Essays on the Demand for International Reserves and Currency Crises

BY

Jie Li

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Approved by:

Thomas D. Willett

We, the undersigned, certify that we have read this dissertation of Jie Li and approve it as adequate in scope and quality for the degree of Doctor of Philosophy.

Dissertation Committee:

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Thomas D. Willett, Chair

____

Arthur T. Denzau, Member

____

Ramkishen S. Rajan, Member

Abstract of the Dissertation

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One of the main lessons from Asian Financial Crises is that a country is more likely to be hit by a currency crisis when it has low levels of international reserves in relation to short-term external debt. What is not clear yet is, to what extent, a country with high reserves is able to avoid currency attacks stemming from weak fundamentals like current account deficits and real effective exchange rate appreciation. First generation crisis models suggest that size of international reserves affects only the timing of a crisis. Second generation crisis models, however, imply that higher reserves may reduce the probability of a crisis in a vulnerable zone. This dissertation investigates systematically the potential tradeoffs between high reserves and weak fundamentals in currency crises and considers the implications for optimal levels of reserve holdings.

In the first essay of the dissertation, *A Simple Model of Precautionary Demand for Reserves*, we develop a model to demonstrate that high reserves are ineffective in protecting against currency crises when the economy is in a zone of bad fundamentals, but can be effective in offsetting weak fundamentals in a vulnerable zone. Furthermore, the countries with weaker

fundamentals in a vulnerable zone require higher levels of international reserves to avoid a crisis.

The second essay, *Can High Reserves Offset Weak Fundamentals*, extends Sachs, Tornell and Velasco (1996) and confirms the predictions in the first essay. It uses a probit model for 42 emerging markets countries to examine the tradeoffs among different measures of weak fundamentals and reserve levels. The empirics suggest that reserve hoarding is effective when the economy is in a vulnerable zone. The weaker are the fundamentals, the higher is the demand for international reserves.

The third essay of the dissertation, *The Imprecision of the Precision Weights,* discusses the inappropriate use of the precision weights in constructing the composite variable, the exchange market pressure (EMP). The precision-weighted EMP discounts the components with higher variability by imposing the inverse of their variance as the weights. However, the higher variability of the components merely reflects the government's preference to use such policy tools to absorb the exchange market pressure more frequently. This essay extends the model in Weymark (1995) and derives the exchange rate elasticities of reserves and interest rates. We develop the new EMP weighted by the elasticities. By comparing the new EMP with the conventional precision-weighted EMP, we conclude that the precision weights are imprecise and conceptually incorrect.

Dedication

To my family, Houde Li, Lihua Zou, Jun Li, Baozhen Huang, Xianxin Lin, Yingzi Li, Zhaoqi Li and Xinfeng Lin.

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ESSAY 1:

A SIMPLE MODEL OF THE PRECAUTIONARY DEMAND FOR INTERNATIONAL RESERVES

1. Introduction

An important element of the ongoing global macroeconomic imbalances is the large and growing stockpile of international reserves by Asian economies. Between 1990 and 2004, international reserves (excluding gold) in Asia rose from US$ 400 billion to US$ 2600 billion (Figure 1). Asia's share of global reserves correspondingly rose from about 40 percent in 1990 to 65 percent by 2004. Part of the motivation behind the reserve accumulation is likely from a deep-rooted mercantilist desire by Asian governments to maintain undervalued exchange rates and bolster domestic employment, as well as a general reluctance to forsake firm US dollar pegged regimes[1]. Apart from these exchange rate objectives which have resulted in rapid reserve accumulation as a side effect, Asian countries have chosen explicitly to build up reserves for precautionary or insurance motives (Bird and Rajan, 2003). For instance, Aizenman and Marion (2003) have noted that the "behavior has changed since the Asian financial crisis", and go on to suggest that the "recent build-up of large international reserve holdings in a number of Asian emerging markets may represent precautionary holdings" (p.11).

Precautionary motives for accumulating reserves encompass both crisis management and crisis prevention. The former refers to the role of reserves in reducing the extent of exchange rate (and output) adjustment if a crisis does happen. This in turn could refer either to (a) the ability to finance underlying payments imbalances, or (b) provide liquidity in the face of runs on the currency. Crisis prevention refers broadly to a reduction in the incidence of a crisis. The argument here is simply that, other things equal,

[1] China, Hong Kong and Malaysia are such examples. It is also possible that countries that have loosened their pegged regimes still choose to hold high reserve levels as they are viewed as a sign of creditworthiness, hence reducing the degree of exchange rate volatility. Some evidence of this thesis is offered by Hviding et al. (2004).

high reserves may be viewed as a sign of strength of an economy, thus reducing the chances of a run against the currency. Indeed, many studies have confirmed that high reserves to short term debt or money supply ratios have consistently stood out as being robust predictors of a crisis (Bird and Rajan, 2003, De Beaufort Wijnholds and Kapetyn, 2001, and Willett et al 2004). Some have even suggested that sufficiently high levels of reserves can fully offset weak fundamentals (Sachs et al., 1996). Counterbalancing these precautionary motives for holding reserves are the opportunity costs which arise from substituting high yielding domestic assets for lower yielding foreign ones. These costs can be proxied as the difference between the domestic marginal product of capital and the returns obtained on the reserve assets (usually US T-Bills)[2].

This paper has a rather modest objective. It attempts to develop a simple optimizing model to determine the optimal reserve holdings by a country looking to minimize the net costs of holding reserves. In so doing the paper also attempts to determine the validity of the Sachs et al. (1996) assertion that sufficiently high levels of reserves can compensate for weak fundamentals.

The remainder of this paper is organized as follows. The next section outlines the basic structure of the model and solution. Section 3 discusses the nexus between weak fundamentals and optimal reserve sizes. Section 4 offers some concluding observations.

2. The Model

2.1 Basic Structure and Assumptions

[2] Two caveats are in order. One, it is sometimes noted that reserves could be used to pay down external debt. The difference of the interest rate paid on the external debt and from that earned on reserve assets could be a proxy for opportunity cost of holding reserves. Two, another set of costs of persistent reserve accumulation arises due to the inflationary consequences of excess liquidity and/or the costs of mopping up the liquidity, i.e. sterilization (for instance, see Kletzer and Spiegel, 2004).

The basic model structure is fairly simple and intuitive. We assume a central bank's aim is to minimize the total costs[3].

As noted, the major precautionary benefits from holding reserves are twofold. One, a stockpile of reserves may reduce the probability of a crisis occurring in the first instance, i.e. crisis prevention role. Two, reserves help reduce the adjustment costs if a crisis does occur, i.e. crisis management role.

In other words:

(1) $TC = PC_C + RC_R$

TC: total costs.

R: level of international reserves.

C_c: unit cost associated with the crisis, measured as the output loss, viz. the difference of the output levels between normal times and crises.

C_R: unit opportunity cost of holding reserves. We assume this to be constant.

P: probability of crises which is a function of *R* as well as a vector of weak fundamentals (X). In addition, $P_X > 0$ and $P_R < 0$.

The output loss (C_C) is assumed to be the difference of the output levels between normal times and crisis.

(2) $C_C = Y_N - Y_C$

Y_N: the output level in normal times;

Y_C: the output level in crises times.

We assume, for simplicity, that the only input of production is capital (*K*):

[3] For an early cost-benefit analysis on the issue of optimal reserves, see Bassat and Gottlieb (1992). For a more recent model of precautionary reserve demand which links the level of reserves to the reduction in the possibility of output collapse due to sovereign partial default, see Aizenman et al (2004).

(3) $Y = F(K)$ where: $\frac{\partial F}{\partial K} > 0,\ \frac{\partial^2 F}{\partial K^2} < 0$.

We need to make explicit the costs of a crisis. Assume that during normal times $K = \overline{K}$. To maintain a degree of generality, we assume that a crisis -- bad state of nature -- acts as a negative supply shock in the sense that either the extent of capital stock deteriorates, or the average productivity of capital declines (A). However, for a given crisis, the bad state of nature is inversely related to the amount of reserves. In other words, the extent of impact of the bad state of nature is lower the higher is the stock of reserves. So:

(4) $$K = \begin{cases} \overline{K}, & \text{in normal times} \\ A(R)\overline{K}, & \text{in crises} \end{cases} \qquad \text{where, } 0 < A(R) < 1 \text{ and } A_R > 0$$[4].

Plugging eqs. (3) and (4) into (2), we can express the output loss as a function of reserves:

(5) $$C_C = Y_N - Y_C = F(\overline{K}) - F[A(R)\overline{K}]$$

From eq. (5) we have:

(6) $$\frac{\partial C_C}{\partial R} = -F'[A(R)\overline{K}] * \overline{K} * \frac{\partial A}{\partial R} < 0.$$

Eq. (6) reveals a negative relationship between the reserve holding and output loss during a crisis.

2.2 Model Solution

[4] If we interpret the shock in terms of capital reversals (CR), viz. the difference of capital flows in crisis and previous inflows, then $CR = K_C - \overline{K} = [A(R) - 1]\overline{K}$.

The central bank minimizes the loss function (eq. 1) so as to choose the optimal reserve. The first order condition of this minimization problem is:

$$(7) \qquad \frac{\partial P}{\partial R} * C_C + \frac{\partial C_C}{\partial R} * P + C_R = 0.$$

For concreteness, we make use of some specific functional forms. Let the probability function of crisis be:

$$P = P(X;R)$$

$$(8) \qquad = \exp[-R/X]$$

Following Sachs et al. (1996), X usually consists of at least four variables, viz. current account deficit (*CAD*), lending boom (*LB*), real exchange rate appreciation (*RER*), and the size of external debt (*STD*)[5]. The probability function reveals that with the accumulation of higher levels of reserves (*R*), the probability of crisis will converge to 0. If the level of reserves is close to 0, the probability of crisis will increase, peaking at 1. Meanwhile, if the weak fundamentals (*X*) are close to 0, the probability of crisis will decrease to 1; and if the weak fundamentals (*X*) are significantly high, the probability of a crisis will increase to 1.

From eq. 8 we have:

$$(9) \qquad \frac{\partial P}{\partial R} = (-1/X)[\exp(-R/X)] = -P/X$$

Plugging eq. 9 into eq. 7 and solving for P derives:

$$(10) \qquad P = \frac{C_R}{\frac{C_C}{X} - \lambda}, \text{ while } \lambda = \frac{\partial C_C}{\partial R}$$

---

[5] For instance, $X = \alpha CAD + \beta LB + \gamma RER + \eta STD$. However, in view of the possible tradeoffs between the various variables, there is not yet a clear indication of the best way of interacting them to come up with a suitable vector of weak fundamentals (Willett et al., 2004).

From eq. 7 and 10 we have:

$$(10^I) \quad \exp(-R/X) = \frac{C_R}{\frac{C_C}{X} - \lambda}$$

In order to solve for R^*, assume

$$Y = K^a \text{ and } A(R) = 1 - \exp(-R)$$

Note that when $R \to 0, A(R) = [1 - \exp(-R)] \to 0;$ when $R \to \infty, A(R) \to 1$.

$$(11) \quad C_C = Y_N - Y_C = F(\overline{K}) - F[A(R)\overline{K}] = \overline{K}^a[1 - (1 - e^{-R})^a]$$

$$(12) \quad \lambda = \frac{\partial C_C}{\partial R} = -a\overline{K}^a e^{-R}(1 - e^{-R})^{a-1}$$

Plug eqs. 11 and 12 into eq. 10 and rearranging derives:

$$(13) \quad \frac{e^{-R/X}\overline{K}^a[1-(1-e^{-R})^a]}{X} + a\overline{K}^a e^{-R-(R/X)}(1-e^{-R})^{a-1} = C_R$$

The left hand side of eq. 13 can be interpreted as the marginal benefit of holding reserves, while the right hand side is the marginal cost of reserves. In other words, an optimizing central bank will continue to build up reserves as long as the marginal benefits of doing exceed the marginal costs (opportunity costs). While this result is intuitive, the contribution of the simple model is to flesh out the factors that impact the marginal benefits which in turn allow us to analyze the nexus between weak fundamentals and reserve holdings. We elaborate on this issue in the next section.

3. Findings and Implications

While the right hand side of eq. 13 is assumed constant, the left hand side. is decreasing in R[6]. Given this, we have the following proposition -- *the sufficient condition for the existence of* R^* *is* $X \le \frac{\overline{K}^a}{C_R}$. Why?

We can set the domain of the left hand side as [0, ∞). If we set the initial R as 0, then, the output loss $C_C = \overline{K}^a$, and the marginal output loss, $\lambda = 0$. Thus, the left hand side of eq. 13 is reduced to $\frac{\overline{K}^a}{X}$. Therefore, the condition that $X \le \frac{\overline{K}^a}{C_R}$ can ensure there is at least one level of R such that the left hand side is greater than or equal to right hand side of eq. 13.

The proposition can be reinterpreted as follows. If the fundamentals (X) are sufficiently weak or the opportunity costs of holding reserves are sufficiently high, such that $X > \frac{\overline{K}^a}{C_R}$, there may not be any positive solution to R*. In other words, for extremely weak fundamentals no amount of reserves can help prevent a crisis from occurring (Figure 2). While this may contradict the conclusion of Sachs et al. (1996), it is broadly consistent with the critique by Nitithanprapas and Willett et al. (2004) and is also consistent with the second-generation models of currency crisis (Obstfeld, 1994, 1996 and Rajan, 2001).

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[6] Taking the partial derivative w.r.t. R we see that as R rises, the lower is $\frac{e^{-R/X}\overline{K}^a}{X}$, $[1-(1-e^{-R})^a]$, $a\overline{K}^a e^{-R-(R/X)}$, and $(1-e^{-R})^{a-1}$. All these terms are positive. Therefore, with the increase of R, all the terms on the left hand side of eq. 13 decrease. In other words, the left hand side is a decreasing function of R.

For the case where $X < \frac{\overline{K}^a}{C_R}$, there is an interior solution for R*. Worsening fundamentals (i.e. rising X) will lead to higher probability of crisis. This in turn, increases the marginal benefit of reserve holdings at any given reserve level. Therefore, the MB schedule will shift up from R* to R** (see Figure 3)[7]. So generally, as fundamentals get weaker, countries need to hold correspondingly more reserves, and high reserves can offset weak fundamentals only if the fundamentals are not "too weak".

4. Concluding Remarks

This paper has explored the issue of optimal reserve holdings by a central bank within a context of a simple analytical model. An important limitation of the model arises from the assumption of a constant opportunity cost of reserves. More realistically, insofar as these costs can be proxied as the opportunity cost, it is important to consider the impact of changes in the capital stock and production on the marginal costs of reserve holdings. This notwithstanding, the model suggests that in general, high reserves can help offset weak fundamentals. However, if fundamentals are sufficiently weak, no level of reserves will be able to offset the weak fundamentals. In other words, for "hopelessly weak" fundamentals, a crisis is inevitable and reserves cannot act as a substitute for domestic policy reforms and adjustments[8]. Conversely, if fundamentals are "sufficiently strong", a crisis will never occur. However, if fundamentals are within a certain range – zone of vulnerability – other things equal, higher levels of reserves may help offset the negative impact of weak fundamentals. With fundamentals in the vulnerable zone, high

[7] In the Annex we derive the specific conditions under which the *MB* curve rises with X.

