What Cause Currency Crises? A Nonlinear Joint Threshold Approach

Terence Tai-Leung Chong[*,†], Isabel Kit-Ming Yan[‡] and Melvin J. Hinich[§]

Abstract

This paper develops a new threhsold model allowing for multiple threshold variables. Using a sample of 16 economies from 1982 to 2004, we estimate a threshold model which can be used to predict currency crises. We find overwhelming evidence for the existence of a joint threshold effect in the ratio of short-term external liabilities to reserves and the lending rate differential. The threshold values of these two crisis indicators provide guidelines for formulating regulatory policies to minimize the stampede of currency crises.

[*]Corresponding author. Department of Economics, Esther Lee Building, Room 930, the Chinese University of Hong Kong, Shatin, New Territories, Hong Kong. Phone: +(852)2609-8193; Fax: +(852)2603-5805; E-mail: chong2064@cuhk.edu.hk. Webpage: http://www.cuhk.edu.hk/eco/staff/tlchong/tlchong3.htm.

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[‡]Department of Economics and Finance, City University of Hong Kong

[§]Applied Research Laboratories, University of Texas at Austin

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1 Introduction

Threshold model is an ideal econometric technique to estimate the critical value of the factor that triggers a currency crisis. However, previous studies on currency crises suggest that the occurrence of currency crises depend on the values of multiple factors (Eichengreen *et al.*, 1995; Sachs *et al.*, 1996; Frankel and Rose, 1996; Kaminsky, 1998; Edison, 2000). A number of the empirical studies have been concerned with finding relevant crisis indicators (Kaminsky *et al.* 1997; Hali, 2000). Conventional threshold models, however, cannot be used if there are several threshold variables. Thus far, no study has provided a joint test and estimation in the existence of multiple threshold variables due to the lack of modelling techniques in the literature[1]. In this paper, we develop a new model to investigate the joint threshold effect. The selection of the threshold variables is closely guided by the three generations of currency crisis models. The first generation model (Krugman, 1979; Flood and Garber, 1984) suggests that exogenous government budget deficits lay at the root of balance of payment crises. Thus, the pressure on the foreign exchange market increases once the fiscal deficit exceeds a certain threshold. The second-generation model (Obstfeld, 1986) suggests the existence of multiple equilibria in the foreign exchange market, and the change from the "good" equilibrium to the "bad" equilibrium is self-fulfilling. It is argued that the threat of a speculative attack generates expectation-driven increases in interest rates. Thus, one should observe a drastic increase in the domestic interest rate prior to an attack. Krugman (1999) observes

[1] To the authors' knowledge, very few studies have been devoted to models with multiple threshold variables. Two related studies are Astatkie, Watts and Watt (1997) and Xia and Li (1999).

that neither the first nor the second-generation models can explain the 1997 Asian Currency Crisis. The third-generation model is thus developed to examine if international illiquidity in a country's financial system can precipitate the collapse of its exchange rate. When governments implicitly guarantee the debts of financial systems, the problem of moral hazard arises, thereby encouraging overborrowing in short-term foreign currency. When foreign reserves are inadequate, the financial system will be internationally illiquid[2] and highly vulnerable to speculative attacks (McKinnon and Huw, 1996; Chang and Velasco, 1998a and 1998b).

The first-generation model suggests that the fiscal deficit should be a threshold variable. The second-generation model suggests to use the interest rate differential as a threshold variable. The third-generation model indicates that short-term external liabilities relative to reserves is a crucial threshold variable[3]. In this paper, we first test the existence of threshold effect in each of these three factors. The significant factors will be used in our estimation. The model is applied to a panel data set consisting of 16 countries to estimate the joint threshold values of these crisis indicators simultaneously. The identification of the critical threshold values has important policy implications, as they provide guidelines for formulating regulatory policies to minimize the stampede of currency crises. The remainder of this paper is organized as follows: Section 2 presents the new threshold model which captures the nonlinear features of currency crisis indicators. Section 3 discusses the estimation and test results for 16 countries. The final section concludes the paper.

[2] A financial system is internationally illiquid if its short-term obligations in foreign currency exceed the amount of foreign currency to which it can have access at short notice.

[3] For more discussions on foreign debts, one is refereed to Bulow and Rogoff (1989a, b) and Bulow (2002).

2 Data and Model

The sample consists of quarterly data from 1982 Q1 through 2001 Q4 of the following economies: Argentina, Brazil, Chile, Colombia, Mexico[4], Uruguay and Venezuela in Latin America, and Mainland China, Hong Kong, Indonesia, South Korea, Malaysia, the Philippines, Singapore, Taiwan and Thailand in Asia. The primary data sources are International Financial Statistics (IFS), and the websites of both the Asian Development Bank (ADB) and the Bank of International Settlements (BIS). Table A gives the sources and definitions of the variables.

[4]For recent studies on the currency crisis in Mexico, one is referred to Aguiar, M. (2005) and Hutchison and Noy (2006).

Table A: Sources and Definitions of Variables

Predictors	Sources and Definitions
1. Ratio of fiscal deficits to GDP	Fiscal deficit is taken from IFS line 80 and GDP is taken from IFS line 99B.
2. Ratio of short-term external liabilities to foreign exchange reserves	The short-term external debt data is obtained from the Asian Development Bank (ADB) website and the Bank of International Settlements (BIS) website. The cumulative portfolio liabilities data is constructed as the cumulative sum of the portfolio liabilities flow data obtained from IFS line 78BGD. The import data is from IFS line 98C. The foreign exchange reserve data is from IFS line 1L.
3. Lending rate differential	The lending rate differential is constructed as the difference between the 3-month domestic lending rate and that of the US. The lending interest rate is taken from IFS line 60P.
4. Real exchange rate appreciation index	The exchange rate data is obtained from IFS line ..AE..ZF. The exchange rate of China before 1994 Q1 is the swap rate obtained from Global Financial Data. The nominal exchange rate is deflated by the Wholesale Price Index (WPI), which is taken from IFS line 63..ZF, and then the real exchange rate is normalized to 1986 Q1=1.
5. Ratio of domestic credit to GDP	The domestic credit data is taken from IFS line 32.ZF and the GDP data is from IFS line 99B.

To capture the nonlinear feature of currency crisis indicators, we estimate the following model:

$$y_t = \beta_1' x_t + (\beta_2' - \beta_1') x_t \Psi \left(\gamma^0, Z_t\right) + \varepsilon_t, \tag{1}$$

where β_1 and β_2 are the pre-shift and post-shift regression slope parameters respectively, with $\beta_i = (\beta_{1i}\ \beta_{2i}\ ...\ \beta_{Ki})'$ being a K by 1 vector of true parameters, $i = 1, 2$;

y_t is the dependent variable;

x_t is a K by 1 vector of covariates;

$(\varepsilon_1\ \varepsilon_2\ ...\ \varepsilon_T)'$ is a T by 1 vector of error term ε_t, which are assumed to be independent of both the regressors and the threshold variables.

$Z_t = (z_{1t}, ..., z_{mt})$ is a vector of m threshold variables, where $0 < m < \infty$;

$\gamma_0 = \left(\gamma^0_{1,...,}\gamma^0_m\right) \in \Pi_{j=1}^m \left[\underline{\gamma_j}, \overline{\gamma_j}\right]$ is a vector of m true threshold parameters to be estimated;

$\Psi\left(\gamma^0, Z_t\right)$ is an indicator function, which equals one when the threshold variables satisfy certain required conditions, and equals zero otherwise. For example, if the parameters change when all of the threshold variables exceed some critical values, then we have:

$$\Psi \left(\gamma^0, Z_t\right) = I \left(z_{1t} > \gamma^0_1, ..., z_{mt} > \gamma^0_m\right). \tag{2}$$

In the scenario of currency crises, imposing such a threshold condition implies that the crisis will not be triggered until all of the threshold variables exceed the critical thresholds. If the condition is that at least one threshold variable exceeds the critical value, then

$$\Psi \left(\gamma^0, Z_t\right) = 1 - I \left(z_{1t} \leq \gamma^0_1, ..., z_{mt} \leq \gamma^0_m\right). \tag{3}$$

In this case, we let $w_{jt} = -z_{jt}$, then

$$\Psi \left(\gamma^0, Z_t\right) = 1 - \Psi \left(-\gamma^0, W_t\right).$$

As the second case can be incorporated into the first, we will focus on the first case in this paper[5]. First, we derive the estimators of the structural and threshold parameters. For notational simplicity, we let

$$\Psi_t\left(\gamma^0\right) = \Psi\left(\gamma^0, Z_t\right) = I\left(z_{1t} > \gamma_1^0, z_{2t} > \gamma_2^0\right). \tag{4}$$

