Predicting Currency Crises with a Nested Logit Model

Lawrence J. Lau\textsuperscript{a} and Isabel K. Yan\textsuperscript{b}\textsuperscript{*}

\textsuperscript{a}Asia/Pacific Research Center, Encina Hall, C320, Stanford University, CA.
\textsuperscript{b}Department of Economics and Finance, The City University of Hong Kong.

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 a 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)

\textsuperscript{*}Corresponding author. Tel: +1-852-2788-7315; Fax: +1-852-2788-8806. E-mail address: efyan@cityu.edu.hk
1 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 deficits 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 “over-borrowing 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 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 their model, there can be multiple equilibria in the foreign exchange market. A high public debt with short maturity is a potential source of self-fulfilling currency crises. In their 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. Nevertheless, neither the first nor the second generation stories seem to be relevant in explaining the 1997 East Asian Crisis (Krugman, 1999). For this reason, the third generation model was developed. The third generation model suggests that international illiquidity in a country’s financial system precipitates the collapse of the exchange rate. A financial system is internationally illiquid if its short-term obligations in foreign currency exceed the amount of foreign currency to which it can have access at short notice. When governments implicitly guarantee the debts of financial systems, the problem of moral hazard arises, thereby encouraging overborrowing in short-term foreign currency. When authorities do not
have adequate foreign reserves, the financial system is internationally illiquid and is highly vulnerable to speculative attack. 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).

The paper is organized as follows: section 1 gives an introduction; section 2 provides a literature review; section 3 discusses the predictors of speculative attacks and unsuccessful defenses employed in this paper; section 4 presents the nested logit model for predicting speculative attacks and successful defenses; section 5 reports the estimation results of the nested logit model and analyses the effect of capital controls; section 6 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 7 analyzes to what extent the increase in the probability of speculative attacks can be attributed to different factors; section 8 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.
2 Literature Review

This section provides a comprehensive survey of the predictors used in the recent empirical studies of speculative attacks and currency crises. The most widely studied predictors fall primarily into the following categories:

1. predictors related to the current account problems (Kaminsky, 1998; Kaminsky and Reinhart, 1999):
   - overvaluation of the real exchange rate (deviations of the real exchange rate from trend)
   - declines in exports
   - increases in imports
   - deterioration in terms of trade
   - ratio of current account deficits to GDP

2. predictors related to the capital account problems (Kaminsky and Reinhart, 1999):
   - declines in foreign exchange reserves
   - differentials between domestic and foreign interest rates

3. predictors related to the compositions of capital inflows (Frankel and Rose, 1996):
   - FDI vs portfolio flows as percentage of total debt
   - long term vs. short-term portfolio capital
4. predictors related to the debt profile (as percentage of total debt) (Frankel and Rose, 1996):

- fixed rate vs. floating rate borrowing
- domestic currency vs. foreign currency denominated debt
- amount of debt lent by commercial banks
- amount of debt which is variable rate
- amount of debt which is borrowed by public sector
- amount of debt which is short-term
- amount of debt lent by multilateral development banks

5. predictors related to the financial vulnerability and financial liberalization (Kaminsky, 1998; Kaminsky and Reinhart, 1999):

- growth in the M2 multiplier (growth in the ratio of M2 to base money)
- ratio of domestic credit to GDP
- lending boom — ratio of claims on the private sector by deposit money banks and monetary authorities to GDP (Sachs, Tornell and Velasco, 1996)
- ratio of lending to deposit interest rates
- dummy for domestic and external financial liberalization

6. predictors related to the overborrowing cycles and international liquidity:
• ratio of external debt to foreign exchange reserves (Frankel and Rose, 1996)

• ratio of short-term foreign liabilities to foreign exchange reserves (Berg and Pattillo, 1998; Kaminsky, 1998 and Hali, 2000)

7. predictors related to the real sector and stock market (Eichengreen, Rose and Wyplosz, 1995; Frankel and Rose, 1996):

  • CPI inflation and wage growth
  • real GDP growth
  • unemployment rate
  • changes in stock prices

8. predictors related to the fiscal and monetary policy (Kaminsky, 1998):

  • ratio of fiscal deficits to GDP
  • excess M1 balances (the residuals from regressing real M1 on real GDP growth, inflation and a deterministic trend)

9. predictors related to the bank runs (Kaminsky, 1998):

  • declines in bank deposits

10. predictors related to the foreign markets (Frankel and Rose, 1996):

  • foreign real GDP growth
  • increases in foreign interest rates
11. predictors related to the political stability (Eichengreen, Rose and Wyplosz, 1995)

- government victory/defeat in election
- left-wing government
- new finance minister

Before the Mexican debt crisis of 1994 and the Asian currency crises of 1997, the currency crises predictors used in the literature focus mainly on variables related to the fiscal and monetary policy as well as the real exchange rate. Among the predictors being examined, real exchange rate overvaluation is considered best in predicting currency crises. (Bilson, 1979; Collins, 1995; Edwards, 1989; Kaminsky and Reinhart, 1996; Moreno, 1995; Ötker and Pazarbasioglu, 1994, 1995). With the outbreak of the Mexican and Asian crises, it is alarming to realize that the traditional models fail to predict these crises as these models have omitted factors related to financial fragility and international illiquidity. Sachs, Tornell and Velasco (1995) shifts the focus of the literature from traditional indicators towards indicators related to the problem of financial vulnerability by presenting solid empirical evidence on the relationship between lending booms in the banking sector (measured as the ratio of claims on the private sector by deposit money banks and monetary authorities) and debt crises. Frankel and Rose (1996) further examine indicators related to the overborrowing cycles and international liquidity such as the ratio of external debt to international reserves and the ratio of short-term foreign debt to international reserves. However, in Frankel
and Rose’s probit analysis, most of the debt variables are not statistically significant. This somewhat weak result probably occurred because there was multicollinearity between their different debt variables and the low frequency data (annual data) reduced the power of the tests. Lau and Park (1995) was the first to provide strong evidence of the role of international illiquidity in triggering currency crises. They found that the ratio of short-term foreign liabilities to foreign exchange reserves together with the real exchange rate appreciation index sent out clear warning signals before the East Asian currency crisis.

