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# The Nonlinear Dynamics of Foreign Reserves and Currency Crises

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# The Nonlinear Dynamics of Foreign Reserves and Currency Crises*

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**Abstract**

A new early-warning system for international currency crises is developed in this paper. The existing crisis indicators in the literature are essentially static. We examine the relationship between the dynamics of foreign reserves and currency crises. It is shown that rapid reserve depletion is a prominent feature before the collapse of the exchange rate system. The results from our threshold autoregressive model suggest that when the Reserves-to-Short-Term External Debt falls by more than 29.1%, or if the Reserves-to-M2 ratio drops by more than 24.3% within six months, the likelihood of a crisis increases. Our model provides clear warning signals for policy makers to take actions before the reserves have reached a critical value that heralds the arrival of a full-blown crisis.

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## 1. Introduction

The accurate prediction of currency crises is an important issue yet to be adequately studied. Various methods have been proposed to give warning signals in advance of a financial crisis. Krugman (1979) develops the first-generation crisis model, which suggests that crises may occur when the fiscal deficit is too high. The second-generation model (Obstfeld, 1986) argues that there is a surge in the domestic interest rate before a crisis, and that the sheer pessimism of investors can cause a capital outflow which leads to the collapse of the exchange rate system. Eichengreen *et al*. (1996), Sachs *et al*. (1996), Frankel and Rose (1996) and Kaminsky and Reinhart (1999) also suggest that the occurrence of currency crises can be predicted by the levels of interest rate and foreign reserves. Krugman (1999) observes that neither the first nor the second generations' stories can explain the 1997 Asian crisis. He develops the third generation crisis model, which suggests that international illiquidity in a country's financial system precipitates the collapse of the exchange rate. A financial system is internationally illiquid if its short-term obligations exceed the amount of foreign currency to which it can have access at short notice. When authorities do not have adequate foreign reserves, the financial system is highly vulnerable to speculative attacks. Thus, external illiquidity is a crucial indicator of currency crises (McKinnon and Pill, 1997)[1].

The aforementioned indicators of crisis are essentially static. Bird and Rajan (2003) argue that a country with a low level of reserves is less vulnerable to crises than a country with a fast depletion of reserves. A rapid depletion of reserves lowers investors' confidence, which in turn accelerates the dissipation of reserves and triggers a currency crisis. Thus, a measure reflecting the dynamics of reserves is also important for central banks to take precautions in advance of crises (Miller,

[1] The third generation model suggests that reserve inadequacy is a major cause of currency crises. In the aftermath of the Asian Financial Crisis, countries in the region have quickly built up large stockpiles of foreign reserves. According to the International Monetary Fund (IMF), Asian countries have nearly doubled their reserves during the period 1998-2005, holding more than the total reserves of all industrialized countries. Although a healthy level of foreign reserves helps to prevent currency crises (Heller, 1966), an excessive accumulation of reserves has a huge opportunity cost (Bird and Rajan, 2003). Recent empirical works show that Asian countries have replenished more than adequate reserves in the post-crisis period (De Beaufort Wijnholds and Kapteyn, 2001; Bird and Rajan, 2003; Hong and Tornell, 2005). For more recent discussions on international reserves, one is referred to Aizenman and Lee (2007).

2000). In light of this, this paper examines the relationship between the depletion rate of foreign reserves and currency crises in eight Asian emerging countries. A threshold autoregressive model is estimated. The predictive ability of three indicators related to the depletion rate of the foreign reserves, namely, the Reserves-to-Imports ratio, the Reserves-to-Short-Term External Debt (R/STED) ratio and the Reserves-to-Broad-Money-Supply (R/M2) ratio are examined in turn. The remainder of this paper is organized as follows. Section 2 describes the model and the data. Section 3 estimates the threshold model using three different threshold variables. The predictive ability of our model is discussed in Section 4. The last section concludes the paper.