[8] Indeed, first generation crisis models imply that if fundamentals are sufficiently weak such that a crisis is inevitable, reserve levels should only influence the timing of crises.

reserves could have a powerful effect in protecting against crises. This also suggests that reserve needs should be related to the state of fundamentals in a non-linear manner.

Return to the issue of reserve stockpiling in Asia. The fact that a number of Asian countries are consciously looking to use part of their accumulated reserves to finance physical infrastructure (e.g. India) or strengthen their financial institutions (e.g. Korea and China), suggests that they have reached a level at which their perceived marginal benefits have been outweighed by their marginal costs. This in turn suggests that the recent build up of reserves in Asia has been more due to exchange rate motivations (i.e. mercantilism or general commitment to pegged regimes which are undervalued) rather than a conscious attempt to buy “insurance cover”.

Annex

This Annex derives the conditions under which the marginal benefit (*MB*) curve rises with X[9]. Taking the first derivative of the left hand side of eq. 13 w.r.t. X derives:

$$MB = e^{-R/X}\{\frac{\overline{K}^a[1-(1-e^{-R})^a]}{X} + a\overline{K}^a e^{-R}(1-e^{-R})^{a-1}\}$$

To simplify the notations, let $y = \overline{K}^a[1-(1-e^{-R})^a]$ and $z = a\overline{K}^a e^{-R}(1-e^{-R})^{a-1}$

$$\frac{\partial MB}{\partial X} = \frac{\mathrm{Re}^{-R/X}}{X^2}(\frac{y}{X}+z) - e^{-R/X}(\frac{y}{X^2})$$

$$= e^{-R/X}(\frac{Ry}{X^3}+\frac{Rz}{X^2}) - e^{-R/X}(\frac{y}{X^2})$$

$$= e^{-R/X}(\frac{yR+XRz-yX}{X^3}) \qquad = e^{-R/X}[\frac{y(R-X)}{X^3}+\frac{Rz}{X^2}]$$

If $R > \frac{yX}{y+Xz}$, then, $y(R-X) + XRz > 0$, and $\frac{\partial MB}{\partial X} > 0$.

[9] While not shown here, the impact of a change of X on the slope of the MB curve (i.e. $\partial(\partial MB/\partial R)/\partial X$) is ambiguous..

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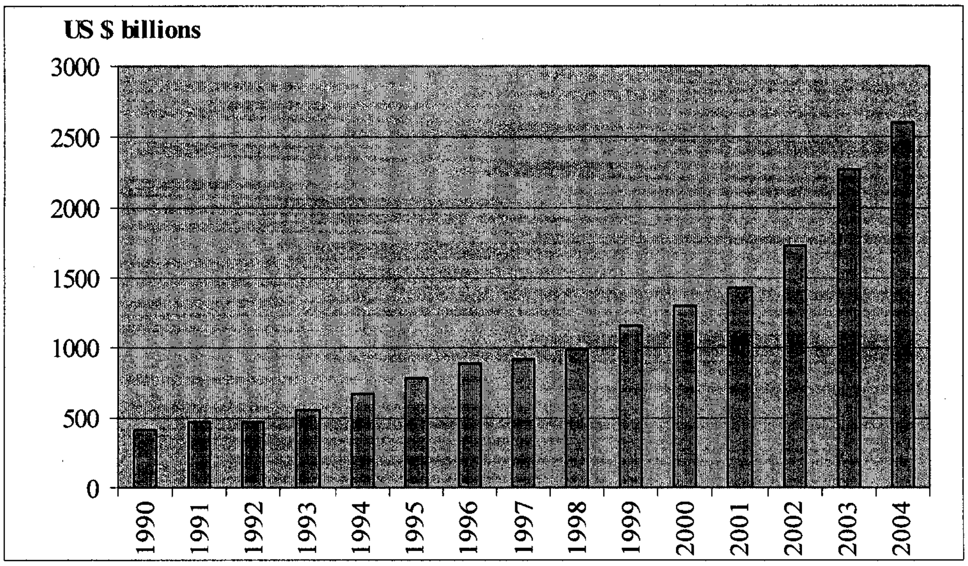
Figure 1
International Reserves in Asia, 1990-2004



Source: International Financial Statistics

Figure 2
Reserves Insufficient to Offset Weak Fundamentals

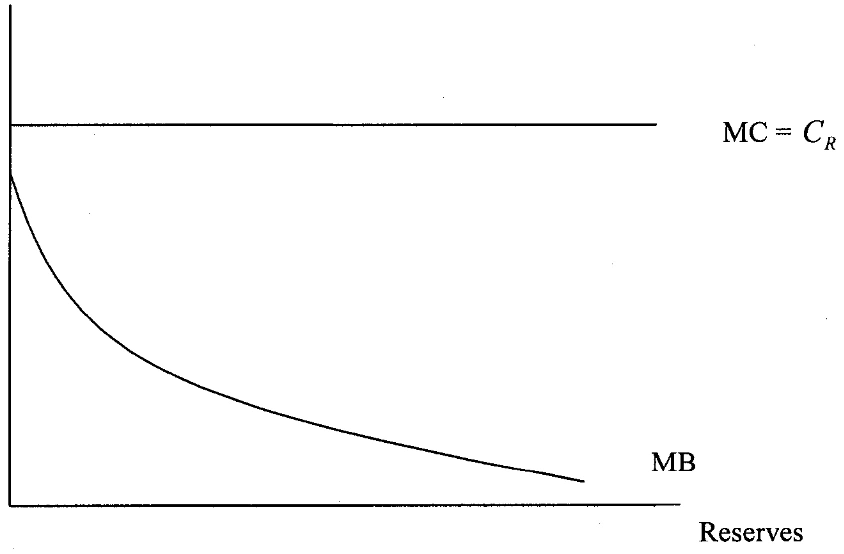
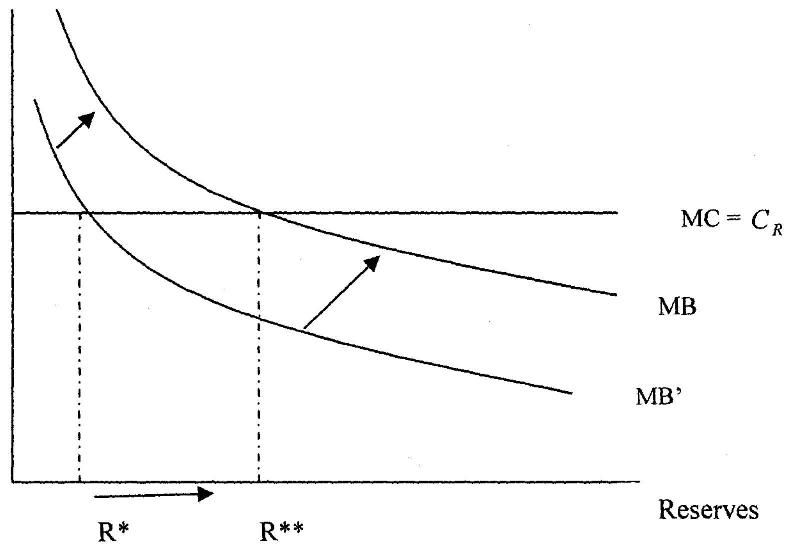


Figure 3
Worsening Fundamentals Compensated for by Higher Reserves



ESSAY 2:

CAN HIGH RESERVES OFFSET WEAK FUNDAMENTALS?

1. Introduction

Since the Asian crisis of 1997-98, a number of countries in Asia have been rapidly stockpiling international reserves in the belief that high reserves can help fortify their countries against future financial crises (Kim et al., 2005 and Bird and Rajan, 2003). As is well known, in first generation currency crisis models a speculative attack on a pegged regime is inevitable if the fundamentals of a country are bad. The focus of the models is predominantly on the timing of the crisis. High reserves relative to weak fundamentals in this case only postpone the inevitable crisis; they cannot prevent the crisis by offsetting the weak fundamentals. By contrast, in second generation models, where expectations play a crucial role in the zone of vulnerability, there is room for high reserves to be effective in avoiding crises.[1] High reserves may provide a signal of the ability of the authority to defend the currency, hence altering market expectations. In this respect, high reserves could possibly offset weak fundamentals provided that the weak fundamentals are not too bad[2].

Sachs, Tornell, and Velasco (STV henceforth) (1996) developed an influential model that was applied to the Mexican Crisis. The authors identified three factors that determined the vulnerability of a country: a high real exchange rate appreciation, a recent lending boom and low reserves. They found that the difference in these fundamentals explained well why some emerging markets were hit by financial crises while others not. In terms of the interactions between high reserves and weak fundamentals, however, they did not refer to the distinction between first and second generation models (the latter were just being developed at the time of their paper) and found that adequate reserves can fully

[1] For detailed discussions of the first and second crisis models with application to Asia, see Rajan (2001).
[2] The previous essay shows that if the fundamentals are too bad, high reserves cannot help avoid any crisis.

offset bad fundamentals. Bussiere and Mulder (1999) moved a step further to construct a linear tradeoff between high reserves and weak fundamentals based on an estimated linear equation.

By recognizing that there should be no tradeoff between bad fundamentals and high reserves according to first generation models, Nitithanprapas, Nitithanprapas and Willett (NNW henceforth) (2001) showed that high reserves may not necessarily offset the effects from weak fundamentals. The implication of the distinction between first and second generation models is that high reserves should be able to lower the probability of crises when fundamentals are in a vulnerable zone, but not in an extremely bad zone. It is not clear *a priori* to what extent the STV's measure of weak fundamentals corresponds to vulnerable or bad fundamentals. It is clear, however, that the tradeoff between reserves and fundamentals should lose the linearity assumed by Bussiere et al (1999) as the fundamentals continue to deteriorate from the vulnerable to a bad zone.

Following the theoretical predictions in essay one, this essay investigates the empirical issues of the interaction of high reserves and weak fundamentals by testing the offsetting role of reserves in a vulnerable zone. The model in essay one bridges the first and second generation crisis and makes clear the distinction between weak fundamentals and bad fundamentals [3] from the standpoint of the optimal demand for reserves. Specifically, if the domestic economy is in an extremely bad zone, reserves cannot help avoid financial crises as predicted in first generation crisis models. Meanwhile, if the fundamentals are in a vulnerable zone, the reserve accumulation can decrease the risk of crises, as is the focus of the current empirical essay. In addition, in a vulnerable zone, the

[3] For an easier interpretation, we refer "weak fundamentals" to the fundamentals in a vulnerable zone and "bad fundamentals" to the ones in a bad zone.

country with weaker fundamentals should accumulate more reserves in order to reduce its vulnerability.

The remainder of the paper is organized as follows. Section 2 reviews the main empirical literature to date on the issue of interaction of weak fundamentals and reserves. Sections 3, 4 and 5 undertake an empirical investigation of the links between reserves, weak fundamentals and crises. In particular, Section 3 discusses the data, definitions and methodology and outlines the empirical model to be estimated, while Section 4 discusses the results. Section 5 goes on to provide some robustness checks for the empirical results. The final section concludes the paper.

2. Review of the Existing Empirical Literature

To date there have been four major studies that have focused intensively on the empirical relationship between reserves, weak fundamentals and crises. We consider each of them briefly below.

2.1 Sachs Tornell and Velasco (1996)

STV defined weak fundamentals as a lending boom and real exchange rate appreciation. The authors developed a lending boom variable as an important determinant of currency crisis and empirically showed that the weak fundamentals worked very well in crisis models in conjunction with low reserves.

STV's model is summarized below:

$$CI = \beta_1 + \beta_2(RER) + \beta_3(LB) + \beta_4(D^{LR} * RER) + \beta_5(D^{LR} * LB) + \beta_6(D^{LR} * D^{WF} * RER)$$
$$+\beta_7(D^{LR} * D^{WF} * LB) + \varepsilon$$

CI is the crisis index that is a measure of the severity of currency crisis. *RER* is the real exchange rate misalignment and LB is the lending boom. D^{LR} is defined as a dummy for countries with low reserves. D^{WF} is the dummy for weak fundamentals.

β_2 and β_3 capture the effects of the fundamentals on the crisis index in countries with high reserves and strong fundamentals. $\beta_2 + \beta_4$ and $\beta_3 + \beta_5$ capture the effects of the fundamentals on the crisis index in countries with low reserves but strong fundamentals. $\beta_2 + \beta_4 + \beta_6$ and $\beta_3 + \beta_5 + \beta_7$ capture the effects of the fundamentals on the crisis index in countries with low reserves and weak fundamentals.

The null hypotheses considered by STV were as follows:

Hypothesis 1: $\beta_2 + \beta_4 = 0$;

Hypothesis 2: $\beta_3 + \beta_5 = 0$

Hypothesis 3: $\beta_2 + \beta_4 + \beta_6 = 0$

Hypothesis 4: $\beta_3 + \beta_5 + \beta_7 = 0$

Their main empirical results were that hypotheses 1 and 2 could not be rejected while 3 and 4 were rejected at a conventionally significant level. The acceptance of the first two hypotheses told us that the effects of the fundamentals on the crisis index in countries with low reserves but strong fundamentals were not significant. The rejection of hypotheses 3 and 4 demonstrated that weak fundamentals coupled with low reserves would have a significant impact on the crisis index. However, none of these results necessarily showed that high reserves could offset the weak fundamentals.

2.2 Tornell (1999)

Tornell (1999) extended the STV model to explore common weak fundamentals in both the Tequila and Asian Crises. His model was

$$CI_{it} = \alpha_0 + \alpha_1 LB_{it} + \alpha_2 RER_{it} + \alpha_3 D^{hr} LB_{it} + \alpha_4 D^{hr} RER_{it} + \alpha_5 D^{sf} LB_{it} + \alpha_6 D^{sf} RER_{it} + \varepsilon_{it}$$

The notations in this paper were similar to STV. The author tested the hypothesis that there were three common weak fundamental variables in both the Tequila and Asian crises which determine the cross-country variation in the severity of crises. These three variables were the strength of the banking system, the real appreciation and the international liquidity of the country.