Given $\gamma = (\gamma_1, \gamma_2)$, the OLS estimators of β are

$$\widehat{\beta}_1'\left(\gamma\right) = \sum_{t=1}^{T} y_t x_t' \left(1 - \Psi_t\left(\gamma\right)\right) \left(\sum_{t=1}^{T} x_t x_t' \left(1 - \Psi_t\left(\gamma\right)\right)\right)^{-1} \tag{5}$$

and

$$\widehat{\beta}_2'\left(\gamma\right) = \sum_{t=1}^{T} y_t x_t' \Psi_t\left(\gamma\right) \left(\sum_{t=1}^{T} x_t x_t' \Psi_t\left(\gamma\right)\right)^{-1}. \tag{6}$$

Define

$$S_T\left(\gamma\right) = \sum_{t=1}^{T} \left(y_t - \widehat{\beta}_1'\left(\gamma\right) x_t - \left(\widehat{\beta}_2'\left(\gamma\right) - \widehat{\beta}_1'\left(\gamma\right)\right) x_t \Psi_t\left(\gamma\right)\right)^2, \tag{7}$$

$$\widehat{\gamma} = \left(\widehat{\gamma}_1, \widehat{\gamma}_2\right) = \arg \min_{(\gamma_1,\gamma_2)\in\Gamma_T} S_T\left(\gamma_1, \gamma_2\right), \tag{8}$$

where

$$\Gamma_T = \Pi_{j=1}^{2}\left(\left[\underline{\gamma_j}, \overline{\gamma_j}\right] \cap \left\{z_{j1}, ..., z_{jT}\right\}\right). \tag{9}$$

The final estimators of β are therefore defined as

$$\widehat{\beta}_1\left(\widehat{\gamma}_1, \widehat{\gamma}_2\right)$$

and

$$\widehat{\beta}_2\left(\widehat{\gamma}_1, \widehat{\gamma}_2\right).$$

[5] For illustration purposes, we will study the case where $m = 2$. The methods extend in a straightforward manner to models with more than two threshold variables.

3 Application to Currency Crises

The empirical relevance of our model is illustrated through an application on currency crisis. The model is specified as follows:

$$y_{it} = \mu_i + \beta_1' \mathbf{x}_{it} + \left(\beta_2' - \beta_1'\right) \mathbf{x}_{it} \Psi\left(\mathbf{z}_{it}, \boldsymbol{\gamma}\right) + \varepsilon_{it}. \tag{10}$$

Currency crises will not be triggered until all of the threshold variables exceed the critical thresholds. This implies

$$\Psi\left(\mathbf{z}_t, \gamma^0\right) = \Pi_{j=1}^{m} I\left(\mathbf{z}_{jt} > \gamma_j^0\right). \tag{11}$$

The fixed effect transformation described in Appendix 1 is used to remove the individual-specific means from the panel data. The number of threshold variables (m) to be included in the model is determined by the test discussed in Appendix 2.

3.1 Dependent variable

In our threshold model, the dependent variable y_{it} is the exchange market pressure index (EMP_{it}), which is measured as the weighted average of the percentage change in the nominal exchange rate, the change in the differential between the domestic and foreign discount rate (the "policy rate"), as well as the percentage change in the foreign exchange reserves of a country[6]. It is defined as:

$$EMP_{it} \equiv [(\alpha_1 \ \%\Delta e_{it}) + (\alpha_2 \ \Delta(i_{it} - i_{US,t})) - (\alpha_3 \ \%\Delta r_{it})], \tag{12}$$

where

$\%\Delta e_{it}$ denotes the percentage change in the exchange rate of country i with respect to the U.S. dollar at time t;

[6] This index has been employed in a number of studies, including Eichengreen *et al.* (1996), Frankel and Rose (1996), Sachs *et al.* (1996) and Goldstein *et al.* (2000). Central banks can respond to a downward pressure in the foreign exchange market in three ways: (1) let the exchange rate depreciate, (2) defend the currencies by depleting reserves, or (3) raise the discount rate.

$\Delta(i_{it} - i_{US,t})$ denotes the change in the differential between the short-term discount rate in country i and the US at time t;

$\%\Delta r_{it}$ denotes the percentage change in the foreign exchange reserves of country i at time t; and

α_1, α_2 and α_3 are the weights that are defined as the inverse of the standard deviations of the respective components over the past ten years. The weights are assigned in order to equalize the volatilities of these three components.

3.2 Regressors and threshold variables

We include two fundamentals as the explanatory variables (x_{it}) in the threshold regression. These variables include the real exchange rate appreciation index and the ratio of domestic credit to GDP (Dornbusch *et al.*, 1995; Frankel and Rose, 1996; Sachs *et al.*, 1996), both in natural logarithm. The real exchange rate appreciation index measures the change in the real exchange rate index relative to the base period (1986 Q1) and is employed to capture the degree of exchange rate misalignment over the sample period. A large cumulative appreciation in the real exchange rate index signifies a high possibility that the currency is overvalued, and hence there is a stronger pressure for it to revert to the mean. Although this measure of misalignment is only an indirect measure and does not control for long-run productivity changes, it is commonly used in the literature to identify countries whose currencies have experienced extreme overvaluations.

The domestic credit variable is measured as the claims on the private sector by deposit money banks and monetary authorities. It reflects the vulnerability of the banking sector to non-performing loans and is dubbed the "lending boom effect" in the literature. As there is no internationally comparable ratio of non-performing loans to total assets, the ratio of domestic credit to GDP is employed because it is presumed that a sharp bank lending boom over a short period reduces the banks' ability

Table 1: Threshold variables implied by the three generations of currency crisis models

Crisis models	$\mathbf{z}_{it}$
First-generation crisis model	ratio of fiscal deficits to GDP
Second-generation crisis model	differentials between the domestic interest rate and foreign interest rate
Third-generation crisis model	ratio of short-term external liabilities to foreign exchange reserves

to screen out marginal projects. This makes the banks more vulnerable to the vagaries of economic fluctuations.

The threshold variables $\mathbf{z}_{it}$ are selected based on the insights from the three generations of currency crisis model. Table 1 summarizes the threshold variables $\mathbf{z}_{it}$ that are implied by the three generations of currency crisis models. The ratio of fiscal deficit to GDP is defined as the total government expenditure minus the total government revenue normalized by GDP. The interest rate differential is constructed as the difference between the 3-month domestic and US lending rates. Short-term external liabilities are measured as the sum of the short-term external debt, the cumulative portfolio liabilities and six-month imports. When the threshold variables exceed their thresholds, the economy endogenously enters an unstable regime that accelerates the downward pressure in the foreign exchange market. To avoid the endogeneity problem in the estimation, we make use of the average of the lags in the previous four quarters for all of the regressors and threshold variables. Appendix 3 provides a detailed description of the sources of the variables.

3.3 Testing the number of threshold variables

In this section, we apply the tests described in Appendix 2 to test the presence of threshold effects of the three threshold variables. The test statistics and p-values[7] for testing zero against one, one against two, and two against three threshold variables are performed and the results are reported in Tables 2(a), 2(b) and 2(c). The tests for zero against one threshold variable are all highly significant, with p-values of 0.000, 0.040 and 0.000 for the fiscal deficits, short-term external liabilities and lending rate differentials variables respectively.

The tests for one against two threshold variables are statistically significant for almost all of the cases with p-values close to 0, except for the cases in which the fiscal deficit variable is dropped from the pair of fiscal deficit and short-term external liabilities, and from the pair of fiscal deficit and lending rate differential under the alternative. The p-values for these two cases are 0.6243 and 0.5746. When testing two against three threshold variables, the null hypothesis that the fiscal deficit variables can be dropped from the list of three cannot be rejected, and the p-value is 0.9906. Thus, we conclude that there is strong evidence of two threshold variables in the regression relationship. They are the ratio of

[7] As the asymptotic distribution of the test statistic is non-standard and generally depends on the moments of the sample, we use a bootstrap procedure to approximate the sampling distribution of the test statistic. First, we estimate the model under the *alternative* hypothesis. Then, we group the regression residuals (after fixed-effect transformation) $\widehat{\varepsilon}_{it}^{*}$ by individual $\widehat{\varepsilon}_{i}^{*}$ =($\widehat{\varepsilon}_{it}^{*}$, $\widehat{\varepsilon}_{i2}^{*}$,....., $\widehat{\varepsilon}_{iT}^{*}$) and draw with replacement error sample of individual i $\widehat{\varepsilon}_{it}^{b*}$ $(t = 1, 2, ..., T)$ from this empirical distribution $\widehat{\varepsilon}_{i}^{*}$. This gives the bootstrap errors. The bootstrap dependent variable y_{it}^{b*} is then generated under the *null* hypothesis, which depends on the LS estimates $\widehat{\beta}$ and $\widehat{\gamma}$ of the threshold model under the null. From the bootstrap sample $\left\{x_{it}^{*}, y_{it}^{b*}\right\}$, we calculate the test statistic. This procedure is repeated a large number of times and the p-value of the test statistic is calculated as $p = \frac{1}{B}\sum_{b=1}^{B} I\left\{F^{b} > F^{actual}\right\}$ where F^{b} is the test statistic computed from one bootstrap sample, F^{actual} is the test statistic computed from the actual data, and B is the number of bootstrap replications. In this paper, 3000 bootstrap replications are used for each of the tests. The null hypothesis is rejected if the p-value is smaller than the desired significance level.