## 2. The Model and Data

A threshold autoregressive (TAR) model will be estimated to forecast currency crises. The TAR model was introduced by Tong (1983), and has become increasingly popular in empirical studies[2]. Recent works of the TAR model includes Dueker *et al*. (2007), who develop a contemporaneous TAR model and apply it to the pricing of bonds. Using a balanced panel data set, we estimate the following TAR model with individual-specific fixed effect:

$$y_{i,t} = \mu_i + \varphi' x_{i,t}(\lambda) + e_{i,t}\,, \qquad (2.1)$$

where

$$x_{i,t}(\lambda) = \begin{pmatrix} x_{i,t} 1_{(z_{i,t-1} \le \lambda)} \\ x_{i,t} 1_{(z_{i,t-1} > \lambda)} \end{pmatrix},$$

$$x_{i,t} = (y_{i,t-1}, \cdots, y_{i,t-p})',$$

$$\varphi = (\alpha' \quad \beta')',$$

[2] Some extensions of the TAR model include the functional-coefficient autoregressive (FAR) model of Chen and Tsay (1993) and the nested threshold autoregressive (NeTAR) model of Astatkie *et al*. (1997). A wide variety of applications of threshold models have been found in recent years. For example, Hansen (1999) studies how financial constraints affect investment decisions. Henry *et al*. (2001) provide evidence of threshold effect in the Australian real exchange rate.

$$\alpha = (\alpha_1, \cdots, \alpha_p)$$

and

$$\beta = (\beta_1, \cdots, \beta_p)\ .$$

$z_{i,t}$ is the threshold variable and $1_{(.)}$ is an indicator function[3]. $\lambda$ is the threshold value and $p$ is the autoregressive order. The individual effect $\mu_i$ is eliminated by removing individual-specific means. The model parameters are estimated by the sequential conditional least squares method of Hansen (1999)[4].

Our sample includes eight Asian emerging countries, namely, China, India, Indonesia, Korea, Malaysia, the Philippines, Singapore and Thailand. Quarterly observations of the Reserves-to-Imports ratio, Reserves -to-Short-Term External Debt ratio, Reserves-to-Broad-Money-Supply ratio from 1990 to 2003 are obtained and transformed into logarithms. We first estimate a fourth-order autoregressive model[5] as our baseline model. We assume that there are two unknown states, namely, a state of relative calmness (tranquil period) and a state prone to currency crisis (speculative attack period). As the movement of foreign reserves during the speculative period is different from that during the tranquil period, we define $z_{i,t} = y_{i,t} - y_{i,t\text{-}2}$[6] as a crisis indicator to classify the sample into

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[3] The threshold model is similar to the structural-change model (Chong, 2001; Bai *et a*l., 2008) in nature. $1_{(A)}$ equals one when event $A$ occurs and equals zero otherwise. While most of the TAR models used in the previous literature are applied to a single time series data, our model is applied to a panel data set. Also, previous models usually use the lag of the dependent variable as the threshold variable, while we use the difference in the dependent variable to construct our threshold variable.

[4] Pesaran and Smith (1995) argue that if slope coefficients differ across countries, fixed effect estimators of models with lagged dependent variables are biased. However, since the parameter of interest in our model is the threshold value, as pointed out by Chong (2003) and Bai *et al*. (2008), the threshold estimate remains consistent even if the model is misspecified. With a consistent estimate of threshold parameter, the bias problem of other parameters should be alleviated.

[5] We calculate the AIC for each reserves variable. For most countries, a model of order which is less than or equal to four generates the smallest value of AIC. As a result, we set p equal to 4. From Chong (2003) and Bai *et al*. (2008), the initial order will not affect the consistency of the threshold estimate. We have also calculated the threshold estimates of the third-order and fifth-order models, they are very close to that of the fourth-order model.

[6] Before the year 2000, the data set for external debt is available on a semi-annual basis only, thus we choose the two-quarter change in the ratios as our threshold variable. The choice of the two-quarter change in reserves is appropriate, as a warning signal based on the one-quarter change will generate too many false alarms, and a signal based on the one-year change may not leave policy makers enough time for taking pre-emptive measures against the crisis.

the two states. Our main parameter of interest is the threshold value. The sampling distribution of an $F$ test for the threshold effect is bootstrapped. The advantage of our model is that it provides an early warning signal for currency crises when the threshold variables drop rapidly.

