Some Market Measures of Capital Account Liberalization in India

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Abstract

This paper examines how market data can be used to infer the impact of capital controls, using data from India. Estimations for different sub-periods are used to infer the evolving impact of controls that have changed over time in a complex and piecemeal manner. We use deviations from covered interest parity utilizing data from 1-month and 3-month offshore non-deliverable forward (NDF) markets for the Indian rupee. Using a non-linear estimation methodology, we estimate no-arbitrage bands whose boundaries are determined by transactions costs and by the effectiveness of capital controls. We find some evidence that recent capital control liberalization in India has been reflected in greater arbitrage through NDF markets.

KEYWORDS: financial liberalization in India, de-facto capital controls, non-deliverable forward market, threshold auto-regression

1. Introduction

India's economy has been one of the best performing in the world over the last two decades, as measured by GDP growth. Arguably, this rapid growth has been enabled, even fueled, by a process of giving more importance to markets as mechanisms for allocating resources, as opposed to stringent regulatory controls accompanied by bureaucratic discretion. In particular, private equipment investment has been identified as an important factor in India's growth process (Sen, 2007). Unsurprisingly, public fixed investment, trade openness and financial deepening have also played roles at various times, but the picture of growth driven by investment is comfortingly familiar. Investment and growth rates have risen roughly in tandem over the recent past, so that the incremental capital output ratio has stayed approximately the same, fluctuating around a value of about 4.

The rise in investment in India has mostly been financed by increases in domestic saving (Table 1). However, there have been increases in capital inflows into India, especially in the years just before the financial crisis of 2008-09. Unlike the fast-growing East Asian countries, India has mostly run current account deficits, albeit modest, so there have been net capital inflows over most of its history. Earlier aid flows, however, have been displaced by private direct and portfolio investment from abroad.

India's sequence of opening up its economy essentially began with significant trade liberalization in 1991, which reduced tariffs dramatically and

replaced quantitative trade restrictions with tariffs. Next, effective current account liberalization, as measured by acceptance of IMF Article VIII, was achieved by August 1994. However, Indian policy-makers proceeded with caution in liberalizing the capital account.[1] A government-sponsored expert committee made tentative recommendations for capital account opening in 1997, but the Asian crisis put the brakes on the process.[2] Several smaller steps were taken thereafter, and another committee revisited the issue of capital account liberalization in 2006. Again, its recommendations were somewhat overshadowed by external events, namely, the global financial crisis that began to surface in 2007, and erupted a year later. Subsequently, of course, proponents of capital account openness have retreated in their recommendations (e.g. Ostry et al., 2010), and there was never uniformity in scholarly views on the subject (e.g. Bhagwati, 1998). It is difficult to say what the final verdict will be on this topic, though one can note that important issues include the quality and nature of capital flows (e.g. their maturity, reversibility, bundling with other inputs, and so on), including

[1] There were concerns among policymakers about possible linkages between capital account and current account transactions, such as capital outflows masked as current account transactions through mis-invoicing. As a result, certain foreign exchange regulations stayed in place, including requirements for repatriation and surrender of export proceeds (allowing some fraction to be retained in foreign currency accounts in India for approved uses), restrictions on dealers and documentation for selling foreign exchange for current account transactions, and various indicative limits on foreign exchange purchases to meet different kinds of current account transactions.

[2] The committee's report emphasized various domestic policy measures and changes in the institutional framework as preconditions for full capital account convertibility. These included fiscal consolidation, low inflation, adequate foreign exchange reserves, and development of a more robust domestic financial system. In fact, progress was made on all of these fronts, though recent global events have contributed to renewed fiscal sustainability concerns and a new roadmap for fiscal consolidation.

differences between portfolio investment, debt and direct investment (e.g. Goldin and Reinert, 2005).

Despite liberalization, Indian controls on capital flows can be fairly described as complex, discretionary and fragmented. For example, Shah and Patnaik (2005, Table 4) detail the easing of capital controls up to November 2004, particularly those on portfolio inflows, as a series of small changes, within a continuing web of detailed quantitative restrictions operated by the RBI.[3] Similar complex restrictions apply to FDI inflows. There are also restrictions on outflows, including external commercial borrowing, and these restrictions have fluctuated over time (sometimes easing, sometimes tightening). Furthermore, as noted by Shah and Patnaik (2005), foreign investment in bonds remains considerably restricted. Another feature of capital controls in India is that foreign entities sometimes have more leeway than domestic institutions in engaging in certain kinds of forward transactions.

Subsequent to the period covered by Shah and Patnaik, in April 2005, the RBI announced several small but significant measures to liberalize foreign exchange markets, in its Annual Policy Statement for 2005-06 (RBI, 2005, p. 10). At various times, it also changed the limits on external commercial borrowings. In

[3] An earlier study, by Jadhav (2003), provides a more institutionally-oriented review of India's experience with capital controls and capital account liberalization through 2002. In general, like the RBI, Jadhav – who held a senior position there at the time of his writing – is relatively cautious about the benefits of such liberalization, and sympathetic to a gradualist approach.

some cases, tightening was motivated by concerns over large portfolio inflows, especially in 2007-08.

Given this complexity, it is somewhat difficult to summarize or measure the overall impact of capital controls. In fact, according to the well-known Chinn-Ito (Chinn and Ito, 2007) index of capital account openness, which relies on measured de-jure controls, and which has been calculated for a large cross-section of countries, India remains one of the most closed economies on the capital account, having the second lowest score on the index in the year 2006, and unchanged from a previous estimation of the index.

Another measurement of de-jure controls has been performed by Nair (2006), specifically for India. One innovation in her work is to construct separate indices for inbound and outbound capital controls. She follows Quinn (1997) in coding quantitatively the de-facto restrictions on capital inflows and outflows for the period 1973-04. Annual indices are constructed. The intensity of restrictions is scaled to range from 0 to 2, with 0 representing the case of transactions being forbidden; 0.5, transactions allowed but subject to very heavy quantitative or other regulatory restrictions; and so on. Both the inbound and outbound indices are zero at the beginning of the period, rise slowly beginning in the 1980s, and then somewhat more rapidly after 1994, to values approaching 1.5 (Nair, 2006, Appendix Figure A1).

While Nair's construction is more informative and detailed than the Chinn-Ito index, both measures (and other de-jure indices) suffer from the problem that all controls produce market responses designed to circumvent them if money can be made as a result of that circumvention. Essentially, controls create arbitrage opportunities, and estimating the extent to which arbitrage operates provides a measure of the de-facto impact of controls. The precise nature of this estimation is postponed to section 4.

