Predicting Currency Crises with a Nested Logit Model

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Abstract

This paper is the first to apply a nested logit model to measure the probabilities of speculative attacks and the probabilities of successful defenses by the central banks. This model has two major virtues: (i) it allows us to predict not only the probability of speculative attacks but also the probability of successful defenses given attacks; (ii) it provides an framework to analyze the degree to which different economic factors affect the likelihood of speculative attacks and the abilities of central banks to defend. This paper finds strong evidence that external illiquidity and financial fragility are reliable predictors of currency crises. The results also shed lights on the validity of the three generations of currency crisis models and what regulatory policies are appropriate to minimize the stampede of currency crises. (JEL: F31 and F32)

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I. Introduction

During the past decade there have been numerous studies attempting to find reliable predictors of currency crises. The studies most widely cited include Sachs, Tornell and Velasco (1996), Frankel and Rose (1996), Kaminsky, Lizondo and Reinhart (1997), Kaminsky (1998) and Hali (2000). The methodologies commonly used in the literature include the signal extraction approach (indicator approach) of Kaminsky (1998) and a number of econometric approaches – the multinomial logit approach of Eichengreen, Rose and Wyplosz(1995), the binary probit approach of Frankel and Rose (1996), the OLS regression model of Sachs, Tornell and Velasco(1996) and the simple logit model of Kumar, Uma and Perraudin (2002).

Each of these approaches has its strengths and limitations. First of all, the signal extraction approach is relatively simple to compute because fundamentally it only involves computing the number of indicators that have exceeded their minimum thresholds within a given time window. However, it is only a univariate approach which considers the signals from different indicators separately. As a result, the relationships among different indicators are ignored. Second, the signal extraction approach often uses composite indexes to summarize the signals of a number of different indicators where the weights used to construct the composite indices are quite arbitrary.

The simple probit, logit and OLS approaches, on the other hand, are multivariate approaches that consider multiple explanatory variables simultaneously in the prediction. However, these approaches are binomial approaches (two-states approaches) which can only predict the occurrence or non-occurrence of speculative attacks or currency crises. No distinction is made between the probability of successful and unsuccessful defenses by the central banks given speculative attacks. This distinction is important because it is always a concern for the policy makers of how likely the central banks can defend successfully against attacks by drastically draining its reserve and raising the interest rate, notwithstanding the potential disastrous economic consequences. The Eichengreen, Rose and Wyplosz study (1995) was the first to use a multinomial logit approach to address instances of successful and unsuccessful defenses. However, this method treats the choice of speculative attacks and defenses in parallel and thus cannot be used to compute the conditional probabilities of successful defenses given speculative attacks, which is exactly the probability that a central bank needs to know when its currency is under attack. Moreover, Eichengreen et al.'s paper focuses mainly on fiscal deficits, current account deficits, money and credit growth as well as inflation in the prediction of currency crises. The role of short term international liquidity is not considered even though it is found by Lau and Park (1995) as well as McKinnon and Huw (1996) to be highly important in explaining for the outbreak of the 1997 Asian currency crisis.

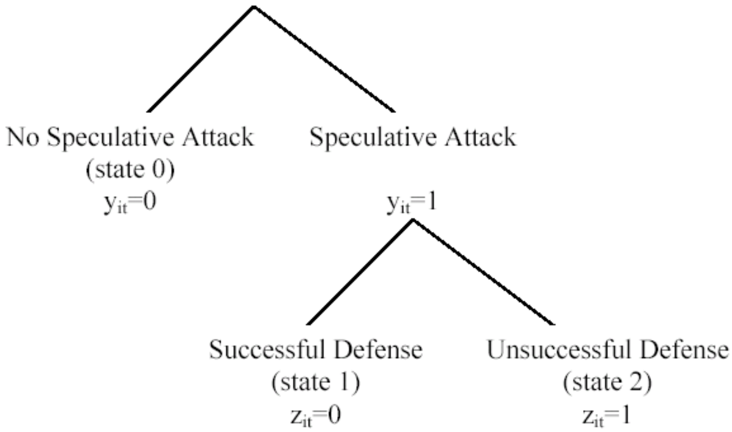
In this paper, a new empirical model is developed to estimate the probability of speculative attacks and the conditional probability of successful defenses given attacks. A major contribution of this model is that it improves on the existing models in the literature in the following dimensions: firstly, unlike the univariate models, the nested logit model allows for the simultaneous analysis of multiple predictors and the examination of the relationship among these predictors. Secondly, the nested logit model subdivides the state of speculative attack into two states – the state of successful defense and unsuccessful defense. This allows us to evaluate both the probabilities of speculative attacks and the conditional probabilities of successful defenses by the central banks given speculative attacks. In order to take into account the differences in nature of speculative attacks and defenses, the multi-state nested logit model was designed as a two-branch model. In the top branch, it analyses the odd of speculative attacks versus no speculative attacks. Then, given a speculative attack, it evaluates the odd of successful defense versus unsuccessful defenses by the central banks.

Using this model, we find strong evidence that international illiquidity, fiscal deficitis and financial fragility are reliable predictors of currency crises. This finding provides strong support to the arguments of McKinnon and Huw (1996) as well as Chang and Velasco (1998a and 1998b) that financial fragility usually precedes currency crises. In addition, the empirical results of this paper demonstrate the importance of the "overborrowing syndrome", which results from moral hazard in the financial market, in triggering speculative attacks in the foreign exchange market. To evaluate the predictive ability of the model, this model is employed to perform out-of-sample predictions of the probabilities of speculative attacks and unsuccessful defenses shortly prior to the recent Argentinian and Brazilian crises.

The paper is organized as follows: section I gives an introduction; section II presents the nested logit model for predicting speculative attacks and successful defenses; section III discusses the predictors of speculative attacks and unsuccessful defenses employed in this paper; section IV reports the estimation results of the nested logit model and analyses the effect of capital controls; section V provides the in-sample and out-of-sample predictions of the model as well as evaluates the predictive ability of the nested logit model vis-à-vis the signal extraction model widely used in the literature; section VI analyzes to what extent the increase in the probability of speculative attacks can be attributed to different factors; section VII concludes by summarizing the model's empirical findings and by making policy recommendations about how central banks can reduce their vulnerabilities to speculative attacks and increase the probability of launching successful defenses. The data description is provided in Appendix A. The dates of successful and unsuccessful defended speculative attacks in the sample countries are reported in Appendix B.

II. Nested Logit Model

The purpose of this section is to develop an empirical model to predict the occurrence of speculative attacks and evaluate the probability of unsuccessful defenses by central banks in case of speculative attacks. The empirical model is structured as a nested logit model, where the top branch represents the choice by speculators of whether or not to launch speculative attacks. The two choices result in two different outcomes: the "no speculative attack" state (state 0) and the speculative attack branch. Given an attack, there are again two possible outcomes. If the speculative attack is successfully defended by the central bank, we come to the state of successful defenses (state 1). Otherwise, we come to the state of unsuccessful defenses (state 2)[1]. The structure of the nested logit model is illustrated in the following diagram:



Based on this structure of the nested logit model, the following equations specify the probability of speculative attacks and the conditional probability of successful defenses in the case of speculative attacks:

Let X_{it} be the vector of predictive variables for country i at period t.

Let γ^{NA} and γ^{A} be the vectors of coefficients associated with the no speculative attack state (state 0) and the speculative attack branch (state 1 and 2) respectively.

Let β^{SD} and β^{UD} be the vectors of coefficients associated with the successful defense state (state 1) and the unsuccessful defense state (state 2) respectively.

$$\text{P(Speculative Attacks)} \equiv P(A)_{it} = P(1,2)_{it} = \frac{e^{\alpha_i^A + X_{it}'\gamma^A}}{e^{\alpha_i^A + X_{it}'\gamma^A} + e^{\alpha_i^A + X_{it}'\gamma^{NA}}} \quad (1)$$

$$\text{P(No Speculative Attacks)} \equiv 1 - P(A)_{it} = 1 - P(1,2)_{it} = P(0)_{it} = \frac{e^{\alpha_i^A + X_{it}'\gamma^{NA}}}{e^{\alpha_i^A + X_{it}'\gamma^A} + e^{\alpha_i^A + X_{it}'\gamma^{NA}}} \quad (2)$$

$$
\begin{aligned}
\text{P(Successful Defenses|Attacks)} &\equiv P(SD|A)_{it} = P(1|1,2)_{it} \\
&= \frac{e^{\alpha_i^{UD}+X_{it}^{'}\beta^{SD}}}{e^{\alpha_i^{UD}+X_{it}^{'}\beta^{SD}}+e^{\alpha_i^{UD}+X_{it}^{'}\beta^{UD}}} \qquad (3) \\
\text{P(Unsuccessful Defenses|Attacks)} &\equiv 1-P(SD|A)_{it} = P(2|1,2)_{it} \\
&= \frac{e^{\alpha_i^{UD}+X_{it}^{'}\beta^{UD}}}{e^{\alpha_i^{UD}+X_{it}^{'}\beta^{SD}}+e^{\alpha_i^{UD}+X_{it}^{'}\beta^{UD}}} \qquad (4)
\end{aligned}
$$

In the estimation of the coefficients, two normalizations are necessary for identification purposes: in the top branch of the model, the probabilities of speculative attack and no speculative attack always sum up to 1. As a result, only the odd of attack and no attack $(\frac{e^{X_{it}^{'}\gamma^{A}}}{e^{X_{it}^{'}\gamma^{NA}}})$ can be identified. This implies that only $e^{X_{it}^{'}(\gamma^{A}-\gamma^{NA})}$ can be identified. In view of this, γ^{NA} is normalized to 0 in the estimation. Similarly, only the odd of successful and unsuccessful defenses can be identified in the lower branch of the model. Hence, β^{SD} is normalized to 0. After normalization, γ^{A} measures the effect of changes in X_{it} on the odd of attack versus no attack. β^{UD} measures the effect of changes in X_{it} on the odd of unsuccessful defenses versus successful defenses.