3 Predictors of Speculative Attacks and Unsuccessful Defenses

This section examines the key economic fundamentals important in determining the probability of speculative attacks and unsuccessful defenses of the central banks. They include variables related to the short-term international illiquidity (the ratio of short-term external liabilities to foreign exchange reserves), variables related to financial fragility (the lending rate differential and the ratio of quasi-money to international reserves), variables related to real exchange rate overvaluation (the real exchange rate appreciation index) and variables related to fiscal over-spending (the ratio of fiscal deficits to GDP). These variables are considered important in predicting which countries are vulnerable to speculative attacks based on both the theoretical models of currency crises and the empirical findings of the literature. When these fundamentals are weak and when the potential costs of defense overweight the poten-
tial benefits, the central banks are less likely to defend successfully, if they are to defend at all.

3.1 Lending Rate Differentials

The lending rate differential between domestic-currency denominated loan and foreign-currency denominated loan is a predictor that has received much attention in the currency crises literature because all three generations of model predict that domestic interest rates should go up prior to currency crises. The first generation model predicts that interest rates should have gone up prior to the crises because fiscal deficits would be at least partially financed by seigniorage revenues or an inflation tax on outstanding nominal debt. This raises the risk premium in the domestic interest rate that associates with the expected exchange rate regime change (it refers to the term $E_t e^{regime-change}_{t+1}$ in the covered interest parity described below). The same implication on the interest rate differential is obtained by the prospective deficits model of Burnside, Eichenbaum and Rebelo (2001) in which the expectation of future deficits can lead to an expectation of the collapse in the fixed exchange rate regimes and drive up the risk premium. Empirically, they find that interest rates in Thailand and S.Korea did rise prior to the major collapse in the baht and won. The second generation currency crises model also predicts that the domestic interest rate would soar prior to the currency crises. However, the mechanism is quite different from that of the first generation model. The second generation model argues that the expectations of speculative attacks generate expectations-driven increases in interest rates and shift the economy from a "no-crisis" equilibrium to a "crisis" equilibrium. A
large interest rate differential implies a market expectation of large exchange rate depreciation or currency risk and hence may precipitate a self-fulfilling crisis (Eichengreen, Rose and Wyplose, 1995). Unlike the first and second generation models, the third generation model maintains that large lending rate differential is important because it contributes seriously to the unhedged overborrowing syndrome which occurred prior to the 1997 East Asian Crisis. A large interest rate differential makes it very costly for importers to hedge in incomplete markets (McKinnon, 2000).

Using the uncovered interest parity:

\[ i_t - i_t^* = E_t e_{t+1}^{\text{regime-change}} + E_t e_{t+1}^{\text{within-regime}} + \rho_t^{\text{currency}} + \rho_t^{\text{country}} \]

where \( i_t \) and \( i_t^* \) are the domestic and foreign interest rate respectively, \( E_t e_{t+1}^{\text{regime-change}} \) is the expected exchange rate depreciation in the event of a regime change and \( E_t e_{t+1}^{\text{within-regime}} \) is the expected exchange rate depreciation if the existing regime persists. \( \rho_t^{\text{currency}} \) is the currency risk premium and \( \rho_t^{\text{country}} \) is the country risk premium. According to the third generation currency crises model, the super-risk premium in the interest rate differentials, \( \rho_t^{\text{super-risk}} = E_t e_{t+1}^{\text{regime-change}} + \rho_t^{\text{currency}} \), provides a temptation for the poorly behaved banks to borrow unhedged. When the decision making horizon is sufficiently short for banks with moral hazard, the bank managers ignore the unpredictable regime change in the exchange rate (McKinnon, 2001). This provides a temptation for the poorly behaved banks to borrow unhedged. McKinnon finds that, before May 1997, the super risk premium almost made up the whole
of the interest rate differentials of S.Korea, Malaysia, Philippines and Thailand.

The predictive power of the interest rate differential is supported by empirical findings. Figure 1(a) shows the lending rate differential of the Asian crisis countries during 1997 (namely, Indonesia, Malaysia, S.Korea and Thailand). They all have higher lending rate differential compared with the non-crisis countries like Singapore and Hong Kong. However, even though all three generations of currency crises models predict 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 compare 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 con-
trolled 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.

3.2 Ratio of Fiscal Deficits to GDP

According to the first generation model, high government deficit lies
at the root of balance of payment crises. Nevertheless, the solid fiscal
situation of most of the East Asian economies before the 1997-98 crisis
suggests that speculative attacks did not arise solely because of fiscal
deficits. Before the 1997-98 crisis, most of the East Asian economies
had achieved such a good fiscal balance that revenue from inflation taxes
were unnecessary (See Figure 2(a)).

Burnside, Eichenbaum and Rebelo (2001) contributes to the recon-
ciliation of the first generation model of Krugman(1979) with the third
generation model of McKinnon and Huw (1996) by articulating the view
that it is the large prospective deficits associated with implicit bailout
guarantees to the weak financial system that triggers the 1997 Asian cur-
rency crisis, notwithstanding the evidence that the crisis countries have
either current surplus or small deficits. They argue that even though
the Asian countries did not have high current fiscal deficits in the pe-
riod preceding the 1997 crisis, the expectation that the future deficits
would be partially financed by seigniorage revenue or an inflation tax on
outstanding nominal debt led to the collapse of the fixed exchange rate regimes in Asia due to the self-fulfilling prophecy.

3.3 Short-term International Liquefiable Liabilities

A high ratio of short-term international liquefiable liabilities to foreign exchange reserves is recognized by the third generation model as a crucial predictor of currency crises after the Mexican debt crisis of 1995 and the Asian currency crisis of 1997 (Lau and Park, 2000). This is because both of these two crises were preceded by soaring ratios of short-term external liabilities to foreign reserves instead of being preceded by large fiscal deficits.