The main results of his model were: $\alpha_1 + \alpha_3 = \alpha_2 + \alpha_4 = 0$. This suggested that neither lending boom nor real exchange rate appreciation matter significantly in countries with high reserves when they were facing weak fundamentals. The result was closest to our hypothesis to be tested in this paper, viz. high reserves can offset weak fundamental in a certain vulnerable zone. However, Tornell (1999) did not test the significance of individual variables like lending boom (LB) and real effective exchange rate (RER). Consequently, his results did not necessarily imply that high reserves could offset weak fundamentals, as weak fundamentals themselves might not be significant in predicting the probability of crisis. Therefore, the insignificance of the combination of high reserves and weak fundamentals might indicate the inability of weak fundamentals themselves instead of offsetting the role of high reserves.

2.3 Bussiere and Mulder (1999)

Bussiere and Mulder (BM henceforth) (1999) tested the usefulness of the variables specified in an early warning system (EWS). One of the main results they found was that a higher reserve level could limit the impact of contagion even when the country was facing the situation of high current account deficit and appreciated real exchange rates.

a) Model for EWS variables:

$$CI = -17.71 - 0.35(RERINS) + 1.71(CA/GDP) + 0.30(STD/R) - 9.93(FUNDP) + \varepsilon$$

RERINS was the real effective exchange rate. *CA/GDP* was a measure of the current account situation. *STD/R* was the ratio of short-term debt over reserves. *FUNDP* was a dummy variable being 1 when there was an IMF rescue program.

BM finds a linear tradeoff between high reserves and weak fundamentals. They investigated the effect of 1% increase of *CA/GDP* on the magnitude of the decrease of *STD/R* required to keep *IND* constant. However, this exercise was not completely convincing. First, it was misleading in the sense of assuming an unlimited constant tradeoff. Put another way, if the linear relationship existed, no matter how bad the current account was, the sufficiently high reserves relative to short-term debt would keep the crisis index unchanged. His findings contradicted the first generation crisis models.

2.4 Nitithanprapas, Nitithanprapas and Willett (2001) [4]

[4] The results are reported in Willett et al (2005).

NNW (2001) adopted the basic structure of the STV approach but replaced STV's focus on real appreciation and lending boom with a set of composite variables based on both behaviors of the real exchange rate and the current account[5].

$$CI = b_1 + b_2(COM_i) + b_3(LB) + b_4(COM_i * Dhr) + b_5(LB * Dhr) + \varepsilon$$

CI: Crisis Index

COM_i : Composite variables of balance of payments disequilibrium, where

COM_1 : Real effective exchange rate if (current account/GDP) <-5%, and 0 otherwise

COM_2 : (Current account/GDP) if real exchange rate appreciation > 10%, and 0 otherwise

COM_3 : (Current account/GDP)*(real exchange rate appreciation) if real exchange rate appreciation > 0% and current account/GDP< 0%, and 0 otherwise

LB: Lending boom[6]

Dhr: Dummy for high international reserves[7].

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[5] IMF (1999) reported the descriptive statistics about the significantly different behaviors of two kinds of composite indicators among crisis countries and non-crisis countries. The first composite is the external imbalances consisting of exchange rate appreciation, productivity growth in the export sector, and current account deficits. The second, named domestic macroeconomic imbalance is made of the fiscal relation in relation to GDP and the growth rate of broad money relative to GDP.
Corsetti et al (2001) independently developed a similar composite variable approach. The authors defined the first composite as shares of current account over GDP when real exchange rate appreciation was present. This composite is an index for external disequilibrium. The second composite associated the share of non-performing loans with a lending boom, which was an indicator for financial system weakness. The results of their empirical analysis supported the view that the crises were systematically related to fundamental weaknesses in the real and financial sectors of the economy.

[6] The percentage change in the ratio of the increase in banking sector credit to the non government sector over the preceding 48 month period.
[7] A ratio of short-term external debt to reserves of one is the baseline for distinguishing high from low reserve countries.

In their results, the estimated coefficients of the composite variables were negative and significant, which was consistent with the conclusions in the studies of STV or Tornell (1999). The implication of this significance was that the weak fundamentals without high reserves do explain the variations of exchange rate market pressure. But when the fundamentals were bad enough, high reserves would be ineffective in offsetting them. Specifically, when real exchange rate appreciation was not large, high reserves might protect a country that has its current account deficit associated with real exchange rate appreciation. As the real exchange rate appreciation increased, high reserves lost their power to protect a country from a crisis. Therefore, high reserves might not be able to offset weak fundamentals in some cases.

2.5 Commentary on These Studies

In line with the second generation models, the liquidity provided by international reserves hoarding can strengthen the confidence of investors, therefore, reducing the probability of currency crisis. The interaction effect of high reserves and weak fundamentals justifies a substantial build up of reserves in Asian countries in the post-crisis era, although the appropriate magnitude of increases remains open to debate[8]. STV showed that weak fundamentals coupled with low reserves were significant in explaining the variation of exchange market pressures. Tornell (1999) demonstrated that neither real exchange rate appreciation nor lending boom had a significant effect on a currency crisis when they were coexisting with high reserves. This result directly pointed to the offsetting role of high reserves. Meanwhile, BM derived a linear relationship between weak fundamentals and high reserves by holding the crisis index constant. NNW

[8] For example, see Kim et al (2004).

challenged the previous empirical studies by arguing that high reserves might be effective in offsetting weak fundamentals only if the fundamentals were not sufficiently bad. From the prediction of first generation crisis models, if the fundamentals are in a "hopeless" zone, the crisis will be inevitable. Empirically, NNW conducted a number of sensitivity tests to see whether the different variable specifications would affect the results significantly or not. They reached the conclusion that high reserves might protect an economy from currency attacks if the real exchange rate appreciation was mild. But as the real exchange rate appreciation increased, high reserves lost their power.

We extend the current literature on the role of reserves by showing that different weak fundamentals require different levels of international reserves in a vulnerable zone. This result implies that there should not be any universal reserve adequacy measure. Depending on the different situations of fundamentals, each country has to adjust to the corresponding appropriate reserve levels. Meanwhile, it seems that there is a positive relationship between weak fundamentals and high reserves. The weaker are the fundamentals in a vulnerable zone, the higher is the demand for reserves. Since the reserve levels generally cannot be quickly adjusted by large amounts, estimates of the future state of fundamentals should feed into the current demand for reserves.

Deviating from the cross-section models in the literature, we adopt a probit model to test the effects of weak fundamentals and reserves on the probability of currency crises. The cross-sectional time-series data allows us to expand the data set significantly in the sense of the numbers of observations.

3. Data and Methodology

42 emerging markets have been chosen on the basis of data availability and the interest of this study[9]. This 42-country set covers Argentina, Bangladesh, Botswana, Brazil, Bulgaria, Chile, China, Columbia, Czech, Ecuador, Egypt, Estonia, Hong Kong, Hungary, India, Indonesia, Israel, Jordan, Kenya, Korea, Latvia, Lithuania, Malaysia, Mexico, Morocco, Nigeria, Pakistan, Peru, Philippines, Poland, Russia, Singapore, Slovak, Slovenia, South Africa, Sri Lanka, Thailand, Turkey, Ukraine, Uruguay, Venezuela and Zimbabwe.

The sample period ranges from 1989 to 2003 and annual data is utilized.

We first test the significance of individual independent variables without adding high reserve dummies. These significant variables will be the weak fundamentals that will affect the probability of a crisis. These variables are also the weak fundamentals that high reserves are meant to offset. Given those weak fundamentals, we add the interaction terms of weak fundamentals with high reserves dummies in the second-run regressions. The following hypotheses will be tested:

Hypothesis 1: If fundamentals are in the vulnerable zone[10], high reserves can help protect the economy from currency attacks.

The expected results are that weak fundamentals will be significant in the first-step regression. In the second-round regressions, the effect from the fundamentals in the vulnerable zone will be offset by the high reserve holdings. At the same time, the different thresholds chosen in constructing the reserve dummies will shed light on the criteria of reserve adequacy measures.

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[9] The dataset is consistent with the one used in an ongoing Claremont project funded by National Science Foundation. This country sample includes major emerging markets with significant capital flows.

[10] There is no definite measure to distinguish the variables in vulnerable zone from the ones in a bad zone in literature yet. Here I adopt a composite variable approach inspired by IMF (1999), Corsetti et al (2001) and NNW (2001) to define the variables in a vulnerable zone.

Hypothesis 2: In the vulnerable zone, the weaker the fundamentals, the greater the need for reserves to avoid a crisis.

As suggested by the theoretical model in section 2, there should be a positive relationship between the optimal reserve level and weak fundamentals in the vulnerable zone. The weaker fundamentals will lead to a larger probability of crisis. In order to offset the weaker fundamentals, a greater amount of reserves should be accumulated to counter the effects from weaker fundamentals.

To implement the methodology described above, we first estimate the composite variables inspired by NNW to see their significance using a probit model.

$$Pr(CI = 1) = F[b_1 + b_2(COM_1) + b_3(D^{LGDP}) + b_4(LB) + \varepsilon] \quad (14)$$

COM_1: Dummy 1 if (current account/GDP) < 0% and real effective exchange rate appreciation > 5% and 0 otherwise

D^{LGDP}: Dummy 1 if lagged real GDP growth is 1% less than the averaged growth in the country and 0 otherwise

LB: Lagged values of (domestic credit – claims on central governments)/GDP

Dependent variable *CI* is a crisis index dummy variable that defines currency crisis. Following Eichengreeen, Rose and Wyplosz (1996) we construct exchange market pressure indices (EMP) based on the excessive depreciation of domestic currency, loss of international reserves and sudden increase in interest rates. This EMP index is a weighted average of the three components. Individual and pooled precision weighting schemes[11]

[11] Two kinds of weights are defined in the Appendix.

are utilized to determine the weights of the three components based on the inverse of their respective standard deviations. The higher the standard deviation of the component, the lower weight would be imposed on the corresponding variable in calculating EMP. If a country's EMP in some years exceeds a certain threshold, we define it as 1. There are four different crisis indices[12] constructed to check the sensitivity of this study. Because the interest rates among 42 countries are rarely comparable, we compute crisis indices by both including interest rates and excluding interest rates to check the robustness of the models. When calculating the crisis index with interest rates, we use the money market rates whenever available. If there are no money market rates, we use lending rates instead.

As developed by Corsetti et al and NNW, COM_1 is an indicator for balance of payment disequilibrium. There are two components in this composite variable, the current account deficit and the appreciation of the *REER*. The ratio of current account to GDP and *REER* are indicators of external competitiveness. The higher the current account deficits, the weaker the external competitiveness, which should lead to higher probability of a crisis.

However, the effects of the *REER* on the probability of crisis are ambiguous. If the *REER* appreciates with a surplus in the current account, it should not be such a concern. For example, the appreciation could be due to an improvement in the terms of trade. On the other hand, the *REER* appreciation would be very worrisome if it is coupled with a large CA deficit. This kind of appreciation does not stem from sound fundamentals. It probably comes from the pegged exchange rate regime. The domestic currency has to

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[12] Please refer to the Appendix for detailed formula of crisis indices.

appreciate in terms of the third country's currency while the pegged currency appreciates significantly. This situation will lead to the overvaluation of the domestic currency, which calls for currency attacks. The appreciation could also be due to the capital inflow surges taking the form of "hot money" before the onset of a crisis. This part of hot money would push up the capital account surplus which can then translate into the overvaluation of the local currency. Therefore, *REER* appreciation coupled with a current account deficit should be considered as a weak fundamental that increases the probability of currency crisis. The expected sign of COM_1 is therefore positive[13].

Real GDP growth is an indicator of general domestic economic performance. In second generation models, a government is less likely to adopt a tight monetary policy to defend its currency when real GDP growth is sluggish. The problems in the domestic financial system would be aggravated since the share of non-performing loans tends to increase. Thus, if the real GDP growth is low, the chance of being hit by crisis should be much higher. D^{LGDP} is defined as a dummy for real GDP growth that takes 1 when the growth rate in the previous year is at least 1% smaller than the country's average growth rate[14]. Thus, this dummy is an indicator for slow or negative real GDP growth, which should increase the probability of currency attacks. The sign, therefore, is expected to be positive in the models.

The first run of regressions sheds light on whether those chosen weak fundamental variables are significant in predicting the probability of currency crisis. If so, the next question is: can high reserves protect the emerging economies from these weak

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[13] Note that there are different ways to construct COM_1 as suggested in NNW.

[14] Other thresholds like 0%, -1%, -2%, and -3% are used to test the robustness of the models.

fundamentals? With the second run of regressions, we add the interaction terms of high reserves dummy and weak fundamentals to test the tradeoff.

$$\Pr(CI = 1) = F[b_1 + b_2(COM_1) + b_3(D^{LGDP}) + b_4(D^{hr}) + b_5(COM_1 * D^{hr}) + b_6(D^{LGDP} * D^{hr}) + \varepsilon] \quad (15)$$

D^{hr}: High reserves dummy, is 1 when the ratio of international reserves over short-term external debt is greater than a certain threshold. The higher the threshold, the more stringent the definition of high reserve dummy, which, therefore, shows more reserve accumulation.

The interpretations of b_2 and b_3 are different from those in the model (14). In model (14), b_2 and b_3 indicate the individual effects from COM_1 and D^{LGDP}. However, b_2 in model (15) shows the effect of the external imbalances (appreciation of *REER* and CA deficits) without high reserves and b_3 shows the role of slow real GDP growth without high reserves. The combined effects of weak fundamentals and lack of high reserves are expected to be significantly positive in increasing the probability of currency crises.

$b_2 + b_5$ measures the combined effects of external imbalances with high reserves. If this sum is significantly different from zero, then we can conclude that the high reserves cannot offset the external imbalances. If this sum is not significantly different from zero, then it demonstrates that the combined effects of external imbalances and high reserves have no significant effects on the probability of a currency crisis. In other words, the high reserves can offset the weak fundamentals.

$b_3 + b_6$ gauges the combined effects of slow real GDP growth and high reserves. The significance of the sum being different from 0 shows the inability of high reserves to offset weak fundamentals like internal imbalances. On the other hand, the insignificance of this test would be indicating that high reserves have offset the effects on probability of currency crises from weak fundamentals.

4. Analysis of Regression Results

Table 1 presents the results of the regressions as we vary the dependent variables from CI1 through CI4. As expected, the coefficients of external imbalances (COM_1) as well as slow GDP growth (D^{LGDP}) show positive signs. The signs of each variable stay constant in all four cases. The positive sign of COM_1 implies that the real effective exchange rate appreciation coupled with current account deficit increases the likelihood of a currency attack. Sluggish real GDP growth has a positive effect on crisis probability as well. The coefficient of COM_1 is significant at all conventional levels across the four crisis indices. The coefficient of D^{LGDP} is significant for the crisis indices 1 and 4, but it is insignificant for indices 2 and 3.

It is worth noticing that the Pseudo-R^2 is very low, about 8%. However, this is not uncommon for probit models in crisis literature[15].