The vector of predictive variables in the basic specification of the nested logit model includes the one-quarter lag of all of the variables discussed in the next section[2].

Let Y_{it} be a zero-one dummy that equals to 1 if the state of speculative attack is realized and Z_{it} be a zero-one dummy that equals to 1 if the state of unsuccessful defense given a speculative attack is realized. That is,

$$
Y_{it} \begin{cases} = 1 \text{ if there is a speculative attack in country i at time t} \\ = 0 \text{ otherwise} \end{cases}
$$

$$Z_{it} \begin{cases} = 1 \text{ if there is an unsuccessful defence in country i at time t} \\ = 0 \text{ otherwise} \end{cases}$$

The likelihood function is:

$$L = \Pi_{i=1}^{N} f_i(\{y_{it}\}_{t=1}^{T}, \{z_{it}\}_{t=1}^{T})$$

where N is the number of countries in our sample (see Appendix B for the list of countries in our sample) and T is the number of periods for each country. Using a fixed effect logit model which assumes that $y_{it} \sim Bernoulli(\Lambda(\alpha_i^A + \mathbf{X}_{it}'\boldsymbol{\gamma}^A))$ and $z_{it}|y_{it} = 1 \sim Bernoulli(\Lambda(\alpha_i^{UD} + \mathbf{X}_{it}'\boldsymbol{\beta}^{UD}))$ where $\Lambda(\alpha_i^A + \mathbf{X}_{it}'\boldsymbol{\gamma}^A) = \frac{e^{\alpha_i^A + \mathbf{x}_{it}'\gamma^A}}{1+e^{\alpha_i^A + \mathbf{x}_{it}'\gamma^A}}$ and $\Lambda(\alpha_i^{UD} + \mathbf{X}_{it}'\boldsymbol{\beta}^{UD}) = \frac{e^{\alpha_i^{UD} + \mathbf{x}_{it}'\beta^{UD}}}{1+e^{\alpha_i^{UD} + \mathbf{x}_{it}'\beta^{UD}}}$. The density function $f_i(\{y_{it}\}_{t=1}^{T}, \{z_{it}\}_{t=1}^{T})$ is defined as follows:

$$\begin{aligned} f_i(\{y_{it}\}_{t=1}^{T}, \{z_{it}\}_{t=1}^{T}) = & \Pi_{t=1}^{T}[1 - \Lambda(\alpha_i^A + \mathbf{X}_{it}'\boldsymbol{\gamma}^A)]^{1-y_{it}} \\ & [\Lambda(\alpha_i^A + \mathbf{X}_{it}'\boldsymbol{\gamma}^A)\Lambda(\alpha_i^{UD} + \mathbf{X}_{\mathbf{it}}'\boldsymbol{\beta}^{\mathbf{UD}})]^{y_{it}z_{it}} \\ & [\Lambda(\alpha_i^A + \mathbf{X}_{it}'\boldsymbol{\gamma}^A)(\mathbf{1} - \Lambda(\alpha_i^{UD} + \mathbf{X}_{\mathbf{it}}'\boldsymbol{\beta}^{\mathbf{UD}}))]^{y_{it}(1-z_{it})} \\ = & \Pi_{t=1}^{T}[1 - \Lambda(\alpha_i^A + \mathbf{X}_{it}'\boldsymbol{\gamma}^A)]^{1-y_{it}} \\ & [\Lambda(\alpha_i^A + \mathbf{X}_{it}'\boldsymbol{\gamma}^A)]^{y_{it}}[\Lambda(\alpha_i^{UD} + \mathbf{X}_{\mathbf{it}}'\boldsymbol{\beta}^{\mathbf{UD}})]^{y_{it}z_{it}} \\ & [\mathbf{1} - \Lambda(\alpha_i^{UD} + \mathbf{X}_{\mathbf{it}}'\boldsymbol{\beta}^{\mathbf{UD}})]^{y_{it}(1-z_{it})} \end{aligned} \tag{5}$$

However, since the number of fixed effect parameters α_i^A and α_i^{UD} increase with the number of countries in the sample (N), α_i^A and α_i^{UD} cannot be consistently estimated for a fixed T. As the estimate of $\boldsymbol{\gamma}^A$ and $\boldsymbol{\beta}^{UD}$ are functions of the estimators for α_i^A and α_i^{UD},the MLE of $\boldsymbol{\gamma}^A$ and $\boldsymbol{\beta}^{UD}$ are not consistent either. This problem is known as the incidental parameter problem (Neyman and Scott (1948), Lancaster (2000)). The solution to get around this incidental parameter problem is to find the sufficient statistics for α_i^A and α_i^{UD} and estimate the conditional likelihood function conditional on the sufficient statistics for α_i^A and α_i^{UD}. By definition of a suffucent statistic, the conditional distribution given the sufficient statistic will not depend on α_i^A and α_i^{UD}. Chamberlain (1980) finds that $\Sigma_{t=1}^T y_{it}$ is the a minimum sufficient statistic for α_i^A. Therefore, Chamberlain suggests maximizing the *conditional* likelihood function to obtain the consistent logit estimates for $\boldsymbol{\gamma}^A$:

$$fc_i^A = f_i^A(y_{i1,}y_{i2,}.....y_{iT}|\Sigma_{t=1}^T y_{it}) \tag{6}$$

The conditional likelihood for the T observations of y_{it} conditional on the number of ones in the set $\{y_{it}\}_{t=1}^T$ as derived in Greene(2000) is:

$$fc_i^A = \frac{\exp(\Sigma_{t=1}^T y_{it}\mathbf{X}_{\mathbf{it}}'\boldsymbol{\gamma}^A)}{\Sigma_{\Sigma_t d_{it}^A = S_i^A}\exp(\Sigma_{t=1}^T d_{it}^A \mathbf{X}_{it}'\boldsymbol{\gamma}^A)} \tag{7}$$

where the function in the denominator is summed over the set of all $\begin{pmatrix} T \\ S_i^A \end{pmatrix}$ different sequences of T zeros and ones that have the same sum as $S_i^A = \Sigma_{t=1}^T y_{it}$. As the denominator of eqt.(7) requires a large amount of computing time when the number of possible sequences of T zeros and ones that have the same sum as $S_i^A = \Sigma_{t=1}^T y_{it}$ is large, the recursive computational method given by Howard (1972) as well as Krailo and Pike (1984) is employed.

Since we know that the distribution of z_{it} given $y_{it} = 1$ is the same as that of y_{it}, a set of sufficient statistics for α_i^{UD} is the sum of z_{it}

and the set of y_{it} which equals to 1 $(\Sigma_{t=1}^{T} z_{it}, \{y_{it} = 1\}_{t=1}^{T})$. That means we can obtain consistent estimates for $\boldsymbol{\beta}^{UD}$ by estimating the following conditional density function:

$$fc_i^{UD} = f_i^{UD}(z_{i1,}z_{i2,}.....z_{iT}|\Sigma_{t=1}^{T} z_{it}, \{y_{it} = 1\}_{t=1}^{T}) \quad (8)$$

$$fc_i^{UD} = \frac{\exp(\Sigma_{t=1}^{T} y_{it} z_{it} \mathbf{X}'_{it} \boldsymbol{\beta}^{UD})}{\Sigma_{\Sigma_t d_{it}^{UD} = S_i^{UD}} \exp(\Sigma_{t=1}^{T} y_{it} d_{it}^{UD} \mathbf{X}'_{it} \boldsymbol{\beta}^{UD})} \quad (9)$$

Given this, the procedure to obtain consistent estimates of $\boldsymbol{\gamma}^A$ and $\boldsymbol{\beta}^{UD}$ is to first apply MLE to eqt.(7) to get consistent estimte of $\boldsymbol{\gamma}^A$, then restrict to the set of data where $y_{it} = 1$ and estimate eqt.(9) to get consistent estimte of $\boldsymbol{\beta}^{UD}$.

i. Indices of Speculative Attacks, Successful Defenses and Unsuccessful Defenses

The next step is to identify the episodes of speculative attacks, successful defenses and unsuccessful defenses in the data. As we mention earlier, the instruments most widely used by the central banks to defend against speculative attacks are foreign exchange reserves and discount rates (the interest rate at which banks borrow from the central banks)[3]. For this reason, our model uses the following measures to define instances of speculative attacks with successful and unsuccessful defenses:

An unsuccessful defense of a speculative attack ($Z_{it} = 1$) (that is, a currency crisis) is defined as an event in which the quarterly exchange rate depreciates by more than the threshold ($\overline{EX}_i$), which is two standard deviations compared to the mean quarterly depreciation of the country in the preceding five years.

$$Z_{it} \begin{cases} = 1 \text{ if } (\Delta EX_{it} > \overline{\triangle EX}_{it}) \\ = 0 \text{ otherwise} \end{cases}$$

A successful defense of a speculative attack $Y_{it}(1 - Z_{it})$ is defined as an event in which either the decline in reserves $(\Delta \operatorname{Re} s_{it})$ or the increase in discount rate $(\Delta DisRate_{it})$ crosses the corresponding threshold but there is no currency crisis in the current quarter $(Z_{it} = 0)$:

$$Y_{it}(1{-}Z_{it}) \begin{cases} = 1 \text{ if } (\Delta \operatorname{Re} s_{it} < -\overline{\triangle \operatorname{Re} s_i} \text{ or } \Delta DisRate_{it} > \overline{DisRate_i}) \\ \qquad \text{and } Z_{it} = 0 \\ = 0 \text{ otherwise} \end{cases}$$

Both the threshold for quarterly reserve loss (-$\overline{\triangle \operatorname{Re} s_i}$) and the threshold for percentage increase in the discount rate $(\overline{DisRate_i})$ are two standard deviations from the means of the country.