The approach we take here captures the de-facto effects of India capital account liberalization by measuring deviations from covered interest parity (CIP) over time. We follow the approach of a significant literature that investigates such deviations from CIP, inferring from these deviations, market segmentation due to capital controls, transactions costs and other institutional impediments to arbitrage. Previous studies that estimated deviations from CIP as an indication of international financial market integration in various contexts included Frenkel and Levich (1975), Peel and Taylor (2002), Obstfeld and Taylor (2004) and others, but all for developed economies.[4]

Following this approach in the literature, Pasricha (2008) analyzes CIP deviations for several developed countries, as well as 8 emerging market economies, including India. The data are for the period 1998 to 2006, and use 1-month and 3-month interbank interest rates. Based on her estimates, Pasricha also

[4] See Pasricha (2008) for additional references and a more detailed discussion of the literature.

constructs an index of de-facto capital account openness for each country in her sample. One of the most striking features of her results is that India's index of openness constructed in this manner suggests that India is more open than would be expected from the Chinn-Ito index. According to Pasricha's de-facto index, India is the 11th most open of 18 countries in the entire sample, while it is firmly the most closed by the Chinn-Ito measure. This is despite the correlation between the two indices for the sample being 0.73. This result highlights the value of Pasricha's approach (or, more generally, the de-facto method based on CIP deviations) for analyzing the Indian case.

One of our innovations relative to Pasricha (2008) is to estimate deviations from CIP over rolling window time periods. This allows us to get a sense of how the impact of capital controls in India has been changing over time. This paper also complements Hutchison et al. (2010), which takes a different approach to estimating these changes over time. Another innovation in this paper, following Hutchison et al. (2010), is in the markets we use to estimate deviations from CIP, namely data from Non-Deliverable Forward (NDF) markets.

The rest of the paper is organized as follows. Section 2 describes the data and discusses NDF markets, including previous analyses of NDF market data for India. In Section 3, we describe the specific non-linear estimation methodology used here. Section 4 presents our results and inferences about the changing nature

of capital controls in India over the past decade. Section 5 is a summary conclusion.

2. Non-Deliverable Forward Markets

In examining the market impact, through arbitrage, of capital controls, a relative innovation (building on Hutchison et al., 2010) of our empirical work is to measure the CIP relationship using the net foreign interest rate from the implied yield derived from the off-shore Non-Deliverable Forward rate (NDF) and the LIBOR dollar interest rate. The off-shore NDF rate is a market-determined forward rate free of capital controls and the implied yield represents the net covered rate of return that would be available on Indian short-term financial instruments in the absence of capital controls. The domestic onshore rate to which the implied NDF yield is compared is the Mumbai Interbank Offer Rate (MIBOR). We consider one- and three-month maturities, and compare results for both.[5]

A consequence of India's partial capital controls has been the development of a significant NDF market. This market develops when the onshore forward markets are either not developed or have restricted access (evidence of exposure requirements in the Indian case).[6] These markets, which are located offshore (in

[5] The data on NDF contracts is from Bloomberg, the MIBOR rates and sport rates are from Global Financial Database, and LIBOR rates are from Federal Reserve Board's online database.
[6] Lipscomb (2005) provides a useful conceptual and institutional overview of NDF markets.

financial centers outside the country of the restricted currency) and involve contract settlement without delivery in the restricted currency, allow offshore agents with the restricted-currency exposures to hedge their exposures. They also allow speculators to take a position on expected changes in exchange rates or exchange rate regimes. Arbitrageurs who have access to both forward markets are also active in NDF markets. Volumes in NDF markets increase with increasing investment or potential investment in the currency and with increasing restrictions on convertibility. When currencies are fully convertible, NDF markets are redundant, and do not operate.

The Indian rupee NDF market is most active in Singapore and Hong Kong, though there is also trading in places such as Dubai. The dominant players in this market are speculators who want to take a position in the currency, and arbitrageurs, mainly Indian exporters and importers who have access to both the onshore forward market[7] and the NDF market (Misra and Behera, 2006). The NDF exchange rate therefore, can also serve as an indicator of the expected future exchange rate of the rupee. This rate also implies a corresponding interest rate, which is called the NDF implied yield, calculated as follows:

$$r = \frac{F_N}{S}\,(1 + i_{\$}) - 1$$

[7] In August 2008, the Reserve Bank of India allowed trading on a domestic currency futures exchange to begin. Prior to this innovation, trading for those permitted to do so was over-the-counter. Restrictions remain on participation in the exchange; for example, only Indian residents can participate.

where S is the spot exchange rate of the US dollar in terms of rupee, F_N is the NDF rate of a particular maturity, and $i_{\$}$ is the interest rate on dollar deposits of corresponding maturity (i.e., LIBOR rates). Therefore, r is what the onshore yield would be, if there were no capital controls and if CIP held, other things equal. The (annualized) difference between the actual onshore yield (i, the MIBOR rate for the corresponding maturity) and r is our measure of the covered interest parity differential.

To state this point more explicitly, without restrictions on capital flows between two countries, deviations from covered interest parity (CIP), which is a "no-arbitrage" condition, would be small and simply reflect transactions costs. Large and persistent positive onshore-offshore differentials ($i - r$), on the other hand, reflect effective stemming of capital inflows, while negative differentials correspondingly suggest an effective stemming of capital outflows.

Indian banking regulations restrict banks' ability to arbitrage deviations from CIP (Shah and Patnaik, 2005). Furthermore, although importers and exporters are allowed to use the onshore forward market ("permitted hedgers"), they do not themselves have the financial capabilities to arbitrage as financial institutions would if permitted to do so. These points are therefore related to domestic financial conditions and restrictions, as well as to external capital

controls. In this environment, deviations from CIP persist over time.[8] At the same time, if there are *some* arbitrage avenues for market participants, then the speed with which deviations from CIP are eliminated (or reduced) should be an indicator of how effective that arbitrage is in the actual working of the market.

Ma et al. (2004) and Misra and Behera (2006) have preceded us in examining variations in deviations from CIP arbitrage conditions in India over time, using NDF yields. While there are differences in the details of their implementations, their approach is similar in that both studies use summary statistics and qualitative methods, rather than formal statistical modeling, to assess changes over time in India (and other countries as well in the case of Ma et al., 2004). They find that, on average, there were smaller deviations from CIP since the advent of India's capital control liberalization, which is therefore evidence of greater de-jure capital account openness reflected de-facto in the marketplace. As noted earlier, Pasricha (2008), investigating interest rate differentials in a different context, also finds that India is de-facto more open than de-jure measures such as the Chinn-Ito index suggest.

