The Effect of Bid-Ask Prices on Brazilian Options
Implied Volatility: a Case Study of Telemar Call Options
Claudio Henrique da Silveira Barbedo and Eduardo Facó Lemgruber
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Abstract

Although not explicitly reported, option traders on the Bovespa exchange pay an implicit bid-ask spread on each trade. Reported transaction prices that comprise the databases previously used to study the Brazilian options markets do not reflect actual option values at the time of the trades, but actual values plus (for purchases) or minus (for sales) the bid-ask spread. We use a chooser American option model to estimate Telemar call options bid-ask spreads, and to create a database of spread-adjusted trade prices. We find that the bid-ask spreads explain several previously reported puzzles regarding asset price volatility.

Keywords: Bid-Ask Spread; Option Market; Implied Volatility
JEL Classification: G13
1. Introduction

Brazilian capital market asset prices incorporate transaction costs that are not visible for investors. Those costs are driven by the way price orders are imputed to the market. While limit orders do not guarantee a trading execution, market orders have an immediate response but generate costs that are transferred to investors. These costs compose the bid-ask spread. As Brazilian prices do not report bid and ask quotes, there is a possibility that transaction prices are contaminated by the difference between the prices paid for immediate purchase and received for immediate sale.


An extensive literature investigates the relationship between order flow costs and changes in asset prices. Brock and Kleidon (1992), for example, show a U-shaped intra-day pattern in NYSE stock prices bid-ask spreads. They argue that high spreads are a response of market makers to the increased order flow at open and close periods, feared that they can be adversely selected by traders who know more than they do. On the other hand, low spreads are an attempt to avoid exposing themselves to the risk of holding unwanted inventory positions. Abhyankar et al (1997) verify the same intraday pattern for the London Stock Exchange volatilities. In the Brazilian market, Moreira and Lemgruber (2004) find a similar pattern to the Bovespa Index volatility.

Papers on volatility present different results for the Brazilian and the American markets. For instance, Latané & Rendleman (1976) and Beckers (1981) verify that implied volatility from options outperform historical estimates with regard to forecast. In Brazil, Sanvicente (1996) claims that the implied volatility of the options market is not actually observed in the underlying asset’s price behavior. Gabe and Portugal (2003) verify that the historical volatility is more efficient to forecast future volatility when compared to the Black and Scholes implied volatility. Araújo, Barbedo and Lemgruber (2004) find extremely high implied volatilities for Telemar call
options for the 2001-2002 years. Galvão (2002) compares the historical and the implied volatility and verifies that the former is most efficient in ordinary periods and the latter in stressful periods.

We use a chooser American option model as an improvement to Copeland and Galai (1983) methodology to estimate the implied bid-ask spread for Telemar call option prices during December 1, 2003 to December 4, 2004. We follow Rubinstein (1985) to organize the data.\(^1\) The procedure of extracting the bid-ask spread from options allows us to reduce the implied volatility estimation errors. Our methodology infers options implicit bid-ask spread and corrects the estimation volatility bias reducing the implied volatility for Telemar options. Additionally, we analyze the bid-ask spread embedded in each option transaction, and present an answer for the conflicting results observed in Brazilian option pricing empirical tests.

The remainder of this work is organized as follows. Section II presents the sample characteristics and the database treatment. Section III gives an overview of the methodology. The results are shown and commented in Section IV. Section V concludes the study.

### 2. Sample and Database Treatment

Our initial sample consists of a series of intraday stock and call option prices obtained by request from the Brazilian Stock Exchange. The sample consists of all reported trades on the floor of the Bovespa during December 1, 2003 to December 4, 2004. Telemar options respond for 85% of the stock options volume in the exchange. Following Rubinstein (1985), we refine the sample selecting options that attend the following criteria: a) At least 5 minutes within a constant stock price interval; b) Options trading only occurred 10 minutes after the exchange opening and 10 minutes before its closing time; c) A minimum of 5 negotiated contracts.

Database treatment reduces the sample from 4,800,000 option prices to 83,000 synchronized observations. To verify if this subset could be biased, ten-paired samples with 5,000 observations are randomly selected for the entire database and for our synchronized sample. For both samples, the difference between market prices and Black and Scholes (1973) prices are statistically similar.