## 3. Threshold Variables

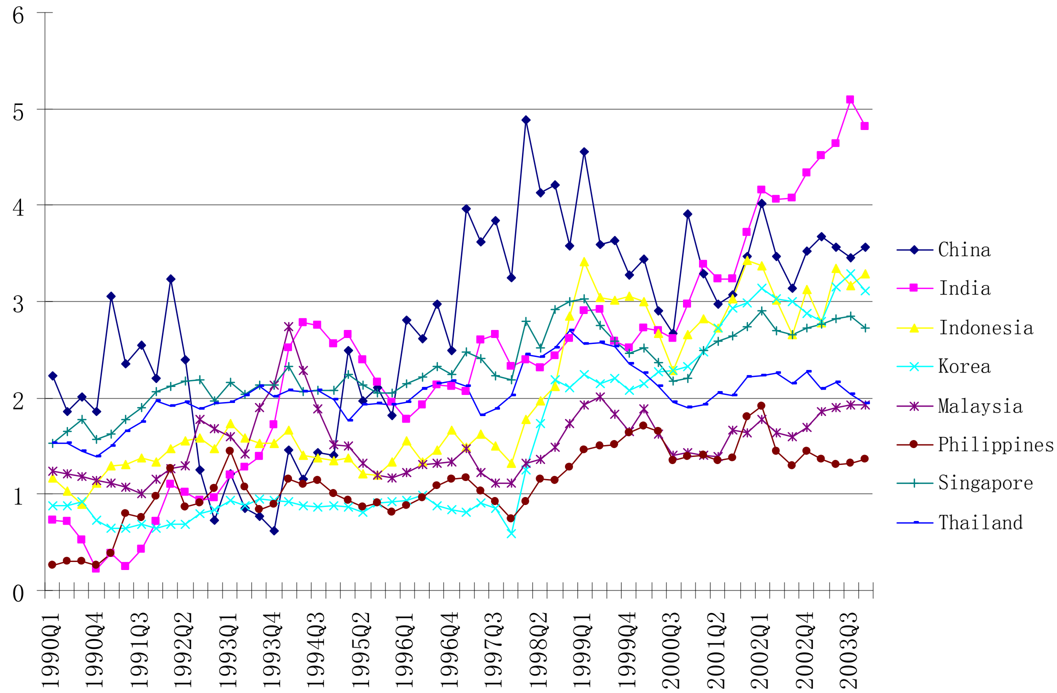
### 3.1 Reserves-to-Imports (R/M) Ratio

International foreign reserves serve as an essential insurance against the uncertain future course of the balance of payment. As a rule-of-thumb, reserves are said to be inadequate if they are less than three to four months' worth of imports (Fischer, 2001). With quarterly data, the threshold value of the Reserves-to-Imports ratio should be approximately equal to unity. However, a visual examination of Figure 1 suggests that most of the countries have achieved this threshold value even during the crisis period. Thus, the crude rule of thumb of the Reserves-to-Imports ratio has lost much of its relevance for these Asian countries. To test the threshold effect, Equation (2.1) is estimated. The value of the $F$ statistic testing the null hypothesis of no threshold, and the associated bootstrapped $p$-value are reported in Table 1. The results from Table 1 show that the test for threshold effect $F$ is insignificant with a bootstrapped $p$-value of 0.622. Thus, there is no threshold effect in the model, and our result is consistent with the observations in Figure 1.

**Table 1:** Testing results for threshold effects of R/M and the TAR estimates

| | |
|---|---|
| Test for threshold effect | |
| $F$ | 33.22 |
| p-value | 0.622 |
| (10%, 5%, 1% critical values) | (93.23, 108.11, 119.06) |