A state in which there is no speculative attack $(Y_{it} = 0)$ is a state in which both $Y_{it}(1 - Z_{it})$ and Z_{it} equal 0. In addition, in order to avoid measuring the same crisis twice (or more), in cases where there are a number of crisis observations in close succession, we accept only the first observation. The window we use in this paper is four quarters.

III. Predictors of Speculative Attacks and Unsuccessful Defenses

The predictors used in the empirical model are selected based on the insights of the three generations of theoretical models of currency crises.

The “first generation model” (Krugman, 1979; Flood and Garber, 1984a) suggests that exogenous government budget deficits lay at the root of balance of payment crises. The empirical implication of the first generation model is that excessively expansionary fiscal policy should be a reliable predictor of currency crises. The “second generation” model (Obstfeld ,1986) formulates the possibility of self-fulfilling speculative attacks. In the model, the threat of an attack generates expectations-driven increases in interest rates and thus there is a strong incentive for the central bank to abandon the peg since devaluation allows the government to roll over the short-term public debt at a lower interest rate. The empirical implication of the second generation model is that, prior to an attack, there is no reason to anticipate excessively expansionary monetary or fiscal policies but we should observe an drastic increase in domestic interest rate. The third generation model of McKinnon and Huw (1996) suggests that international illiquidity in a country’s financial system precipitates the collapse of the exchange rate. The empirical implication of the third generation model is that external illiquidity is a crucial factor in financial crises and currency crises (McKinnon and Huw, 1996; Chang and Velasco, 1998a and 1998b).

Even though all three generations of currency crises models expect the interest rate differential to rise prior to the crises, the different reasons for the rise suggested by the three models yield different implications on the regression estimation which allow us to test the validity of one model against the other. For the first generation model, the large fiscal deficits lays at the root of the currency crises and the high interest rate differential is only a consequence of such excessively expansionary fiscal policy. For this reason, the fiscal deficit variable should be a significant predictor of currency crises in the estimation and the interest rate differential should not be significant once the fiscal deficit variable is controlled for. Similarly, the third generation model argues that the overborrowing of short term foreign liabilities caused by the moral hazard problem is the immediate cause of the currency crises and the high interest rate differential is only an indirect cause of the overborrowing syndrome. In regard of this, the short-term international liquidity variable should be a strong predictor of currency crises in the estimation but the interest rate differential should not be significant once the short-term international liquidity variable is controlled for. In contrast to the first and third generation model, the second generation model suggests that the high interest rate differential is itself a strong predictor as it reflects the shift in the market expectation of currency risk. For this reason, the interest rate differential variable should remain significant even after the fiscal deficit and short-term international liquidity variables are controlled for. In the section on estimation results, we compare the validity of one generation of models against the other by examining whether the major implications of the models are supported by the data.

In the estimation of the nested logit model, the predictors used include the one quarter lag of the lending rate differential (the differential between the lending rates on domestic-currency denominated loan and US dollar denominated loan), the ratio of fiscal deficits to GDP, the ratio of short-term external liquefiable liabilities to foreign exchange reserves (where external liquefiable liabilities are measured as the sum of the short-term external debt, the cumulative portfolio liabilities and six months' imports), the ratio of quasi-money to foreign exchange reserves, the ratio of domestic credit to GDP, the ratio of public debt to GDP, the real exchange rate appreciation index, the deviations of unemployment rates from historical means and the real GDP growth. The unemployment rates and real GDP growth are included because they are two major factors that affect the willingness of the central banks to commit resources to defend against speculative attacks[4].

IV. Estimation Results and An Analysis of the Effects of Capital Control

i. Estimation Results

Column (a) of Table 1 shows the estimates of the nested logit model and their corresponding t-statistics. The estimation result shows that the significant predictors of speculative attacks include: (i) the ratio of short-term external liquidity to foreign exchange reserves, (ii) the ratio of fiscal deficits to GDP and (iii) the real exchange rate appreciation. Once these variables are controlled for, the lending rate differential does not show up to be a significant predictor of speculative attacks. This suggests that external illiquidity, fiscal deficits and real exchange rate overvaluation lays at the root of currency crises. The sheer shift in the expectation of the investors is not sufficient to trigger an attack. As mentioned in section III, this finding is an evidence that supports the first and third generation models of currency crises but not the second generation model.

In addition, the estimation result indicates that the significant predictors of unsuccessful defenses are: (i) the ratio of short-term external liquidity to foreign exchange reserves; (ii) the ratio of quasi-money to international reserves; (iii) high unemployment rate relative to the historical mean and (iv) low real GDP growth. The significance of the quasi-money ratio indicates that financial deepening without prudent regulatory policies can weaken the ability of the central bank to control capital outflow and hence reduces it ability to defend against speculative attack. High domestic unemployment and weak real GDP growth also reduces the incentive of the central banks to employ their two key weapons (namely, the discount rate and the foreign reserves) to defend against speculative attacks.

ii. An Analysis of the Effects of Capital Controls

Column (b) of Table 1 analyses the effectiveness of capital controls in reducing a country's vulnerability to speculative attacks and its ability to mount a successful defense. This analysis is important because there have been lots of debates among policy makers of whether capital controls are effective in lowering the susceptibility of a country to currency crises. Whilst economists like Desai (2000) argues that timely capital controls would have prevented the East Asian countries from the balance of payment crises of 1997 and Russia from the balance of payment crisis of 1998, the IMF and the U.S. Treasury held the opposite view. The capital control adopted by Malaysia in the aftermath of the 1997 Asian financial crisis also aroused lots of controversy.

In view of this hot debate, we employ the nested logit model to examine the effectiveness of capital controls in stemming speculative attacks in countries that are externally illiquid (as measured by a high ratio of short-term external liabilities to foreign exchange reserves) and countries that have fragile financial markets (as measured by a high ratio of quasi-money to foreign exchange reserves). A capital control index is defined based on the IMF's *Annual Report on Exchange Arrangements and Exchange Restrictions (AREAER).* The capital control index is constructed by taking the average of the 0/1 dummies of restrictions on 13 items in the capital account [5]. This capital control index is multiplied by the ratio of short-term international liabilities to international reserves as well as the ratio of quasi-money to international reserves.

The estimation result of Table 1 column (b) shows that the cross product of the capital control index and the ratio of quasi-money to international reserves is significantly negative in the speculative attack state, while the cross product of the capital control index and the ratio of short-term international liabilities to international reserves is significantly negative in the unsuccessful defense state. This implies that capital control is effective in lowering the probability of speculative attacks for countries that have weak financial systems and effective in raising the probability of successful defense for countries that are externally illiquid. Nevertheless, this analysis rely on the assumption that capital controls are not endogenous and do not affect the underlying strength of the financial system and international liquidity. If this assumption does not hold (that is, if the Lucas critique applies), the above conclusion on capital controls needs to be taken with caution.

Predictors (X)	Column (a)		Column (b)	
	γ^A	β^{UD}	γ^A	β^{UD}
Lending Rate Differentials	0.0786 (1.5560)	0.7398 (1.6853)	0.0799 (1.5667)	0.2716 (0.9326)
Ratio of short external liabilities to FX reserves	0.3640 (3.0302)**	0.9312 (2.8639)**	0.2273 (2.7587)**	0.9859 (2.1564)*
Real Exchange Rate Appreciation Index (86Q1=1)	0.1298 (2.8767)**	0.4224 (1.2987)	0.1683 (2.1286)*	1.2167 (2.8171)**
Ratio of Quasi-money to FX reserves	0.0688 (0.4863)	0.9134 (2.2231)*	0.4983 (3.2048)**	0.8865 (2.2539)*
Ratio of fiscal deficits to GDP	0.4152 (2.5456)**	0.8228 (1.5599)	0.4206 (2.5810)**	0.9051 (1.5200)
Ratio of domestic credit to GDP	0.2249 (1.2628)	0.6826 (1.7913)	0.2713 (1.5049)	0.6509 (1.4898)
Unemployment rate (deviations from historical histroical mean)	0.0929 (0.9068)	0.3018 (2.2454)*	0.0688 (0.6681)	0.5612 (2.2094)*
Real GDP growth	-0.0711 (-0.5337)	-0.5013 (-2.3992)*	-0.0465 (-0.3487)	-0.1424 (-0.3420)
Ratio of public debts to GDP	0.0193 (0.6195)	0.2299 (1.6078)	0.0627 (0.5357)	0.2088 (1.0219)
Capital controls index× ratio of short term foreign liabilities to FX reserves	– –	– –	-0.2440 (-1.6635)	-2.1050 (-4.2594)**
Capital controls index× ratio of quasi-money to FX reserves	– –	– –	-0.8208 (-3.7329)**	-0.6548 (-1.1403)

Note: 1. The numbers in paretheses are the t-statistics
2. * indicates the t-statistic is significant at 5% level of significance and
** indicates the t-statistic is significant at 1% level of significance.