\(^1\) Rubinstein (1985) was the first to present a methodology to treat intraday databases for option pricing tests.
3. Methodology

We use the Black and Scholes and the Merton jump model (1976) to measure call options market price errors. Relative errors are calculated as the difference between market and model price divided by the former price. To value the options we use the last trade implied volatility and a minimum square error procedure, considering previous month market prices, to estimate the jump frequency and its magnitude parameters. Table 1 presents the root mean square error for each model according to the moneyness and the time to maturity.  

<table>
<thead>
<tr>
<th>Moneyness</th>
<th>Model</th>
<th>Working Days to Maturity</th>
<th>All Maturities</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>1 - 5</td>
<td>6 - 10</td>
</tr>
<tr>
<td>Extremely Out-of-the-Money</td>
<td>Black&amp;Scholes</td>
<td>3.77%*</td>
<td>4.83%*</td>
</tr>
<tr>
<td></td>
<td>Merton</td>
<td>4.02%*</td>
<td>5.21%*</td>
</tr>
<tr>
<td></td>
<td>KW Statistic</td>
<td>0.0000</td>
<td>0.0000</td>
</tr>
<tr>
<td>Observations</td>
<td>942</td>
<td>2032</td>
<td>2995</td>
</tr>
<tr>
<td>Out-of-the-Money</td>
<td>Black&amp;Scholes</td>
<td>9.34%*</td>
<td>11.76%*</td>
</tr>
<tr>
<td></td>
<td>Merton</td>
<td>8.88%*</td>
<td>11.27%*</td>
</tr>
<tr>
<td></td>
<td>KW Statistic</td>
<td>0.0000</td>
<td>0.0000</td>
</tr>
<tr>
<td>Observations</td>
<td>1902</td>
<td>6687</td>
<td>15218</td>
</tr>
<tr>
<td>At-the-Money</td>
<td>Black&amp;Scholes</td>
<td>12.71%*</td>
<td>8.92%*</td>
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<tr>
<td></td>
<td>Merton</td>
<td>12.37%*</td>
<td>8.59%*</td>
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<td>KW Statistic</td>
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<td>0.0000</td>
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<tr>
<td>Observations</td>
<td>3415</td>
<td>7850</td>
<td>10422</td>
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<td>KW Statistic</td>
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<td>0.0000</td>
</tr>
<tr>
<td>Observations</td>
<td>3077</td>
<td>5884</td>
<td>6989</td>
</tr>
<tr>
<td>Extremely In-the-Money</td>
<td>Black&amp;Scholes</td>
<td>36.22%*</td>
<td>20.97%*</td>
</tr>
<tr>
<td></td>
<td>Merton</td>
<td>36.18%*</td>
<td>20.99%*</td>
</tr>
<tr>
<td></td>
<td>KW Statistic</td>
<td>0.0000</td>
<td>0.0000</td>
</tr>
<tr>
<td>Observations</td>
<td>1899</td>
<td>1600</td>
<td>1271</td>
</tr>
</tbody>
</table>

Kruskal-Wallis (KW) Statistic is Used to Compare Both Models. Reported p-values in Parentheses. A star indicates a variable statistically different from zero.

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2 Moneyness classification follows: delta options lower than 0.15 are extremely out-of-the-money; higher than 0.85 are extremely in-the-money. To keep a uniform distribution among the other 3 subsets, the out-of-the-money options are characterized by deltas between 0.15 and 0.4, at-the-money options deltas are between 0.4 and 0.6 and the in-the-money options present deltas between 0.6 and 0.85.
Table 1 shows an errors pattern that gets larger as options approach maturity and as strike prices decrease. Merton’s model presents a lower average error, except for the extremely out-of-the-money options. To verify if the result produced by the Merton’s models is actually different from Black and Scholes, we perform the Kruskal-Wallis nonparametric test. Except for extremely in-the-money options with time to maturity higher than 31 days, we reject the null hypothesis of similar distribution functions for both models at the 10% significance level. The Kruskal-Wallis test is used to verify if the values are statistically equal to zero. We reject this null hypothesis. Merton’s errors results are smaller than Black and Scholes for most of the moneyness classifications. For both models, errors increase as options get in the money.