**Figure 1**: Level of Reserves-to-Imports Ratio

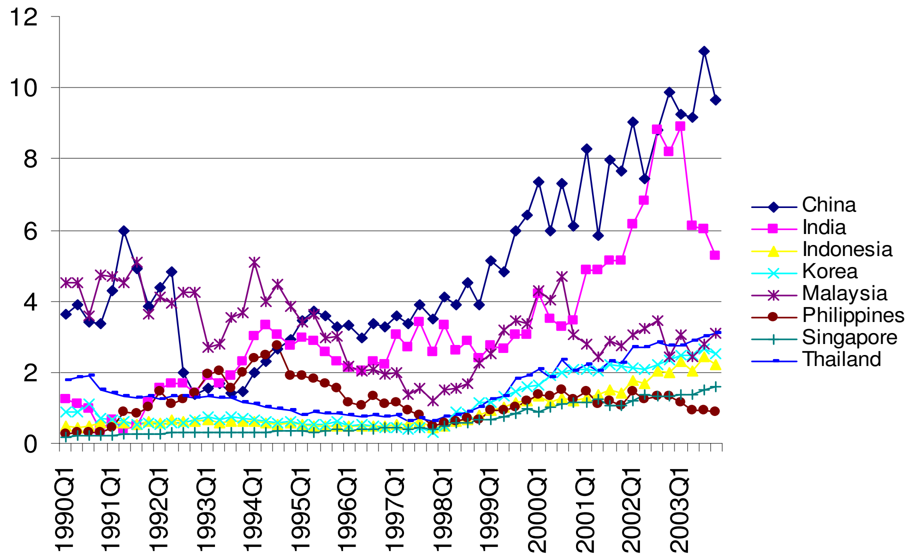



### 3.2 Reserves-to-STED Ratio

The financial crises over the past decades have led to the development of several leading indicators of international illiquidity. Two such indicators are the Reserves-to-Short-Term External Debt (R/STED) ratio and the Reserves-to-Broad-Money-Supply (R/M2) ratio. The ratios of Reserves-to-Short-Term External Debt[7] (R/STED) for the eight Asian emerging countries are plotted in Figure 2.

[7] Following De Beaufort Wijnholds and Kapteyn (2001), all the data are extracted from IMF's *International Financial Statistics* (line 1.1.d. for non-gold reserves, line 71.d for imports c.i.f. and the sum of lines 34 and 35 for broad money), except for the short-term external debt data (residual maturity within one year) which is from the *Joint BIS/IMF/OECD/World Bank Statistics* on External Debt (line 15 to line 22). Before the first quarter of 2000, the consolidated statistics are available on a semi-annual basis only. When quarterly data are not available, the available data are regressed on the polynomials of time trend, and the estimated coefficients are used to construct the quarterly data.

**Figure 2**: Level of R-to-STED ratio




In the aftermath of the Asian crisis, the level of short-term indebtedness has been suggested as a crucial indicator of illiquidity and a good predictor of financial crises (Rodrik and Velasco, 1999). According to the Guidotti-Greenspan rule, a country should hold reserves equal to their foreign liabilities coming due within a year. (De Beaufort Wijnholds and Kapteyn, 2001; Bird and Rajan, 2003). Figure 2 shows that the R/STED ratios for most countries fall below unity during the crisis period. Countries with a high R/STED ratio, such as China and India, have successfully avoided the currency crisis in 1997. Thus, the likelihood of an occurrence of a crisis is negatively related to the R/STED ratio. In contrast to the existing studies, which focus on the level of this ratio, we establish a link between the dynamics of the R/STED ratio and currency crises.

Table 2 reports the corresponding estimation and testing results. Figure 3 plots the concentrated likelihood ratio function. The likelihood ratio function helps us to identify the threshold effect and provides a confidence interval for the true threshold value if it exists. From Figure 3, the 95% confidence interval for the threshold value is (-0.306, -0.263), which contains the values of $\hat{\lambda}$ for which the likelihood ratio lies beneath the dashed line[8].

Since the test value $F$ is significant, there is a threshold effect in the model. The

[8] Hansen (1999) provides the asymptotic distribution of this likelihood ratio statistic $LR(\lambda)$ and its corresponding inverse function $c(a)$, where $a$ is the confidence level. The asymptotic confidence interval for the threshold estimation is the set of values of $\lambda$ such that $LR(\lambda) < c(a)$.

point estimate of the threshold is found to be -0.291. Thus, the TAR model splits the observations into two regimes. Which regime an observation belongs to depends on whether $z_{i,t-1} = y_{i,t-1} - y_{i,t-3}$ lies above or below -0.291. We denote the case where $z_{i,t-1} \le -0.291$ regime 1 or the speculative attack regime, and the case where $z_{i,t-1} > -0.291$ regime 2 or the tranquil regime. Thus, when the dissipation rate of R/STED is higher than 29.1% over two quarters, there is a high chance of having a crisis. Note from Table 2 that the standard errors of the model estimates for regime 1 are roughly triple those of regime 2, indicating that there is a considerable variation in the estimates of regime 1.