Table 2: (a) Testing one threshold variable against no threshold variable

	$H_0 : m = 0$		
	$H_1 : m = 1$ (fiscal deficit)	$H_1 : m = 1$ (short liability)	$H_1 : m = 1$ (lending rate diff.)
F	32.91	18.14	63.33
p-value	0.0000**	0.0400*	0.0000**

Note: The numbers in parentheses are the p-values. "*" means the test statistic is significant at the 5% level and "**" means the test statistic is significant at the 1% level. 3000 bootstrap replications are used for each of the test.

short-term external liabilities to reserves and the lending rate differential. For the remainder of the paper we employ a threshold model with these two threshold variables.

An explanation for the absence of threshold effect in the fiscal deficit variable is that fiscal deficits are often closely related to the interest rate differentials in practice and hence only one of the two needs to be included as the threshold variable. This is because large fiscal deficits are commonly financed by excessively expansionary monetary policies, which drive up the risk premium of the domestic currency and widen the interest rate differential. In addition, if a large fiscal deficit is accompanied by a high public debt, the government can only roll over its short-term public debt by offering a higher domestic interest rate, which results in a larger interest rate differential.

3.4 Estimation Results

We estimate the threshold values of the two threshold variables: the ratio of short-term external liabilities to reserves and the lending rate

Table 2: (b) Testing two threshold variables against one threshold variable

	$H_0 : m = 1$ (fiscal deficit)	$H_0 : m = 1$ (short liabilities)
	$H_1 : m = 2$ (fiscal deficit, short liabilities)	
F	10.74	3.62
p-value	0.0000**	0.6243
	$H_0 : m = 1$ (fiscal deficit)	$H_0 : m = 1$ (lending rate diff.)
	$H_1 : m = 2$ (fiscal deficit, lending rate diff.)	
F	34.56	1.1813
p-value	0.0000**	0.5746
	$H_0 : m = 1$ (short liabilities)	$H_0 : m = 1$ (lending rate diff.)
	$H_1 : m = 2$ (short liabilities, lending rate diff.)	
F	92.74	42.40
p-value	0.0000**	0.0000**

Table 2: (c) Testing three threshold variables against two threshold variables

	$H_0 : m = 2$ (fiscal deficit, short liabilities)	$H_0 : m = 2$ (fiscal deficit, lending diff.)	$H_0 : m = 2$ (short liabilities, lending diff.)
	$H_1 : m = 3$ (fiscal deficit, short liabilities, lending rate diff.)		
F	89.07	41.42	0.2393
p-value	0.0000**	0.0000**	0.9906

differential. The threshold estimates are obtained by searching through values of γ that equal the distinct values of the threshold variables in our sample[8]. To allow for different thresholds for countries in different geographical regions, we divide the sample countries into two groups: the Asian and the Latin American group. The estimation results are shown in Table 3. The estimates of the ratio of short-term external liabilities to reserves for the Asian and Latin American countries are 3.1758 and 3.9851 respectively. The point estimates for the lending rate differential for the Asian and Latin American countries are 2.0566 and 21.8866 percentage points (or 205.66 and 2188.66 basis points). The test statistics for testing the joint significance of the two threshold variables ($H_0 : m = 0$ against $H_1 : m = 2$) are highly significant for countries in both regions. The test statistic along with the p-value are 33.83 and 0.0000 for the Asian countries and are 34.03 and 0.0000 for the Latin American countries. The p-values are obtained by the bootstrap procedure and they provide strong evidence of presence of threshold effects. When both threshold variables exceed the critical thresholds, the economy enters a zone of vulnerability and is likely to undergo an extreme downward adjustment in the foreign exchange market. Thus, our estimates can be used by governments to formulate regulatory policies to reduce the risk of currency crises by taking preemptive measures to avoid the threshold variables from crossing these critical values.

The coefficients of the ratio of domestic credit to GDP for both the Asian and Latin American countries are significantly positive when both threshold variables surpass the critical thresholds (i.e., $\Psi\left(\mathbf{z}_{it}, \boldsymbol{\gamma}\right) = 1$). This indicates that the vulnerability of the banking sector is a crucial factor in determining the exchange market pressure under this regime.

[8]As it is undesirable for a threshold $\widehat{\gamma}$ to be selected if too few observations fall into one or the other regime, we eliminate the smallest and largest 15 percent of each threshold variable when setting up the values of γ to be searched for $\widehat{\boldsymbol{\gamma}}$. The $\widehat{\boldsymbol{\gamma}}$ that minimizes the sum of squared residuals is selected.

Table 3: Estimates of the threshold models with two threshold variables

$\mathbf{y}_{it} \equiv$ exchange market pressure index (EMP_{it})

$\mathbf{z}_{it} \equiv \{\frac{\text{short term external liabilities}}{\text{reserves}}$, lending rate differentials$\}$

$\mathbf{x}_{it} \equiv \{1$, real exchange rate appreciation index, $\frac{\text{Domestic credit}}{\text{GDP}}\}$

	Asian countries		Latin American countries	
	(i)	(ii)	(iii)	(iv)
Explanatory variables	$\Psi(\mathbf{z}_{it}, \boldsymbol{\gamma}) = 0$	$\Psi(\mathbf{z}_{it}, \boldsymbol{\gamma}) = 1$	$\Psi(\mathbf{z}_{it}, \boldsymbol{\gamma}) = 0$	$\Psi(\mathbf{z}_{it}, \boldsymbol{\gamma}) = 1$
Constant	0.0448	-0.1869	0.0487	0.1718
	(0.4604)	(-1.2341)	(0.3814)	(0.9664)
Real exch. rate appreciation	0.3016	2.0908	-1.0869	3.8312
	(0.7183)	(3.8008)**	(-2.7877)**	(6.4454)**
$\frac{\text{Domestic credit}}{\text{GDP}}$	1.3863	0.7857	1.4432	4.5549
	(3.2736)**	(2.4092)*	(2.0413)*	(5.5229)**
threshold estimates				
$\frac{\text{Short term external liabilities}}{\text{Reserves}}$	1.8532		2.0036	
Lending rate differentials	1.3425		10.39	
F stat	16.63		73.45	
p value	0.0346*		0.0000**	
Observations	641		379	

Note: The numbers in parentheses are the t-statistics. "*" means that the t statistic is significant at the 5% level and "**" means that the t statistic is significant at the 1% level.

3.5 Predicting the crises

Given the threshold estimates of 1.8532 for the short-term external liability variable and 1.3425 for the lending rate differential variable for the Asian countries, and given the estimates of 2.0036 and 10.39 for the Latin American countries, we study how well these threshold values can be used to distinguish the normal regime from the crisis regime in foreign exchange markets. We define crisis episodes as extreme values of the exchange market pressure index,

$$\begin{aligned} Crisis_{it} &= 1 \quad \text{if } EMP_{it} > \mu_{EMP,it} + 3\sigma_{EMP,it} \\ &= 0 \quad \text{otherwise} \end{aligned}$$

where $\mu_{EMP,it}$, $\sigma_{EMP,it}$ are the mean and standard deviation of the exchange market pressure index in country i and time t. The dates of the crisis episodes in the sample are reported in Table 4.