We present three suggested arguments, usually mentioned in the finance literature, to explain the systematic pricing errors observed. First, option market prices in Brazil can be inefficient; second, the models’ mathematical structures are incorrect and; third, inputs have been mismeasured because bid-ask spread are not taken into account. Although there can be sporadically inefficiency in market prices as shown by Torres, Bonomo and Fernandes (2002) this situation is extremely unlikely in a mature market with a reasonable number of traders. Furthermore, despite models’ imperfections noticed by literature, Hull (2003) argues that no model has better performed and a wider utilization than Black and Scholes. We are left with the third alternative.

To evaluate the implied volatility we use a dynamic hedging scheme. Riskless portfolios are set up to lock profits originated by selling options and hedging with stocks according to the delta indicated by the model. Eight-five strategies are created from July 5, 2004 to December 4, 2004. Figure I indicates profit results for all strategies. Initial portfolios are created for each option series shorting 1,000 options. Continuum rebalancing is allowed by trading new options, with the restriction that daily options traded cannot overcome the effectively traded options in the exchange. Maximum and minimum observed profits are R$ 1,092.85 and –R$ 1,365.24. Positive profits average R$ 300.00. The mean of all negative results is –R$ 186.00. Average profit for an arbitrageur that have engaged in all strategies is R$ 242.69 with a median of R$ 170.68. Almost 90% of the strategies present profits at maturity, meaning that the market volatility implied in the option price is higher than the stock’s true volatility. Although the huge percentage of winning

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3 We do not consider transaction costs. Although Fama and Blume (1966) show that even a floor trader pays at least 0.1% costs per transaction, transaction costs in Brazil are very low. For instance, even if they are carried out profits
strategies ascertained, investors may not succeed in practice because they cannot trade options by the sample prices. The systematic profits can be explained by microstructural biases. Option prices are biased by the embedded bid-ask spreads that affect arbitrage opportunities.

Roll (1984) argues that the existence of an effective bid-ask spread can be verified by the negative first-order serial covariance of price changes, provided that the market is informationally efficient. Fama (1965) argues that price changes occur if and only if unanticipated information arrives in the market. So, the variance is likely to be dominated by new information and the covariance between successive price changes depends on whether successive sampled transactions are at the bid or at the ask prices. Roll’s estimative of the stock price percentage bid-ask spread is equal to \( 2 \sqrt{-\text{cov}_{j,t}} \), where \( \text{cov}_{i,j} \) is the estimated serial covariance of the returns of asset \( j \) at time \( t \). Figure II presents the histogram and the descriptive statistic for Telemar sample spreads estimated by Roll’s methodology.

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are so high that they will not vanish. On the other hand, it is possible that the low liquidity observed in the Brazilian market rebalancing strategies would not perform well.
It was possible to estimate the spread for 83 series in the sample. Mistaken positive covariances were obtained just for two series. Spreads vary from a maximum of almost 250% to zero. For three series, estimate spreads are above 200%. When these series are excluded from the sample, the maximum value reduces to 44.11%, with a mean of 6.70%. The spread estimated according to this method presents a tendency to get large as the strike price increases. Deep out-of-the-money options have the highest spreads and deep in-the-money options have the lowest spreads.

The huge variance of the reported spreads suggests that Roll’s ex-post technique may not be applicable for Brazilian short-term option series. Furthermore, given the substantial cross-sectional variation volatility, spread varies over time as well, suggesting that an alternative method to estimate the bid-ask spread that allows for time variation should be used.