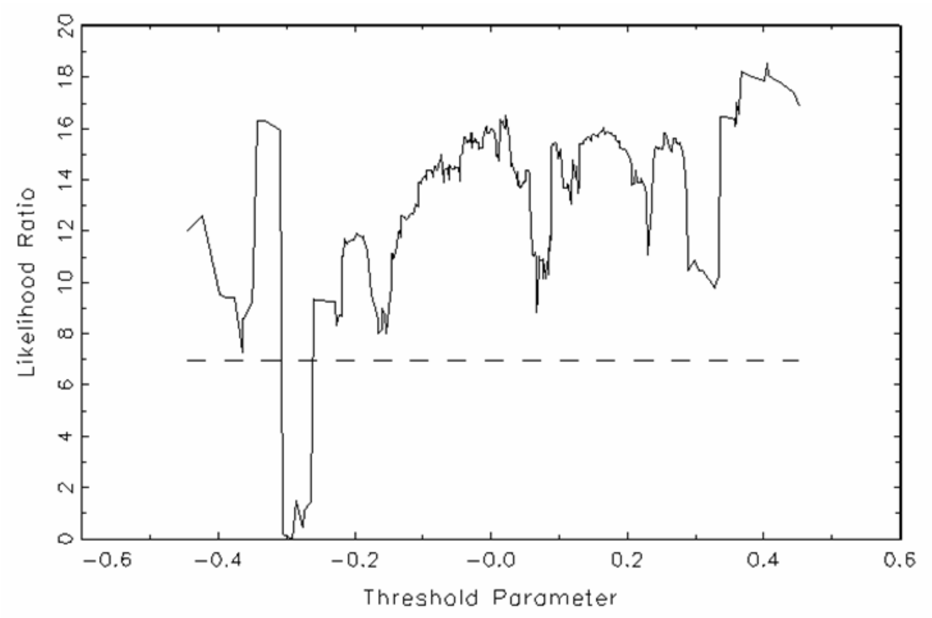
**Table 2:** Testing result for threshold effects of R/STED and the TAR estimates

| Test for threshold | |
|---|---|
| $F$ | 37.477 |
| p-value | 0.047 |
| (10%, 5%, 1% critical values) | (30.482, 36.671, 40.283) |

| | Threshold estimate | 95% confidence interval |
|---|---|---|
| $\hat{\lambda}$ | -0.291 | [-0.306, -0.263] |

| | TAR estimates | | | | | |
|---|---|---|---|---|---|---|
| | $Z_{t-1} < \hat{\lambda}$ | | | $Z_{t-1} \ge \hat{\lambda}$ | | |
| Regressor | Estimate | OLS SE | White SE | Estimate | OLS SE | White SE |
| $y_{t-1}$ | 0.624 | (0.108) | (0.194) | 0.860 | (0.056) | (0.063) |
| $y_{t-2}$ | 0.274 | (0.127) | (0.284) | 0.323 | (0.069) | (0.091) |
| $y_{t-3}$ | 0.540 | (0.200) | (0.318) | -0.236 | (0.069) | (0.074) |
| $y_{t-4}$ | -0.641 | (0.199) | (0.340) | 0.004 | (0.049) | (0.054) |

**Figure 3:** Confidence interval construction for the R/STED ratio




### 3.3 Reserves-to-M2 Ratio

The R/STED ratio indicates the vulnerability of a country to an external drain, but it fails to indicate the threat of an internal drain associated with capital outflows caused by nationals (De Beaufort Wijnholds and Kapateyn, 2001). As a result, the R/M2 ratio, which indicates the extent to which liabilities of domestic credit are supported by foreign assets, emerges as a supplement to the R/STED ratio. A low and declining R/M2 ratio is a leading indicator of the occurrence of a currency crisis (Kaminsky and Reinhart, 1999).