Table 1: Nested Logit Estimates with and without the Capital Control Indices

V. Evaluation of the In-sample and Out-of-sample Predictive Abilities

The model's in-sample predictive power of currency crises and unsuccessful defenses are evaluated using three statistical scores suggested by Kaminsky (1998): the quadratic probability score (QPS), the log probability score (LPS) and the global squared bias (GSB). The time period used in performing the in-sample predictions is 1982Q1 to 1999Q4, and the time period used in performing the out-of-sample predictions is 2000Q1 to 2001Q4.

The quadratic probability score (QPS) is defined as $QPS = \frac{1}{IT}\sum_{t=1}^{T}\sum_{i=1}^{I} 2(P_{it} - R_{it})^2$ where P_{it} is the predicted probability of speculative attacks in country i at time t and R_{it} is the realization of speculative attacks. QPS ranges from 0 to 2, with a score of 0 corresponding to perfect accuracy. The log probability score (LPS) is defined as $LPS = -\frac{1}{IT}\sum_{t=1}^{T}\sum_{i=1}^{I}[(1-R_{it})\ln(1-P_{it}) + R_{it}\ln(P_{it})]$. LPS ranges from 0 to ∞, with a score of 0 corresponding to perfect accuracy. The loss function associated with LPS differs from that corresponding to QPS, as large mistakes are penalized more heavily under LPS. The global squared bias (GSB) measures the average forecast calibration, it is defined as $GSB = \frac{1}{I}\sum_{i=1}^{I} 2(\overline{P}_i - \overline{R}_i)^2$ where $\overline{P}_i = \frac{1}{T}\sum_{t=1}^{T} P_{it}$ and $\overline{R}_i = \frac{1}{T}\sum_{t=1}^{T} R_{it}$. GSB$\in [0, 2]$,with GSB=0 corresponding to perfect global calibration, which occurs when the average probability forecast equals the average realization.

Part (a) of Table 2 reports the results of the goodness of fit tests for the prediction of currency crises and part (b) reports the results of the tests for the prediction of successful defenses. All three test scores indicate that the nested logit model performs consistently better than the signal indicator approach in the prediction of the currency crisis instances. The predicted unconditional probabilities of successful speculative attacks and the prediced conditional probabilities of successful defenses given attacks are plotted in Figure 1(a)-1(p). The predicted probabilities assuming full capital controls (with capital control index set to one) are also reported for comparison. Notice that the nested logit model also performs well in predicting which countries are likely to fail to defend against speculative attacks. For example, the model performs well in predicting the unsuccessful defenses in S.Korea and Thailand during 1997Q3, in Brazil during 1999Q1 and in Mexico during 1994Q4.

To evaluate how well the model predicts episodes of successful and unsuccessful defenses outside the sample periods, out-of-sample predictions are performed using data from 2000Q1 to 2001Q4, subject to the availability of data. The out-of sample forecasts are shown in Figure 1(a)-1(p) together with the in-sample predictions. The out-of-sample forecasts indicate that Argentina was highly susceptible to a speculative attack in 2001 (the end of the sample period), so was Uruguay in 2000.

VI. Exploring the Importance of Various Factors in Attributing to the Speculative Attack Pressure

Table 3 explores further to what extent different factors lead to the increase in the speculative attack pressure in various countires. First degree Taylor series expansion is used to disaggregate the increase in

Part (a): Goodness of Fit for Crisis Periods (State 2) and Non-crisis Periods (State 0 and 1)						
Model	QPS		LPS		GSB	
	Non-Crisis Periods	Crisis Periods	Non-Crisis Periods	Crisis Periods	Non-Crisis Periods	Crisis Periods
Kaminsky's Composite Indicator	0.110	0.862	0.240	1.161	0.071	0.735
Nested Logit (with capital control variable)	0.1063	0.5057	0.1650	0.7367	0.0639	0.1385

Part (b): Goodness of Fit for Periods with Successful Defenses given Speculative Attacks			
Model	QPS	LPS	GSB
Nested Logit (with capital control variable)	0.5262	0.7375	0.2991

Table 2: Goodness of Fit of the Nested Logit Model Compared with the Signal Indicator Approach

the predicted probability of speculative attack into different causality factors. Let $P(A)_{it}$ and $P(A)_{it_0}$ be the probability of speculative attack in country i in period t and the base period t_0 respectively, and $t' = \frac{t+t_0}{2}$ be the period half way between period t and the base period t_0. In this exercise, period t is taken to be the period when our predicted probability of speculative attacks peaks, and the base period is the period five years ahead of the peak period [6]. This exercise allows us to examine the factors that give rise to the increase in the speculative attack pressure during the years preceding the period with peak predicted speculative attack pressure. The first degree Taylor series expansion of the increase in the probability of speculative attacks, $P(A)_{it} - P(A)_{it_0}$, with respect to the predictive variables X_1, X_2,.....,X_j is written as follows:

$$P(A)_{it}-P(A)_{it_0}=\frac{\partial P(A)_{it'}}{\partial X_{1,it'}}(X_{1,it}-X_{1,it_0})+\frac{\partial P(A)_{it'}}{\partial X_{2,it'}}(X_{2,it}-X_{2,it_0})$$
$$+.....+\frac{\partial P(A)_{it'}}{\partial X_{j,it'}}(X_{j,it}-X_{j,it_0})+\varepsilon_{it}$$
$$=[P(A)_{it'}]^2[\gamma_{A1}(X_{1,it}-X_{1,it_0})+\gamma_{A2}(X_{2,it}-X_{2,it_0})$$
$$+.....\gamma_{Aj}(X_{j,it}-X_{j,it_0})]+\varepsilon_{it}$$

Each term $[P(A)_{it'}]^2\gamma_{A1}(X_{1,it}-X_{1,it_0}), [P(A)_{it'}]^2\gamma_{A2}(X_{2,it}-X_{2,it_0}), ...,$ $[P(A)_{it'}]^2\gamma_{Aj}(X_{j,it}-X_{j,it_0})$ on the right hand side measures how much the increase in the predicted proabability of speculative attacks can be attributed to each predictive variable, with γ_{A1}, γ_{A2}, ..., γ_{Aj} denote the estimated coefficients of the predictive variables X_1, X_2,.....,X_j in the speculative attack state. Table 3 shows that the most important factor that leads to the rise in the speculative attack pressure of Thailand, S.Korea, Indonesia and Philippines in 1997 was the increase in the ratio of short-term external liabilities to foreign exchange reserves. The increase in the speculative attack pressure of Brazil in 1999 was mainly attributable to its high ratio of fiscal deficits to GDP. In the case of Hong Kong in 1998, the major contributing factor was the high ratio of dometsic credit to GDP.

VII. Conclusions and Policy Implications

In this paper, a multi-state nested logit model is employed to predict the probabilities of speculative attacks and the conditional probabilities of successful defenses. This model is also used to analyze the relative importance of various internal and external economic factors in triggering the recent speculative attacks and in affecting the likelihood of successful defenses by the central banks. The nested logit estimates indicate that high ratio of short-term external liabilities to foreign exchange reserves,

	(t_0, t)	$P(A)_{it}$ $-P(A)_{it_0}$	lending rate differential	ratio of short term external liabilities to reserves	real exchange rate appreciat.	ratio of quasi money to reserves
Argentina	(94Q1,95Q1)	0.126	0.032	0.029	0.0001	*0.065*
Brazil	(98Q1,99Q1)	0.248	-0.002	0.030	-0.022	*0.028*
Chile	(92Q4,97Q4)	0.359	-0.057	*0.318*	0.001	0.037
China	(91Q4,98Q1)	0.106	-0.0006	0.008	0.003	*0.102*
HK(SAR)	(96Q4,97Q4)	0.068	0.072	-0.034	0.081	-0.109
Colombia	(93Q1,98Q1)	0.098	-0.0006	0.0450	0.006	*0.068*
Indonesia	(92Q3,97Q3)	0.149	0.069	*0.071*	-0.030	0.006
S.Korea	(92Q3,97Q3)	0.194	-0.010	*0.398*	-0.013	0.049
Malaysia	(92Q3,97Q3)	0.203	-0.0104	0.187	-0.068	*0.356*
Mexico	(93Q4,94Q4)	0.248	0.005	0.104	-0.059	*0.177*
Philip.	(94Q2,97Q3)	0.213	-0.0004	*0.410*	-0.063	0.143
Singapore	(95Q4,97Q4)	0.068	0.0006	*0.043*	-0.007	0.001
Taiwan	(96Q4,97Q4)	0.076	-0.003	0.032	-0.033	-0.015
Thailand	(92Q3,97Q3)	0.114	-0.0007	*0.042*	-0.016	0.002
Uruguay	(86Q2,96Q2)	0.190	-0.011	-0.039	0.032	-0.340
Venezuela	(93Q2,94Q2)	0.099	-0.0006	0.014	0.017	0.008

	ratio of govt. deficits to GDP	ratio of domestic credit to GDP	deviation of unemploy. rate from mean	decline of real GDP	ratio of public debt to GDP
Argentina	0.002	0.003	0.027	-0.038	0.002
Brazil	*0.133*	0.005	-0.008	0.007	0.076
Chile	0.004	0.007	0.173	0.046	-0.174
China	-0.003	0.003	0.030	-0.007	-0.030
HK(SAR)	-0.051	*0.432*	-0.123	-0.200	0
Colombia	0.011	0.014	0.037	-0.027	-0.055
Indonesia	0.049	0.025	-0.007	-0.031	-0.003
S.Korea	-0.016	0.044	-0.026	0.002	-0.233
Malaysia	-0.043	0.047	-0.135	-0.078	-0.052
Mexico	0.002	-0.026	0.011	0.032	0.001
Philip.	-0.0005	0.094	-0.185	-0.065	-0.119
Singapore	0.004	0.002	0	0.028	-0.004
Taiwan	-0.029	0.034	-0.028	0.003	*0.115*
Thailand	0.023	0.013	0.042	-0.020	0.027
Uruguay	0.347	-0.155	*0.557*	-0.143	-0.056
Venezuela	-0.002	0.011	*0.042*	-0.020	0.027