The threshold effects are illustrated in Figures 1 and 2, which show the values of the threshold variables (represented by the bars in the figures), the critical thresholds (the dashed lines), as well as the exchange market pressure index (the solid lines) of the Latin American and Asian countries. The crisis episodes are shaded in grey. The figures indicate that the threshold variables perform reasonably well in predicting regime shifts. For instance, Figure 1(i) shows that the ratio of short-term external liabilities to reserves and lending rate differential started to go above the critical thresholds less than two years before the 1997 Thai crisis, and remained above the thresholds at the outbreak of the crises. Figure 1(d) indicates that the 1997 South Korean crisis occurred just 3

Table 4: Dates of Crisis Episodes

Countries	Crisis Episodes
1. Argentina	2001Q4
2. Brazil	1995Q4, 1998Q3-1999Q1, 2000Q2
3. Chile	1990Q4
4. China	1992Q3-1993Q2
5. Colombia	None
6. Hong Kong	None
7. Indonesia	1997Q3-1998Q2
8. S. Korea	1997Q4
9. Malaysia	1997Q3-Q4, 1998Q2
10. Mexico	1994Q4
11. Philippines	1984Q1, 1997Q3
12. Singapore	1997Q3-Q4, 1998Q2
13. Taiwan	1997Q4
14. Thailand	1981Q3, 1997Q3-Q4
15. Uruguay	1994Q3-1995Q2
16. Venezuela	1994Q2
Note: Crisis episodes that occurred within one year of each other in the same country are considered as one continuous episode.	

quarters after the lending rate differential exceeded the critical threshold, given that the short-term external liabilities had already surpassed the threshold a while ago. Figure 2(b) indicates that both the ratio of short-term external liabilities to reserves and lending rate differential started to exceed the critical thresholds within half a year prior to the Brazilian crisis of 1998 and remained above the thresholds throughout the crisis. Thus, our model predicts currency crises with high accuracy. However, we do observe a false alarm, which occurred in S. Korea in 1992-94. One possible explanation for this is that the major Chaebols in Korea had taken sizeable increases in investment during this period as a result of the Chaebol reform[9]. The reform partially helped to pull the Korean economy out of an imminent crisis (Bedeski, 1994).

4 Conclusions

In this article, we examine the currency crises in 16 countries. Three candidates of crisis indicators are examined in turn. The first one is fiscal deficit of a country. The second indicator is the differential between the domestic interest rate and the foreign interest rate. The third one is a measure of the external illiquidity. We find evidence of threshold effects in the latter two indicators, which suggests that switches from the non-crisis state to the crisis state are characterized by a widening of the interest rate differential combined with a substantial rise in the short-term external liabilities. Evidence of nonlinearity in the currency crisis indicators has several important implications: First, our results indicate the validity of the second- and third-generation currency crisis models. Second, a better currency crisis prediction method can be developed by improving the new threshold model of this paper. Finally, since our model is able to forecast currency crises with a fairly good

[9]The Hyundai group cast the 1990s as a decade for high-tech development. The Lucky-Goldstar group, Samsung group and the Daewoo group also made a great leap forward in their investment.

accuracy, the joint threshold values of the crisis indicators can be used by governments as guidelines in the regulation of short-term external borrowing and interest rate differentials.

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Appendix 1: Model with Panel Data

The model in Section 2 can be extended to incorporate panel data. We consider a balanced panel with n individuals over T periods. We assume that all individuals have the same threshold value for each threshold variable and let

$$\Psi_{it}(\gamma) = I(z_{1it} > \gamma_1, z_{2it} > \gamma_2).$$

The observations are divided into two regimes depending on whether the threshold variable vector satisfies the threshold conditions. We assume that x_{it} and Z_{it} are not time invariant. The model is

$$y_{it} = \mu_i + \beta_1' x_{it} + \varepsilon_{it}, \quad \Psi_{it}(\gamma) = 0, \tag{13}$$

$$y_{it} = \mu_i + \beta_2' x_{it} + \varepsilon_{it}, \quad \Psi_{it}(\gamma) = 1. \tag{14}$$

Let

$$x_{it}(\gamma) = x_{it}\Psi_{it}(\gamma), \tag{15}$$

$$y_{it} = \mu_i + \beta_1' x_{it} + \delta' x_{it}\Psi_{it}(\gamma) + \varepsilon_{it}. \tag{16}$$

Averaging the above panel equation over t, we have

$$\overline{y}_i = \mu_i + \beta_1' \overline{x}_i + \delta' \overline{x}_i(\gamma) + \overline{\varepsilon}_t, \tag{17}$$

where

$$\overline{y}_i = \frac{1}{T}\sum_{t=1}^{T} y_{it}, \tag{18}$$

$$\overline{x}_i = \frac{1}{T}\sum_{t=1}^{T} x_{it}, \tag{19}$$

$$\overline{x}_i(\gamma) = \frac{1}{T}\sum_{t=1}^{T} x_{it}\Psi_{it}(\gamma), \tag{20}$$

$$\overline{\varepsilon}_t = \frac{1}{T}\sum_{t=1}^{T} \varepsilon_{it}. \tag{21}$$

Taking the difference, we have

$$y_{it}^* = \beta_1' x_{it}^* + \delta' x_{it}^*(\gamma) + \varepsilon_{it}^*, \tag{22}$$

where

$$y_{it}^* = y_{it} - \overline{y}_i, \tag{23}$$

$$x_{it}^* = x_{it} - \overline{x}_i, \tag{24}$$

$$x_{it}^*(\gamma) = x_{it}(\gamma) - \overline{x}_i(\gamma), \tag{25}$$

$$\varepsilon_{it}^* = \varepsilon_{it} - \overline{\varepsilon}_i. \tag{26}$$

We let

$$y_i^* = \begin{bmatrix} y_{i2}^* \\ \vdots \\ y_{iT}^* \end{bmatrix}, x_i^* = \begin{bmatrix} x_{i2}^* \\ \vdots \\ x_{iT}^* \end{bmatrix}, x_i^*(\gamma) = \begin{bmatrix} x_{i2}^*(\gamma) \\ \vdots \\ x_{iT}^*(\gamma) \end{bmatrix}, \varepsilon_i^* = \begin{bmatrix} \varepsilon_{i2}^* \\ \vdots \\ \varepsilon_{iT}^* \end{bmatrix}$$

denote the stacked data and errors for an individual, with one time period deleted. Let Y^*, $X^*(\gamma)$ and ε^* denote the data that is stacked over all individuals, i.e.,

$$Y^* = \begin{bmatrix} y_1^* \\ \vdots \\ y_i^* \\ \vdots \\ y_n^* \end{bmatrix}, X^* = \begin{bmatrix} x_1^* \\ \vdots \\ x_i^* \\ \vdots \\ x_n^* \end{bmatrix}, X^*(\gamma) = \begin{bmatrix} x_1^*(\gamma) \\ \vdots \\ x_i^*(\gamma) \\ \vdots \\ x_n^*(\gamma) \end{bmatrix}, \varepsilon^* = \begin{bmatrix} \varepsilon_1^* \\ \vdots \\ \varepsilon_i^* \\ \vdots \\ \varepsilon_n^* \end{bmatrix}.$$

Thus, the model becomes

$$Y^* = X^*\beta_1 + X^*(\gamma)\boldsymbol{\delta} + \varepsilon^*. \tag{27}$$

Thus, the estimation method in the previous section can be applied in the panel model. We have

$$S_{nT}(\gamma) = (Y - X^*\beta_1 - X^*(\gamma)\boldsymbol{\delta})'(Y - X^*\beta_1 - X^*(\gamma)\boldsymbol{\delta})$$

$$\widehat{\gamma} = (\widehat{\gamma}_1, \widehat{\gamma}_2) = \arg\min_{\gamma\in\Gamma_n} S_T(\gamma_1, \gamma_2). \tag{28}$$

$$\Gamma_n = \Pi_{j=1}^2 \left(\left[\underline{\gamma_j}, \overline{\gamma_j} \right] \cap \left(\cup_{i=1}^n \{z_{ji1}, ..., z_{jiT}\} \right) \right) \tag{29}$$

The final estimators for β are then defined as

$$\widehat{\beta}_1(\widehat{\gamma}_1, \widehat{\gamma}_2)$$

and

$$\widehat{\beta}_2(\widehat{\gamma}_1, \widehat{\gamma}_2).$$

and the residual variance is

$$\widehat{\sigma}^2 = \frac{1}{n(T-1)} S_{nT}(\widehat{\gamma}). \tag{30}$$

Appendix 2: Testing for the Number of Threshold Variables

To test for the number of threshold variables, we start with a threshold model without thresholds, and sequentially test whether this model can be rejected in favor of a threshold model with one additional threshold variable. First, we test the hypothesis of no threshold against the alternative hypothesis of one threshold variable,

$$H_0 : m = 0$$
$$H_1 : m = 1$$

Define

$$F(0,1,1) = T\frac{S_T(-\infty,-\infty) - S_T(\widehat{\gamma}_1,-\infty)}{S_T(\widehat{\gamma}_1,-\infty)}, \tag{31}$$

$$F(0,1,2) = T\frac{S_T(-\infty,-\infty) - S_T(-\infty,\widehat{\gamma}_2)}{S_T(-\infty,\widehat{\gamma}_2)}, \tag{32}$$

where

$S_T(-\infty,-\infty)$ is the residual sum of squares from the regression without any threshold variable;

$S_T(\widehat{\gamma}_1,-\infty)$ is the residual sum of squares from the regression without the second threshold variable; and

$S_T(-\infty,\widehat{\gamma}_2)$ is the residual sum of squares from the regression without the first threshold variable.