Option price theory can help to estimate the Telemar call options bid-ask spreads. In a “market order” market, investors pay the market maker a premium, the bid-ask spread, to buy or to sell the option by its fair price. Copeland and Galai (1983) argue that those spreads can be estimated by the standard Black and Scholes model, with the European style option maturing at the open quote interval. Note that, the possibility of trading at any time during the quote interval implies that spreads are similar to an American style option. Furthermore, given that investors can execute buy or sell orders, this choice has to be included in the evaluation methodology. We use an American chooser option model to estimate the spreads, with the exercise price equals to Telemar call option fair price and the underlying parameter equals to the call option fair price plus or minus the spread. The time to maturity is the open quote interval, i.e. one and a half minute. The model’s other two parameters are: the one-day interbank certificate of deposit as a proxy for the risk-free rate and Telemar implied volatility. Equations (1) and (2) show the bid and

![Figure II: Roll’s Bid-Ask Spread Histogram and Descriptive Statistic](image-url)
the ask spreads, respectively, as a call and a put functions of the five model parameters. The model result is given by the \( \text{Max}(\text{bidspread}, \text{askspread}) \).

\[
\begin{align*}
\text{bid}^{\text{spread}} &= f(K + \text{bid}^{\text{spread}}, K, T, R_f, \sigma) \\
\text{ask}^{\text{spread}} &= f(K + \text{ask}^{\text{spread}}, K, T, R_f, \sigma)
\end{align*}
\]

The bid-ask spreads are evaluated by an iterative procedure backed by a binomial tree model and by a finite difference method. We use a binomial model, with 50 steps, because it is an American style option and there is no closed-form solution for its price. Hull (2003) describes different simulation correction procedures to improve models performance. We used the control variate technique because it is simple and easily applicable to the binomial model.

Finite difference methods can also be used to solve the problem. Several methodologies are suggested in the finance literature. As pointed out by Ikonen and Toivanen (2005), the stability and consistency of the time discretization is the most important property for pricing options with those methods. Our first step was to examine the effectiveness of the finite difference numerical schemes evaluating an at-the-money option and comparing the results to the Black and Scholes benchmark. Table 2 presents the root mean squared error for the five selected methods. We choose the implicit finite difference method, reported in the third box of Table 2, because of its simplicity, CPU time results and the smaller error observed.

<table>
<thead>
<tr>
<th>Number of Time Intervals</th>
<th>Explicit Method</th>
<th>Implicit Method</th>
<th>Brennan-Schwart Method</th>
<th>Courtadon Method</th>
<th>Crank-Nicolson Method</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>RMSE</td>
<td>CPU Time (seconds)</td>
<td>RMSE</td>
<td>CPU Time (seconds)</td>
<td>RMSE</td>
</tr>
<tr>
<td>25</td>
<td>0.05880</td>
<td>0.05</td>
<td>0.00470</td>
<td>0.04</td>
<td>0.00320</td>
</tr>
<tr>
<td>50</td>
<td>0.03940</td>
<td>0.11</td>
<td>0.00230</td>
<td>0.04</td>
<td>0.00120</td>
</tr>
<tr>
<td>100</td>
<td>0.00110</td>
<td>0.16</td>
<td>0.00120</td>
<td>0.05</td>
<td>0.00330</td>
</tr>
<tr>
<td>200</td>
<td>0.00060</td>
<td>0.33</td>
<td>0.00060</td>
<td>0.05</td>
<td>0.00110</td>
</tr>
</tbody>
</table>

4. Results

We estimate bid-ask spreads between 1% and 35% for call option prices. They have a strong positive relationship with the implied underlying-asset volatility and with the option price, and a negative relationship with the quantity of traded options. Similar association is predicted in the seminal work by Demsetz (1968) who analyzes the cost of exchanging titles in NYSE and concludes that prices and liquidity are forces that dominate the spread. Table 3 shows the least squares estimation of the spread as a function of the three variables described above. For the sample size employed, results are statistically significant as p-values suggest.