Table 3: The Increase in the Probabilities of Attacks Attributable to Various Factors

large fiscal deficits and large real exchange rate appreciation are significant predictors of speculative attacks. Also, high ratio of short-term external liabilities to foreign exchange reserves, high ratio of quasi-money to foreign reserves, high unemployment rate and low real GDP growth are significant predictors of unsuccessful defense.

To evaluate the predictive abilities of the nested logit model, three statistical scores are used: the quadratic probability score (QPS), the log probability score (LPS) and the global squared bias (GSB). All scores indicate that the nested logit model outperforms the signal indicator approach in predicting currency crises. To further evaluate how well the model is in forecasting currency crises, out-of-sample forecasts are performed for all the countries in the sample. It is observed that, even as early as 2000, Argentina was highly vulnerable to speculative attacks and was unlikely to be able to mount a successful defense. The high ratio of short-term external liabilities to international reserves (nearly 500 percent) and the rising unemployment rate (around 18 percent in 2001Q3) in Argentina indicates that it is highly vulnerable to currency crises and has low defense ability.

The empirical findings of the nested logit model have several important policy implications: (i) adequate foreign exchange reserves needs to be maintained relative to the short-term external liabilities in order to serve as a caution against the out-flight of hot money. It would be very risky for the central bank to implicitly guarantee private debts if the central bank is financially insolvent or illiquid in terms of hard currencies; (ii) debt-maturity lengthening is recommended, as suggested by Calvo and Mendoza (2000). However, the trade-off is that lengthening debt maturity generally increases debt-serving costs and hence this is an important topic that requires future research; (iii) a strong discipline over the fiscal deficits should be maintained by the government; and (iv) financial liberalization should be accompanied by prudent supervision of short-term foreign borrowings in the banking sector. Pre-matured capital liberalization is one of the major factors leading to financial crises in many countries, such as Indonesia, S.Korea, Malaysia, Philippines, Thailand and Mexico. McKinnon(1993) stresses that capital controls should be liberalized only after everything else, including macroeconomic stabilization and prudent bank regulation and control, are securely in place.

The empirical results of this paper also provide insights on whether capital controls can insulate an economy from crises. The policy implication is especially important for China because, with China's accession to the WTO on November 11 2001, there is a hot debate on whether China should continue to maintain capital controls in the medium run and whether China's capital controls are effective in reducing its currency risk. The empirical results of this paper show that capital controls to some extent is effective in reducing massive withdrawal of loans or hot money. Nevertheless, all these conclusions rely on the assumption that capital controls are not endogenous and do not affect the underlying strength of the financial system and international liquidity. If this assumption does not hold, the above conclusion on capital controls needs to be interpreted with caution.

Appendix A: Data Description

The sample data consists of quarterly data from 1982 Q1 through 2001 Q4 of the following economies: Argentina, Brazil, Chile, Mainland China, Colombia, Hong Kong, S.Korea, Malaysia, Mexico, the Philippines, Singapore, Taiwan, Thailand, Uruguay and Venezuela. The primary data source is International Financial Statistics (IFS), supplemented by the World Development Indicator CD-ROM and the webpages of the Asian Development Bank (ADB) and the Bank of International Settlements (BIS). The following table shows the sources and definitions of the variables:

Predictors	Sources and Definitions
1. Lending rate differential	The lending rate differential is constructed as the difference between the 3-month lending interest rate in the domestic country and the US. The lending interest rate is taken from IFS line 60P.
2. Ratio of short-term international liquefiable liabilities to foreign exchange reserves	The short-term external debt data is obtained from the Asian Development Bank (ADB) web page and the Bank of International Settlements (BIS) web page. 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 reserves data is from IFS line 1L.
3. Real exchange rate appreciation index	The exchange rate data is obtained from IFS line ..AE..ZF. The exchange rate for China before 1994 Q1 is the swap rate obtained from Global Financial Data. The exchange rate is deflated by WPI (IFS line 63..ZF) and then the real exchange rate is normalized to 1986 Q1=1.
4. Ratio of quasi-money (M2-M1) to foreign exchange reserves	M2 is calculated as IFS line 34 plus 35. M1 is from IFS line 34. The foreign exchange reserves data is from IFS line 1L.
5. Ratio of fiscal deficits to GDP	Fiscal deficit is from IFS line 80 and GDP is from IFS line 99B.
6. Unemployment rate	Historical unemployment rate is from the World Development Indicator CD-ROM. Recent data are from the official webpages of various countries.
7. Public Debt	The total public debt is from IFS line 88ZF. The public debt in domestic currency is from IFS line 88AZF. The public debt in foreign currency is from IFS line 89AZF.

Appendix B:
Dates of Attacks that were Successfully and Unsuccessfully Defended

(In-sample period:1982-99, Out-of-sample period:2000-01)

Countries	Successful Defense Dates	Unsuccessful Defense Dates
1. Argentina	1992Q4, 1995Q1	1982Q3, 1987Q3, 1989Q2, 2001Q3
2. Brazil	None between 1982Q1 -2001Q4	1983Q1, 1987Q2, 1989Q3, 1999Q1
3. Chile	1997Q4	1982Q2, 1985Q3
4. China, PRC	1992Q3, 1998Q1	1989Q4, 1994Q1
5. Colombia	1986Q3, 1993Q4, 1995Q2, 1998Q1	1982Q4, 1985Q1, 1990Q1Q2
6. Hong Kong, SAR	1993Q1, 1997Q4	None between 1982Q1 -2001Q4
7. Indonesia	1994Q2, 2000Q4	1997Q3
8. S.Korea	1986Q3	1997Q3
9. Malaysia	None between 1982Q1 -2001Q4	1997Q3
10. Mexico	1992Q3	1985Q3, 1987Q4, 1994Q4
11. Phiilippines	1982Q4, 1989Q2, 1993Q2, 1995Q2	1982Q4, 1990Q3, 1997Q3
12. Singapore	1995Q1	1997Q4
13. Taiwan	1983Q4, 1988Q1, 1990Q2	1995Q3, 1997Q4
14. Thailand	1988Q1, 1994Q1	1984Q4, 1997Q3
15. Uruguay	1996Q2	1982Q4, 1989Q2, 1994Q3
16. Venezuela	None between 1982Q1 -2001Q4	1983Q2, 1986Q4, 1989Q1, 1992Q4, 1994Q2

