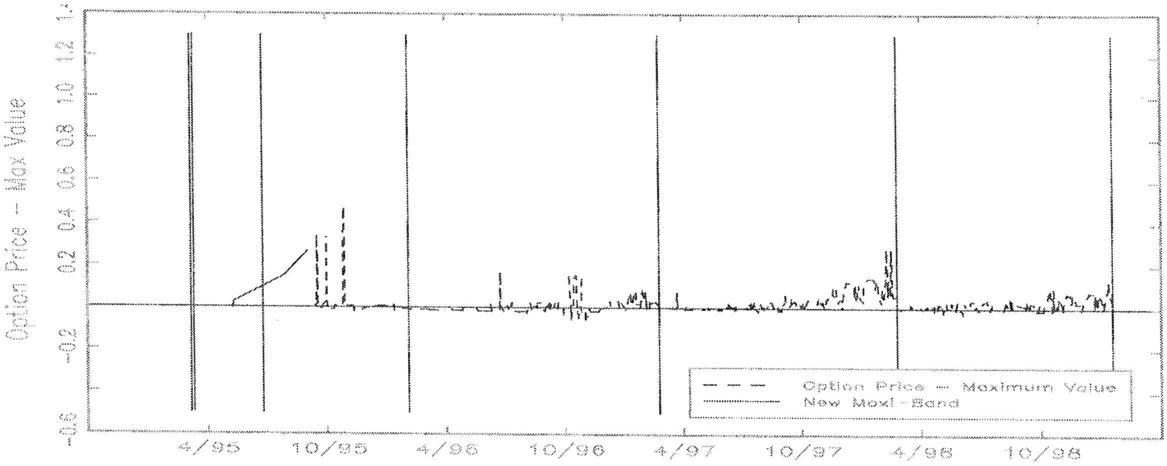
Test 1. Options with Maturities between 61 and 90 days, 10/94-1/99



Observation date

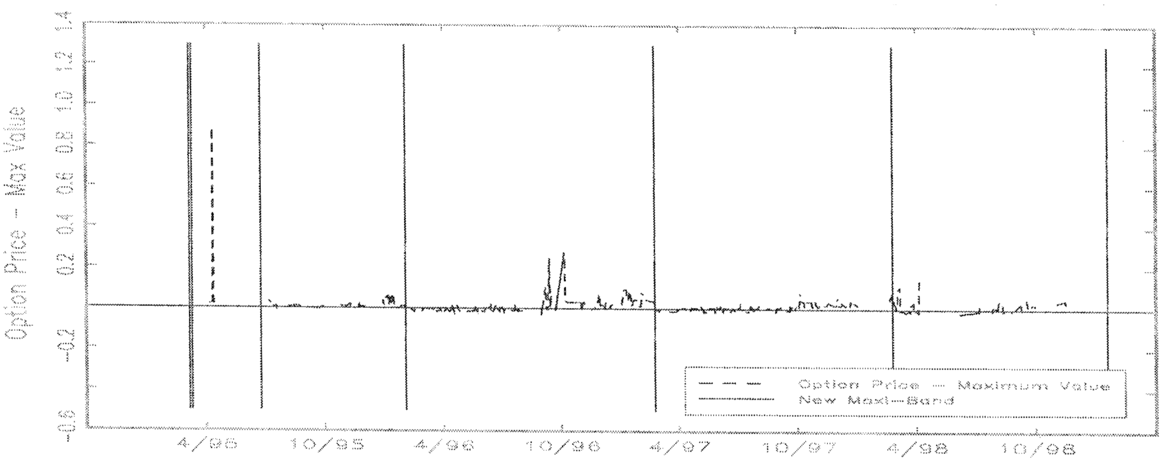
(continued)

Test 2. Options with Maturities between 1 and 30 days, 10/94-1/99



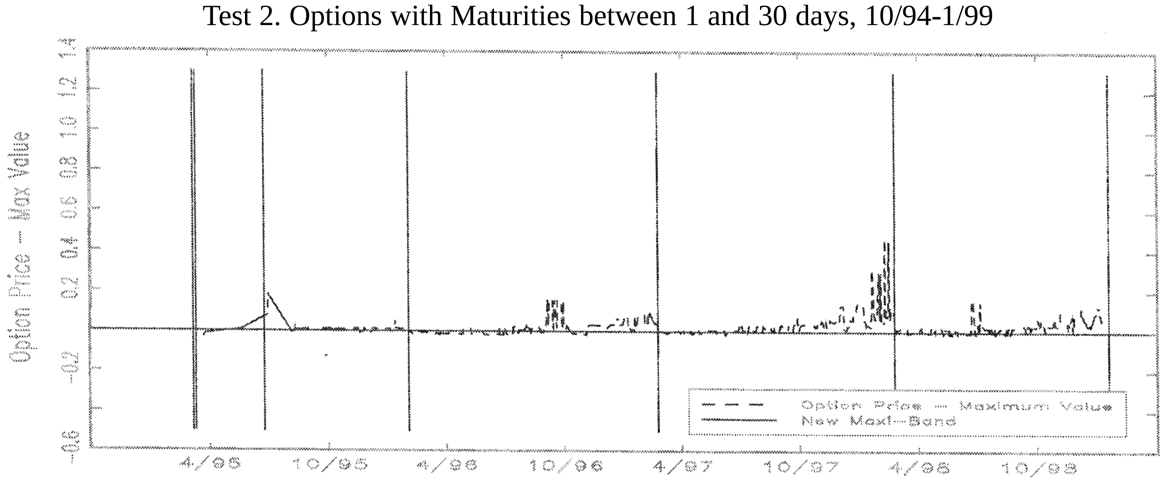
Observation Date

Test 2. Options with Maturities between 1 and 30 days, 10/94-1/99



Observation Date

Test 2. Options with Maturities between 1 and 30 days, 10/94-1/99



Observation Date