For the notation $F(\cdot,\cdot,\cdot)$, the first entry in the parenthesis stands for the value of m under the null hypothesis. The second entry represents the value of m under the alternative hypothesis. The last entry indicates that the test is on the i^{th} threshold variable. If the null cannot be rejected for both threshold variables, then we conclude that there is no threshold effect. If the null is rejected for at least one of the threshold variables, then we proceed to the second step of testing one threshold variable against two threshold variables:

$$H_0 : m = 1$$
$$H_1 : m = 2$$

Define

$$F(1,2,1) = T \frac{S_T(\widehat{\gamma}_1, -\infty) - S_T(\widetilde{\gamma}_1, \widetilde{\gamma}_2)}{S_T(\widetilde{\gamma}_1, \widetilde{\gamma}_2)}, \tag{33}$$

$$F(1,2,2) = T \frac{S_T(-\infty, \widehat{\gamma}_2) - S_T(\widetilde{\gamma}_1, \widetilde{\gamma}_2)}{S_T(\widetilde{\gamma}_1, \widetilde{\gamma}_2)}, \tag{34}$$

where $S_T(\widetilde{\gamma}_1, \widetilde{\gamma}_2)$ is the residual sum of squares from the regression by imposing both threshold variables. If the null is rejected in both cases, then we conclude that there are two threshold variables. If we reject the null in the first step for the first threshold variable and cannot reject it in the second test, then we conclude that the first variable is the only threshold variable. A similar argument applies to the second threshold variable.

As the asymptotic distributions of the above tests are non-standard, we bootstrap their critical values. For the case of $m = 0$ against $m = 1$, the bootstrap is carried out R times if we have R potential candidates of threshold variables. For the tests in the next steps, we first treat the regressors and the threshold variables as given, holding their values fixed in repeated bootstrap samples. We then use the regression residuals under H_1 as the empirical distribution. Next, we draw a sample of size T with replacement from this empirical distribution and use the errors to create a bootstrap sample under H_0. The values of β and threshold parameters are fixed at their estimated values under H_0. We repeat this procedure and calculate the percentage of draws for which the simulated statistic exceeds the actual value. This is the bootstrap estimate of the asymptotic p-value under H_0. The null hypothesis is rejected if the p-value is too small. For example, consider a panel model, if we are to test

$$H_0 : m = 1$$
$$H_1 : m = 2$$

We estimate the threshold model with two threshold variables, take its OLS residuals and draw the bootstrap $\widehat{\varepsilon}_{it}^{b*}$ residuals from them ($i = 1, 2, ..., n$; $t = 1, 2, ..., T$). Then we use the bootstrap residuals along with the estimated threshold model with one threshold variable to generate the bootstrap dependent variable:

$$y_{it}^{b*} = \widehat{\beta}_1' \mathbf{x}_{it}^* + \left(\widehat{\beta}_2' - \widehat{\beta}_1'\right) \mathbf{x}_{it}^* \Psi\left(z_{it}, \widehat{\gamma}_1\right) + \widehat{\varepsilon}_{it}^{*b}. \tag{35}$$

Using the set of dependent and independent variables $\left\{\mathbf{x}_{it}^*, y_{it}^{b*}\right\}$, we can estimate the model under the alternative hypothesis (in this case, a threshold model with two threshold variables) and compute its sum of squared residuals $S_{nT}\left(\widetilde{\gamma}_1^b, \widetilde{\gamma}_2^b\right)$. The sum of squared residuals under the null is $S_{nT}\left(\widehat{\gamma}_1, -\infty\right) = \sum_{t=1}^{T}\sum_{i=1}^{n} \widehat{\varepsilon}_{it}^{*b}$. The test statistic for testing two threshold variables under the alternative against the null that only the first threshold variable should appear in the model is

$$F\left(1, 2, 1\right) = nT \frac{S_{nT}\left(\widehat{\gamma}_1, -\infty\right) - S_{nT}\left(\widetilde{\gamma}_1^b, \widetilde{\gamma}_2^b\right)}{S_{nT}\left(\widetilde{\gamma}_1^b, \widetilde{\gamma}_2^b\right)}. \tag{36}$$

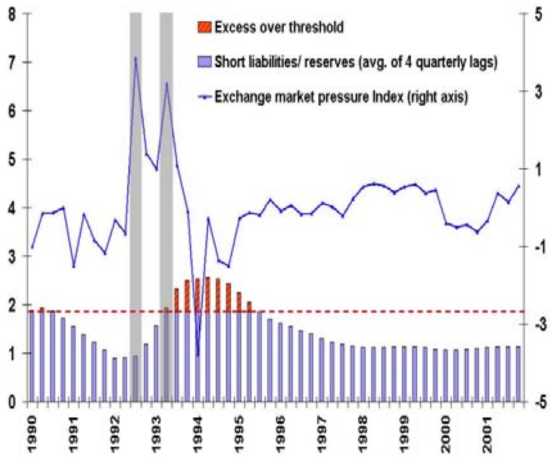
For testing whether only the second threshold variable should appear in the model, the test statistic is

$$F\left(1, 2, 2\right) = nT \frac{S_{nT}\left(-\infty, \widehat{\gamma}_2\right) - S_{nT}\left(\widetilde{\gamma}_1^b, \widetilde{\gamma}_2^b\right)}{S_{nT}\left(\widetilde{\gamma}_1^b, \widetilde{\gamma}_2^b\right)}. \tag{37}$$

Figure 1: Threshold Effects and Exchange Market Pressure Index of selected Asian Countries

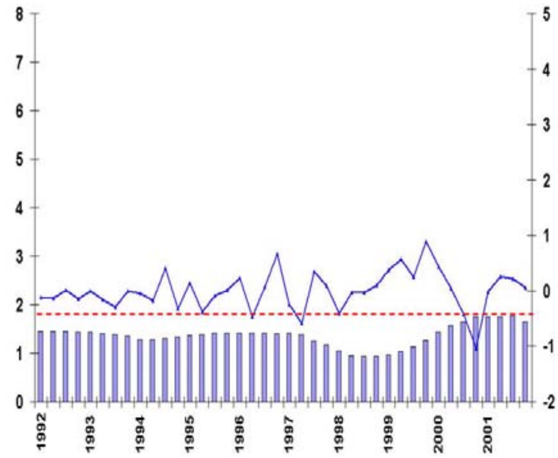
(a): **China**

$\frac{\text{Short-term external liabilities}}{\text{Reserves}}$

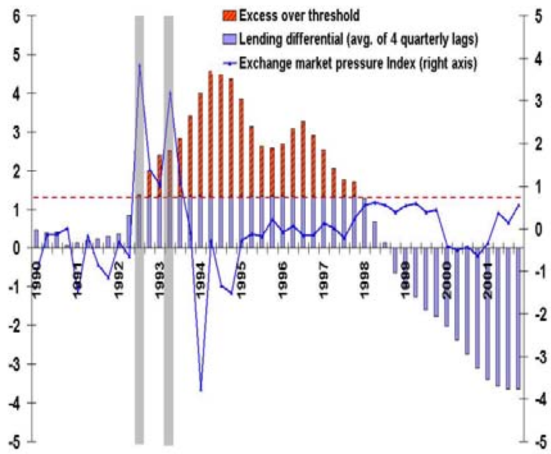


(b): **Hong Kong**

$\frac{\text{Short-term external liabilities}}{\text{Reserves}}$



Lending rate differential



Lending rate differential

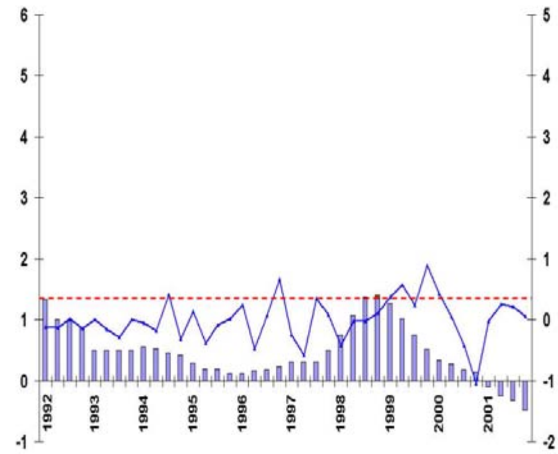
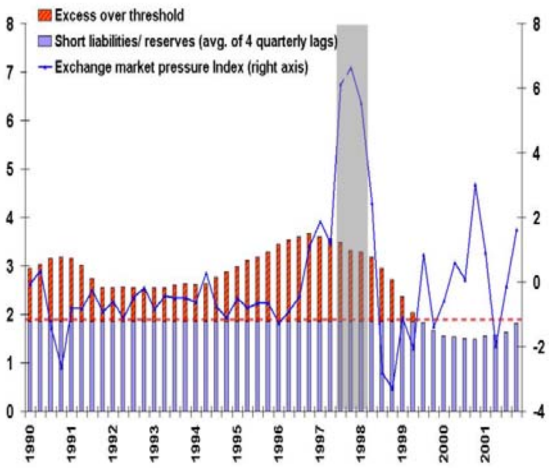