Since the magnitudes of the coefficients of the independent variables do not give meaningful information in probit models, we compute the marginal effects of the explanatory variables on the probability of a crisis. The results are presented in Table 2. As shown in regression (1), the change of the dummy of external imbalances from 0 to 1

[15] See Kamin, Schindler and Samuel (2001), and Frenkel and Rose (1996).

increases the probability of crisis by about 11%, while the dummy of slow real GDP growth increases the probability of crisis by about 6%. Looking at the regressions using the other three different crisis indices, we find that the marginal effects of COM_1 on the probability of currency crisis are around 10%. As we would expect, the marginal effects of D^{LGDP} are much smaller than those of COM_1.

Table 3 reports the probit regression results of adding high reserve dummies to interact with external imbalances (COM_1) and sluggish real GDP growth (D^{LGDP}). X values in the second row of the table are the ratios of reserves over short-term external debt (STED) beyond which the reserves amount can be defined as "high". For instance, when the threshold X is 1.1, those countries with reserve levels equal to or greater than 110% of their respective short-term external debts are considered as high reserves countries. High reserves dummies (D^{hr}) for those countries are set to be 1. X values vary from 0.9 to 2.7[16]. We choose CI1 as the benchmark crisis index. Throughout the regressions in the Table 3, 4 and 5, COM_1 is defined as 1 when the ratio of current account over GDP is less than 0 and *REER* appreciation is over 5% and D^{LGDP} is defined as 1 when real GDP growth in a country is 1% less than the average growth rate in the country.

In regression (1), D^{hr} is set as 1 when the amount of international reserves is over 90% of STED. The estimates of b_2 and b_3 are significant, which means that weak fundamentals such as COM_1 and D^{LGDP} in the absence of high reserves are likely to increase the probability of a crisis. Across the 10 regressions in Table 3, all b_2 and b_3

[16] In Table 4, we consider the cases when X ranges from 0.5 to 0.8.

estimates are significant. $b_2 + b_5$ shows the effect of external imbalances on the likelihood of crisis when D^{hr} equals 1. $b_3 + b_6$ indicates the impact of slow real GDP growth with the presence of high reserve accumulation. In regression (1), the p values of the Wald tests of $b_2 + b_5 = 0$ and $b_3 + b_6 = 0$ are 0.006 and 0.29 respectively. 0.6% indicates that the combined effects of external imbalances (COM_1) and high reserves (defined as 90% of STED) are significantly different from zero. In other words, the reserve level at 90% of STED is not enough to offset the significant effect from this weak fundamental (COM_1). Meanwhile, the p value of 29% implies that the combined effect of slow GDP growth and high reserves is not significantly different from zero. In this case, we can say that the high reserves have successfully offset the effect of the slow real GDP growth[17]. Therefore, the reserve level at 90% of STED is enough to offset the weak fundamental like slow real GDP growth but not enough to offset the external imbalances[18].

In regression (2), we increase the standard for the high reserves to be 110% of STED, and find that this level of reserves is still not enough to bring the combined effects of COM_1 and D^{hr} to an insignificant level (p value is 0.0265). We keep increasing the X ratios. Only when the reserves reach 170% of STED, we find high reserves are enough to offset external imbalances (the p value of the test $b_2 + b_5 = 0$ is 0.1095). The p values for $b_3 + b_6 = 0$ are always greater than 10% across all these regressions. Therefore, the reserve level at 170% of STED can provide sufficient cushion to offset the weak

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[17] The benchmark definition is that D^{LGDP} equals 1 when real GDP growth in a country is 1% less than the average growth rate in the country.
[18] The external imbalances refer to the case when there is a coexistence of both current account deficit and *REER* appreciation by at least 5%.

fundamentals in a vulnerable zone[19]. If we take 170% of STED as reserve adequacy measure for offsetting both external imbalances and sluggish real GDP growth, we would expect that reserve levels higher than 170% of STED should provide the similar role of protection too. This expectation is confirmed by the following exercises in which we let the standard of setting D^{hr} increase further from 1.8 through 2.7[20]. All the results point to one conclusion: reserve levels at or higher than 170% of STED are enough to provide protection against the weak fundamentals for the domestic economy (all the p values for both Wald tests are greater than 10%).

Figure 1 gives a graphical representation of the results we just described. The vertical line shows the p values of the two Wald tests and the horizontal line represents the ratios of reserves over short-term external debt. Taking 0.1 as the critical p value, we notice that the crimson (darker) bar crosses the horizontal line from 0.9 on and the blue (lighter) bar does it from 1.7 on. The different critical reserve adequacy measures show that the countries with the different weak fundamentals may require different levels of adequate reserves. The country with an external imbalance needs to accumulate more reserves to avoid a currency crisis than the country with slow real GDP growth.

Table 4 presents the results when we set the X values at low levels from 0.5 to 0.8. The estimates of b_3, however, are barely significant, which counters our intuition. b_3 measures the effects of slow GDP growth with the absence of high reserves. The reason of these results lies in Table 5. When X values are too low, the observations of D^{hr} will be

[19] Notice that the vulnerable zone in this particular case refers to current account deficits, mild REER appreciation (as defined in COM_1) and slow real GDP growth (as defined in D^{LGDP}).

[20] The thresholds which are higher than 2.8 seem too high for setting D^{hr} since too many zeroes in the interaction term $COM_1 * D^{hr}$ make further regressions questionable.

mostly 1. Therefore, the correlation coefficients of the two pairs of the independent variables ($COM_1, COM_1 * D^{hr}$) and ($D^{LGDP}, D^{LGDP} * D^{hr}$) are very high, 0.91 and 0.89, for example, when X = 0.5. This problem will make the regression results themselves questionable. The fourth row of Table 5 shows the number of observations when $D^{hr} = 1$ out of 355 total observations. These exercises validate the appropriate choice of starting point of X values being 0.9 in Table 3.

In Table 6, we present the results for testing the hypothesis that the weaker the fundamentals, the greater the need for reserves in a vulnerable zone. In the second row of Table 6, the X values still refer to the ratios of reserves over STED beyond which high reserve dummies are defined. The Y values in the third row are the thresholds of current account in defining COM_1. For instance, Y being equal to 0.01 means COM_1 takes value of 1 when current account over GDP is less than 0.01 and REER appreciation is 5%. When Y equals -0.01, COM_1 is defined as 1 if current account over GDP is less than -0.01 and REER appreciation is held constant at 5%. Therefore, the decreasing Y values indicate that the current account part of COM_1 is deteriorating. As shown in the Table 6, current account is worsening from 1% to -3%[21]. Among all 13 regressions in Table 6, D^{LGDP} is defined as 1 when the real GDP growth is 1% less than the average growth rate.

In regression (1) of Table 6, the high reserve dummy is 1 when the ratios of reserves over STED are greater than 1.7. The current account over GDP is less than 1%. The p values of the two Wald tests tell us that this level of reserves is enough to cover the two kinds of weak fundamentals. In regression (2), we use the worsened current account

[21] The thresholds which are lower than -3% seem too strict for setting D^{hr}. Too many zeroes in the interaction term $COM_1 * D^{hr}$ make further regressions invalid.

part of COM_1 by setting the threshold as 0%. We find that the reserve level at 170% of STED is still enough to counter the effects from COM_1. In regression (3), we set the threshold for current account part of COM_1 as -1%, which in turn nullifies the offsetting role of reserves at 170% of STED. The p value for the test $b_2 + b_5 = 0$ drops under 10%. Since the reserve level at 170% of STED is not enough to offset the weak fundamentals, we increase the reserve adequacy measure to 180% of STED in regression (4). This level of reserves is still not enough (the p value is 0.0827). But when the reserve adequacy measure reaches 210% of STED in regression (6), the p value of the Wald test climbs to 0.1407. This indicates that the level of reserves at 210% of STED is enough to offset the specific level of weak fundamentals when current account over GDP is less than -1% and *REER* appreciation is over 5%. In regression (7), we test whether the level at 210% of STED is enough to offset a further worsened COM_1 in which the threshold for current account over GDP is -2%. The p value at 0.0524 demonstrates the inability of the high reserves at 210% of STED. In regression (8), however, the reserve adequacy measure at 220% of STED is sufficient to offset COM_1. But the worsened fundamental (-3% as the cutting point of current account part of COM_1) in regression (9) nullifies the effects of high reserves at 220% of STED again. Even when we increase the standard of setting D^{hr} as 250% of STED, it is still not enough (p value is 0.0698) as in regression (10). Until we increase the reserve adequacy measure at 290% of STED, we find that high reserves can offset the weak fundamentals in regression (11).

Based on the results in Table 6, we draw a nonlinear positive relationship between weakening fundamentals and higher reserve adequacy measures in Figure (5). This positive relationship supports the prediction in our theoretical model that a country with weaker fundamentals requires more reserves in order to avoid a currency crisis. The vertical line gives the reserve adequacy measures in terms of the ratios of reserves over STED while the horizontal line represents the corresponding weak fundamentals. These five combinations are drawn from the results in regression (2), (3), (6) (9) and (11) in Table 4.

From the upward trend of the curve in Figure 2, we deduce that the reserve adequacy measures may get explosive as the fundamentals slide into a bad zone. The required reserve adequacy measure would possibly approach infinity when fundamentals are bad enough. Put another way, when fundamentals are out of the vulnerable zone, high reserves lose their ability to protect the economy form speculative attacks. This is the prediction of first generation models as derived in our theoretical model as well.

In Table 7, we follow the same strategy as in Table 6 and redo the similar exercises. Throughout the regressions in this table, we keep the threshold of current account over GDP constant as 0%, and change the *REER* part of COM_1 from 0% through 7%. As evidenced in regressions (1) and (2), reserve levels at 130% and 140% of STED are not enough to protect the economy against COM_1 when the threshold for *REER* appreciation is 0% and the ratios of current account and GDP are less than 0. In regression (3), however, the reserve level at 150% of STED seems sufficient (the p value is 0.1406). However, the levels of reserves at 150% and 160% of STED are not enough to the external imbalances when the thresholds for *REER* appreciation increases from 0% to 1% as evidenced in regressions (4) and (5) (the p values in both cases are lower than 0.10). Regression (6) shows that as the *REER* appreciation rises to 1%, the reserve level of

170% of STED is required to offset it. The same reserve level of 170% of STED will offset *REER* appreciation at 5% but is not enough for *REER* appreciation at 6% as shown in regressions (7) and (8). The regressions (9) and (11) indicate that the reserve levels at 210% and 220% are adequate to offset the *REER* appreciation at 6% and 7% respectively.

A similar non-linear positive relationship between *REER* appreciation and reserve adequacy measures is plotted in Figure 3. As the fundamentals weaken in the vulnerable zone, the reserves required to offset them increase. However, when fundamentals jump into the bad zone, the amount of reserves required would sky-rocket to a level unreachable in reality.

5. Robustness Checks

5.1 Sensitivity Tests of Different Definitions of COM_1 and D^{LGDP}

In the benchmark regression, we used (current account/GDP) < 0% and real effective exchange rate appreciation > 5% as the definition of COM_1. In the following tests, we vary the threshold values for COM_1 to check the robustness of the construction of this variable. In Table 8, we report the results with various degrees of the current account deficits while keeping the extent of *REER* appreciation constant at 5% level. The range of current account deficits varies from -1% through -13%. There are no noticeable changes in the results. Both COM_1 and D^{LGDP} show the correct signs as expected. These two weak fundamentals both have positive effects on the probability of crisis at conventional significance levels.

In Table (9), we present the sensitivity tests with different definitions of the *REER* part of COM_1. We fix the first part of COM_1 as the current account deficit (CA/GDP <

0%), but we vary the degrees of *REER* appreciation from 6% through 20%. Among all these specifications of COM_1, the results are very stable. Both COM_1 and D^{LGDP} show their significance in predicting the probability of crisis.

Table 10 presents the results of robustness checks for different thresholds for D^{LGDP}, holding the benchmark definition of COM_1 constant. The range of the thresholds for D^{LGDP} from -2% to -8% does not change the results of the regressions.

5.2 Sensitivity Tests of Using Logit Models

To test whether the model is sensitive to the specific assumption about error terms, we adopt logit models to re-run the regressions in Table 3. Table 11 presents the results with logit models. There are almost the same results in Table 11 as in Table 3. The reserve adequacy measure for offsetting external imbalances is still at 170% of STED and the measure for offsetting sluggish real GDP growth is at 90% of STED.

After the sensitivity tests we conducted above, it seems that the model is quite robust. The results are basically stable across the different specifications of dependent variable (Crisis Index), independent variables (COM_1 and D^{LGDP}) and model selections (probit or logit models).

5.3 Other Sensitivity Tests

In literature, there are a number of papers using the individual weak fundamental variables like current account deficit and real exchange rate appreciation in crisis models. In this section, we try to split up the COM_1 we used in the previous sections. Conceptually, the individual CA deficit or real exchange rate appreciation are considered as less weak fundamentals than the composite variable (COM_1). The reserve adequacy level to offset the effects from individual variables is expected to be lower. Table 12 reports the results of using CA deficit and REER appreciation as the individual weak fundamental variables. Variable CA is defined as dummy 1 if CA/GDP < -1%, and 0 otherwise. Variable REER is defined as dummy 1 when REER > 5%, and 0 otherwise. As predicted, the reserve adequacy level for offsetting the effect from current deficit is only equivalent with the 90% of short-term external debt. If emerging countries can accumulate reserve level around 100% percent of STED, it would be enough to offset the REER appreciation.

In general, the reserve level at 100% of STED is good for offsetting the effects on the probability of crisis from the individual weak fundamental variables. Obviously, the composite variable like COM_1 represents the weaker fundamental which requires more reserves (170% of STED) to offset. This result is consistent with the prediction in the theoretical model in essay 1.

Table 13 presents the results of robustness checks for using COM_2 instead of COM_1. COM_2 is defined as *REER* deviation from the mean when current account is in deficit, and 0 otherwise. This composite variable was proposed by Nitithanprapas and Willett (2000) in order to capture the effect of REER appreciation together with current account deficit on the probability of crisis. While the reserve adequacy level for slow real GDP growth is the same as before, the level for offsetting the effect from COM_2 is completely different. From Eq. (1) through (10), the p values for the test $b_2 + b_5 = 0$ are consistently less than 10%. This result reveals that the reserve accumulation cannot offset the effect from REER appreciation combined with current account deficit. This result sounds a bit contradicting with before. This may be due to the different specifications of the composite variables. COM_1 captures only mild REER appreciation since it does not differentiate the REER appreciation above 5%.

Table 14 presents the results of using COM_3 as the composite variable. COM_3 is defined as the lag values of CA/GDP when REER appreciation is over 5%. This composite does not seem to be significant in predicting the probability of crisis. However, all the signs of the independent variables are still correct.

Instead of using the deviation from 15-year average of the REER as the appreciation of REER, we use HP filter to detrend the REER. Table 15 shows the results when we replace the REER component of COM_1 with the HP-filtered REER. This specification of REER does not change the results at all. The reserve adequacy level for offsetting the external imbalances consisting of current account deficits and REER appreciation is still about the level of 170% of short-term external debt.