[8] If forward rates are determined primarily by expected future currency needs from importers and exporters, rather than by pure arbitrage by currency traders or others, the direction of deviation from CIP can be an indicator of market expectations with respect to future currency appreciation or depreciation. A related point is that variations in deviations from CIP may reflect changing relative risk premia for the two currencies. However, these risk premia are unobservable: our maintained hypothesis that the source of variation is changes in controls is consistent with the data and our estimated model.

3. Exploratory Data Analysis

Figures 1 and 2 show the evolution of the annualized deviations from covered interest parity (CIP), as defined in the previous section, calculated for NDF contracts and interest rates of 1-month and 3-month maturity.[9] The graph shows weekly observations, as well as six-week moving averages, starting in January 1999 and ending in January 2008. Large and persistent deviations from CIP are evident, indicating large transactions costs and the effectiveness of capital controls. At several points in each series, deviations from CIP exceed 1000 basis points.

A 1000 basis points deviation implies that, in the absence of capital controls and transactions costs, an arbitrageur could have obtained a profit of over $100,000 per year for every $1 million of volume transacted. Of course, even with no frictions, such a strategy requires the ability to commit some capital, which has a real cost, either through borrowing, or as an opportunity cost. However, an arbitrate strategy of this nature is almost completely risk free.[10] The existence of deviations of this magnitude in CIP indicate that capital controls have affected these markets and hindered arbitrage and market integration. Looking at both series graphs, a rough observation is that restrictions on capital outflows (negative deviations from CIP indicate that the MIBOR rate is lower than the offshore rate)

[9] The discussion of the 3-month series draws on Hutchison et al. (2010).
[10] As the recent financial crisis made clear, even in the absence of all other frictions, there can still be counterparty risk in arbitrage or hedging transactions, especially in exceptional circumstances.

are predominant during 1999-02, while restrictions on inflows are predominant from 2003 to mid-2005, and fluctuate since that time. This effect is stronger in the 3-month series, which also happens to have higher volumes.

Figures 1 and 2 indicate considerable volatility in the calculated deviations, and, as is the case with any fast-moving financial market, there is a constant stream of new information coming in. This makes model identification very difficult in practice, especially since non-linear models, which we choose here, do not have standard diagnostic statistics, nor well-documented small-sample distributional properties. We use some standard diagnostics as a guide to the subsequent formal, non-linear analysis, while recognizing that these are just indicative, as a preliminary exercise.

Hence, we begin by performing augmented Dickey-Fuller (ADF) tests for evidence of unit root behavior in the CIP deviation series and the two component interest rate series (the MIBOR rate and the NDF-offshore implied yield). The results suggest[11] that the interest rate series (at each maturity) exhibit evidence of a unit root, while the CIP differential series do not. Stationarity of the CIP series is consistent with the view that, when the deviations get too large, arbitrage reduces the deviations, possibly[12] towards zero. This very rough base line

[11] Of course, if the underlying series are subject to structural breaks or non-linearities, this could show up as a unit root (Taylor, 2001).

[12] We say possibly, because in the model we estimate, arbitrage only works outside a band of deviations, so arbitrage pressure brings the deviation to the edge of the band, but not necessarily to zero. Since the existence of even small transactions costs can be shown to create a no-arbitrage

indicates that there limits to the geographic market segmentation that can be achieved by capital controls, due to the existence of NDF markets.

To get further insight into the effectiveness of capital controls, and their evolution over time, we next analyze (Figures 3 and 4) the speed at which CIP deviations tend back towards zero in the context of a linear autoregressive model. We estimate two-year rolling AR(1) regressions of the deviations from CIP. The figures display the AR(1) parameter and the +/-95% confidence bands for each maturity. The AR (1) parameter in this context is a measure of how fast the series converges to a constant. The short, two year window is consistent with the idea of capturing arbitrage activity over a defined period. An AR(1) parameter near one implies a near unit root process, where the time to adjust back to zero is nearly infinite, whereas a value close to zero implies almost instantaneous adjustment. The level of arbitrage activity should be a function of the costs to arbitrage, including those imposed by capital controls, and the profitability of arbitrage, which is positively related to the magnitude of the deviation.

Figures 3 and 4 indicates substantial variation in potential arbitrage activity in this market, based on the behavior of the AR(1) parameter over time. The AR(1) parameters appear to exhibit somewhat cyclical patterns, consistent with the notion that larger deviations from CIP (thereby increasing the profitability to arbitrage) are associated with more rapid speed of adjustment

zone (Pasricha, 2008) we implement the former case, where arbitrage only works to the boundaries of the estimated band.

towards zero, i.e. a lower AR(1) parameter. In other words, even in the absence of policy changes, one might observe some variation over time in the rolling AR(1) estimates. There is also an observationally significant difference in the detailed patterns of the two maturities, although they are broadly similar in terms of ups and downs in the magnitude of the AR(1) parameter. One strong observation seems to be that, in both series, the AR(1) parameter in both series of CIP differentials declines in 2006 (recall that this is based on a window of 104 weeks prior to that time), and stays low. This would be consistent with increased arbitrage pressures in this period, which in turn could have followed from capital account liberalization.

We also performed some other suggestive tests on the data. The Tsay test (Tsay, 1989) for non-linearities rejects the null hypothesis of linearity in the data. This test does not explicitly take into account a threshold model as the alternative hypothesis, so we also discuss an alternative approach in the next section, once the methodology has been laid out. Another possibility is that of structural breaks. Bai-Perron tests for structural change (Bai and Perron, 2003) indicate structural breaks for the two CIP differential series. In Hutchison et al. (2010), we focus on the 3-month series and use the suggested structural breaks as a guide for splitting the sample into three sub-periods. In this paper, we offer the alternative approach of using rolling regressions, in the spirit of the rolling AR(1) models whose parameters are displayed in Figures 3 and 4. Since the Bai-Perron test is only

suggestive if the true model is non-linear, it merely reinforces the idea that the model parameters are not constant over time.

4. Estimation Methodology

The exploratory analysis relied on the maintained assumption of linearity, and therefore was only preliminary, though it had the virtue of familiarity of approach. Deviations from CIP may exhibit non-linear properties that linear statistical models cannot capture. In particular, transaction costs and capital controls can create bands, within which arbitrage will not be profitable. Outside of these no-arbitrage threshold boundaries, arbitrage will be able to exploit profit opportunities, with the strength of the return to the no-arbitrage boundaries depending on the specifics of capital controls and other institutional and technological factors. The band threshold values and the speeds of adjustment above and below the bands may also be asymmetric, reflecting the institutional specifics, such as asymmetries between controls on inflows and outflows.