The short-term international liquefiable liabilities of a country can be viewed largely as consisting of three components: the short-term external debt, the cumulative portfolio liabilities and the four-to-six months’ imports. The sum of these three items provides an estimate of the amount of liquidity required in the event of crises. The short-term external debt component is closely associated with the “original sin” problem suggested by McKinnon(2001) as well as Eichengreen and Hausmann(1999). “Original sin” is a situation in which the domestic currency cannot be used to borrow abroad or to borrow long term, even domestically. This incompleteness causes financial fragility because all domestic investments will have either a currency mismatch (projects that guarantee pesos will be financed with dollars) or a maturity mismatch (long term projects will be financed by short-term loans). This makes the financial system externally illiquid and thus vulnerable to speculative attacks. When the speculative attacks occur, sufficient foreign exchange
reserves are needed if the central banks want to bail out the troubled financial institutes. The second component of the short-term liquefiable external liabilities is the cumulative portfolio liabilities which reflects the potential amount of hot money that can flow out. During the 1997 Asian currency crisis, the sudden switch from capital inflows to capital outflows left the central banks helpless to prevent their currencies from depreciating. Worse still, there is evidence that foreign portfolio investors were positive feedback traders (rushing to buy when the market is booming and rushing to sell when the market is declining). Rather than responding to information about the fundamentals, traders mimicked each other (Kim and Wei, 2000). This herding behavior exacerbates the destabilizing effect of hot money outflow on foreign exchange rates. On top of the short-term external debt and portfolio liabilities components, six months’ imports are included as another component of the short-term external liquefiable liabilities in view of the IMF’s recommendation that central banks should keep more than three months’ import equivalence of foreign exchange reserves as a cushion threshold to smooth import transactions.

The danger of having high short-term external liabilities are twofold: firstly, as pointed out in the third generation currency crises model, countries with high ratios of hard currency short-term liquefiable liabilities to hard currency liquid assets were extremely vulnerable to reversals of capital inflows. This capital out-flight occurred massively in East Asia during the second half of 1997. Secondly, if banks and firms have high short-term external liquefiable liabilities relative to their short-term external assets, increases in short-term foreign interests adversely affect
their ability to serve interest payments. Figure 3(a) and Figure 3(b) clearly reveals the financial weaknesses of the crisis countries: all of the crisis countries in the East Asia and Latin America (namely, S.Korea, Indonesia, Thailand, Argentina, Brazil and Mexico) had high short-term external liquefiable liabilities prior to the currency crises. During the period of 1995-1997, S.Korea had a ratio of short-term external liabilities to foreign exchange reserves in excess of five and Thailand had a ratio of more than three. This was a financially fragile situation because international reserves would have been insufficient to repay short-term debt and portfolio liabilities had foreign banks and foreign investors decided not to roll them over.

3.4 Ratio of Quasi-money to Foreign Exchange Reserves

Other variables related to financial fragility also receive much attention in the prediction of currency crises as a result of the third generation currency crisis model. As suggested by Chang and Velasco (1998c), one major cause of financial fragility is financial liberalization without prudent supervision of the international liquidity of the financial sector. Among the indicators being examined in this area, the ratio of M2 to foreign exchange reserves is the indicator most widely used to measure “financial deepening” and the vulnerability of financial systems to capital outflows. This indicator rises quickly before currency crises: in Chile the share of financial system loans to the private sector rose from 5 percent of the GDP in 1974 to over 82 percent in 1982; for Mexico this share
went from 26 percent in 1991 to 41 percent in 1994. However, because M1 is used mostly for transaction purposes, quasi-money (the difference between M2 and M1) is a better measure of the quantity of domestic currency that may potentially be dumped and moved out of the country as capital outflow during speculative attacks. Figure 4(a) and Figure 4(b) show the evolution of the ratio of quasi money to foreign exchange reserves in the Asian and Latin American countries respectively. The high ratios for the crisis countries were consistent with the financial fragility hypothesis. For instance, the ratios were in excess of three in S.Korea, Thailand, Philippines and Malaysia at the end of 1996, so was Mexico before the 1994 debt crisis.

3.5 Ratio of Domestic Credit to GDP

Since the overborrowing cycle suggested by McKinnon and Huw (1996) plays an important role in the third generation model, the ratio of domestic credit to GDP is used by Kaminsky (1998) and Kaminsky and Reinhart (1999) as indicators of the overborrowing cycle in the prediction of currency crises. It is argued that both banking and currency crises have been linked to rapid growth in credit fueled by liberalization of the domestic financial system and by the elimination of capital account restrictions. As a result, the crises are preceded by an explosion of domestic credit which finally results in problems in the banking sector when the economy enters a recession. Figure 5(a) and Figure 5(b) show the ratio of domestic credit to GDP of the Asian and Latin American countries in the last decade. The figure shows that the ratio of domestic credit to GDP grew steadily since 1990. Take the case of Thailand in
Asia, the ratio grew from three in 1991 to nearly five prior to the 1997 Asian financial crisis. In Latin America, similar upward trend was observed in Mexico prior to the 1994 Mexican crisis and in Brazil prior to the 1999 Brazilian crisis. Nevertheless the growth was found to be quite steady.

### 3.6 Ratio of Public Debt to GDP

As suggested by the second generation model, a high public debt with short maturity is a potential source of self-fulfilling currency crises. 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. This “debt-burden effect” reduces the central bank’s incentive to defend when the government has a high public debt. However, there is another effect, the “signaling effect”, that works in the opposite direction. Resisting a crisis enhances the credibility of the central bank and allows the government to roll-over its debt at a lower interest rate. This makes the central bank more likely to launch a defense when public debt is high. Thus, whether a high short-term public debt strengthens or weakens the central bank’s ability and incentive of defend depends on the relative strength of the debt burden effect versus the signaling effect. Figure 6(a) and Figure 6(b) show the ratio of public debt to GDP for various Southeast Asian and Latin American countries. The Southeast Asian countries in our sample have a ratio of around one (or below) prior to the 1997 Asian crisis, with the exception of Indonesia. The Latin American countries
also have a ratio of one or less preceding the 1994 Mexican crisis and the 1999 Brazilian crisis.