Figure 1: Threshold Effects and Exchange Market Pressure Index of selected Asian Countries (Continued)

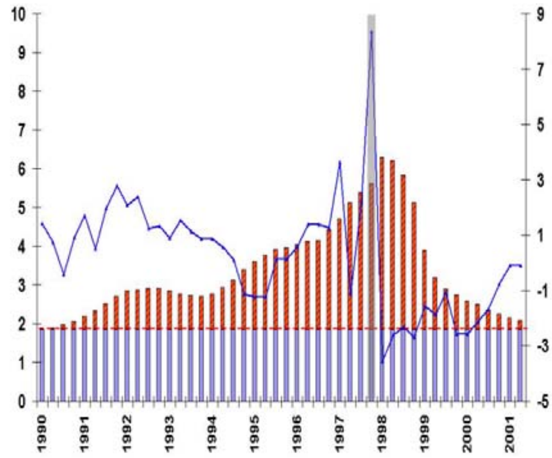
(c): **Indonesia**

$\frac{\text{Short-term external liabilities}}{\text{Reserves}}$

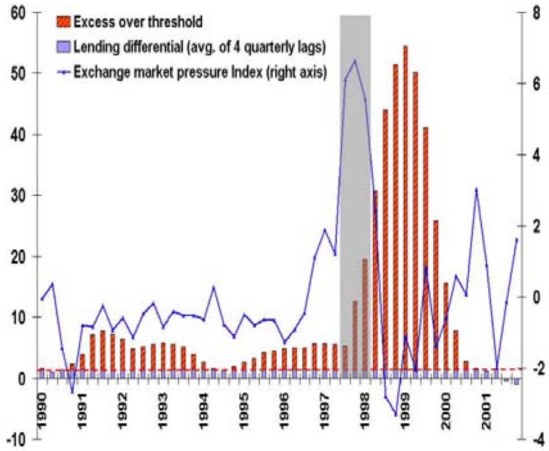


(d): **S. Korea**

$\frac{\text{Short-term external liabilities}}{\text{Reserves}}$



Lending rate differential



Lending rate differential

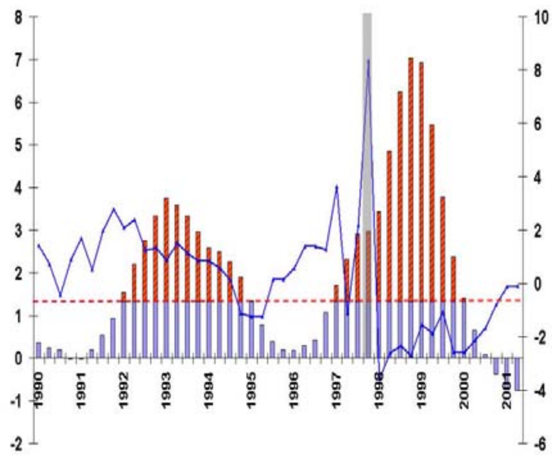
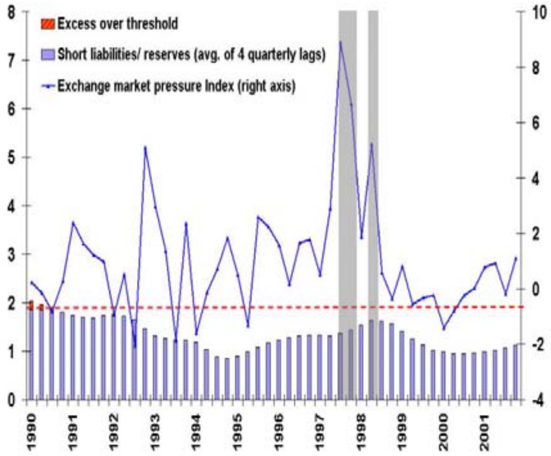


Figure 1: Threshold Effects and Exchange Market Pressure Index of selected Asian Countries (Continued)

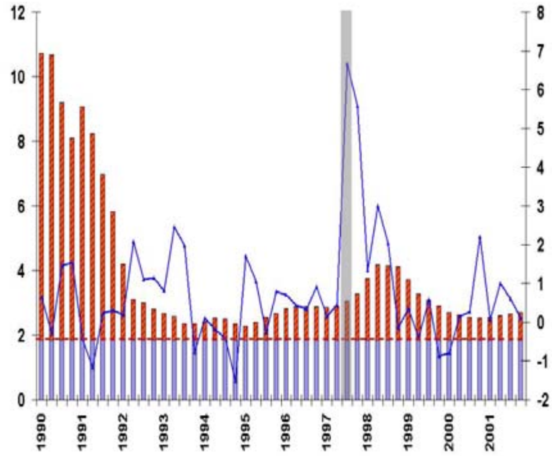
(e): **Malaysia**

$\frac{\text{Short-term external liabilities}}{\text{Reserves}}$

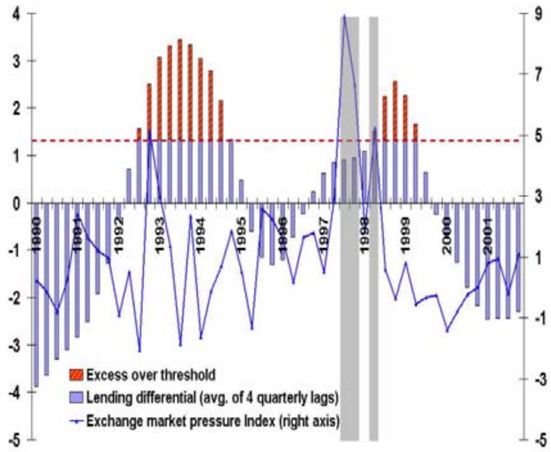


(f): **Philippines**

$\frac{\text{Short-term external liabilities}}{\text{Reserves}}$



Lending rate differential



Lending rate differential

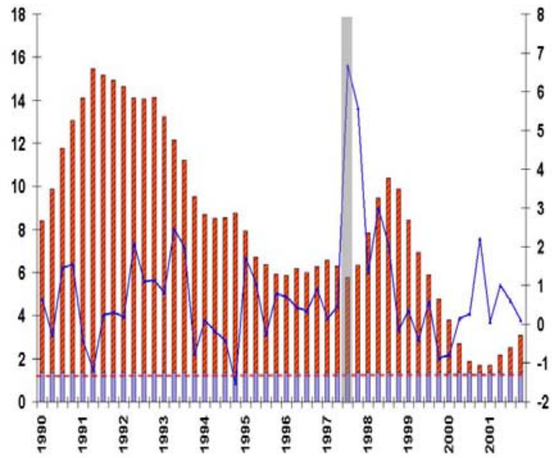
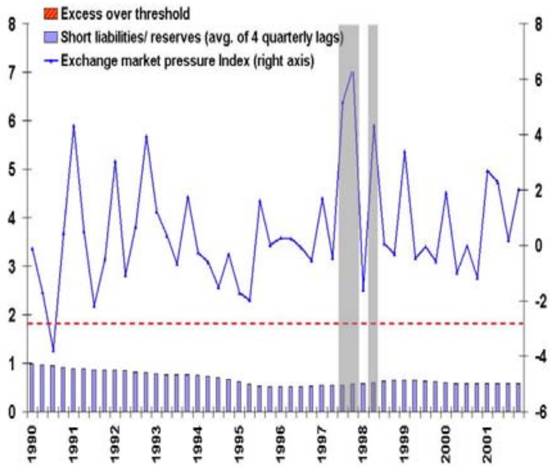