Our formal approach therefore examines the effects of liberalization on threshold boundaries of a no-arbitrage band, as well as speeds of adjustment outside the band. A narrowing of the bands over time is an indication of greater de-facto capital account openness, while an increase in the speed of adjustment to the band threshold indicates that arbitrage acts more rapidly in returning the market closer to CIP, and has a similar implication (though it may also indicate

other changes in market efficiency, including technology and information flows). We employ the self exciting threshold auto-regressions (SETAR) methodology in order to obtain consistent estimates of the upper and lower threshold points of the no-arbitrage band, as well as estimates of the speeds of adjustment (possibly asymmetric) to the boundaries.

The SETAR model is a particular class of piece-wise autoregressive models due to Tong (1978).[13] The SETAR model is therefore a parsimonious approximation of a general non-linear autoregressive model (Hansen, 1999b). The SETAR model is an attractive statistical methodology for the problem we face in terms of bands and adjustment parameters, and as noted in the introduction, has been used heavily in the literature.[14]

The Self-Exciting Threshold Autoregressive (SETAR) model estimated here allows for three regimes with differing autoregressive parameters, with upper and lower thresholds which divide the three regimes. The region between the two thresholds is the no-arbitrage band, where restrictions prevent market equilibration through arbitrage. We therefore estimate the following model:

[13] Surveys of TAR and SETAR models, respectively, are given by Potter (1999) and Hansen (1999b). As the names indicate, the SETAR model is a special case of the TAR model, in which regime-switch thresholds depend on lagged values of the autoregressive variable itself, yielding the "self-exciting" nomenclature.

[14] In addition to the earlier references, Levy Yeyati, Schmukler and Van Horen (2006) is a recent study that examine cross-market premia for emerging markets. They examine the ratio between the domestic and the international market price of cross-listed stocks for nine emerging market economies, as a measure of international financial integration. Though they use the general term TAR, their model is in fact a SETAR model.

$$\delta_t = \rho_i \delta_{t-1} + \varepsilon_t; \qquad \kappa_n < \delta_{t-1} < \kappa_p$$

$$\delta_t - \kappa_n = \rho_n(\delta_{t-1} - \kappa_n) + \varepsilon_t; \qquad \delta_{t-1} \leq \kappa_n$$

$$\delta_t - \kappa_p = \rho_p\left(\delta_{t-1} - \kappa_p\right) + \varepsilon_t; \qquad \delta_{t-1} \geq \kappa_p$$

where δ_t is our onshore-offshore differential, $\varepsilon_t \sim N(0, \sigma^2)$ and κ_n and κ_p are the negative and positive thresholds respectively. The model assumes that within the bounds defined by κ_n and κ_p, speculative activity is not profitable because of transactions costs and capital controls, so the differential inside the band may follow a unit root or otherwise non-stationary process.

With arbitrage activity, however, the AR(1) process outside the bands will be stationary. This model assumes that speculative activity will push the deviations to the edges of the band, rather than to its center, since the logic of the model suggests that once the threshold is breached, arbitrage is inoperative. If the thresholds were known, the model could simply be estimated by OLS, applied separately to the inner and outer regime observations. In fact, the thresholds are not known, and must be revealed by the market data – this is an aspect of the distinction between *de facto* and *de jure* views of controls.

Since the thresholds are not known, they may be estimated by a sequential grid search method suggested in Hansen (1999) that also yields confidence intervals for the thresholds. In this method, a grid search is first made for a single threshold, yielding a minimum residual sum of squares, say $S_1(\widetilde{\kappa_1})$, where the

function S everywhere denotes the residual sum of squares function. In a two regime model, the first search would yield the stronger of the two threshold effects. Fixing the first-stage estimate $\widetilde{\kappa_1}$, the second-stage criterion is:

$$\mathrm{S}_2(\kappa_2) = \begin{cases} \mathrm{S}_1(\widetilde{\kappa_1}, \kappa_2) & if \quad \widetilde{\kappa_1} < 0 \\ \mathrm{S}_1(\kappa_2, \widetilde{\kappa_1}) & if \quad \widetilde{\kappa_1} > 0 \end{cases}$$

and the second-stage threshold estimate is the one that minimizes the above function, i.e.:

$$\widehat{\kappa_2} = argmin\mathrm{S}_2(\kappa_2)$$

The estimate of the first threshold is then refined as follows:

$$S_1^r(\kappa_1) = \begin{cases} \mathrm{S}_1(\widehat{\kappa_2}, \kappa_1) & if \quad \widehat{\kappa_2} < 0 \\ \mathrm{S}_1(\kappa_1, \widehat{\kappa_2}) & if \quad \widehat{\kappa_2} > 0 \end{cases}$$

and the refinement estimator for the first threshold is:

$$\widehat{\kappa_1} = argmin S_1^r(\kappa_1)$$

All values between the 5th and 95th percentiles are taken and separated into sets of negative and positive threshold candidates.[15] This process of optimization also yields confidence intervals for the thresholds. Define

$$L_2^r(\kappa_2) = \frac{\mathrm{S}_2(\kappa_2) - \mathrm{S}_2(\widehat{\kappa_2})}{\sigma^2}$$

and

$$L_1^r(\kappa_1) = \frac{S_1^r(\kappa_1) - S_1^r(\widehat{\kappa_1})}{\sigma^2}$$

[15] Thus, 5% was trimmed on each side. Every actual value of the CID between the 5th and 95th percentiles was used as a possible threshold in the unrestricted model. For the negative thresholds, the estimated values are not close to the cutoffs. For the positive, they are close to the 0-cutoff if the positive search is restricted to be between zero and the 95th percentile.

The asymptotic (1-α)% confidence intervals for $\kappa_1$and κ_2 are the set of values of each such that $L_1^r(\kappa_1) \leq c(\alpha)$ and $L_2^r(\kappa_2) \leq c(\alpha)$. Hansen (1999b) also shows that

$$c(\alpha) = -2\log(1 - \sqrt{1-\alpha})$$

To examine the hypothesis that capital controls have had less bite over time, as measured by opportunities for arbitrage, we estimate SETAR models of the above form, allowing the period to adjust. Rather than a rolling model, which is computationally very intensive and subject to estimation problems with a short window, we sequentially remove one year at a time from the sample, giving a series of estimates more heavily weighted toward the later period as one proceeds. Hence we obtain a series of arbitrage bands.