Table 16 and 17 present the results of the sensitivity tests using two different specifications for lending boom (LB). The LB in Table 16 is defined as the lag values of the rates of changes in the credit to private sectors. The LB in Table 17 takes 2 periods lag values instead of one period lag values. Neither of the two specifications differentiates from the benchmark regression substantially.

We test the significance of COM_1 when we replace the REER component with the deviations from 5-year average. The results are reported in Table 18. The COM_1 seems insignificant in predicting the probability of currency crisis. The only difference between the benchmark specification and the current one is that the benchmark uses the deviations from 15-year average instead of 5-year average in current one. It seems that the REER appreciation deviating from the long term average is more important in predicting currency crisis.

6. Conclusions and Future Research

In first generation models, all high reserves can do is to postpone the occurrence of a crisis instead of avoiding it. In second generation models, high reserves may reduce the chances of a shift to a bad equilibrium in a multiple-equilibrium model. This paper demonstrates in a simple model that reserve accumulation does help avoid currency crisis when the fundamentals are in a vulnerable zone. In the meantime, the offsetting role of reserves totally evaporates when the fundamentals are in a "hopelessly" bad zone. The model further predicts that the weaker the fundamentals are (as long as they remain in a vulnerable zone), the higher the reserve levels needed to prevent a crisis.

In the empirical part of the paper, we adopt a composite variable approach inspired by Corsetti et al (2001) and NNW (2001) to analyze the interactions of weak fundamentals and international reserves. In order to attain this goal, I utilize two-run regressions. The first run of regressions sheds light on what weak fundamental variables we need to focus on. As confirmed in the empirical models, both external imbalances, proxied by the coexistence of current account deficits and real effective exchange rate appreciation, and sluggish real GDP growth increase the likelihood of currency crises.

We find that a country with external imbalances requires a different reserve adequacy level from a country with slow real GDP growth. It seems easier for reserves to offset the effects from slow real GDP growth than those from external imbalances. Roughly speaking, it requires the adequate amount of reserves at 170% of short-term external debt to offset external imbalances while only 90% of short-term external debt to offset slow real GDP growth.

Consistent with the predictions in the theoretical part of this study, we find the empirical support for a positive relationship between weak fundamentals and high reserves in the vulnerable zone. The proposition says that the weaker fundamentals in a vulnerable zone require higher reserves in order to better avoid currency attacks. However, the demand for international reserves would sky-rocket as the weak fundamentals are sliding into a hopelessly bad zone. In this case, high reserves lose their ability to prevent crises just as is complied by first generation models.

While the empirical study of this paper remains to verify the tradeoff between high reserves and weak fundamentals in a vulnerable zone, it is interesting to extend the current model to empirically divide the bad fundamental zone from a vulnerable zone. Theoretically, we know that there should be a clear cut between a vulnerable zone and a bad zone, the limited number of observations of the interaction terms in the current empirical models prevent us to do a further testing.

A natural extension of this paper is to look at the political economy of the high reserves policy. High political instability and polarization would imply that the international reserves could be looted; hence, the role of high reserves would be limited.

Appendix:

(1) Crisis index:

CI1 = 1 if EMP_1 > Mean + 3 * Standard Deviation of EMP_{it} ; 0 otherwise, while

$$EMP_{it} = \frac{\Delta ER_{it}}{\sigma^j_{\Delta ER}} - \frac{\Delta RES_{it}}{\sigma^j_{\Delta RES}} + \frac{\Delta INT_{it}}{\sigma^j_{\Delta INT}}$$

CI2 = 1 if EMP_2 > Mean + 3 * Standard Deviation of EMP_{it} ; 0 otherwise, while

$$EMP_{it} = \frac{\Delta ER_{it}}{\sigma^j_{\Delta ER}} - \frac{\Delta RES_{it}}{\sigma^j_{\Delta RES}}$$

CI3 = 1 if EMP_3 > Mean + 3 * Standard Deviation of EMP_{it} ; 0 otherwise, while

$$EMP_{it} = \frac{\Delta ER_{it}}{\sigma_{\Delta ER}} - \frac{\Delta RES_{it}}{\sigma_{\Delta RES}} + \frac{\Delta INT_{it}}{\sigma_{\Delta INT}}$$

CI4 = 1 if EMP_4 > Mean + 3 * Standard Deviation of EMP_{it} ; 0 otherwise, while

$$EMP_{it} = \frac{\Delta ER_{it}}{\sigma_{\Delta ER}} - \frac{\Delta RES_{it}}{\sigma_{\Delta RES}}$$

So far, the crisis index is still monthly data; therefore, I need to convert them to annual data. If there is one monthly data which shows the crisis, I then regard any crises detected in the following 23 months to be the continuation of the first crisis. Thus, the following 23 monthly data would be coded as zeroes, which means no new crisis. The year which contains that first month will be coded as crisis year. CI1 and CI2 are indexes using individual precision weighting system while CI3 and CI4 are in pooled precision weighting system.

All independent variables are taken with one year lag.

(2) $reer = \left(\left(\frac{reer_t}{\frac{reer_{1989-2003}}{15}} \right) - 1 \right)$, data is from JP Morgan and WDI.

(4) Current account deficit equals the ratio of current account over GDP. Data is from IFS.

(5) Real GDP growth: first, convert the nominal GDP into real GDP by dividing nominal GDP by GDP deflator; second, take the growth rate of real GDP. Data is from IFS.

(6) LB = Lagged values of (domestic credit – claims on central governments)/GDP

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Table 1: Probit Regression Results

	Dependent Variables			
	(1)	(2)	(3)	(4)
	CI1	CI2	CI3	CI4
CONST	-1.72*** (0.21)	-1.88*** (0.22)	-1.85*** (0.23)	-1.92*** (0.23)
COM_1	0.67*** (0.19)	0.80*** (0.19)	0.60*** (0.20)	0.68*** (0.21)
D^{LGDP}	0.41** (0.19)	0.19 (0.20)	0.25 (0.21)	0.38* (0.21)
LB	-0.10 (0.32)	0.10 (0.33)	0.02 (0.34)	-0.05 (0.35)
# of obs.	376	386	376	386
Prob > Chi-Square	0.0001	0.0001	0.0058	0.003
Pseudo R2	0.08	0.08	0.05	0.08

COM_1 : *Dummy 1 if (current account/GDP) < 0% and real exchange rate appreciation > 5%, and 0 otherwise*

D^{LGDP} : *Dummy 1 if real GDP growth of a country< (averaged growth rate of the country- 1%) and 0 otherwise*

Table 2: Marginal Effects (dy/dx)

	Dependent Variables			
	(1)	(2)	(3)	(4)
	CI1	CI2	CI3	CI4
COM_1	0.11*** (0.03)	0.12*** (0.03)	0.08*** (0.03)	0.09*** (0.03)
D^{LGDP}	0.06* (0.03)	0.02 (0.02)	0.03 (0.02)	0.04* (0.02)
LB	-0.01 (0.04)	0.01 (0.04)	0.002 (0.03)	-0.005 (0.03)

COM_1 : *Dummy 1 if (current account/GDP) < 0% and real exchange rate appreciation > 5%, and 0 otherwise*

D^{LGDP} : *Dummy 1 if real GDP growth of a country< (averaged growth rate of the country- 1%) and 0 otherwise*

Table 3: Probit Regression Results

		(1)	(2)	(3)	(4)	*(5)*	(6)	(7)	(8)	(9)	(10)
	X Values♠	*0.9*	1.1	1.3	1.5	*1.7*	1.9	2.1	2.3	2.5	2.7
b_1	*CONST*	*-1.51**** *(0.24)*	-1.67*** (0.23)	-1.68*** (0.22)	-1.64*** (0.20)	*-1.67**** *(0.20)*	-1.72*** (0.19)	-1.72*** (0.19)	-1.75*** (0.18)	-1.74*** (0.18)	-1.75*** (0.18)
b_2	COM_1 ♣	*0.61*** *(0.29)*	0.70** (0.28)	0.67*** (0.26)	0.68*** (0.24)	*0.67**** *(0.23)*	0.69*** (0.23)	0.69*** (0.22)	0.74*** (0.22)	0.67*** (0.21)	0.68*** (0.21)
b_3	D^{LGDP} ♥	*0.52** *(0.30)*	0.60** (0.28)	0.60** (0.26)	0.48** (0.24)	*0.45** *(0.23)*	0.48** (0.23)	0.50** (0.22)	0.48** (0.22)	0.52** (0.21)	0.52** (0.21)
b_4	D^{hr}	*-0.39* *(0.31)*	-0.12 (0.31)	-0.12 (0.31)	-0.22 (0.31)	*-0.15* *(0.31)*	-0.03 (0.32)	-0.04 (0.33)	0.05 (0.34)	0.01 (0.37)	0.05 (0.37)
b_5	$(COM_1) * D^{hr}$	*0.11* *(0.39)*	-0.09 (0.39)	-0.02 (0.40)	-0.06 (0.41)	*-0.10* *(0.43)*	-0.12 (0.43)	-0.15 (0.47)	-0.42 (0.51)	-0.05 (0.56)	-0.09 (0.56)
b_6	$D^{LGDP} * D^{hr}$	*-0.24* *(0.40)*	-0.45 (0.40)	-0.52 (0.41)	-0.33 (0.43)	*-0.33* *(0.47)*	-0.41 (0.47)	-0.69 (0.55)	-0.61 (0.57)	-4.50 (194.00)	-4.51 (194.90)
# of observations		355	355	355	355	355	355	355	355	355	355
Null Hypotheses						*P Values*					
$b_2 + b_5 = 0$		*0.0067*	0.0265	0.0285	0.0661	*0.1095*	0.1205	0.1909	0.4757	0.2331	0.2587
$b_3 + b_6 = 0$		*0.2903*	0.6156	0.8113	0.6811	*0.7789*	0.8552	0.7046	0.8128	0.9836	0.9837

♠: *X values refer to the ratios of reserves over STED beyond which high reserve dummies are defined.*

♣ COM_1 : *Dummy 1 if (current account/GDP) < 0% and real exchange rate appreciation > 5%, and 0 otherwise*

♥ D^{LGDP} : *Dummy 1 if real GDP growth of a country< (averaged growth rate of the country- 1%) and 0 otherwise*

Table 4: Probit Regression Results

		(1)	(2)	(3)	(4)
X Values♠		0.5	0.6	0.7	0.8
b_1	*CONST*	-1.36*** (0.32)	-1.45*** (0.30)	-1.45*** (0.26)	-1.47*** (0.24)
b_2	COM_1 ♣	1.01** (0.44)	0.70* (0.37)	0.63* (0.33)	0.49 (0.31)
b_3	D^{LGDP} ♥	0.38 (0.44)	0.42 (0.38)	0.54 (0.33)	0.60* (0.31)
b_4	D^{hr}	-0.49 (0.37)	-0.39 (0.35)	-0.44 (0.32)	-0.43 (0.32)
b_5	$(COM_1)*D^{hr}$	-0.36 (0.49)	-0.06 (0.44)	0.08 (0.41)	0.28 (0.40)
b_6	$D^{LGDP}*D^{hr}$	0.03 (0.49)	-0.01 (0.44)	-0.19 (0.42)	-0.35 (0.41)
# of observations		355	355	355	355
Null Hypotheses		*P Values*			
$b_2+b_5=0$		0.0034	0.0055	0.004	0.0026
$b_3+b_6=0$		0.0665	0.078	0.1643	0.3591

♠: *X values refer to the ratios of reserves over STED beyond which high reserve dummies are defined.*

♣ COM_1 : *Dummy 1 if (current account/GDP) < 0% and real exchange rate appreciation > 5%, and 0 otherwise*

♥ D^{LGDP} : *Dummy 1 if real GDP growth of a country< (averaged growth rate of the country- 1%) and 0 otherwise*

Table 5: Correlation between COM_1 and COM_1*D^{hr}, D^{LGDP} and $D^{LGDP}*D^{hr}$

X Values	0.5	0.6	0.7	0.8
Corr(COM_1, COM_1*D^{hr})	0.91	0.82	0.79	0.74
Corr($D^{LGDP}, D^{LGDP}*D^{hr}$)	0.89	0.85	0.81	0.76
# of observations when $D^{hr}=1$	313	293	272	256

Figure 1: P Values of Wald Tests with Varying the Ratios of Reserves and Short-term External Debt

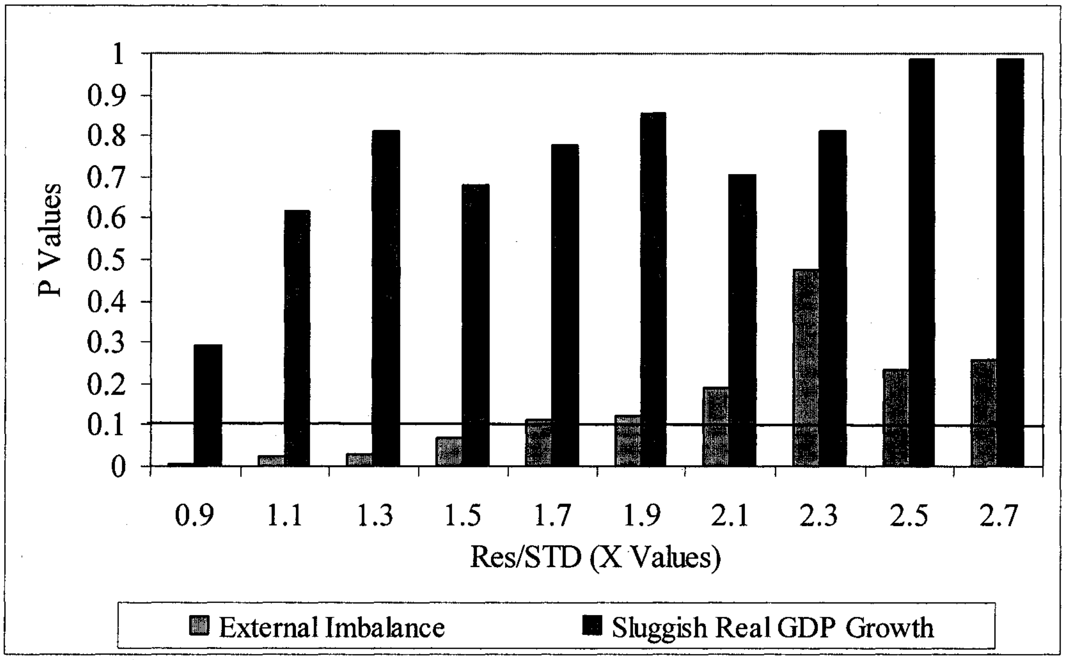


Table 6: Probit Regression Results when current account component of COM_1 deteriorates