3.7 Real Exchange Rate Appreciation

Real exchange rate appreciation was considered one of the most reliable indicators in the currency crises literature, especially before the third generation currency crisis model was introduced. For instance, the real exchange rates appreciated by at least 15-20 percentage points between 1986 and 1996 for Thailand, S.Korea and the Philippines (see Figure 7(a) and 7(b)). When a country’s real exchange rate appreciates vis-à-vis its trade competitors, it becomes less competitive in exports. Therefore relative exchange rate appreciation has a negative impact on current account balances. The competitive devaluation of exchange rates – what is called the “beggar-thy-neighbor” phenomenon – proved to be important in generating speculative attack pressure for S.Korea and Thailand during the last decade. The cause of the persistent real exchange rate appreciation can be explained by the Balassa-Samuelson theorem which states that the high productivity growth in the tradable sector relative to the non-tradable sector generates an upward pressure on the real exchange rate, which is exactly the case for the South-east Asian countries.

3.8 Unemployment Rate and Real GDP Growth

In addition to the aforementioned variables, unemployment rate and real GDP growth are two key variables that affect the willingness of the central banks to commit resources to defend against speculative attack. If
the GDP is weakening and the unemployment rate is rising, authorities will hesitate to raise interest rates to defend the currency. Knowing this, speculators will have a greater incentive to attack and a better likelihood of success (Jeanne, 1997). Using data for France, Caramazza (1993) as well as Drazen and Masson (1994) find that ever since 1987 unemployment has positively affected realignment expectations of the exchange rates. This result was confirmed by Alun (1994). Using the UK data, Masson (1995) concludes similarly that persistent high unemployment increased the perception that the government would abandon the sterling parity. For this reason, our empirical model takes into account the effects of real GDP growth rates and unemployment rates on the likelihood that central banks will be successful in defending against speculative attacks.

Figure 8 and 9 plot the unemployment rate and the four-quarter moving average of real GDP growth for the selected East Asian and Latin American countries. The figures show that countries which have high unemployment rate relative to their historical mean are less likely to defend successfully. For instance, high unemployment rates in Colombia since 1990 jeopardize the central bank’s ability and willingness to raise interest rates in order to defend against speculative attacks, thereby contributing to the outbreak of currency crises in the 1990s. A similar pattern is observed in Argentina, where rising unemployment rates since 1992 tied the hands of the central banks so that the central bank hesitated to use the interest rate as a weapon of defend. In combination with rising unemployment rates, declining real GDP growth further weakens the central bank’s willingness to defend because central banks may fear
that raising the interest rate will contract the economy further and ex-acerbate the problem of high unemployment. In view of this, rising unemployment rates and slow growth in real GDP are important indicators of unsuccessful defenses against speculative attacks. These two variables proved to be highly relevant in predicting the ability of central banks to launch successful defenses. However, it should be emphasized that steadily low unemployment rate and satisfactory real GDP growth per se do not necessarily insulate a country from speculative attacks. A country can be growing fast but financially illiquid. Analogously, we can imagine it as a company that is profitable, but has no liquid assets with which to meet financial needs. This was the circumstance of the East Asian countries during the 1997 crisis. In Asia, crisis countries like Thailand and S.Korea had steadily low unemployment rates (below 2 percent) before the outbreak of the 1997 crisis. These rates are below their ten-year historical average. However, high ratio of short-term external liabilities to international reserves clearly indicate a problem of external illiquidity. This gives speculators an incentive to attack. In the face of vigorous attacks, Thailand was the first country to abandon its defense in July 1997, followed by Malaysia and the Philippines later in the same month, Indonesia in August 1997 and S.Korea in November 1997.

4 Nested Logit Model

The purpose of this section is to develop an empirical model to (i) predict the occurrence of speculative attacks and (ii) evaluate the probability of
unsuccessful defenses by central banks in the case of speculative attack. 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 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). 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 $\gamma^{NA}$ and $\gamma^{A}$ be the vectors of coefficients associated with the no speculative attack state (state 0) and the speculative attack branch.
Let $\beta^{SD}$ and $\beta^{UD}$ be the vectors of coefficients associated with the successful defense state (state 1) and the unsuccessful defense state (state 2) respectively.

\[
\begin{align*}
\text{P(Speculative Attacks)} & \equiv P(A)_{it} = P(1,2)_{it} \\
& = \frac{e^{\alpha_{A} + \gamma_{A}}}{e^{\alpha_{A} + \gamma_{A}} + e^{\alpha_{NA} + \gamma_{NA}}} \\
\text{P(No Speculative Attacks)} & \equiv 1 - P(A)_{it} = 1 - P(1,2)_{it} = P(0)_{it} \\
& = \frac{e^{\alpha_{NA} + \gamma_{NA}}}{e^{\alpha_{A} + \gamma_{A}} + e^{\alpha_{NA} + \gamma_{NA}}} \\
\text{P(Successful Defenses|Attacks)} & \equiv P(SD|A)_{it} = P(1|1,2)_{it} \\
& = \frac{e^{\alpha_{UD} + \gamma_{UD} + \beta_{SD}}} {e^{\alpha_{UD} + \gamma_{UD} + \beta_{SD}} + e^{\alpha_{UD} + \gamma_{UD} + \beta_{UD}}} \\
\text{P(Unsuccessful Defenses|Attacks)} & \equiv 1 - P(SD|A)_{it} = P(2|1,2)_{it} \\
& = \frac{e^{\alpha_{UD} + \gamma_{UD} + \beta_{UD}}} {e^{\alpha_{UD} + \gamma_{UD} + \beta_{SD}} + e^{\alpha_{UD} + \gamma_{UD} + \beta_{UD}}}
\end{align*}
\]

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 \(\left(\frac{e^{\alpha_{A} + \gamma_{A}}}{e^{\alpha_{NA} + \gamma_{NA}}}\right)\) can be identified. This implies that only \(e^{\gamma_{NA}}\) can be identified. In view of this, $\gamma^{NA}$ 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, $\beta^{SD}$ is normalized to 0. After normalization, $\gamma^{A}$ measures the effect of changes in $X_{it}$ on the odd of attack versus no attack. $\beta^{UD}$ 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 Section 3².