As previously discussed, standard diagnostic tests have the maintained hypothesis of linearity, or do not take full account of the implications of the non-linear alternative. If the alternative is a threshold model, the threshold parameter is not identified under a null hypothesis of linearity, so classical tests have non-standard distributions. Hansen (1996, 1999a) has developed a bootstrapping procedure to simulate the asymptotic distribution of the likelihood ratio (LR) test. However, when we applied LR tests of this form, the results were somewhat mixed. We believe that these results are driven by the low power of the tests. We would argue that the threshold model has an economic interest and intuitive

appeal in its own right, and therefore we prefer to report the two-threshold model estimates, with their associated confidence intervals.[16]

5. Results and Interpretation

The SETAR estimates are reported in Tables 2 and 3, for 1-month and 3-month maturities, respectively. Each table has the same structure, which we describe first. Column (1) reports the beginning date for each estimation. All end dates are January 30, 2008: as noted earlier, the data is at weekly frequencies. Columns (4) and (5) report the lower and upper thresholds of what we have argued is an arbitrage band. Columns (2) and (3) (respectively, (6) and (7)) report the lower (upper) confidence intervals for the two thresholds.

Columns (9) and (10) report, respectively, the median negative and positive deviations from CIP for each sub-sample. Columns (8), (11) and (12), labeled "LCR," "OutObs" and "3rd Quartile" refer, respectively, to (1) the longest continuous run outside of the band (i.e. the number of continuous observations), (2) the percentage of observations that lie outside of the no-arbitrage band, and (3) the 75th percentile of the number of weeks that any run outside of the threshold lasts. Columns (13) and (14) report the residual sum of squares for the linear model and the SETAR model, respectively. A major point to note is that the fit of

[16] As noted in Hansen (2000) in a related context, the statistical theory is asymptotic, and so it may be less applicable to small samples. The simulated confidence intervals generated along with the test statistics are also conservative, which is another way of saying the test has low power.

either model is much worse for the 1-month maturities than the 3-month maturities. We believe this is because there is more noise in the shorter-dated series, and lower volumes, making any kind of estimation less precise.[17] Moreover, the burden imposed by capital controls, or their implicit tax rate, could be higher for shorter maturity contracts. The easiest way to see the essence of the results in Tables 2 and 3 is visually. Figures 5 and 6 achieve this, and show clearly that, at least for the 3-month forward series, there is evidence from the SETAR model of liberalization in the capital account, reflected in market price behavior. This follows from the narrowing of the arbitrage bands over time, as earlier observations are dropped. While the period after 2005 did not see any major liberalization of capital controls that could be readily associated with the tightening of the bands, a series of small changes were periodically announced. Moreover, expectations were built that the process of reform was largely irreversible. This may be one of the factors that contributed to upgrades in India's sovereign rating to investment grade, by the three major rating agencies. Moody's upgraded Indian sovereign rating to investment grade in January 2004, Fitch in August 2006 and Standard and Poor in January 2007. These upgrades to investment grade were likely an important factor in increasing liquidity in the market for Indian instruments.

[17] For this reason, in Hutchison et al. (2010), we focused only on the 3-month series. However, the comparison of the two series' results can still be informative.

Finally, Tables 4 and 5 report the autoregressive parameters for the three components of the SETAR model, inside the band, below it, and above it, along with associated standard errors. In general, the estimates conform well with the theory, so that inside the band, the AR(1) coefficients are not significantly different from 1, whereas outside, they are indeed indicative of stationarity. The exception is the last sub-period, which is probably too short for stable estimates to be derived. This fact should therefore be kept in mind in assessing the other results, as illustrated in the previous two tables and figures. Interestingly, whereas the 3-month maturity data indicates that the arbitrage band has been narrowing, the speed of reversion to the thresholds, as measured by the AR(1) coefficient estimates, does not increase over the different sub-periods[18]. However, the AR(1) parameter for the 1-month maturity series declines sharply in 2006.

6. Conclusions

This paper uses market data to examine the de-facto effectiveness of Indian capital controls. The premise is that such controls create a wedge between domestic and foreign implied yields (measured by NDF rates), this wedge being captured by deviations from CIP. By varying a sequence of estimations toward later periods, we can infer whether incremental and gradual moves to liberalize

[18] Note that the AR(1) parameter for the positive threshold does not change in the first five sub-samples in Table 5. This is because the estimated positive threshold is higher than the largest observed positive value during 1999-2002 (Figure 6).

India's capital controls in recent years have narrowed the barriers to capital inflows and outflows, as measured by price discrepancies. In this context, we postulate the existence of no-arbitrage bands where the boundaries are determined by transactions costs and limitations to arbitrage due to capital controls, and CIP deviations are random within the boundaries. A narrowing of the bands over time is an indication of greater de-facto capital account openness.

Overall, liberalization of capital controls in India has occurred in conjunction with the development of domestic money and offshore markets and increases in market liquidity. Average daily turnover of NDF contracts in the Indian Rupee increased from about US$35 million in mid-2001 to US$3.7 billion in early 2007 (Ma et al., 2004; Misra and Behera, 2006), indicating that market liquidity has increased dramatically. In turn, this has presumably created stronger pressures for market arbitrage. Clearly, the complex nature of Indian capital controls and their discretionary application over time, combined with the evolution of financial markets themselves, present challenges for drawing very refined conclusions. Nevertheless, we believe that our work here and in Hutchison et al. (2010) provides an important starting point for further analysis.

Acknowledgments

We would like to thank the participants at the March and October 2008 conferences of the National Institute for Public Finance and Policy-Department of Economic Affairs, Indian Ministry of Finance (NIPFP-DEA) in New Delhi, India for their valuable input regarding related work, especially Robert McCauley, Ila Patnaik, Sergio Schmukler, Ajay Shah and Matthieu Stigler. Funding for this project from the NIPFP-DEA Program on Capital Flows and their Consequences is gratefully acknowledged. We would also like to acknowledge the valuable collaboration with Jake Kendall on related work: he also constructed four of the figures reported in this paper. The views expressed in the paper are of the authors – no responsibility for them should be attributed to the Bank of Canada.