		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
X Values♠		1.7	1.7	1.7	1.8	2.0	2.1	2.1	2.2	2.2	2.5	2.9
Y Values♣		0.01	0.00	-0.01	-0.01	-0.01	-0.01	-0.02	-0.02	-0.03	-0.03	-0.03
b_1	*CONST*	-1.66*** (0.20)	-1.67*** (0.20)	-1.64*** (0.19)	-1.67*** (0.19)	-1.69*** (0.19)	-1.70*** (0.18)	-1.62*** (0.17)	-1.64*** (0.17)	-1.60*** (0.16)	-1.63*** (0.16)	-1.67*** (0.16)
b_2	COM_1	0.63*** (0.23)	0.67*** (0.23)	0.64*** (0.23)	0.66*** (0.23)	0.62*** (0.23)	0.66*** (0.22)	0.56** (0.23)	0.63*** (0.22)	0.63*** (0.23)	0.61*** (0.23)	0.64*** (0.23)
b_3	D^{LGDP} ♥	0.47** (0.23)	0.45* (0.23)	0.46* (0.23)	0.47** (0.23)	0.55** (0.23)	0.51** (0.22)	0.52** (0.22)	0.50** (0.22)	0.54** (0.22)	0.58*** (0.21)	0.58*** (0.21)
b_4	D^{hr}	-0.15 (0.32)	-0.15 (0.31)	-0.20 (0.31)	-0.14 (0.31)	-0.11 (0.32)	-0.08 (0.33)	-0.21 (0.33)	-0.16 (0.33)	-0.22 (0.33)	-0.16 (0.36)	0.00 (0.37)
b_5	$(COM_1) * D^{hr}$	-0.10 (0.42)	-0.10 (0.43)	0.00 (0.43)	-0.03 (0.43)	0.14 (0.45)	-0.05 (0.47)	0.27 (0.49)	0.02 (0.53)	0.22 (0.55)	0.41 (0.61)	0.26 (0.62)
b_6	$D^{LGDP} * D^{hr}$	-0.35 (0.46)	-0.33 (0.47)	-0.31 (0.47)	-0.34 (0.47)	-0.78 (0.54)	-0.66 (0.55)	-0.59 (0.56)	-0.52 (0.57)	-0.53 (0.57)	-4.76 30(4.40)	-4.62 (209.80)
# of observations		355	355	355	355	355	355	355	355	355	355	355
Null Hypotheses							*P Values*					
$b_2 + b_5 = 0$		0.1328	0.1095	0.0742	0.0827	0.0502	0.1407	0.0524	0.1775	0.09	0.0698	0.1136
$b_3 + b_6 = 0$		0.7649	0.7789	0.7079	0.7436	0.6412	0.7636	0.8949	0.9688	0.9861	0.989	0.9847

♠: *X values refer to the ratios of reserves over STED beyond which high reserve dummies are defined.*

♣: *Thresholds of current account/GDP component of* COM_1 *for defining dummies while holding REER appreciation at 5% level.*

♥ D^{LGDP} *: Dummy 1 if real GDP growth of a country< (averaged growth rate of the country- 1%) and 0 otherwise*

Table 7: Probit Regression Results when *REER* component of COM_1 is deteriorating

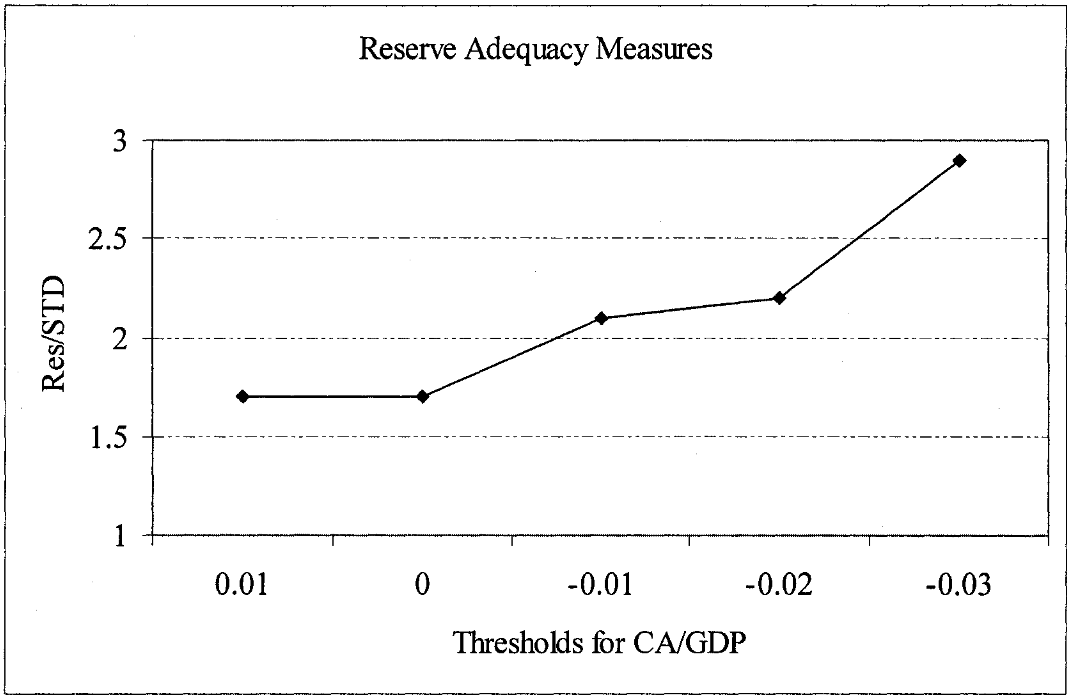
		(1)	(2)	*(3)*	(4)	(5)	*(6)*	*(7)*	(8)	*(9)*	(10)	*(11)*
	X Values♠	1.3	1.4	*1.5*	1.5	1.6	*1.7*	*1.7*	1.7	*2.1*	2.1	*2.2*
	Y Values♣	0.00	0.00	*0.00*	0.01	0.01	*0.01*	*0.05*	0.06	*0.06*	0.07	*0.07*
b_1	*CONST*	-1.73*** (0.24)	-1.74*** (0.24)	*-1.78**** *(0.23)*	-1.78*** (0.23)	-1.77*** (0.23)	*-1.79**** *(0.23)*	*-1.67**** *(0.20)*	-1.58*** (0.18)	*-1.64**** *(0.17)*	-1.58*** (0.17)	*-1.60**** *(0.16)*
b_2	COM_1	0.59** (0.27)	0.66** (0.26)	*0.71**** *(0.25)*	0.74*** (0.25)	0.68*** (0.25)	*0.70**** *(0.25)*	*0.67**** *(0.23)*	0.55** (0.23)	*0.58**** *(0.22)*	0.53** (0.23)	*0.59**** *(0.22)*
b_3	D^{LGDP} ♥	0.63** (0.26)	0.58** (0.25)	*0.53*** *(0.24)*	0.52** (0.24)	0.48* (0.24)	*0.49*** *(0.23)*	*0.45** *(0.23)*	0.44* (0.23)	*0.49*** *(0.22)*	0.49** (0.22)	*0.45*** *(0.22)*
b_4	D^{hr}	-0.20 (0.36)	-0.16 (0.36)	*-0.11* *(0.36)*	-0.12 (0.35)	-0.15 (0.35)	*-0.07* *(0.35)*	*-0.15* *(0.31)*	-0.25 (0.30)	*-0.14* *(0.32)*	-0.22 (0.32)	*-0.16* *(0.33)*
b_5	$(COM_1)*D^{hr}$	0.09 (0.41)	-0.10 (0.41)	*-0.21* *(0.42)*	-0.18 (0.42)	-0.05 (0.42)	*-0.15* *(0.43)*	*-0.10* *(0.43)*	0.12 (0.43)	*0.07* *(0.48)*	0.20 (0.48)	*-0.07* *(0.52)*
b_6	$D^{LGDP}*D^{hr}$	-0.53 (0.41)	-0.52 (0.43)	*-0.39* *(0.43)*	-0.39 (0.43)	-0.30 (0.44)	*-0.43* *(0.47)*	*-0.33* *0(.47)*	-0.35 (0.47)	*-0.71* *(0.55)*	-0.63 (0.55)	*-0.53* *(0.56)*
# of observations		355	355	355	355	355	355	355	355	355	355	355
Null Hypotheses							*P Values*					
$b_2+b_5=0$		0.0275	0.0802	*0.1406*	0.0955	0.0653	*0.1135*	*0.1095*	0.0635	*0.1192*	0.0831	*0.2588*
$b_3+b_6=0$		0.7711	0.862	*0.6985*	0.7247	0.6213	*0.8828*	*0.7789*	0.8295	*0.6602*	0.7812	*0.8863*

♠: *X values refer to the ratios of reserves over STED beyond which high reserve dummies are defined.*

♣: *Thresholds of REER component of* COM_1 *for defining dummies while holding current account/GDP at 0% level.*

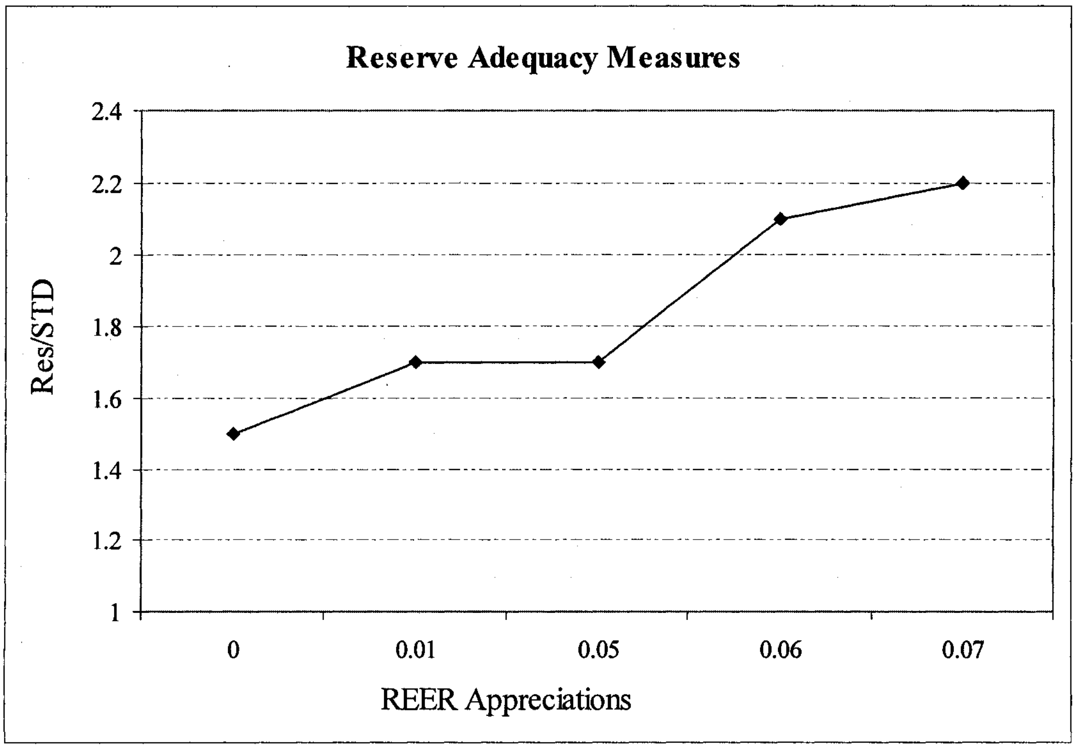
♥ D^{LGDP} *: Dummy 1 if real GDP growth of a country< (averaged growth rate of the country- 1%) and 0 otherwise*

Figure 2: A Nonlinear Relationship Between Reserve Adequacy Measures and CA/GDP*



*: *Holding REER appreciation as 5% level.*

Figure 3: A Nonlinear Relationship Between Reserve Adequacy Measures and *REER* Appreciation*



*: *Holding CA/GDP as 0%.*

Table 8: Robustness Checks for the Different Definitions of COM_1

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
X Values♠	-0.01	-0.03	-0.05	-0.07	-0.09	-0.11	-0.13
CONST	-1.93*** (0.16)	-1.89*** (0.16)	-1.75*** (0.14)	-1.73*** (0.14)	-1.73*** (0.14)	-1.73*** (0.14)	-1.73*** (0.14)
COM_1	0.66*** (0.20)	0.73*** (0.22)	0.57* (0.29)	0.65* (0.38)	0.92* (0.50)	1.02** (0.52)	1.02** (0.52)
D^{LGDP} ♥	0.39* (0.20)	0.46** (0.21)	0.44** (0.21)	0.44** (0.20)	0.47** (0.21)	0.46** (0.21)	0.46** (0.21)
Prob > Chi-Square	0.0008	0.0006	0.0146	0.0227	0.0179	0.0142	0.0142

♠*X values:* COM_1 *= 1 if (current account/GDP) < X and real exchange rate appreciation >5%, and 0 otherwise*

♥ D^{LGDP} *: Dummy 1 if real GDP growth of a country< (averaged growth rate of the country- 1%) and 0 otherwise*

Table 9: Robustness Checks for the Different Definitions of COM_1

	(1)	(2)	(3)	(4)	(5)
Y Values♠	0.06	0.08	0.10	0.15	0.20
CONST	-1.72*** (0.14)	-1.68*** (0.14)	-1.62*** (0.13)	-1.58*** (0.13)	-1.54*** (0.12)
COM_1	0.63*** (0.19)	0.64*** (0.20)	0.57*** (0.21)	0.70*** (0.24)	0.64* (0.33)
D^{LGDP} ♥	0.38** (0.19)	0.41** (0.19)	0.38** (0.19)	0.36* (0.19)	0.40** (0.19)
Prob > Chi-Square	0.0001	0.0001	0.0001	0.0001	0.0001

♠Y values: COM_1 *= 1 if (current account/GDP) < 0 and real exchange rate appreciation >Y%, and 0 otherwise*

♥ D^{LGDP} *: Dummy 1 if real GDP growth of a country< (averaged growth rate of the country- 1%) and 0 otherwise*

Table 10: Robustness Checks for the Different Definitions of D^{LGDP}

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
X Values♠	-0.02	-0.03	-0.04	-0.05	-0.06	-0.07	-0.08
CONST	-1.96*** (0.17)	- 2.00*** (0.17)	-2.01*** (0.17)	-2.01*** (0.17)	-1.97*** (0.16)	-1.95*** (0.16)	-1.95*** (0.16)
COM_1 ♣	0.68*** (0.21)	0.68*** (0.21)	0.66*** (0.21)	0.66*** (0.22)	0.71*** (0.21)	0.75*** (0.21)	0.75*** (0.21)
D^{LGDP}	0.48** (0.22)	0.70*** (0.22)	0.87*** (0.23)	1.07*** (0.25)	1.04*** (0.28)	1.05*** (0.32)	1.11*** (0.32)
Prob > Chi-Square	0.0003	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001