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,
\[
Y_{it} = \begin{cases} 
1 & \text{if there is a speculative attack in country } i \text{ at time } t \\
0 & \text{otherwise}
\end{cases}
\]
\[
Z_{it} = \begin{cases} 
1 & \text{if there is an unsuccessful defence in country } i \text{ at time } t \\
0 & \text{otherwise}
\end{cases}
\]

The likelihood function is:
\[
L = \prod_{i=1}^{N} f_i(\{y_{it}\}_{t=1}^{T}, \{z_{it}\}_{t=1}^{T})
\]

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
\[
y_{it} \sim Bernoulli(\Lambda(\alpha_i^A + X_{it}'\gamma^A)) \quad \text{and} \quad z_{it|y_{it}=1} \sim Bernoulli(\Lambda(\alpha_i^{UD} + X_{it}'\beta^{UD}))
\]
where \( \Lambda(\alpha_i^A + X_{it}'\gamma^A) = \frac{e^{\alpha_i^A + X_{it}'\gamma^A}}{1 + e^{\alpha_i^A + X_{it}'\gamma^A}} \) and \( \Lambda(\alpha_i^{UD} + X_{it}'\beta^{UD}) = \frac{e^{\alpha_i^{UD} + X_{it}'\beta^{UD}}}{1 + e^{\alpha_i^{UD} + X_{it}'\beta^{UD}}} \).
The density function \( f_i(\{y_{it}\}_{t=1}^T, \{z_{it}\}_{t=1}^T) \) is defined as follows:

\[
f_i(\{y_{it}\}_{t=1}^T, \{z_{it}\}_{t=1}^T) = \prod_{t=1}^T [1 - \Lambda(\alpha_i^A + X^A_{it}\gamma^A)]^{1-y_{it}} \\
+ [\Lambda(\alpha_i^A + X^A_{it}\gamma^A)\Lambda(\alpha_i^{UD} + X_{it}^U\beta^{UD})]^{y_{it}z_{it}} \\
+ [\Lambda(\alpha_i^A + X^A_{it}\gamma^A)(1-\Lambda(\alpha_i^{UD} + X_{it}^U\beta^{UD}))]^{y_{it}(1-z_{it})}
\]

However, since the number of fixed effect parameters \( \alpha_i^A \) and \( \alpha_i^{UD} \) increase with the number of countries in the sample (N), \( \alpha_i^A \) and \( \alpha_i^{UD} \) cannot be consistently estimated for a fixed \( T \). As the estimate of \( \gamma^A \) and \( \beta^{UD} \) are functions of the estimators for \( \alpha_i^A \) and \( \alpha_i^{UD} \), the MLE of \( \gamma^A \) and \( \beta^{UD} \) 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 \( \alpha_i^A \) and \( \alpha_i^{UD} \) and estimate the conditional likelihood function conditional on the sufficient statistics for \( \alpha_i^A \) and \( \alpha_i^{UD} \). By definition of a sufficient statistic, the conditional distribution given the sufficient statistic will not depend on \( \alpha_i^A \) and \( \alpha_i^{UD} \). Chamberlain (1980) finds that \( \Sigma_{t=1}^Ty_{it} \) is the a minimum sufficient statistic for \( \alpha_i^A \). Therefore, Chamberlain suggests maximizing the conditional likelihood function to obtain the consistent logit estimates for \( \gamma^A \):

\[
f_{\epsilon_i^A} = f_i^A(y_{i1}, y_{i2}, ...., y_{iT} | \Sigma_{t=1}^Ty_{it}) \quad (6)
\]
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:

\[
f_{c_i}^A = \frac{\exp(\sum_{t=1}^T y_{it} X'_{it} \gamma^A)}{\sum_{S_i \in \mathcal{A}} \exp(\sum_{t=1}^T d_{it} X'_{it} \gamma^A)}
\]

(7)

where the function in the denominator is summed over the set of all \( \binom{T}{S_i^A} \) different sequences of T zeros and ones that have the same sum as \( S_i^A = \sum_{t=1}^T y_{it} \). 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 \( S_i^A = \sum_{t=1}^T y_{it} \) 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 \( \alpha_{i UD} \) is the sum of \( z_{it} \) and the set of \( y_{it} \) which equals to 1 \( (\sum_{t=1}^T z_{it}, \{ y_{it} = 1 \}_{t=1}^T) \). That means we can obtain consistent estimates for \( \beta_{UD} \) by estimating the following conditional density function:

\[
f_{c_i}^{UD} = \frac{\exp(\sum_{t=1}^T y_{it} z_{it} X'_{it} \beta_{UD})}{\sum_{S_i \in \mathcal{D}_i \subset \mathcal{D}} \exp(\sum_{t=1}^T d_{it} z_{it} X'_{it} \beta_{UD})}
\]

(8)

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

It is widely known that in a logit or probit model, the magnitude of the marginal impact of a unit change in a predictor $X_j$ on the predicted probability $\left( \frac{\partial P}{\partial X_j} \right)$ is not directly measured by the coefficient associated with $X_j$ but is measured by a function of both the predictors (which are time varying) and the coefficients associated with the predictors (see equation (10) and (11) below). Nevertheless, the direction of relationship between a predictor and the predicted probability is uniquely determined by the sign of the estimation coefficient associated with the predictor. The relative importance of various predictors in predicting the occurrences of recent crises are examined in greater details in Section 7. Below is an analysis of the relationship between a unit change in a predictor $X_j$ and the predicted probability $\left( \frac{\partial P}{\partial X_j} \right)$:

Let $\gamma_j^A$ be the estimation coefficient associated with the predictor $X_j$ in the prediction of speculative attacks. That is, it is the $j^{th}$ component of the coefficient vector $\gamma^A$. The marginal impact of a unit change in a predictor $X_j$ on the predicted probability of speculative attack $\left( \frac{\partial P(A)}{\partial X_j} \right)$ is measured by:

\[
\frac{dP(A)}{dX_j} = \frac{d\left( \frac{e^{X'\gamma^A}}{1+e^{X'\gamma^A}} \right)}{dX_j} = \gamma_j^A \left[ \frac{e^{X'\gamma^A}}{(1 + e^{X'\gamma^A})^2} \right]
\]  

(10)

Since the second component $\left[ \frac{e^{X'\gamma^A}}{(1 + e^{X'\gamma^A})} \right]^2$ is always positive, the marginal impact of a unit change in a predictor $X_j$ on the predicted probability of speculative attacks is of the same sign as the estimation coefficient associated with this predictor ($\gamma_j^A$).
Similarly, let $\beta_{UD}^j$ be the estimation coefficient associated with the predictor $X_j$ in the prediction of unsuccessful defenses given speculative attacks. That is, it is the $j^{th}$ component of the coefficient vector $\beta^{UD}$. The marginal impact of a unit change in a predictor $X_j$ on the predicted probability of speculative attack $\left(\frac{\partial P(UD|A)}{\partial X_j}\right)$ is measured by:

$$
\frac{dP(UD|A)}{dX_j} = \frac{d(e^{X_0^j \beta_{UD}})}{dX_j} = \beta_{UD}^j \left[\frac{e^{X_0^j \beta_{UD}}}{1 + e^{X_0^j \beta_{UD}}}\right]^2.
$$

(11)

Again, since the second component $\left[\frac{e^{X_0^j \beta_{UD}}}{1 + e^{X_0^j \beta_{UD}}}\right]^2$ is always positive, the marginal impact of a unit change in a predictor $X_j$ on the predicted probability of unsuccessful defenses given speculative attacks is of the same sign as the estimation coefficient associated with this predictor $\left(\beta_{UD}^j\right)$.

4.1 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). 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.

\[
Z_{it} \begin{cases} 
1 & \text{if } (\Delta EX_{it} > \overline{EX}_it) \\
0 & \text{otherwise}
\end{cases}
\]

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

\[
Y_{it}(1 - Z_{it}) \begin{cases} 
1 & \text{if } (\Delta Re_{s_it} < -\overline{Re}_{s_it} \text{ or } \Delta DisRate_{it} > \overline{DisRate}_i) \\
& \text{and } Z_{it} = 0 \\
0 & \text{otherwise}
\end{cases}
\]

Both the threshold for quarterly reserve loss (\( -\overline{Re}_{s_it} \)) 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.
5 Estimation Results and An Analysis of the Effects of Capital Control

5.1 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 3.1, 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.

5.2 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. 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) | | |
|--------------|-----------|---|---|-----------|---|
| | | | | | |
| Lending Rate Differentials | | | | | |
| | | | | | |
| Ratio of short external liabilities to FX reserves | 0.3640 | 0.9312 | 0.2273 | 0.9859 | |
| | (3.0302)** | (2.8639)** | (2.7587)** | (2.1564)* | |
| Real Exchange Rate Appreciation Index (86Q1=1) | 0.1298 | 0.4224 | 0.1683 | 1.2167 | |
| | (2.8767)** | (1.2987) | (2.1286)* | (2.8171)** | |
| Ratio of Quasi-money to FX reserves | 0.0688 | 0.9134 | 0.4983 | 0.8865 | |
| | (0.4863) | (2.2231)* | (3.2048)** | (2.2539)* | |
| Ratio of fiscal deficits to GDP | 0.4152 | 0.8228 | 0.4206 | 0.9051 | |
| | (2.5456)** | (1.5599) | (2.5810)** | (1.5200) | |
| Ratio of domestic credit to GDP | 0.2249 | 0.6826 | 0.2713 | 0.6509 | |
| | (1.2628) | (1.7913) | (1.5049) | (1.4898) | |
| Unemployment rate (deviations from historical mean) | 0.0929 | 0.3018 | 0.0688 | 0.5612 | |
| | (0.9068) | (2.2454)* | (0.6681) | (2.2094)* | |
| Real GDP growth | -0.0711 | -0.5013 | -0.0465 | -0.1424 | |
| | (-0.5337) | (-2.3992)* | (-0.3487) | (-0.3420) | |
| Ratio of public debts to GDP | 0.0193 | 0.2299 | 0.0627 | 0.2088 | |
| | (0.6195) | (1.6078) | (0.5357) | (1.0219) | |
| Capital controls index× ratio of short term foreign liabilities to FX reserves | – | – | -0.2440 | -2.1050 | |
| | – | – | (-1.6635) | (-4.2594)** | |
| Capital controls index× ratio of quasi-money to FX reserves | – | – | -0.8208 | -0.6548 | |
| | – | – | (-3.7329)** | (-1.1403) | |

Note: 1. The numbers in parentheses 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
6 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

\[ QPS = \frac{1}{TT} \sum_{t=1}^{T} \sum_{i=1}^{I} 2(P_{it} - R_{it})^2 \]

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:

\[ LPS = -\frac{1}{TT} \sum_{t=1}^{T} \sum_{i=1}^{I} [(1 - R_{it}) \ln(1 - P_{it}) + R_{it} \ln(P_{it})] \]

LPS ranges from 0 to \( \infty \), 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 average forecast calibration is measured by the global squared bias (GSB):
\[ GSB = \frac{1}{T} \sum_{t=1}^{T} 2(P_i - R_i)^2 \]

where \( P_i = \frac{1}{T} \sum_{t=1}^{T} P_{it} \) and \( R_i = \frac{1}{T} \sum_{t=1}^{T} R_{it} \). 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 predicted conditional probabilities of successful defenses given attacks are plotted in Figure 11(a)-11(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 11(a)-11(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.
Part (a): Goodness of Fit for Crisis Periods (State 2) and Non-crisis Periods (State 0 and 1)