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Table 1: Domestic Savings and Investment Trends

Year	Gross Domestic Saving (percent of GDP)	Gross Domestic Capital Formation (percent of GDP)
1954-55	9.1	9.3
1959-60	10.8	12.3
1964-65	11.6	13.8
1969-70	14.0	14.5
1974-75	15.7	16.5
1979-80	19.8	20.3
1984-85	18.2	19.6
1989-90	21.8	24.3
1994-95	24.4	25.5
1999-00	24.8	25.9
2004-05	31.8	32.2
2005-06	34.3	35.5
2006-07	34.8	35.9

Table 2: SETAR Results, 1-month maturities

Sample Begin Date	Negative Threshold		Positive Threshold		LCR	Median Deviation		OutObs	3rd Quartile	Residual Sum of Squares	
	Est.	Conf. Interval	Est.	Conf. Interval		Negative	Positive			OLS	TAR
30/01/1999	-6.50	(-8.58, -3.47)	0.01	(-4.96, 1.75)	17	-2.07	1.67	39%	3	4732.7	4256.1
08/01/2000	-6.85	(-8.58, -4.77)	0.01	(-4.96, 1.58)	17	-1.73	1.71	40%	4	3797.0	3331.3
13/01/2001	-5.00	(-7.75, -3.59)	0.01	(-2.74, 1.58)	17	-1.94	1.85	47%	4	2963.8	2708.3
12/01/2002	-5.00	(-7.71, -3.14)	0.01	(-2.51, 1.67)	17	-2.10	1.87	51%	4	2715.0	2516.8
11/01/2003	-5.00	(-8.30, -3.14)	0.07	(-2.26, 1.91)	17	-2.28	1.93	58%	4	2546.7	2347.0
10/01/2004	-5.91	(-8.58, -2.86)	0.01	(-4.98, 2.39)	13	-1.64	1.98	53%	4	2289.5	2070.4
08/01/2005	-5.53	(-9.00, -3.05)	0.14	(-2.86, 2.68)	7	-2.02	1.55	43%	2	1793.5	1452.6
14/01/2006	-5.00	(-10.10, -1.92)	0.14	(-6.77, 3.03)	5	-2.59	1.87	50%	2	1534.8	1281.0
13/01/2007	-4.96	(-11.00, 3.03)	2.68	(-2.86, 3.53)	4	-3.41	0.59	41%	2	795.6	662.3

Notes: All samples end at 30/01/2008. Est. refers to the point estimate of the respective threshold and Conf. interval is its confidence interval. The end points of the confidence interval are the two points where the LR curve, which is at a minimum at the estimated threshold, crosses the c(a) line. When the LR curve does not cross c(a) twice, the confidence interval uses, for the missing limit, the end points of the range over which the thresholds were searched. LCR is the longest continuous run, in weeks, of deviations outside thresholds. Median Deviation Negative (Positive) is the median of all deviations that lie below (above) the negative (positive) threshold. OutObs is the percentage of observations lying outside the estimated no-arbitrage band. 3rd Quartile is the third quartile of continuous runs of deviations outside thresholds. OLS refers to ordinary least squares estimates of a linear AR(1) model and Tar refers to the SETAR model.

Table 3: SETAR Results, 3-month maturities

Sample Begin Date	Negative Threshold		Positive Threshold		LCR	Median Deviation		OutObs	3rd Quartile	Residual Sum of Squares	
	Est.	Conf. Interval	Est.	Conf. Interval		Negative	Positive			OLS	TAR
30/01/1999	-4.22	(-4.48, -2.17)	3.49	(-2.11, 3.61)	7	-0.69	0.38	11%	3	732.7	692.5
08/01/2000	-4.16	(-4.16, -2.13)	3.49	(-1.64, 3.67)	7	-0.80	0.38	11%	3	638.8	603.4
13/01/2001	-2.37	(-3.18, 0.09)	3.49	(3.09, 3.71)	8	-0.65	0.38	17%	3	494.7	476.1
12/01/2002	-1.01	(-2.58, 0.12)	3.49	(-0.39, 3.79)	19	-0.67	0.38	34%	4	426.0	401.8
11/01/2003	-1.07	(-2.37, 0.53)	3.49	(-0.55, 3.86)	15	-0.69	0.38	31%	4	396.5	373.2
10/01/2004	-1.07	(-2.81, 0.65)	3.51	(-1.35, 3.83)	15	-0.69	0.61	34%	3	344.4	324.9
08/01/2005	-0.73	(-2.97, 0.40)	1.59	(-1.44, 2.42)	26	-0.93	0.62	55%	3	232.56	221.8
14/01/2006	-0.73	(-3.01, 0.68)	1.59	(-1.44, 2.41)	11	-0.92	0.48	57%	4	187.3	179.0
13/01/2007	-0.03	(-3.73, 2.75)	0.95	(-3.73, 2.75)	8	-1.20	0.83	88%	4	121.1	116.2

Notes: All samples end at 30/01/2008. Est. refers to the point estimate of the respective threshold and Conf. interval is its confidence interval. The end points of the confidence interval are the two points where the LR curve, which is at a minimum at the estimated threshold, crosses the c(a) line. When the LR curve does not cross c(a) twice, the confidence interval uses, for the missing limit, the end points of the range over which the thresholds were searched. Median Deviation Negative (Positive) is the median of all deviations that lie below (above) the negative (positive) threshold. OutObs is the percentage of observations lying outside the estimated no-arbitrage band. 3rd Quartile is the third quartile of continuous runs of deviations outside thresholds. OLS refers to ordinary least squares estimates of a linear AR(1) model and Tar refers to the SETAR model.

Table 4: AR (1) coefficients – 1-month maturities

Sample Begin Date	Inner Regime		Negative Regime		Positive Regime	
	Est.	Std. Err.	Est.	Std. Err.	Est.	Std. Err.
01/30/1999	0.90	0.06	-0.24	0.11	0.43	0.09
01/08/2000	0.95	0.06	-0.42	0.13	0.46	0.09
01/13/2001	0.86	0.07	0.03	0.12	0.46	0.09
01/12/2002	0.79	0.09	0.01	0.13	0.46	0.09
01/11/2003	0.82	0.11	0.01	0.14	0.46	0.10
01/10/2004	0.96	0.11	-0.23	0.18	0.46	0.11
01/08/2005	0.99	0.11	-0.13	0.16	-0.25	0.23
01/14/2006	0.85	0.18	0.01	0.17	-0.30	0.31
01/13/2007	0.93	0.25	0.22	0.22	-4.05	1.40