♠*X values: Dummy 1 if lagged real GDP Growth is less than (the average growth rate + X).*

♣COM_1 *: Dummy 1 if (current account/GDP) < 0 and real exchange rate appreciation >5%, and 0 otherwise*

Table 11: Logit Regression Results

		(1)	(2)	(3)	(4)	*(5)*	(6)	(7)	(8)	(9)	(10)
	X Values♠	*0.9*	1.1	1.3	1.5	*1.7*	1.9	2.1	2.3	2.5	2.7
b_1	*CONST*	*-2.64*** (0.47)*	-2.98*** (0.48)	-2.99*** (0.44)	-2.92*** (0.41)	*-2.97*** (0.41)*	-3.08*** (0.41)	-3.07*** (0.39)	-3.13*** (0.38)	-3.10*** (0.37)	- 3.12*** (0.37)
b_2	COM_1♣	*1.11** (0.54)*	1.33** (0.52)	1.25*** (0.49)	1.27*** (0.45)	*1.27*** (0.45)*	1.31*** (0.45)	1.30*** (0.43)	1.41*** (0.42)	1.27*** (0.41)	1.29*** (0.41)
b_3	D^{LGDP}♥	*0.96* (0.53)*	1.13** (0.51)	1.11** (0.48)	0.91** (0.45)	*0.85* (0.44)*	0.92** (0.44)	0.94** (0.42)	0.91** (0.41)	0.96** (0.40)	0.97** (0.40)
b_4	D^{hr}	*-0.81 (0.66)*	-0.24 (0.66)	-0.27 (0.66)	-0.47 (0.68)	*-0.31 (0.68)*	-0.06 (0.68)	-0.12 (0.72)	0.07 (0.73)	-0.03 (0.81)	0.05 (0.81)
b_5	$(COM_1)*D^{hr}$	*0.33 (0.76)*	-0.08 (0.77)	0.09 (0.78)	0.01 (0.84)	*-0.10 (0.86)*	-0.16 (0.86)	-0.15 (0.95)	-0.69 (1.04)	-0.01 (1.13)	-0.09 (1.13)
b_6	$D^{LGDP}*D^{hr}$	*-0.43 (0.76)*	-0.91 (0.78)	-1.01 (0.81)	-0.70 (0.87)	*-0.74 (0.96)*	-0.90 (0.96)	-1.47 (1.21)	-1.24 (1.23)	-13.69 (502.20)	-13.74 (503.90)
# of observations		355	355	355	355	355	355	355	355	355	355
Null Hypotheses						*P Values*					
$b_2+b_5=0$		*0.0079*	0.0278	0.0291	0.0675	*0.1106*	0.1191	0.1748	0.4535	0.228	0.2541
$b_3+b_6=0$		*0.3272*	0.7078	0.874	0.7769	*0.8971*	0.9766	0.6406	0.7712	0.9798	0.9798

♠: *X values refer to the ratios of reserves over STED beyond which high reserve dummies are defined.*

♣COM_1 : *Dummy 1 if (current account/GDP) < 0% and real exchange rate appreciation > 5%, and 0 otherwise*

♥D^{LGDP} : *Dummy 1 if real GDP growth of a country< (averaged growth rate of the country- 1%) and 0 otherwise*

Table 12: Probit Regression Results

		(1)	**(2)**	(3)	(4)	(5)	(6)	(7)
		0.9	**1.0**	1.1	1.3	1.5	1.7	1.9
b_1	*CONST*	-1.84*** (0.38)	**-1.89***** **(0.38)**	-1.88*** (0.38)	-1.93*** (0.36)	-2.03*** (0.35)	-2.06*** (0.35)	-2.08*** (0.34)
b_2	CA	0.74* (0.39)	**0.72*** **(0.39)**	0.63* (0.39)	0.69* (0.37)	0.72** (0.36)	0.70** (0.36)	0.67* (0.35)
b_3	*REER*	0.61* (0.32)	**0.66**** **(0.32)**	0.62** (0.31)	0.57** (0.28)	0.64** (0.28)	0.67** (0.27)	0.70** (0.26)
b_4	*RES/STED*	-0.41 (0.57)	**-0.35** **(0.57)**	-0.36 (0.57)	-0.32 (0.59)	-0.09 (0.57)	0.04 (0.58)	0.12 (0.59)
b_5	*CA*(RES/STED)*	-0.31 (0.61)	**-0.27** **(0.61)**	-0.12 (0.61)	-0.52 (0.65)	-0.66 (0.68)	-0.74 (0.74)	-0.58 (0.76)
b_6	*REER*(RES/STD)*	0.05 (0.51)	**-0.02** **(0.51)**	0.05 (0.51)	0.28 (0.59)	0.05 (0.63)	-0.25 (0.71)	-0.36 (0.73)
# of observations		239	**239**	239	239	239	239	239
Null Hypothesis					*P Values*			
$b_2 + b_5 = 0$		0.364	**0.3447**	0.2843	0.2843	0.9148	0.9488	0.8925
$b_3 + b_6 = 0$		0.0966	**0.1146**	0.1038	0.1038	0.2311	0.5177	0.619

CA: *Dummy 1 if (current account/GDP) < -1% and 0 otherwise*
REER: Dummy 1 if real exchange rate appreciation > 5% and 0 otherwise
RES/STD: Dummy 1 if reserves/short-term external debt > 1 and 0 otherwise

Table 13: Robustness checks for using COM_2

		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
X Values♠		0.9	1.1	1.3	1.5	1.7	1.9	2.1	2.3	2.5	2.7
b_1	$CONST$	-1.36***	-1.46***	-1.51***	-1.49***	-1.49***	-1.54***	-1.54***	-1.55***	-1.58***	-1.61***
		(0.19)	(0.19)	(0.18)	(0.17)	(0.16)	(0.16)	(0.15)	(0.15)	(0.15)	(0.14)
b_2	COM_2 ♣	2.92**	3.04**	3.44***	3.76***	3.53***	3.67***	3.40***	3.32***	3.32***	3.41***
		(1.43)	(1.38)	(1.30)	(1.28)	(1.21)	(1.22)	(1.14)	(1.12)	(1.11)	(1.11)
b_3	D^{LGDP} ♥	0.43	0.46*	0.46*	0.34	0.43*	0.45**	0.44**	0.42**	0.48**	0.48**
		(0.28)	(0.27)	(0.25)	(0.24)	(0.22)	(0.22)	(0.21)	(0.21)	(0.21)	(0.21)
b_4	D^{hr}	-0.51*	-0.35	-0.28	-0.40	-0.45	-0.34	-0.41	-0.37	-0.29	-0.22
		(0.26)	(0.26)	(0.26)	(0.27)	(0.28)	(0.29)	(0.31)	(0.31)	(0.32)	(0.33)
b_5	$COM_2 * D^{hr}$	1.44	1.19	0.32	-0.10	0.49	0.26	0.85	1.28	1.43	1.21
		(1.93)	(1.93)	(1.93)	(1.94)	(2.02)	(2.03)	(2.18)	(2.33)	(2.50)	(2.49)
b_6	$D^{LGDP} * D^{hr}$	-0.12	-0.19	-0.26	0.02	-0.63	-0.67	-0.53	-0.43	-4.49	-4.53
		(0.39)	(0.39)	(0.40)	(0.41)	(0.54)	(0.54)	(0.55)	(0.56)	(258.50)	(268.10)
Null Hypotheses						*P Values*					
$b_2 + b_5 = 0$		0.0008	0.0017	0.0086	0.0122	0.0127	0.0151	0.0223	0.0245	0.0336	0.038
$b_3 + b_6 = 0$		0.2478	0.3184	0.5337	0.272	0.6844	0.6604	0.8638	0.9945	0.9876	0.9879

♠: *X values refer to the ratios of reserves over STED beyond which high reserve dummies are defined.*

♣ COM_2 : *REER if (current account/GDP) < 0% and 0 otherwise*

♥ D^{LGDP} : *Dummy 1 if real GDP growth of a country< (averaged growth rate of the country- 1%) and 0 otherwise*

Table 14: Robustness checks for using COM_3

		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
X Values♠		0.9	1.1	1.3	1.5	1.7	1.9	2.1	2.3	2.5	2.7
b_1	*CONST*	-1.38*** (0.19)	-1.47 (0.18)	-1.48*** (0.17)	-1.43*** (0.16)	-1.43*** (0.15)	-1.47*** (0.15)	-1.46*** (0.14)	-1.48*** (0.14)	-1.51*** (0.14)	-1.53*** (0.14)
b_2	COM_1 ♣	-0.33 (0.85)	-0.39 (0.86)	-0.41 (0.85)	-0.40 (0.84)	-0.39 (0.84)	-0.43 (0.84)	-0.43 (0.84)	-0.46 (0.84)	-0.47 (0.84)	-0.49 (0.84)
b_3	D^{LGDP} ♥	0.65** (0.27)	0.70 (0.26)	0.69*** (0.24)	0.57** (0.23)	0.58*** (0.22)	0.59*** (0.22)	0.57*** (0.21)	0.55*** (0.21)	0.60*** (0.21)	0.61*** (0.20)
b_4	D^{hr}	-0.20 (0.25)	-0.24 (0.27)	-0.22 (0.27)	-0.33 (0.28)	-0.37 (0.29)	-0.29 (0.30)	-0.24 (0.30)	-0.19 (0.31)	-0.08 (0.32)	0.00 (0.33)
b_5	$(COM_1) * D^{hr}$	10.84 (66.20)	-12311 (5069)	- 12354** (5969)	-11287* (6351)	-12408 (8311)	-15255 (9376)	-9526 (10252)	-11032 (10566)	-11600 (11428)	-11631 (11650)
b_6	$D^{LGDP} * D^{hr}$	-0.38 (0.39)	-0.52 (0.39)	-0.63 (0.42)	-0.35 (0.43)	-0.70 (0.54)	-0.74 (0.55)	-0.68 (0.56)	-0.58 (0.57)	-4.53 (199.70)	-4.62 (205.00)
Null Hypotheses		*P Values*									
$b_2 + b_5 = 0$		0.8739	0.0152	0.0385	0.0756	0.1355	0.1037	0.3528	0.2964	0.31	0.3181
$b_3 + b_6 = 0$		0.3259	0.5317	0.8645	0.5597	0.8023	0.7666	0.8303	0.9553	0.9843	0.9844

♠: *X values refer to the ratios of reserves over STED beyond which high reserve dummies are defined.*

♣ COM_3 : *lag value of CA/GDP if REER > 5% and 0 otherwise*

♥ D^{LGDP} : *Dummy 1 if real GDP growth of a country< (averaged growth rate of the country- 1%) and 0 otherwise*

Table 15: Sensitivity tests with HP-filtered REER

		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
X Values♠		0.9	1.1	1.3	1.5	1.7	1.9	2.1	2.3	2.5	2.7
b_1	$CONST$	-1.54***	-1.65***	-1.72***	-1.76***	-1.81***	-1.85***	-1.87***	-1.89***	-1.93***	-1.95***
		(0.24)	(0.23)	(0.22)	(0.22)	(0.21)	(0.21)	(0.21)	(0.21)	(0.20)	(0.20)
b_2	COM_1♣	0.49*	0.49*	0.59**	0.72***	0.82***	0.80***	0.84***	0.85***	0.87***	0.86***
		(0.28)	(0.27)	(0.26)	(0.25)	(0.24)	(0.24)	(0.23)	(0.23)	(0.23)	(0.23)
b_3	D^{LGDP}♥	0.50*	0.57**	0.53**	0.43*	0.43*	0.46**	0.44**	0.42*	0.46**	0.48**
		(0.28)	(0.27)	(0.25)	(0.24)	(0.23)	(0.23)	(0.22)	(0.22)	(0.22)	(0.21)
b_4	D^{hr}	-0.70*	-0.52	-0.37	-0.31	-0.12	-0.04	0.04	0.10	0.37	0.45
		(0.38)	(0.38)	(0.38)	(0.38)	(0.38)	(0.38)	(0.39)	(0.40)	(0.40)	(0.41)
b_5	$COM_1 * D^{hr}$	0.64	0.65	0.45	0.18	-0.20	-0.13	-0.32	-0.34	-0.64	-0.62
		(0.43)	(0.43)	(0.43)	(0.44)	(0.46)	(0.47)	(0.49)	(0.50)	(0.56)	(0.57)
b_6	$D^{LGDP} * D^{hr}$	-0.27	-0.44	-0.52	-0.29	-0.65	-0.71	-0.60	-0.49	-4.33	-4.43
		(0.41)	(0.42)	(0.45)	(0.45)	(0.57)	(0.58)	(0.58)	(0.60)	(215.20)	(221.80)
Null Hypotheses		*P Values*									
$b_2 + b_5 = 0$		0.0005	0.0006	0.0028	0.0131	0.121	0.1004	0.2332	0.2553	0.6518	0.634
$b_3 + b_6 = 0$		0.4542	0.6898	0.9692	0.7047	0.6815	0.6453	0.7669	0.897	0.9857	0.9858

♠: *X values refer to the ratios of reserves over STED beyond which high reserve dummies are defined.*

♣ COM_1 : *Dummy 1 if (current account/GDP) < 0% and real exchange rate appreciation > 5%, and 0 otherwise. REER is measured by the HP-filtered REER..*

♥ D^{LGDP} : *Dummy 1 if real GDP growth of a country< (averaged growth rate of the country- 1%) and 0 otherwise*

Table 16: Probit Regression Results Using the Different Specifications of Lending Boom

	Dependent Variables			
	(1)	(2)	(3)	(4)
	CI1	CI2	CI3	CI4
CONST	-1.82*** (0.22)	-1.89*** (0.23)	-1.87*** (0.23)	-1.93*** (0.24)
COM_1	0.47** (0.23)	0.53** (0.25)	0.40* (0.25)	0.40 (0.25)
D^{LGDP}	0.41** (0.19)	0.24 (0.20)	0.25 (0.21)	0.40* (0.21)
LB	-0.02 (0.07)	-0.08 (0.24)	-0.05 (0.16)	-0.42 (0.38)

COM_1 : *Dummy 1 if (current account/GDP) < 0% and real exchange rate appreciation > 5%, and 0 otherwise*

D^{LGDP} : *Dummy 1 if real GDP growth of a country< (averaged growth rate of the country- 1%) and 0 otherwise*

LB: Lag values of rates of changes in Credit to Private Sector (32D in IFS)

Table 17: Probit Regression Results Using the Different Specifications of Lending Boom