<table>
<thead>
<tr>
<th>Model</th>
<th>QPS Non-Crisis Periods</th>
<th>QPS Crisis Periods</th>
<th>LPS Non-Crisis Periods</th>
<th>LPS Crisis Periods</th>
<th>GSB Non-Crisis Periods</th>
<th>GSB Crisis Periods</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kaminsky’s Composite Indicator</td>
<td>0.110</td>
<td>0.862</td>
<td>0.240</td>
<td>1.161</td>
<td>0.071</td>
<td>0.735</td>
</tr>
<tr>
<td>Nested Logit</td>
<td>0.1063</td>
<td>0.5057</td>
<td>0.1650</td>
<td>0.7367</td>
<td>0.0639</td>
<td>0.1385</td>
</tr>
</tbody>
</table>

Part (b): Goodness of Fit for Periods with Successful Defenses given Speculative Attacks

<table>
<thead>
<tr>
<th>Model</th>
<th>QPS</th>
<th>LPS</th>
<th>GSB</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nested Logit</td>
<td>0.5262</td>
<td>0.7375</td>
<td>0.2991</td>
</tr>
</tbody>
</table>

(with capital control variable)

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

7 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 countries. First degree Taylor series expansion is used to disaggregate the increase in 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. 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, \( P(A)_{it} - P(A)_{i0} \), with respect to the predictive variables \( X_1, X_2, \ldots, X_j \) is written as follows:

\[
P(A)_{it} - P(A)_{i0} = \frac{\partial P(A)_{it}}{\partial X_1} (X_1_{it} - X_1_{i0}) + \frac{\partial P(A)_{it}}{\partial X_2} (X_2_{it} - X_2_{i0}) + \ldots + \frac{\partial P(A)_{it}}{\partial X_j} (X_j_{it} - X_j_{i0}) + \varepsilon_{it}
\]

Each term \([P(A)_{i0}]^2 \gamma_{A1} (X_{1, it} - X_{1, i0})\), \([P(A)_{i0}]^2 \gamma_{A2} (X_{2, it} - X_{2, i0})\), \ldots, \([P(A)_{i0}]^2 \gamma_{Aj} (X_{j, it} - X_{j, i0})\) on the right hand side measures how much the increase in the predicted probability of speculative attacks can be attributed to each predictive variable, with \( \gamma_{A1}, \gamma_{A2}, \ldots, \gamma_{Aj} \) denote the estimated coefficients of the predictive variables \( X_1, X_2, \ldots, X_j \) 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 domestic credit to GDP.
<table>
<thead>
<tr>
<th>Country</th>
<th>Time Period</th>
<th>( (t_0, t) )</th>
<th>( P(A)<em>{it} - P(A)</em>{ito} )</th>
<th>lending rate differential</th>
<th>ratio of short term external liabilities to reserves</th>
<th>real exchange rate appreciat.</th>
<th>ratio of quasi money to reserves</th>
</tr>
</thead>
<tbody>
<tr>
<td>Argentina</td>
<td>(94Q1,95Q1)</td>
<td>0.126</td>
<td>0.032</td>
<td>0.029</td>
<td>0.0001</td>
<td>0.065</td>
<td></td>
</tr>
<tr>
<td>Brazil</td>
<td>(98Q1,99Q1)</td>
<td>0.248</td>
<td>-0.002</td>
<td>0.030</td>
<td>-0.022</td>
<td>0.028</td>
<td></td>
</tr>
<tr>
<td>Chile</td>
<td>(92Q4,97Q4)</td>
<td>0.359</td>
<td>-0.057</td>
<td>( 0.318 )</td>
<td>0.001</td>
<td>0.037</td>
<td></td>
</tr>
<tr>
<td>China</td>
<td>(91Q4,98Q1)</td>
<td>0.106</td>
<td>-0.0006</td>
<td>0.008</td>
<td>0.003</td>
<td>( 0.102 )</td>
<td></td>
</tr>
<tr>
<td>HK(SAR)</td>
<td>(96Q4,97Q4)</td>
<td>0.068</td>
<td>0.072</td>
<td>-0.034</td>
<td>0.081</td>
<td>-0.109</td>
<td></td>
</tr>
<tr>
<td>Colombia</td>
<td>(93Q1,98Q1)</td>
<td>0.098</td>
<td>-0.0006</td>
<td>0.0450</td>
<td>0.006</td>
<td>( 0.068 )</td>
<td></td>
</tr>
<tr>
<td>Indonesia</td>
<td>(92Q3,97Q3)</td>
<td>0.149</td>
<td>0.069</td>
<td>( 0.071 )</td>
<td>-0.030</td>
<td>0.006</td>
<td></td>
</tr>
<tr>
<td>S.Korea</td>
<td>(92Q3,97Q3)</td>
<td>0.194</td>
<td>-0.010</td>
<td>( 0.398 )</td>
<td>-0.013</td>
<td>0.049</td>
<td></td>
</tr>
<tr>
<td>Malaysia</td>
<td>(92Q3,97Q3)</td>
<td>0.203</td>
<td>-0.0104</td>
<td>0.187</td>
<td>-0.068</td>
<td>( 0.356 )</td>
<td></td>
</tr>
<tr>
<td>Mexico</td>
<td>(93Q4,94Q4)</td>
<td>0.248</td>
<td>0.005</td>
<td>0.104</td>
<td>-0.059</td>
<td>( 0.177 )</td>
<td></td>
</tr>
<tr>
<td>Philip.</td>
<td>(94Q2,97Q3)</td>
<td>0.213</td>
<td>-0.0004</td>
<td>( 0.410 )</td>
<td>-0.063</td>
<td>0.143</td>
<td></td>
</tr>
<tr>
<td>Singapore</td>
<td>(95Q4,97Q4)</td>
<td>0.068</td>
<td>0.0006</td>
<td>( 0.043 )</td>
<td>-0.007</td>
<td>0.001</td>
<td></td>
</tr>
<tr>
<td>Taiwan</td>
<td>(96Q4,97Q4)</td>
<td>0.076</td>
<td>-0.003</td>
<td>0.032</td>
<td>-0.033</td>
<td>-0.015</td>
<td></td>
</tr>
<tr>
<td>Thailand</td>
<td>(92Q3,97Q3)</td>
<td>0.114</td>
<td>-0.0007</td>
<td>( 0.042 )</td>
<td>-0.016</td>
<td>0.002</td>
<td></td>
</tr>
<tr>
<td>Uruguay</td>
<td>(86Q2,96Q2)</td>
<td>0.190</td>
<td>-0.011</td>
<td>-0.039</td>
<td>0.032</td>
<td>-0.340</td>
<td></td>
</tr>
<tr>
<td>Venezuela</td>
<td>(93Q2,94Q2)</td>
<td>0.099</td>
<td>-0.0006</td>
<td>0.014</td>
<td>0.017</td>
<td>0.008</td>
<td></td>
</tr>
</tbody>
</table>