Table 5: AR (1) coefficients – 3-month maturities

Sample Begin Date	Inner Regime		Negative Regime		Positive Regime	
	Est.	Std. Err.	Est.	Std. Err.	Est.	Std. Err.
01/30/1999	0.89	0.03	-0.10	0.16	-0.04	0.30
01/08/2000	0.89	0.04	-0.03	0.16	-0.04	0.30
01/13/2001	0.85	0.04	0.34	0.14	-0.04	0.28
01/12/2002	0.86	0.05	0.35	0.11	-0.04	0.28
01/11/2003	0.87	0.05	0.31	0.14	-0.04	0.30
01/10/2004	0.81	0.07	0.31	0.14	-0.09	0.33
01/08/2005	0.80	0.19	0.45	0.12	-0.08	0.25
01/14/2006	0.58	0.28	0.34	0.15	0.05	0.33
01/13/2007	1.35	1.37	0.46	0.18	0.44	0.23

Figure 1: CIP deviation series using 1-month instruments

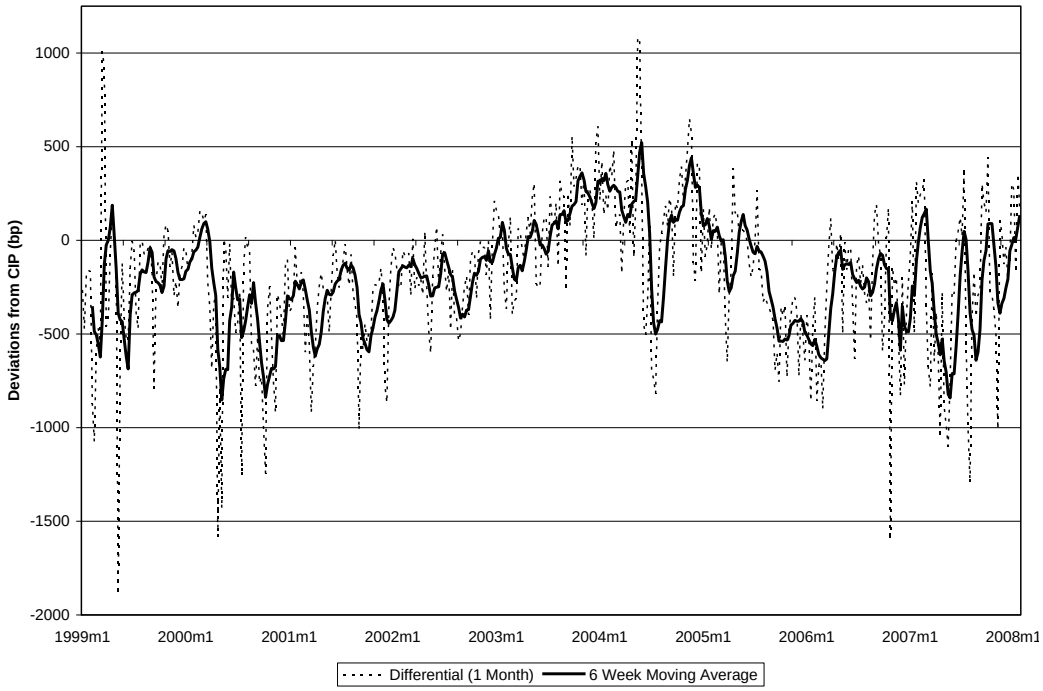

Figure 2: CIP deviation series using 3-month instruments

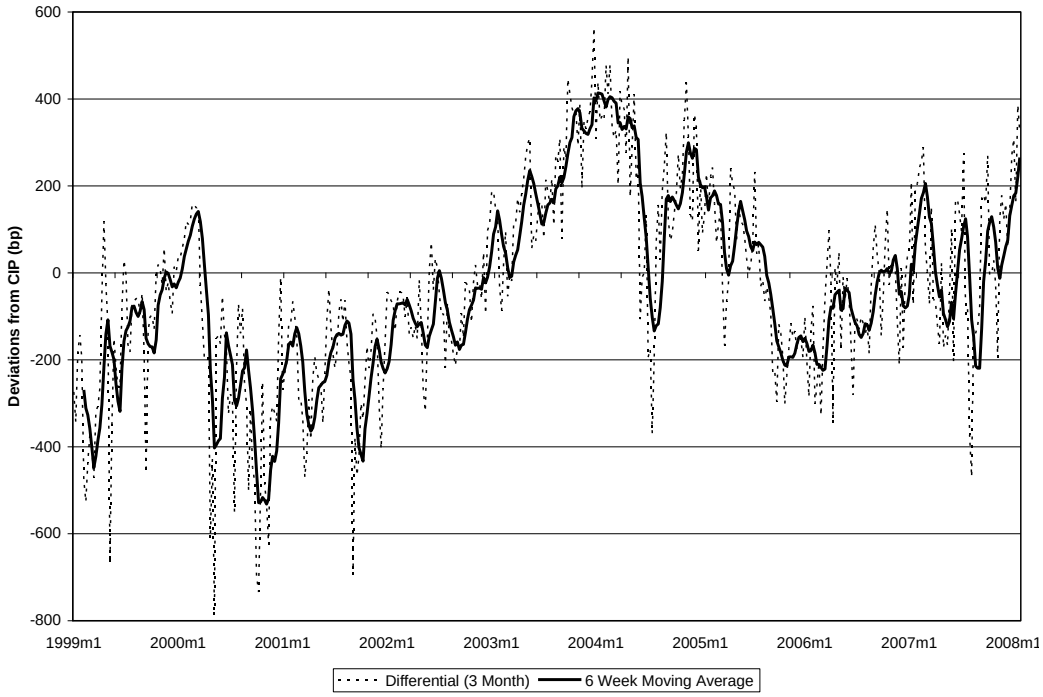

Figure 3: Plot of AR(1) parameter from rolling regressions on CIP deviation series with 1-month instruments. Rolling regression windows are 2 years (104 weeks). Dotted lines are +/-95% errors.