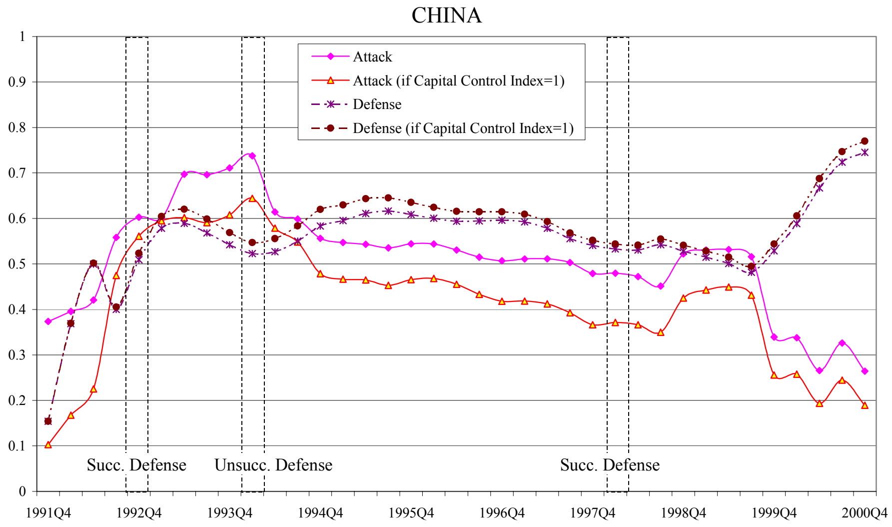


Figure 1(a): Predicted Probabilities - China

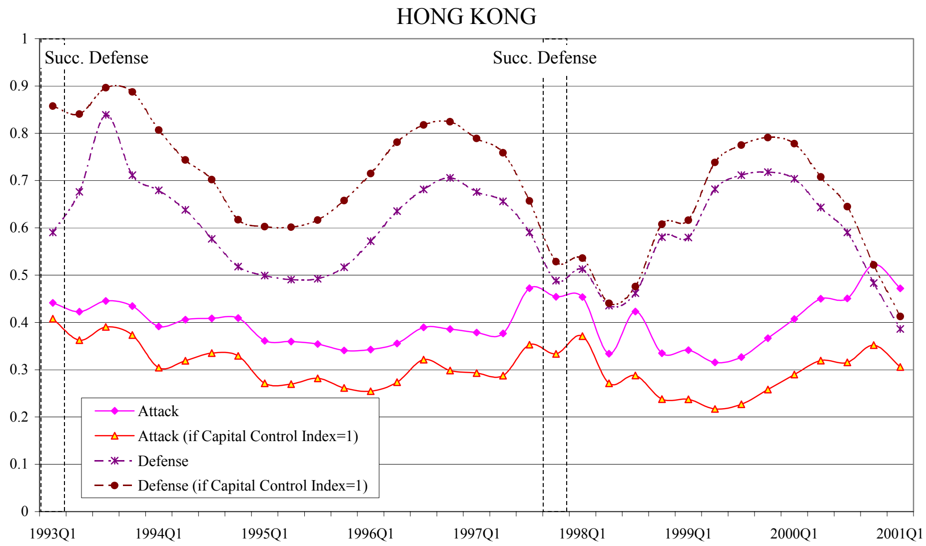


Figure 1(b): Predicted Probabilities - Hong Kong

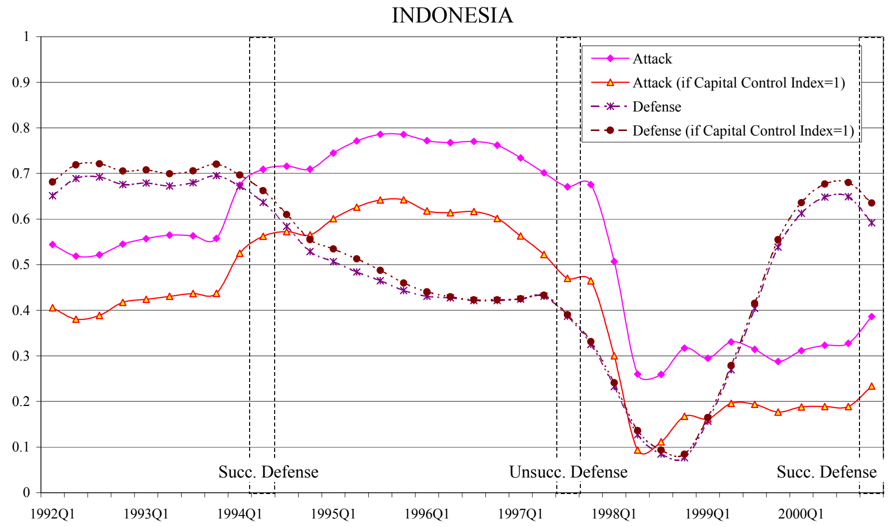


Figure 1(c): Predicted Probabilities - Indonesia

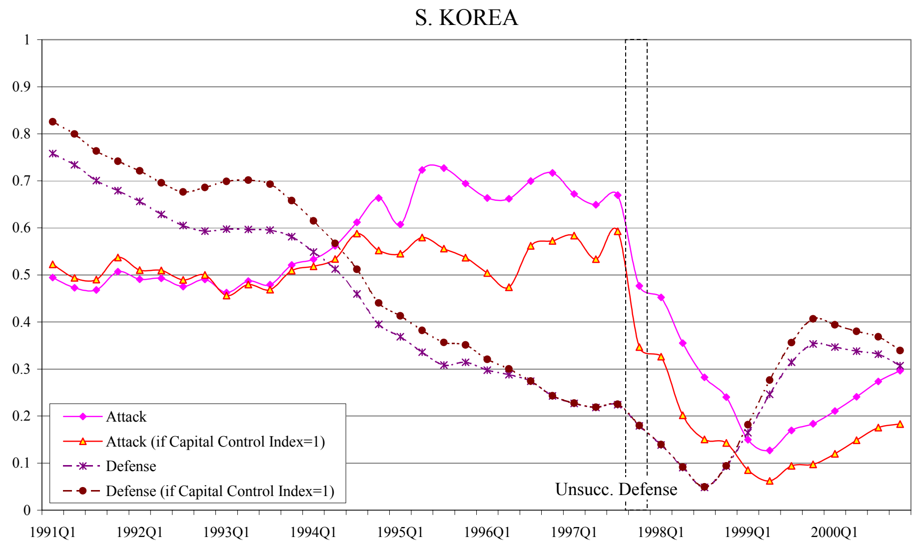


Figure 1(d): Predicted Probabilities - S.Korea

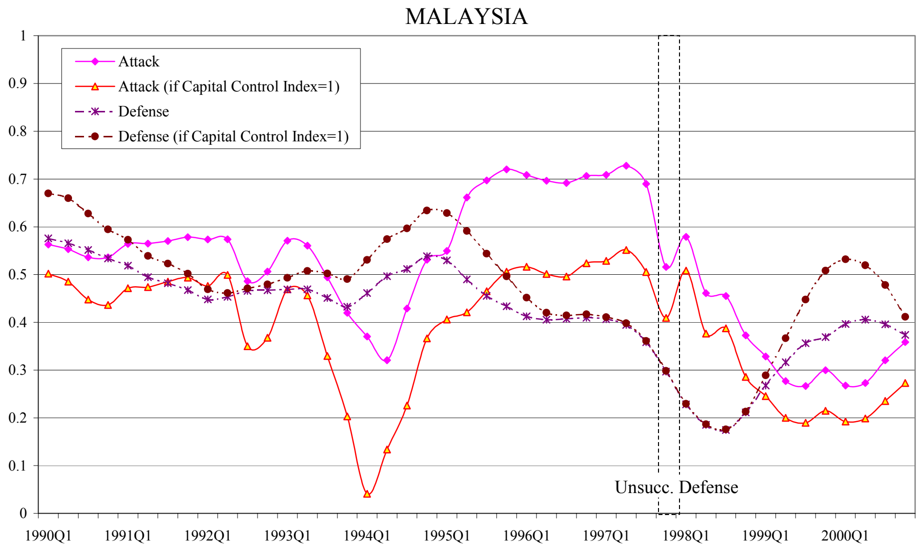


Figure 1(e): Predicted Probabilities - Malaysia

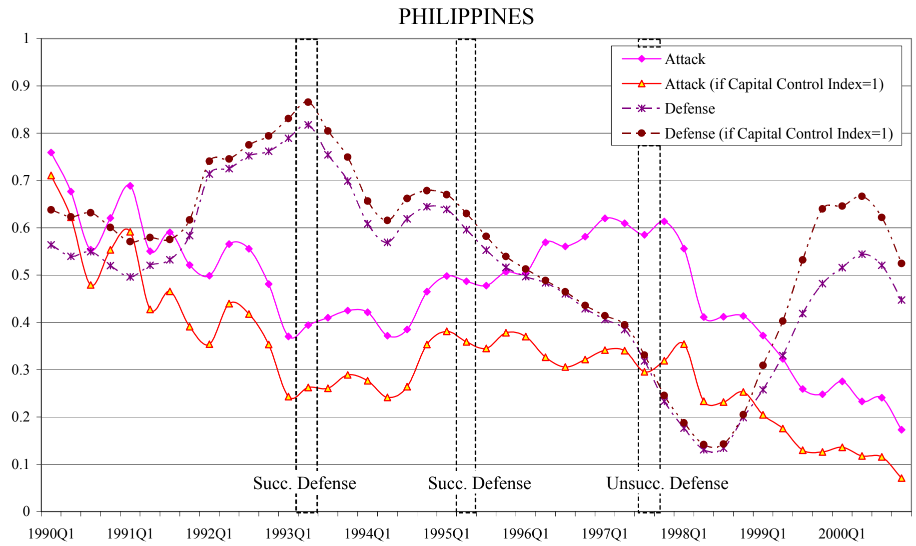


Figure 1(f): Predicted Probabilities - Philippines

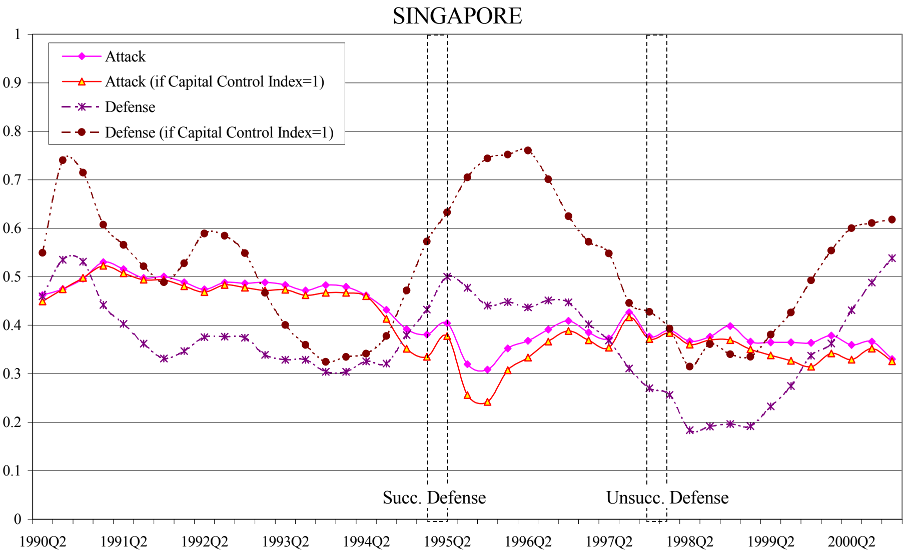


Figure 1(g): Predicted Probabilities - Singapore

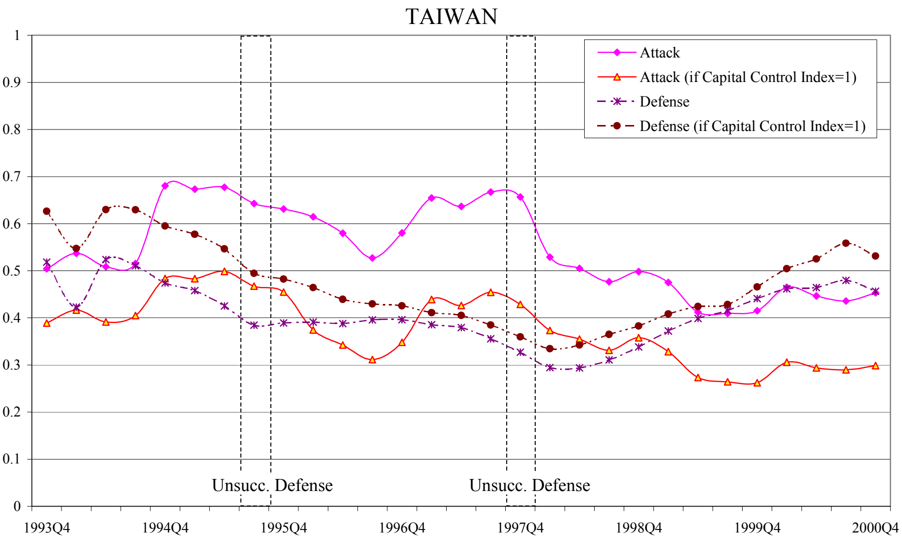


Figure 1(h): Predicted Probabilities - Taiwan

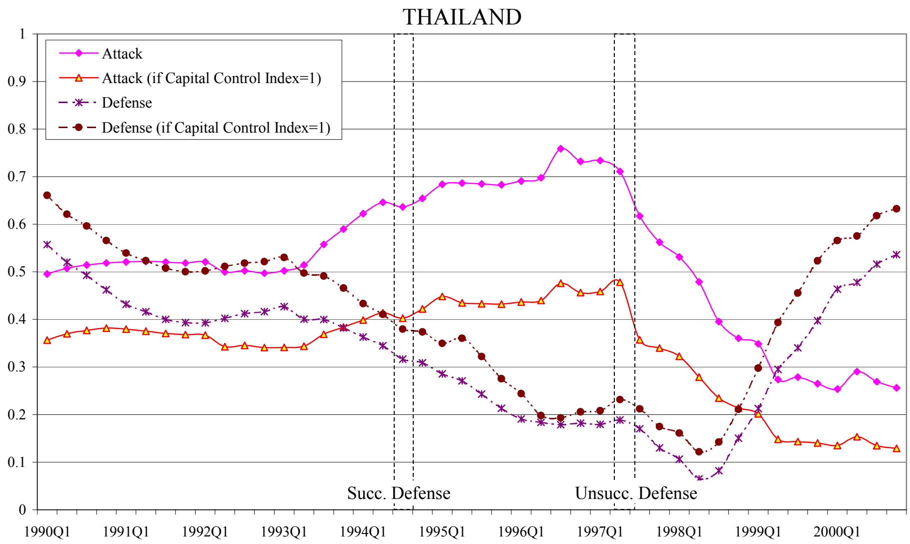


Figure 1(i): Predicted Probabilities - Thailand

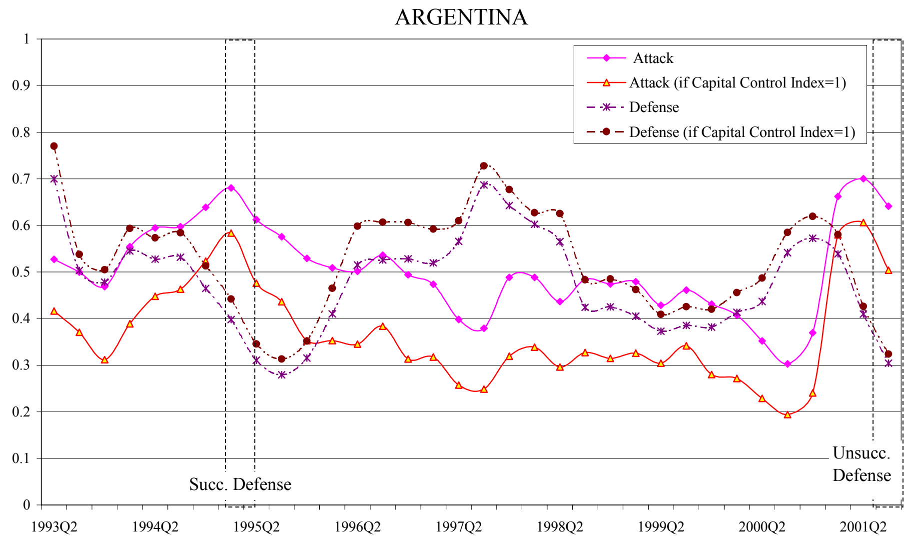


Figure 1(j): Predicted Probabilities - Argentina

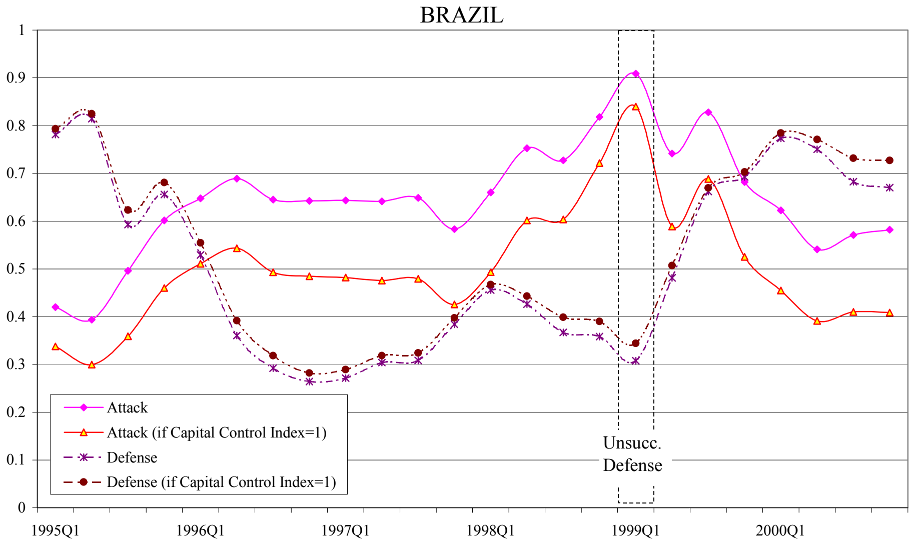


Figure 1(k): Predicted Probabilities - Brazil

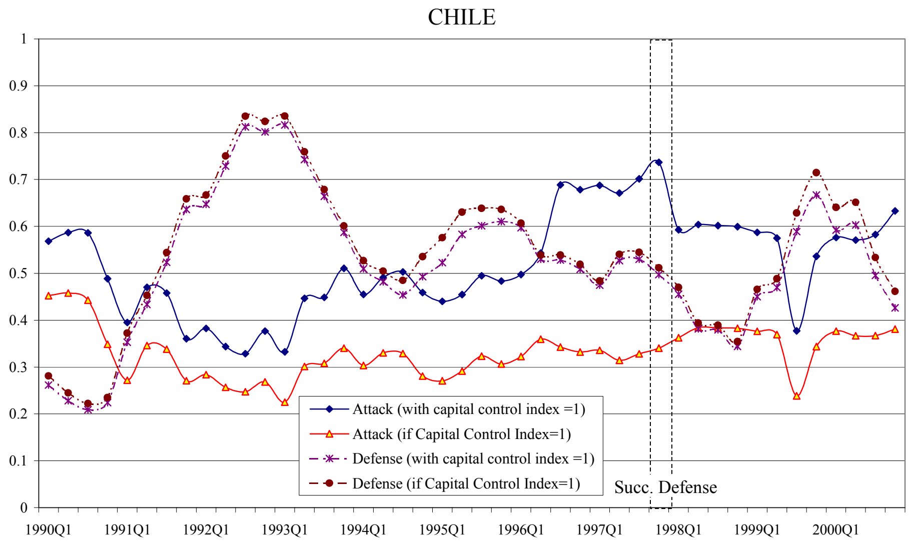


Figure 1(l): Predicted Probabilities - Chile

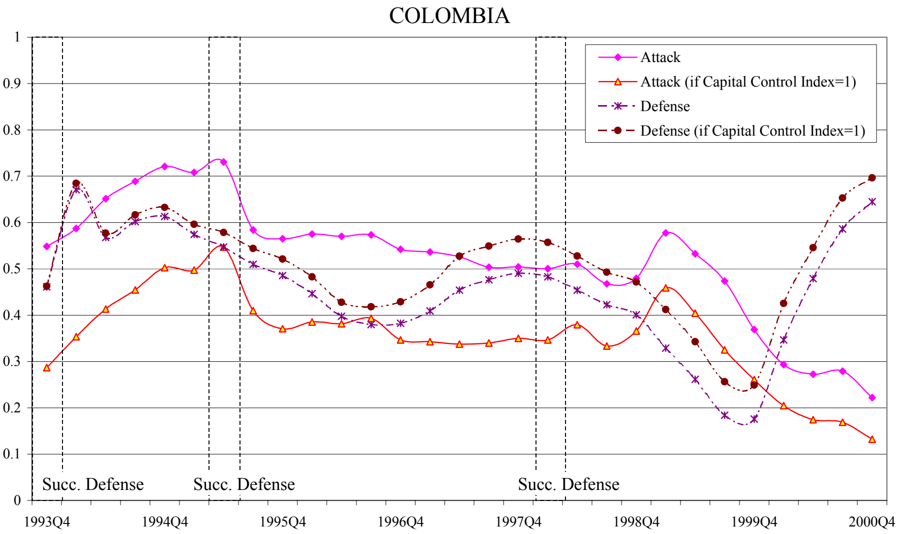


Figure 1(m): Predicted Probabilities - Colombia

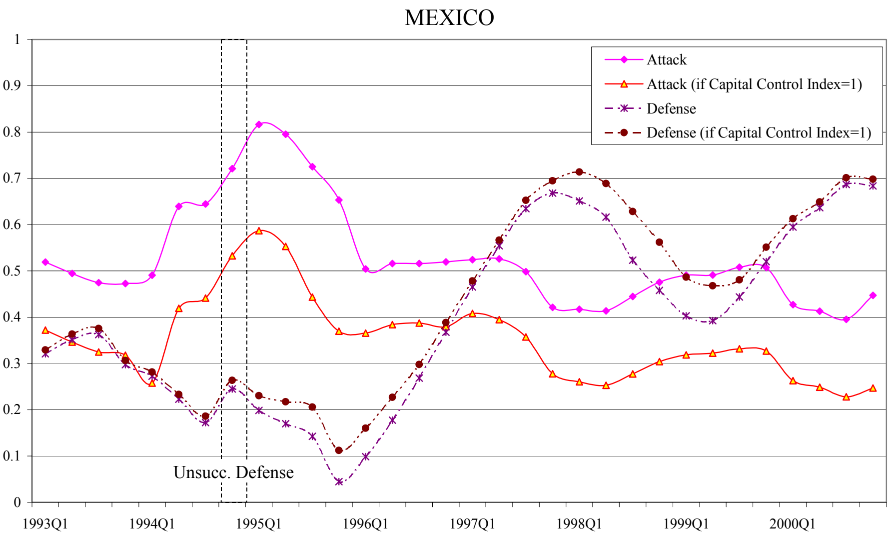


Figure 1(n): Predicted Probabilities - Mexico

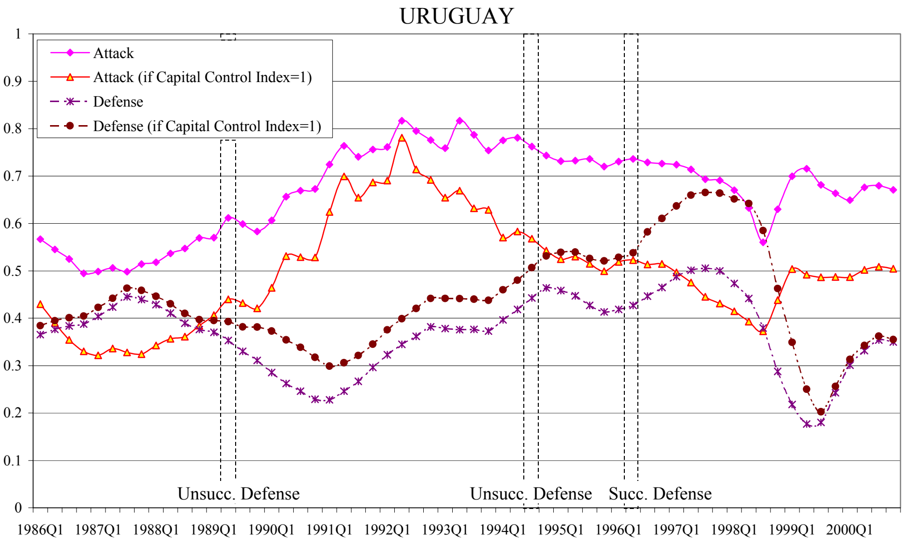


Figure 1(o): Predicted Probabilities - Uruguay

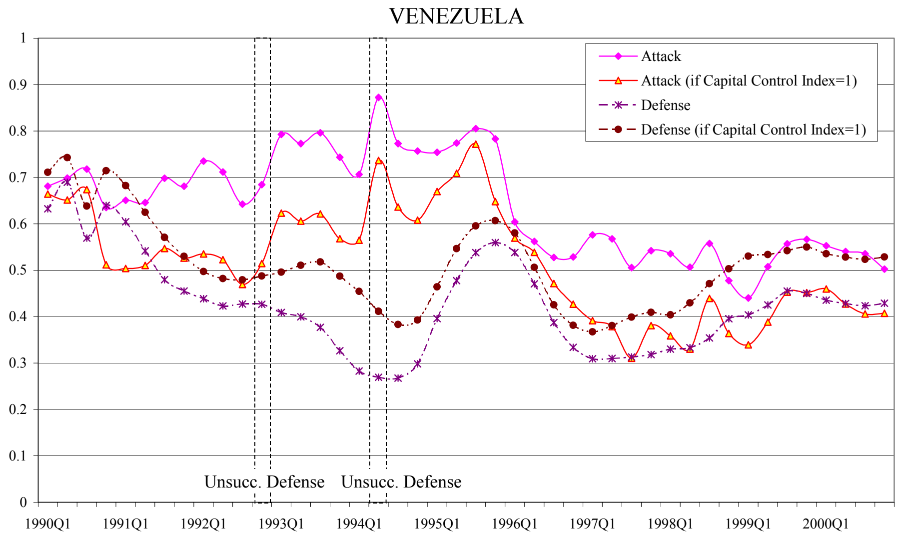


Figure 1(p): Predicted Probabilities - Venezuela

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Notes