<table>
<thead>
<tr>
<th>Variables</th>
<th>Coefficient</th>
<th>P-Value (t Statistic)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intersection</td>
<td>-0.0884</td>
<td>0.00000</td>
</tr>
<tr>
<td>Quantity of Traded Options</td>
<td>-1.30E-10</td>
<td>0.00072</td>
</tr>
<tr>
<td>Implied Volatility</td>
<td>0.26137</td>
<td>0.00000</td>
</tr>
<tr>
<td>Option Price</td>
<td>0.02464</td>
<td>0.00000</td>
</tr>
<tr>
<td>R-Square</td>
<td>0.75499</td>
<td></td>
</tr>
<tr>
<td>F Test</td>
<td>0.00000</td>
<td></td>
</tr>
</tbody>
</table>

Figure III presents the results of all implemented delta-hedging strategy procedures considering the bid-ask spread costs. Although it is not possible to know if a strategy is a buyer-initiated or a seller-initiated trade, we assume that all procedures are initiated by a purchaser. According market contacts we inferred that the Brazilian option market has a rare frequency of seller-initiated trades. Besides, analyzing our database it is clear that most of the acquired options are taken to maturity. Consequently, available prices in the database are the ask prices. Bid prices are determined indirectly by the subtraction of two times the spread.
The new results reported in Figure III are drastically different from the presented in Figure I. Profits and losses are distributed around zero. Strategy returns are negative for all methods. Roll’s results are smaller. Three observed spreads are higher than 100% of the option price and when excluded, the mean result becomes equal to R$ 46.29. The delta-hedging strategy maximum returns drop to R$ 998.51 with Roll’s estimate spreads, and to R$ 758.03 and R$ 776.30 when spreads are estimated by the binomial model and by the finite difference method. Our delta-hedging results are less concentrated for the extremes and converge toward the middle of the profit distribution.

A nonparametric Kruskal-Wallis test is performed under the null hypothesis that all methodologies produce results that have identical distribution functions. At the 95% confidence level, we do not reject this null hypothesis. It means that our results are compatible with the ones found by Roll’s methodology. Besides, signal changes in the strategies returns for both techniques are similar.

Roll’s technique delta-hedging schemes present positive returns for 46 of the 85 strategies, indicating a fair game. Although, our delta-hedging schemes present positive returns for 56% and 39% of the strategies, they are not different from the mean. It shows that when spreads are taken into account profitable delta-hedging strategies vanish and the implied volatility is correctly evaluated. As a consequence, we have now an adjusted-spread database.

To emphasize our findings we annualized all sample volatilities. Table 4 shows the sample month annual volatility mean and standard deviation results for the adjusted and non-
adjusted spread database. The adjusted sample presents smaller means and standard deviation for all months. The last measure indicates that our volatility estimates for the adjusted sample are more precise. The mean results show that the Telemar actual volatility is smaller when the bid-ask spread is considered.

<table>
<thead>
<tr>
<th>Maturity</th>
<th>Non Adjusted Sample</th>
<th>Adjusted Sample</th>
</tr>
</thead>
<tbody>
<tr>
<td>January, 2004</td>
<td>35.54% 10.31%</td>
<td>34.09% 8.21%</td>
</tr>
<tr>
<td>February, 2004</td>
<td>33.87% 5.12%</td>
<td>30.32% 2.52%</td>
</tr>
<tr>
<td>March, 2004</td>
<td>41.64% 8.77%</td>
<td>38.82% 5.17%</td>
</tr>
<tr>
<td>April, 2004</td>
<td>40.84% 4.49%</td>
<td>39.03% 4.36%</td>
</tr>
<tr>
<td>May, 2004</td>
<td>38.31% 1.52%</td>
<td>37.23% 1.51%</td>
</tr>
<tr>
<td>June, 2004</td>
<td>36.11% 3.17%</td>
<td>34.73% 2.65%</td>
</tr>
<tr>
<td>July, 2004</td>
<td>35.77% 6.05%</td>
<td>34.13% 3.18%</td>
</tr>
<tr>
<td>August, 2004</td>
<td>38.26% 4.21%</td>
<td>37.18% 3.77%</td>
</tr>
<tr>
<td>September, 2004</td>
<td>33.88% 3.79%</td>
<td>32.83% 3.08%</td>
</tr>
<tr>
<td>October, 2004</td>
<td>33.16% 3.97%</td>
<td>32.07% 3.18%</td>
</tr>
<tr>
<td>November, 2004</td>
<td>29.22% 3.22%</td>
<td>28.43% 2.80%</td>
</tr>
</tbody>
</table>

Finally, we divide our samples according to Telemar call options moneyness. Table 5 shows that non-adjusted sample volatilities are higher than the true volatilities for all five groups. We also observe the same error behavior reported in Table 1. As option get deeper in the money, model prices relative errors increases. Our research suggests an explanation for the overvalued volatility forecasting errors observed in previous Brazilian literature.