Figure 4 shows that the R/M2 ratio ranges from 0.01 to 0.98. Table 3 shows the corresponding estimation and testing results. The results suggest that there is a threshold in our model. The point estimate of this threshold is -0.243, and the 95% confidence interval is also reported. Figure 5 plots the concentrated likelihood ratio function and the 95% confidence interval for the threshold value. Similar to the R/STED ratio, we label the period where the R/M2 ratio drops by more than 24.3% within two quarters regime 1 (the speculative attack regime), and the period with a drop of less than 24.3% regime 2 (the tranquil regime). Note also that the standard errors of the first regime estimates are much higher than those of the second regime. In particular, the slope estimates in regime 1 are insignificant if the White-corrected standard error is used. Thus, for regime 1, the movement of R/M2 ratio can be considered as random walks while for regime 2, it is more likely to display mean reversion.

**Table 3**: Testing result for threshold effects of R/M2 and the TAR estimates

| Test for threshold effect | | |
|---|---|---|
| | $F$ | 54.819 |
| | p-value | 0.034 |
| | (10%, 5%, 1% critical values) | (36.56, 50.25, 72.53) |
| | Threshold estimate | 95% confidence interval |
| $\lambda$ | -0.243 | [-0.254, -0.196] |

| | TAR estimates | | | | | |
|---|---|---|---|---|---|---|
| | $Z_{t-1} < \hat{\lambda}$ | | | $Z_{t-1} \geq \hat{\lambda}$ | | |
| Regressor | Estimate | OLS SE | White SE | Estimate | OLS SE | White SE |
| $y_{t-1}$ | 0.547 | (0.132) | (0.313) | 0.931 | (0.052) | (0.067) |
| $y_{t-2}$ | 0.743 | (0.177) | (0.388) | -0.057 | (0.067) | (0.101) |
| $y_{t-3}$ | -0.056 | (0.238) | (0.225) | -0.121 | (0.064) | (0.087) |
| $y_{t-4}$ | -0.350 | (0.163) | (0.349) | 0.098 | (0.045) | (0.060) |

**Figure 4**: Level of R-to-M2 ratio

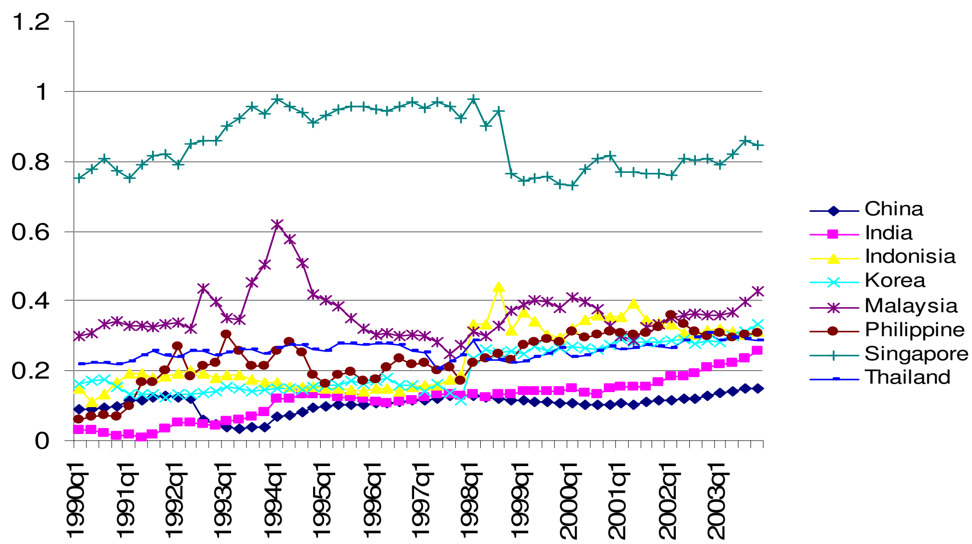
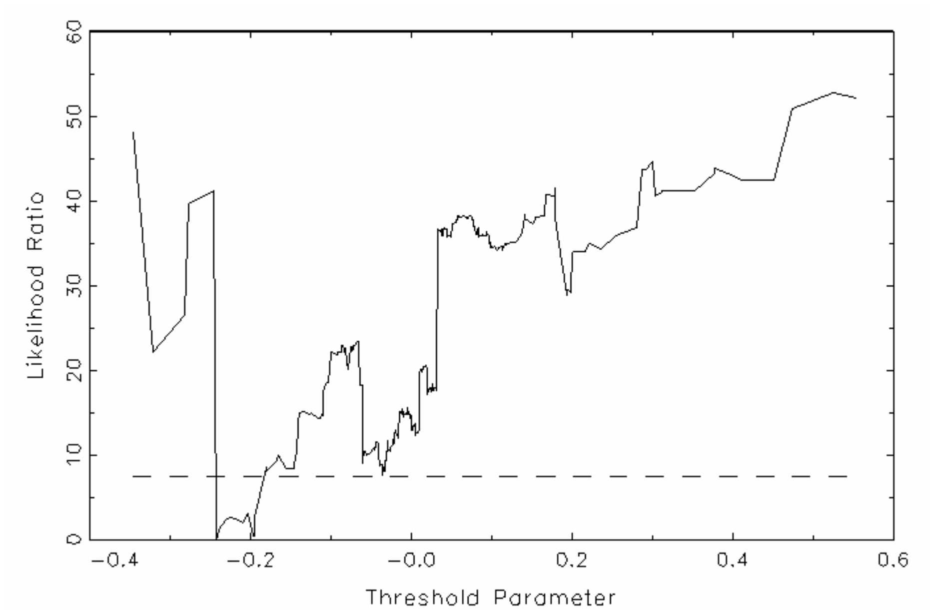