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

Table 3: The Increase in the Probabilities of Attacks Attributable to Various Factors
8 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 as well as analyze the relative importance of various internal and external economic factors in triggering 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, 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) stressed 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 1982Q1 through 2001Q4 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 web-pages of the Asian Development Bank (ADB) and the Bank of International Settlements (BIS). The following table shows the sources and definitions of the variables:
<table>
<thead>
<tr>
<th>Predictors</th>
<th>Sources and Definitions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Lending rate differential</td>
<td>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.</td>
</tr>
<tr>
<td>2. Ratio of short-term international liquefiable liabilities to foreign exchange reserves</td>
<td>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.</td>
</tr>
<tr>
<td>3. Real exchange rate appreciation index</td>
<td>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.</td>
</tr>
<tr>
<td>4. Ratio of quasi-money (M2-M1) to foreign exchange reserves</td>
<td>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.</td>
</tr>
<tr>
<td>5. Ratio of fiscal deficits to GDP</td>
<td>Fiscal deficit is from IFS line 80 and GDP is from IFS line 99B.</td>
</tr>
<tr>
<td>6. Unemployment rate</td>
<td>Historical unemployment rate is from the World Development Indicator CD-ROM. Recent data are from the official webpages of various countries.</td>
</tr>
<tr>
<td>7. Public Debt</td>
<td>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.</td>
</tr>
</tbody>
</table>
Appendix B:
Dates of Attacks that were Successfully and Unsuccessfully Defended


<table>
<thead>
<tr>
<th>Countries</th>
<th>Successful Defense Dates</th>
<th>Unsuccessful Defense Dates</th>
</tr>
</thead>
<tbody>
<tr>
<td>2. Brazil</td>
<td>None between 1982Q1-2001Q4</td>
<td>1983Q1, 1987Q2, 1989Q3, 1999Q1</td>
</tr>
<tr>
<td>3. Chile</td>
<td>1997Q4</td>
<td>1982Q2, 1985Q3</td>
</tr>
<tr>
<td>6. Hong Kong, SAR</td>
<td>1993Q1, 1997Q4</td>
<td>None between 1982Q1-2001Q4</td>
</tr>
<tr>
<td>8. S.Korea</td>
<td>1986Q3</td>
<td>1997Q3</td>
</tr>
<tr>
<td>9. Malaysia</td>
<td>None between 1982Q1-2001Q4</td>
<td>1997Q3</td>
</tr>
<tr>
<td>12. Singapore</td>
<td>1995Q1</td>
<td>1997Q4</td>
</tr>
</tbody>
</table>
Figure 1(a): Lending Rate Differentials - Selected Asian Countries

Figure 1(b): Lending Rate Differentials - Selected Latin American Countries
Figure 2(a): Ratio of Fiscal Balance to GDP - Selected Asian Countries

Figure 2(b): Ratio of Fiscal Balance to GDP - Selected Latin American Countries
Figure 3(a): Ratio of Short-Term External Liabilities to Foreign Exchange Reserves  
- Selected Asian Countries

Figure 3(b): Ratio of Short-Term External Liabilities to Foreign Exchange Reserves  
- Selected Latin American Countries
Figure 4(a): Ratio of Quasi-money to Foreign Reserves - Selected Asian Countries

Figure 4(b): Ratio of Quasi-money to Foreign Reserves - Selected Latin American Countries
Figure 5(a): Ratio of Domestic Credit to GDP - Selected Asian Countries

Figure 5(b): Ratio of Domestic Credit to GDP - Selected Latin American Countries
Figure 6(a): Ratio of Public Debt to GDP - Selected Asian Countries

Figure 6(b): Ratio of Public Debt to GDP - Selected Latin American Countries
Figure 7(a): Real Exchange Rate Index - Selected Asian Countries

Figure 7(b): Real Exchange Rate Index - Selected Latin American Countries
Figure 8(a): Unemployment Rate - Selected Asian Countries

Figure 8(b): Unemployment Rate - Selected Latin American Countries
Figure 9(a): Growth of Real GDP - Selected Asian Countries

Figure 9(b): Growth of Real GDP - Selected Latin American Countries
Figure 10(a): Capital Control Index of the Asian Countries as at March 1997

Figure 10(b): Capital Control Index of the Latin American Countries as at March 1997
Figure 11(a): Predicted Probabilities - China

Figure 11(b): Predicted Probabilities - Hong Kong
Figure 11(c): Predicted Probabilities - Indonesia

Figure 11(d): Predicted Probabilities - S.Korea
Figure 11(e): Predicted Probabilities - Malaysia

Figure 11(f): Predicted Probabilities - Philippines
Figure 11(g): Predicted Probabilities - Singapore

Figure 11(h): Predicted Probabilities - Taiwan
Figure 11(i): Predicted Probabilities - Thailand

Figure 11(j): Predicted Probabilities - Argentina
Figure 11(k): Predicted Probabilities - Brazil

Figure 11(l): Predicted Probabilities - Chile
URUGUAY

Figure 11(o): Predicted Probabilities - Uruguay

VENEZUELA

Figure 11(p): Predicted Probabilities - Venezuela
References


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 devaluing the domestic currency may have great potential benefits. In both the cases of unsuccessful defenses and successful nondefenses, currency crises occur. Instances of "successful nondefenses" include those of Taiwan and Singapore in 1997Q4.

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.

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.

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.

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.