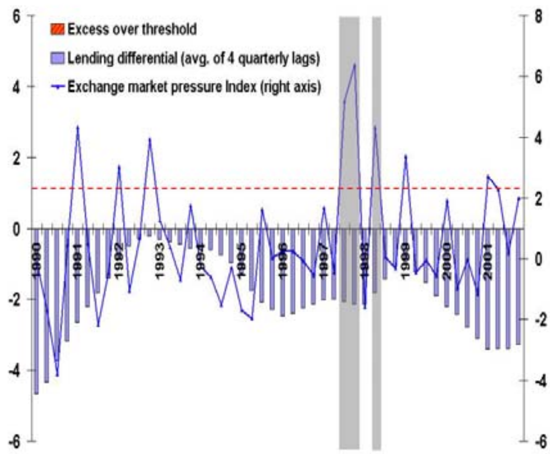
Figure 1: Threshold Effects and Exchange Market Pressure Index of selected Asian Countries (Continued)

(g): **Singapore**

$\frac{\text{Short-term external liabilities}}{\text{Reserves}}$

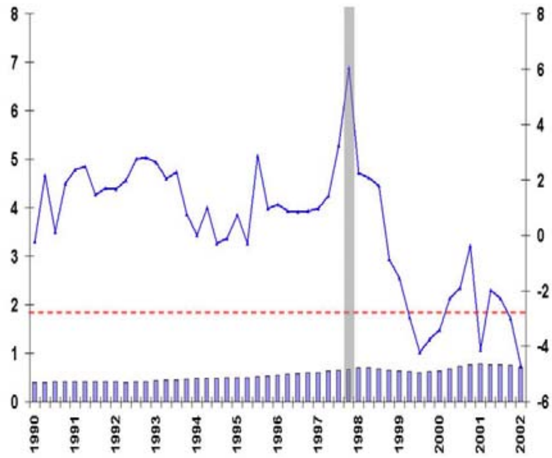


Lending rate differential



(h): **Taiwan**

$\frac{\text{Short-term external liabilities}}{\text{Reserves}}$



Lending rate differential

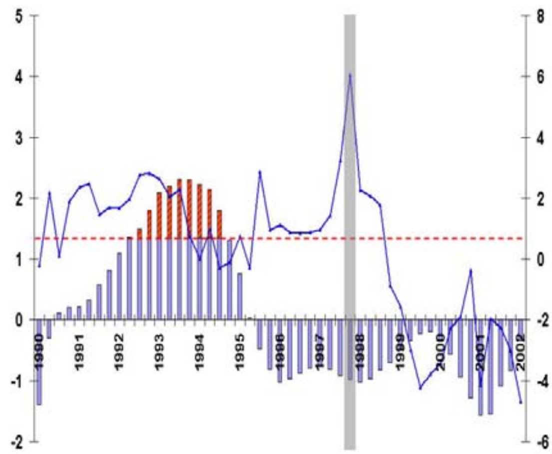
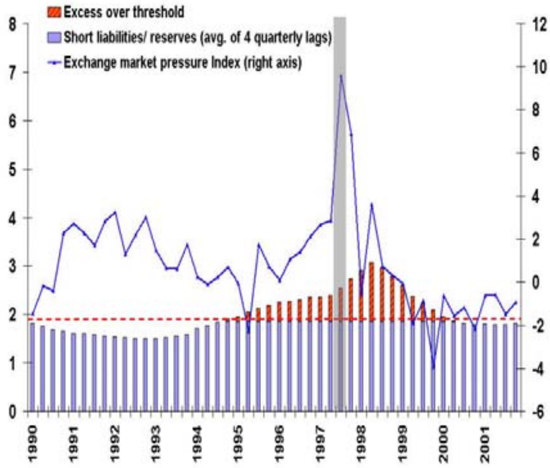


Figure 1: Threshold Effects and Exchange Market Pressure Index of selected Asian Countries (Continued)

(i): **Thailand**

$\frac{\text{Short-term external liabilities}}{\text{Reserves}}$



Lending rate differential

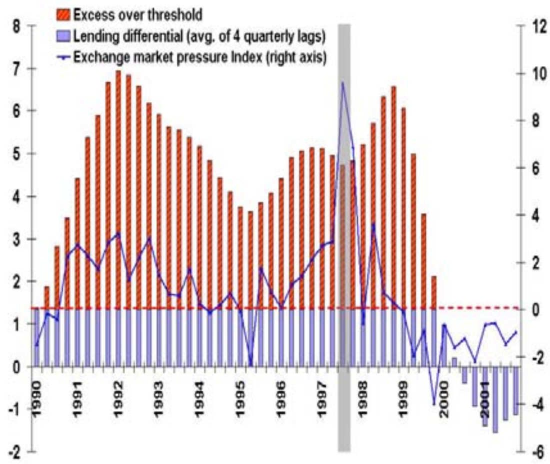
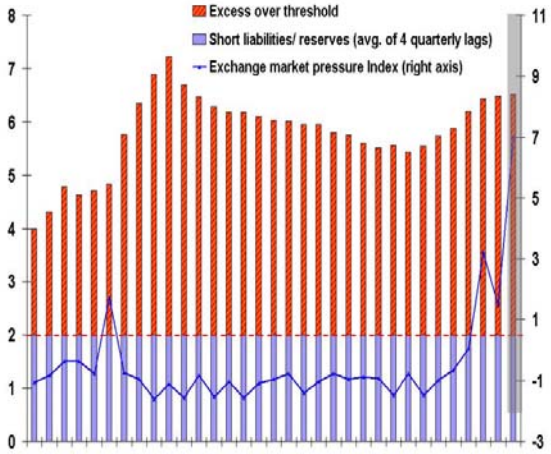


Figure 2: Threshold Effects and Exchange Market Pressure Index of selected Latin American Countries

(a): **Argentina**

$\frac{\text{Short-term external liabilities}}{\text{Reserves}}$



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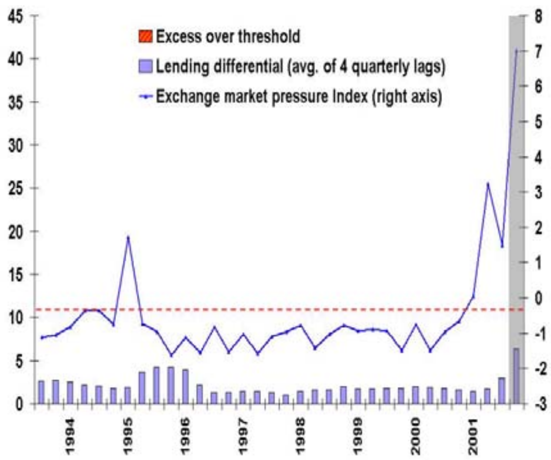
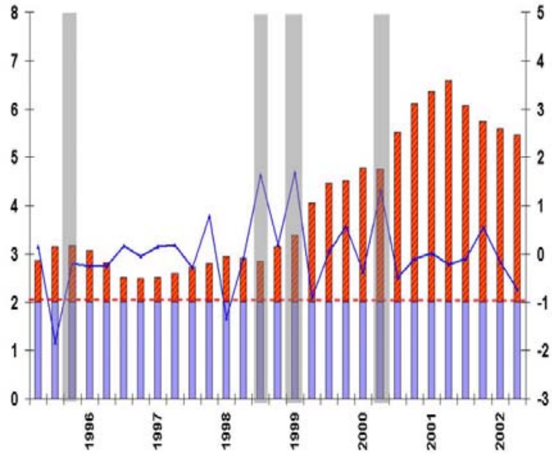