<table>
<thead>
<tr>
<th>Moneyness</th>
<th>Non Adjusted Sample</th>
<th>Adjusted Sample</th>
<th>Relative Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extremely Out-of-the-Money</td>
<td>37.12%</td>
<td>36.22%</td>
<td>2.48%</td>
</tr>
<tr>
<td>Out-of-the-Money</td>
<td>35.91%</td>
<td>35.04%</td>
<td>2.49%</td>
</tr>
<tr>
<td>At-the-Money</td>
<td>34.78%</td>
<td>33.38%</td>
<td>4.20%</td>
</tr>
<tr>
<td>In-the-Money</td>
<td>35.79%</td>
<td>33.40%</td>
<td>7.15%</td>
</tr>
<tr>
<td>Extremely In-the-Money</td>
<td>36.83%</td>
<td>31.45%</td>
<td>17.10%</td>
</tr>
</tbody>
</table>

The nonparametric Kruskal-Wallis test rejects the hypotheses that both implied volatilities are identical.
5. Conclusion

The article estimates the bid-ask spread for the Telemar options in the Brazilian market. The database chosen is composed by intraday prices of stocks and options effectively traded in the BOVESPA Exchange from December 2003 to December 2004. When the spread is taken in account, the underlying asset implied volatility significantly reduces to consistent and steady values.

Delta-hedging strategies are created to verify profit arbitrages. When the bid-ask spreads are considered the strategy systematic profits vanish indicating that the spread presence in the Brazilian market explains the positive profits verified in previous research.
References


Hull, J. 2003, Options, Futures & Other Derivatives, Prentice Hall.


<table>
<thead>
<tr>
<th>No.</th>
<th>Title</th>
<th>Author(s)</th>
<th>Date</th>
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</thead>
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<td>1</td>
<td>Implementing Inflation Targeting in Brazil</td>
<td>Joel Bogdanski, Alexandre Antonio Tombini and Sérgio Ribeiro da Costa Werlang</td>
<td>Jul/2000</td>
</tr>
<tr>
<td>2</td>
<td>Política Monetária e Supervisão do Sistema Financeiro Nacional no Banco Central do Brasil</td>
<td>Eduardo Lundberg</td>
<td>Jul/2000</td>
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<td>6</td>
<td>Optimal Interest Rate Rules in Inflation Targeting Frameworks</td>
<td>José Alvaro Rodrigues Neto, Fabio Araújo and Marta Baltar J. Moreira</td>
<td>Jul/2000</td>
</tr>
<tr>
<td>7</td>
<td>Leading Indicators of Inflation for Brazil</td>
<td>Marcelle Chauvet</td>
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<td>8</td>
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<td>José Alvaro Rodrigues Neto</td>
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<td>9</td>
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<td>Análise do Financiamento Externo a uma Pequena Economia</td>
<td>Carlos Hamilton Vasconcelos Araújo and Renato Galvão Flóres Júnior</td>
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<td>Márcio I. Nakane</td>
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<td>Francisco Marcos Rodrigues Figueiredo</td>
<td>Mar/2001</td>
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<td>15</td>
<td>Is It Worth Tracking Dollar/Real Implied Volatility?</td>
<td>Sandro Canesso de Andrade and Benjamin Miranda Tabak</td>
<td>Mar/2001</td>
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<td>16</td>
<td>Avaliação das Projeções do Modelo Estrutural do Banco Central do Brasil para a Taxa de Variação do IPCA</td>
<td>Sergio Afonso Lago Alves</td>
<td>Mar/2001</td>
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<td>Estimando o Produto Potencial Brasileiro: uma Abordagem de Função de Produção</td>
<td>Tito Níciás Teixeira da Silva Filho</td>
<td>Abr/2001</td>
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<td>18</td>
<td>A Simple Model for Inflation Targeting in Brazil</td>
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