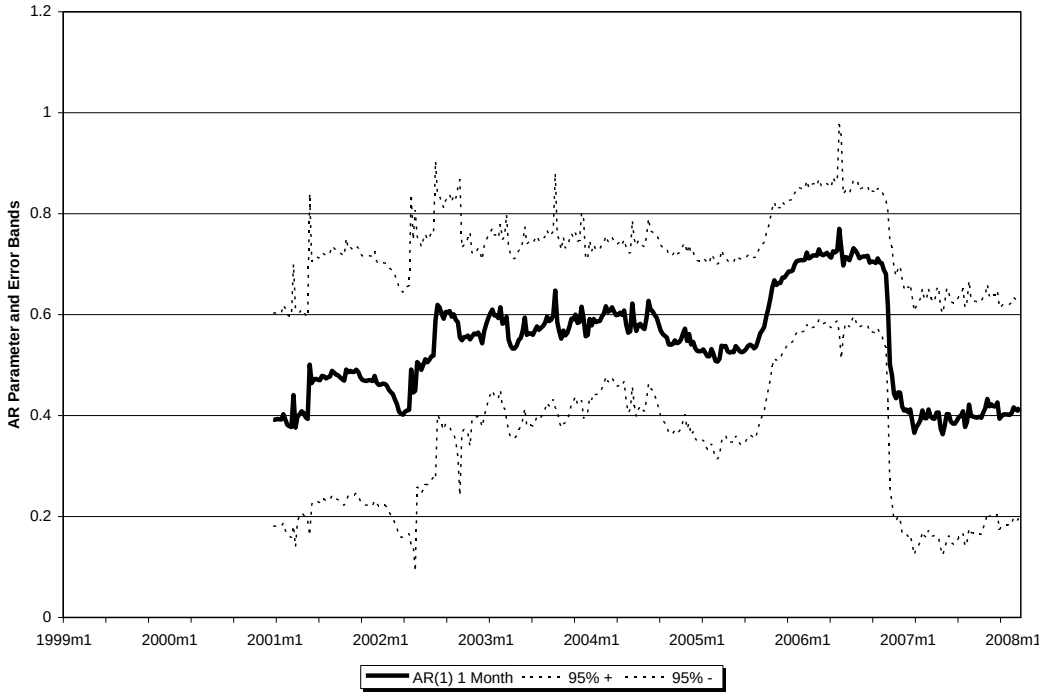

Figure 4: Plot of AR(1) parameter from rolling regressions on CIP deviation series with 3-month instruments. Rolling regression windows are 2 years (104 weeks). Dotted lines are +/-95% errors.

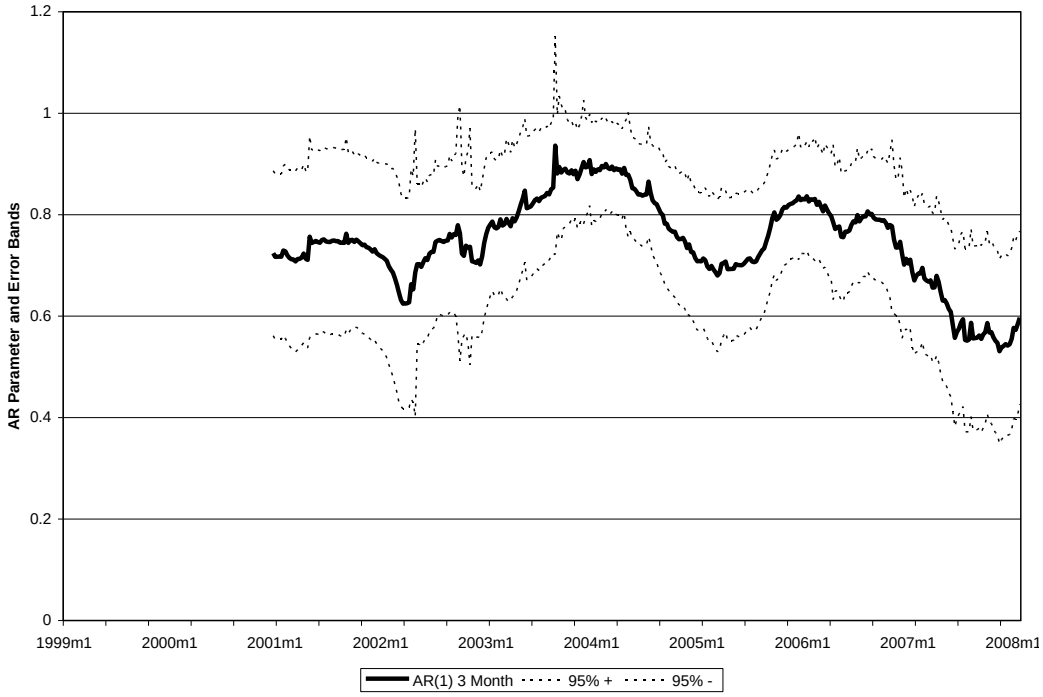

Figure 5: CIP Differentials – Estimated Thresholds for 1-month maturities

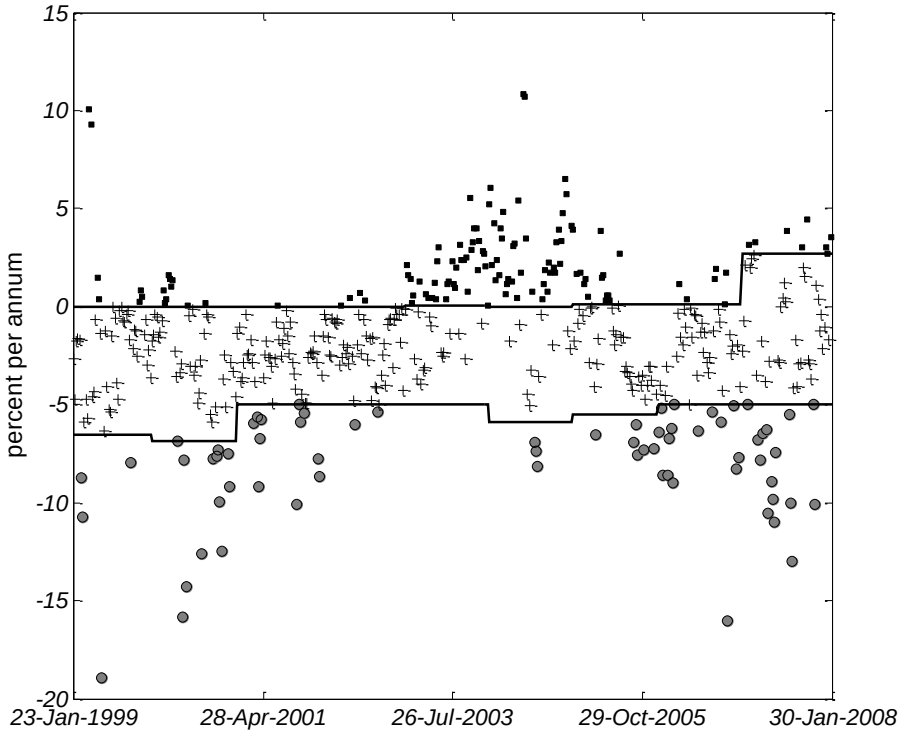

Figure 6: CIP Differentials – Estimated Thresholds for 3-month maturities