**Figure 5**: Confidence interval construction for the R/M2 ratio



## 4. Predictive Ability

In the previous section, we obtain a threshold estimate of -0.291 for the R/STED ratio and -0.243 for the R/M2 ratio. We now examine how well these threshold values can be used to distinguish the tranquil regime from the speculative attack regime. The exchange market pressure index (Eichengreen *et al*., 1996; Frankel and Rose, 1996; Sachs *et al*., 1996; Goldstein *et al*., 2000) is used to identify the crisis episodes of the eight Asian emerging countries[9]. The results are reported in Table 4. The periods of rapid depletion of reserves are also listed in Table 4.

**Table 4**: Crisis episodes for Asian countries

| Countries | Crisis episodes identified by the exchange market pressure index | Rapid depletion of reserves identified by our model | |
|---|---|---|---|
| | | R/STED | R/M2 |
| China | 1992Q3-1993Q2 | 1991Q4, 1992Q3-Q4, 1993Q1 | 1992Q3-Q4, 1993Q1-Q2 |
| India | 1991Q1-Q2 | 1990Q4, 1991Q1-Q3, 2003Q2-Q3 | 1990Q3-Q4, 1991Q2 |
| Indonesia | 1997Q3-1998Q2 | 1997Q3 | 1999Q3 |
| Korea | 1997Q4 | 1991Q1, 1997Q4 | 1991Q1, 1997Q4 |
| Malaysia | 1997Q3-Q4, 1998Q2 | 1993Q1-Q2, 1995Q1, 1996Q1-Q2,1997Q2-Q3, 2000Q4, 2001Q1, 2002Q4 | 1993Q1, 1994Q3-Q4, 1995Q1, 2001Q1 |
| Philippines | 1997Q3 | 1995Q1, 1996Q1-Q2, 1997Q3-Q4, 1998Q1, 2003Q2 | 1992Q3, 1993Q3, 1994Q4, 1995Q1 |
| Singapore | 1997Q3-Q4, 1998Q2 | | 1999Q1 |
| Thailand | 1997Q3-Q4 | 1991Q1 | 1997Q2, 1998Q3 |