[1]In this paper, the definition of the unsuccessful defense state (state 2) includes cases of "unsuccessful defenses" and "nondefenses". The latter are cases in which central banks simply abandon the exchange rate peg without attempting to defend it at all. This scenario occurs when the central banks are reluctant to employ their two major weapons — foreign exchange reserves and discount rates — to defend the exchange rate and when central banks feel that devaluating the domestic currency may have great potential benefits. In both the cases of unsuccessful defenses and successful **non**defenses, currency crises occur. Instances of "successful nondefenses" include those of Taiwan and Singapore in 1997Q4.

[2]A number of alternative specification have also been tried. In the short spectrum, we tried to examine the contemporary influences of the indicators on the probability of currency crises. However, this specification is not chosen as the final specification because it may be subject to the endogeneity problem. We have also allowed for predictive variables lagged up to two, three, four quarters. In addition, to conserve degrees of freedom, we have tried to model the lags using moving averages instead of including different lags into the estimation separately. The results reported in this paper correspond to one-quarter lag of the predictive variables.

[3]For example, the central bank of Chile and the Bank of Mexico spent large quantities of reserves defending their pegged currencies. Mexico allowed international reserves to fall from nearly US $30 billion in early 1994 to US $6 billion at the end of the year. However, the increased importance and flexibility of the price mechanism in the new market environment has caused many central banks to focus more heavily on discount rates in the defenses.

[4]See Lau and Yan (2003) for a more detail discussion of each of the predictors.