(b): **Brazil**

$\frac{\text{Short-term external liabilities}}{\text{Reserves}}$



Lending rate differential

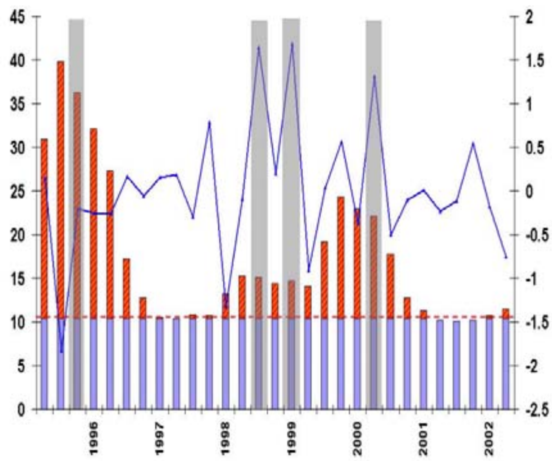
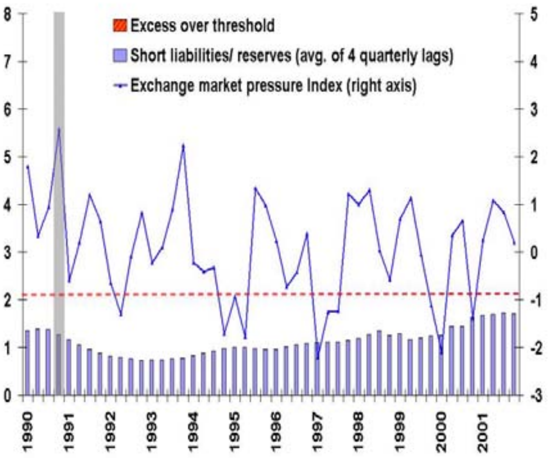


Figure 2: Threshold Effects and Exchange Market Pressure Index of selected Latin American Countries (Continued)

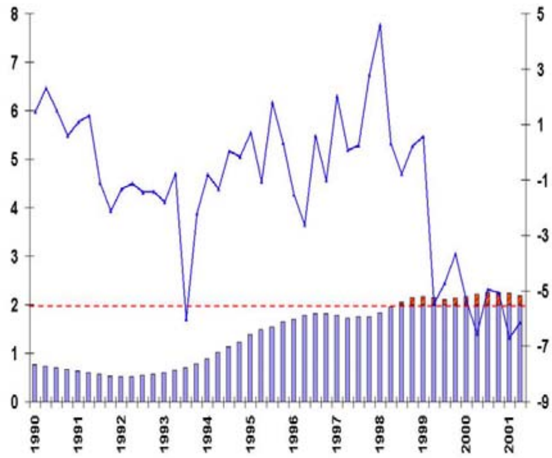
(c): **Chile**

$\frac{\text{Short-term external liabilities}}{\text{Reserves}}$

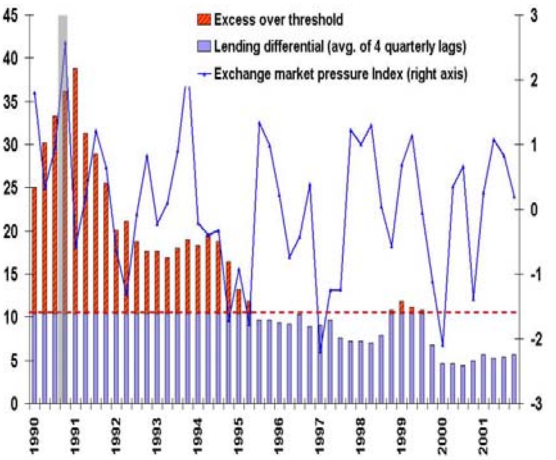


(d): **Colombia**

$\frac{\text{Short-term external liabilities}}{\text{Reserves}}$



Lending rate differential



Lending rate differential

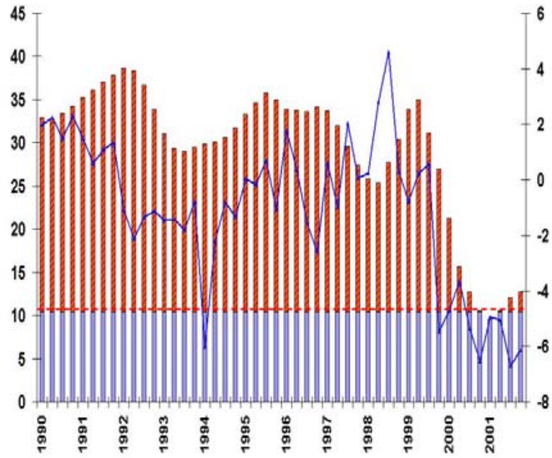
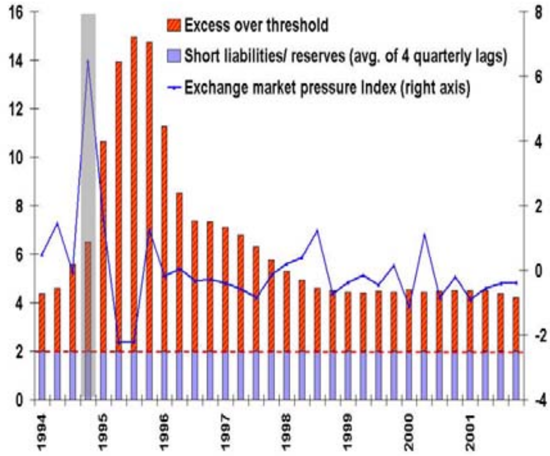


Figure 2: Threshold Effects and Exchange Market Pressure Index of selected Latin American Countries (Continued)

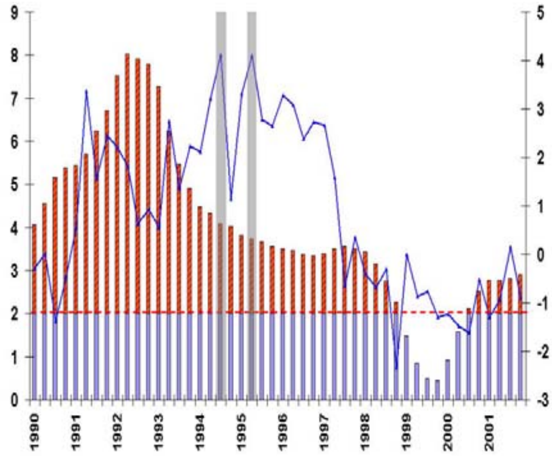
(e): **Mexico**

(f): **Uruguay**

Short-term external liabilities / Reserves



Short-term external liabilities / Reserves



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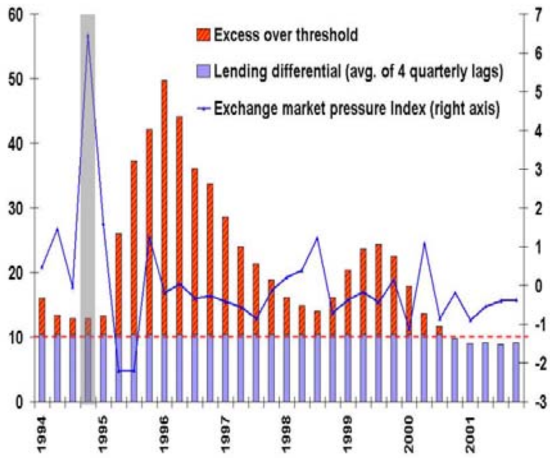


Lending rate differential

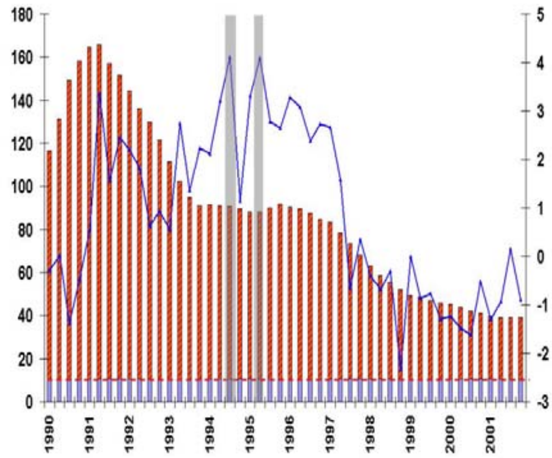
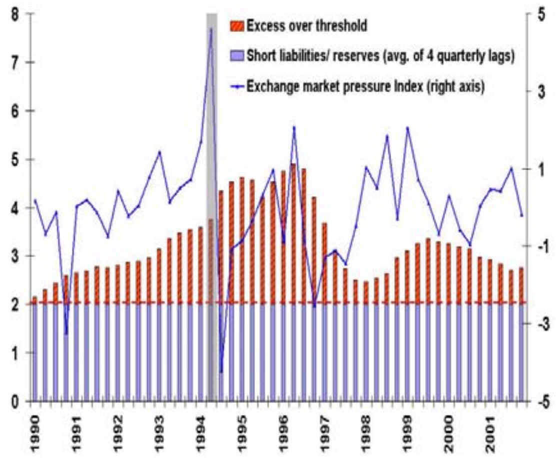


Figure 2: Threshold Effects and Exchange Market Pressure Index of selected Latin American Countries (Continued)

(g): **Venezuela**

$\frac{\text{Short-term external liabilities}}{\text{Reserves}}$



Lending rate differential