9 A crisis is identified when the index is two standard deviations above the mean.

The results in Table 4 indicate that the threshold variables perform well in forecasting the currency crises identified by the exchange market pressure index. If one of the threshold variables falls below the corresponding critical value, the likelihood of the occurrence of a crisis rises. In most cases, a crisis occurs when the threshold variable crosses the critical value. For instance, the depletion rate of the R/STED ratio for Malaysia crosses the critical threshold value in 1997Q2, one quarter before the crisis. Meanwhile, the R/M2 ratio also drops 18.3% before the crisis. For Thailand, the depletion rate of the R/M2 ratio crosses the critical threshold value one quarter prior to the crisis. There is also a large drop of R/STED ratio of 18% during the pre-crisis period. In addition, the R/M2 ratio for Philippines also drops substantially (-16.7%) before the crisis. It should be mentioned that if we just use the R/M2 ratio alone, the predictive performance is bad for Philippines, Malaysia, Indonesia and Singapore. For Philippines, four signals have been generated between 1992 and 1995, but the crisis occurs only in 1997. For Malaysia, there are also four signals, all of which are at least 2 years apart from the 1997 crisis. For Indonesia and Singapore[10], the signals for the 1997 crisis are not generated until 1999. The results are not totally unexpected. If we compare the movement of R/STED in Figure 2 with that of R/M2 in Figure 4, the R/M2 ratio is relatively more stable than the R/STED ratio. As such, R/STED should generate a more timely warning signal as compared to R/M2. However, there are also cases where the R/M2 ratio performs better than or at least as good as the R/STED ratio. For the Thailand case, R/M2 generates a correct signal while R/STED does not. For the cases of China, India and Korea, both indicators have good performance. The results suggest that we should combine the two indicators to generate warning signals.

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[10] Both indicators perform badly in the case of Singapore, even with a lower signal cutoff. A possible explanation is that Singapore has a more developed financial market and a willingness to take effective policies to counter the adverse effects of the crisis, which significantly reduces its vulnerability to the withdrawal of capital. This helps to lower the downward pressure in the foreign exchange market.

**Table 5**: Measures of Predictive Power

| | Using the original threshold estimate | Using 0.75 times the original threshold estimate |
|---|---|---|
| Percentage of pre-crisis periods correctly called | 86 | 86 |
| False alarms as a percentage of total alarms | 36 | 51 |

Table 5 reports the predictive ability of the model. The threshold estimate correctly calls 86 percent of pre-crisis periods, with 36% of false alarms[11]. To see if the predictive power can be improved by using a more conservative threshold, we also use another threshold, which is the original threshold estimate multiplied by 0.75, to see if it gives a better warning with fewer false alarms. Note from Table 5 that if the 75% threshold estimate is used, there is no improvement in the percentage of correctly called pre-crisis periods, but the fraction of false alarms increases. Almost half of the signals are false alarms, which come mainly from the cases of Malaysia and Philippines in 1992Q3-1995Q1, a period when exchange rates are highly volatile in both countries[12].

## 5. Conclusions

The existing crisis indicators in the literature are essentially static. This paper explores the connection between the dynamics of reserves and currency crises. Using a panel data set of eight Asian countries from 1990 to 2003, a threshold model is estimated to monitor the dynamics of foreign reserves. We show that there is no threshold effect for the depletion rate of the Reserves-to-Imports ratio.

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[11] Similar to Abiad (2003), a pre-crisis period is correctly called when either the depletion of R/STED or R/M2 is below the cutoff value and the crisis ensues within 4 quarters. A false alarm is observed when the depletion of R/STED or R/M2 falls below the cutoff value but there is no crisis within 4 quarters.

[12] Zhang (2001) and Abiad (2003) have identified these periods as Speculative Pressure Episodes in Malaysia.

However significant threshold effects are found for the depletion rates of the Reserves-to-STED ratio and the Reserves-to-M2 ratio. It is observed that the depletion rates tend to cross the threshold values one to three quarters before the occurrence of a crisis. Our method implies that when the Reserves-to-STED ratio drops by more than 29.1%, or when the Reserves-to-M2 ratio drops by more than 24.3% within six months, there is a high likelihood of the occurrence of a crisis. The success in anticipating future currency crises in real time demonstrates that the two leading dynamic indicators can be informative tools that allow the authority to take preemptive measures to avoid a full-blown crisis or at least to mitigate its potential severity. Finally, it should be mentioned that for simplicity our TAR model assumes i.i.d. error terms. Future research along this line may allow the error terms to have long memory (Chong, 2000; Chong and Hinich, 2007).

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