[5]The 13 items include capital controls on (i) capital market securities, (ii) money market instruments, (iii) collective investment securities, (iv) derivatives and other instruments, (v) commercial credits, (vi) financial credits, (vii) guarantees, sureties and financial backup facilities, (viii) direct investment, (ix) liquidation of direct investment, (x) real estate transactions, (xi) personal capital movements and, finally, provisions specific to (xii) commercial banks and other credit institutions (xiii) institutional investors. An alternative measure is proposed by Hali and Warnock (2001) which captures the intensity of foreign ownership restrictions and is available at a higher frequency than annual for a wide range of countries. However, this measure is only a narrow measure of capital controls, focusing only on restrictions on foreign ownership of domestic equities. The measure they propose is the ratio of the market capitalization underlying a country's Investable and Global Indices as computed by the International Finance Corporation (IFC). For each emerging market country, the IFC computes a Global Index (IFCG) designed to represent the market. The IFC also computes an Investable index (IFCI), designed to represent that portion of the market available to foreign investors. Hence, the ratio of the market capitalization of a country's IFCI and IFCG is a quantitative measure of the availability of the country's equities to foreigners, and one minus the ratio is a measure of the intensity of capital controls.

[6]If the data five years ahead of the peak period is not available for a country, we use the earliest period subject to the availability of data.