	Dependent Variables			
	(1)	(2)	(3)	(4)
	CI1	CI2	CI3	CI4
CONST	-1.81*** (0.22)	-1.99*** (0.25)	-1.87*** (0.23)	-1.93*** (0.24)
COM_1	0.48** (0.23)	0.66** (0.27)	0.41* (0.25)	0.38 (0.25)
D^{LGDP}	0.40** (0.19)	0.17 (0.20)	0.24 (0.21)	0.40* (0.21)
LB	-0.18 (0.32)	-0.03 (0.07)	-0.03 (0.09)	-0.02 (0.07)

COM_1 : *Dummy 1 if (current account/GDP) < 0% and real exchange rate appreciation > 5%, and 0 otherwise*

D^{LGDP} : *Dummy 1 if real GDP growth of a country< (averaged growth rate of the country- 1%) and 0 otherwise*

LB: 2-Period Lag values of rates of changes in Credit to Private Sector (32D in IFS)

Table 18: Probit Regression Results Using the Different Specifications of *REER*

	Dependent Variables			
	(1) CI1	(2) CI2	(3) CI3	(4) CI4
CONST	-1.41*** (0.20)	-1.50*** (0.20)	-1.58*** (0.22)	-1.66*** (0.22)
COM_1	0.26 (0.27)	0.24 (0.28)	0.49* (0.27)	0.04 (0.32)
D^{LGDP}	0.48** (0.20)	0.26 (0.21)	0.26 (0.23)	0.48** (0.22)
LB	-0.09 (0.33)	0.08 (0.33)	-0.06 (0.36)	0.03 (0.36)

COM_1 : *Dummy 1 if (current account/GDP) < 0% and real exchange rate appreciation > 5%, and 0 otherwise. Instead of using the deviations from 15-year average, we use the deviations from 5-year average as the real exchange rate appreciation*

D^{LGDP} : *Dummy 1 if real GDP growth of a country< (averaged growth rate of the country- 1%) and 0 otherwise*

ESSAY 3:

THE IMPRECISION OF THE PRECISION WEIGHTS

1 Introduction

The empirical research in currency crises requires the measure of the magnitude of speculative attacks on currencies. The degree of nominal exchange rate depreciation only captures the magnitude of crises from successful currency attacks[1]. In order to capture unsuccessful currency attacks, the measure of exchange market intervention has to be taken into account. Girton and Roper (1977) made the first effort to combine exchange rate depreciation with reserve loss to construct the composite variable called exchange market pressure (EMP). Eichengreen et al (1994) argued that the interest rate hikes were the central banks' response to speculative attacks as well and should be added into the calculation of the EMP. Therefore, in current currency crisis literature, the EMP is usually comprised of exchange rate changes, reserve changes, and/or interest rate fluctuations[2]. However, how to weigh the different components in the EMP is subject to more controversy.

In Girton and Roper's specification, the exchange rate depreciation shared the same weight with reserve loss. Without further justification, they assumed the equal weights to the two components. However, Eichengreen, Rose and Wyplosz (1994, 1995) recognized that the relatively large volatility of one component might dominate the movement of the EMP. They originated the use the precision weighting scheme (also

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[1] The definition of "successful currency attacks" is that the monetary authority gives up the pegged exchange rate and depreciates after a series of speculative attacks.

[2] Due to the lack of consistent market determined interest rates, many studies omitted this component in constructing the EMP. See Eichengreen et al (1994, 1995), Kaminsky and Reinhart (1999), Edison (2003), Kamin et al (2001), Glick and Hutchison (2001), Hutchison and Noy (2002) among others for the use of two-component crisis indices.

called variance-weighted scheme) in which the inverse of each component's variance served as the weight in constructing the EMP. By doing so, the precision weighting scheme equalized the volatilities of the changes in exchange rates, reserves, and/or interest rates.

Besides the equal weighting scheme by Girton and Roper and the precision weighting scheme by Eichengreen et al (1994, 1995), there is a third weighting scheme in literature called elasticity approach. Weymark (1995, 1997a, 1997b, 1998) used structural models to derive how the exchange rate would have changed in response to one percentage change in reserves in order to keep the money market equilibrium. The elasticity was taken as the weight of the two components.

Thus, there is no consensus yet in literature how the components of the EMP should be weighted. This essay critically reviews and compares the different weighting schemes in constructing the EMP. In particular, we will focus on the inappropriate use of precision weights despite of its popular application in the literature.

The next section reexamines the original idea of EMP proposed by Girton and Roper (1977). Section 3 extends the model in Weymark (1995) to include interest rate fluctuations in constructing EMP. Section 4 discusses the inappropriate use of precision weights scheme. Section 5 concludes the essay. The annex provides a brief discussion about the inconsistency among the different crisis indices.

2 The Idea of EMP Reexamined: Girton and Roper (1977)

In Girton and Roper (1977), the EMP derived from a monetary model was first proposed to measure the volume of intervention necessary to achieve any desired exchange rate target. The EMP was comprised of two components: the bilateral real balance of payments and the rate of appreciation of currency *i* in terms of currency *j*. The model, which helped construct this EMP, is summarized below.

(1) $$H_i = F_i + D_i = P_i Y_i^{\beta_i} \exp(-\alpha_i \rho_i)$$

where H_i = supply of base money issued by the central bank of country *i*

F_i = base money created against the purchase of foreign assets

D_i = base money created by domestic credit expansion

P_i = price level

Y_i = real income

ρ_i = index of interest rates

β_i = income elasticity > 0

α_i = interest rate coefficient > 0

F is determined by

(2) $$F_i(t) = \int_{-\infty}^{t} E_i(\tau) R_i'(\tau) d\tau$$

where $R_i(t)$ = stock of international reserves held by the authorities in country i

$R_i'(t)$ =time derivative of R_i denominating net purchases at time t

$E_i(t)$ = parity or *i* currency value of primary reserve assets at time t

Substituting the time derivative of (2), $F'_i = E_i R_i'$, in the differentiated version of (1) and stating the results in percent changes yields

(3) $h_i = r_i + d_i = \pi_i + \beta_i y_i - \alpha_i \rho_i^{'}$

where $h_i = H_i^{'} / H_i \qquad d_i = D_i^{'} / H_i \qquad \rho_i^{'}(t) = d\rho_i / dt$

$$\pi_i = P_i^{'} / P_i \qquad r_i = E_i R_i^{'} / H_i \qquad y_i = Y_i^{'} / Y_i$$

The real measure of the balance of payments, r_i, is the rate of change of international reserves valued in domestic currency $E_i R_i^{'}$ deflated by domestic base money H_i.

To examine the monetary interaction between countries, subtract the monetary equilibrium condition (3) for country j from the monetary equilibrium condition for country i:

(4) $r_i - r_j = -d_i + d_j + \beta_i y_i - \beta_j y_j + \pi_i - \pi_j - \alpha(\rho_i^{'} - \rho_j^{'})$

where α_i and α_j have been assumed equal ($\alpha_i = \alpha = \alpha_j$). Some further notations are introduced:

e = rate of appreciation of currency i in terms of currency j

$\theta_{ij} = \pi_i - \pi_j + e$ = differential inflation rate adjusted for exchange rate changes

$\delta_{ij} = \rho_i^{'} - \rho_j^{'}$ = change in the uncovered interest differential

Eq. (4) can be rewritten as

(5) $r_i - r_j + e = -d_i + d_j + \beta_i y_i - \beta_j y_j + \theta_{ij} - \alpha\delta_{ij}$

The composite variable, the left hand side of eq. (5), measures what Girton and Roper refer to as exchange market pressure with two components: relative reserve changes and rate of appreciation between two currencies. Eq. (5) implies that the EMP should be affected by the domestic and foreign credit growth, the percentage change in the real income in domestic and foreign countries, exchange rate adjusted inflation rate differential and change in the uncovered interest differential.

In this simple monetary model, it was the first time in the literature to add exchange rate appreciations to the changes in real balance of payment to construct exchange market pressure. However, the authors did not consider different weights that should be assigned to each component. The assumption the article carried on was that the unit change in exchange rate should enter the EMP equally as the unit change of reserves. Implicitly, they proposed the equal weights.

3 A Model Extending Weymark (1995)

Weymark (1995) fixed the problem of monetary approach about not assigning weights to each component. She utilized a small open economy model to track the exchange rate elasticity of reserve changes and used it as the weight in constructing two-component EMP. In doing so, she converted the percentage change of reserves into the equivalent percentage change of the exchange rate. She defined the EMP in this way:

> *EMP measures the total excess demand for a currency in international markets as the exchange rate change that would have been required to remove this excess demand in the absence of exchange market intervention, given the expectations generated by the exchange rate policy actually implemented.*

We adopt the basic framework of Weymark (1995) but extend the concept of EMP from two components (exchange rate changes and reserves changes) to three components (interest rate changes combined with exchange rate changes and reserve changes). Therefore, we can convert the percentage changes in reserves and interest rates into the respective percentage changes in exchange rates. The EMP indicates the magnitude of the exchange rates changes would have been if the monetary authority did not intervene the market using the policy tools of reserves and interest rates. In order to compare the results with Weymark (1995), the notations adopted in this study are consistent with Weymark (1995) wherever possible. Using this methodology, the weights for the EMP in different countries should disagree from each other based on the various structures of the different economies. The following subsection explains why the different slopes of demand and supply curves in the foreign exchange market might have different implications for the weights in the EMP.

3.1 The General Framework in the Analysis of a Foreign Exchange Market

Figure 1 shows the basic demand and supply of foreign exchange in exchange market and the determination of the relative prices (exchange rates). The exchange rates are expressed by the units of foreign exchange per unit of domestic currency. The increase in the exchange rates indicates devaluation or depreciation of a domestic currency.

If the speculators attack the domestic currency, the speculative demand for foreign currency is increased. This in turn shifts out the demand curve from D to D'. The equilibrium point moves from point A to B without the intervention of the central bank. Thus, the domestic currency depreciates from E_1 to E_2 while the supply of and demand for foreign currency are met in R_2. There are no changes in the reserve holding of the central bank since it does not conduct the foreign market intervention and just let the currency depreciate. However, if the central bank, in order to stabilize the exchange rates, intervenes the foreign exchange market by selling reserves, the supply curve shifts out accordingly. The equilibrium point moves from B to C, which brings the exchange rates back to their original level. The amount of reserves sold in this intervention equals R_3 minus R_1.

Therefore, Points B and C stand for two extreme equilibriums in the foreign exchange market. B is reached with no intervention at all and the exchange market pressure is captured by the magnitude of depreciation (E_2 - E_1). C is reached with no exchange rate movement and the EMP is measured by the loss of reserves in intervention ($R_3 - R_1$). Depending on the degree of the central bank's tolerance of exchange rate depreciation, the actual equilibrium could land on any point between B and C on the new demand curve (D'). The EMP in this case is the weighted average of exchange rate depreciation as well as loss of reserves. In reality, due to the "Fear of Floating", the central banks in many emerging markets tend to pick the equilibrium points closer to C, which leads to the greater variability of reserve changes and less movement of exchange rates. That's why the greater variability of reserves captures the full exchange market pressure and should not be discounted as suggested in the precision weights.

Depending on the different slopes of the demand and supply curves, the responses to the same magnitude of the EMP might be different across countries. Figure 2 demonstrates the case when the slopes of the supply curves are different in two countries.

Like in Figure 1, point B is still the new equilibrium when the country M with the supply curve S_1 does not intervene the exchange market. Facing the same amount of exchange market pressure, the country N with the supply curve S_2 has to depreciate until E_3 to reach the new equilibrium point F.

Interestingly, the reserve responses of the two countries with the different supply curves, facing the same amount of the EMP, are the same. If both countries conduct complete intervention by keeping the level of exchange rates constant at E_1, their new equilibrium points are common at C. The country M incurs the reserve loss at the level of $(R_3 - R_1)$ while the country N's reserve loss is also at $(R_3 - R_1)$.

Thus, the same unit change in either exchange rates might not indicate the same exchange market pressure across countries.

Figure 3 shows the case when the two countries have different slopes of demand curves. Country M has the original demand and supply curves: D_1 and S_1 while country N's demand and supply curves are D_2 and S_2. When the speculative attacks move the demand curves from D_1 to D_1'and D_2 to D_2', the new equilibrium for both countries is point B at which the exchange rates depreciate to E_2 without market intervention. If the countries employ exchange market intervention to keep the exchange rate constant at E_1, country M has to sell the amount of reserves at $(R_3 - R_1)$ while country N only has to sell at $(R_4 - R_1)$ respectively.

Therefore, depending on the different slopes of demand curves, different countries need to sell different amount of reserves in order to bring back the same magnitude of exchange rate depreciation. The higher the slope of the demand curve, the less intervention needed.

3.2 The Model Settings

The different exchange rate or reserve responses to the same exchange market pressure may be indicative to the necessity of a structural model. This model can be used to derive the appropriate weights for the components. The model is a small open economy model in which the domestic price level is influenced by both the level of foreign prices and the exchange rates. The domestic output is determined by its interest and exchange rate among other factors. The foreign price level is exogenous. Domestic residents hold domestic currency for transaction purposes as well as speculative balances of foreign claims.

(6) $$m_t^d = p_t + b_1 y_t - b_2 i_t + v_t$$

(7) $$p_t = a_0 + a_1 p_t^* + a_2 e_t$$

(8) $$y_t = c_0 - c_1 i_t + c_2 e_t + c_3 X_t$$

(9) $$m_t^s = m_{t-1}^s + \Delta d_t + \Delta r_t$$

where

m_t = the logarithm of the money stock in period t with the superscripts s and d denoting supply and demand, respectively

p_t = the logarithm of domestic price level in period t

y_t = the logarithm of real domestic output in period t

i_t = the logarithm of the domestic interest rate level in period t

v_t = the stochastic money demand disturbance in period t

e_t = the logarithm of the period t exchange rate expressed as the domestic currency cost of one unit of foreign currency

X_t = the logarithm of the determinants of real domestic output other than i_t and e_t

$\Delta d_t = [h_t D_t - h_{t-1} D_{t-1}] / M_{t-1}$ where h_t is the money multiplier in period t, D_t is the stock of domestic credit, and M_{t-1} is the inherited money stock in period t.

$\Delta r_t = [h_t R_t - h_{t-1} R_{t-1}] / M_{t-1}$ where R_t is the stock of foreign exchange reserves in period t.

All coefficients are assumed to be positive.

Eq. (6) is a domestic money demand function revealing the determination of the money demand: the domestic price level, the domestic income, the domestic interest rates and the disturbance term. As shown in Eq. (7), the domestic price level is influenced by the foreign price as well as the exchange rates. The inflated foreign price and depreciated domestic currency will boost the domestic price level. Eq. (8) describes the goods market equilibrium where the domestic income is a function of the interest rates, the exchange rates as well as other factors. Eq. (9) reveals that the changes of domestic monetary base are from the changes in domestic credits and reserves.

3.3 Solving the Model

Substituting Eqs. (7) and (8) into (6) reveals that the demand for money in this economy is determined by:

(10) $$m_t^d = a_0 + a_1 p_t^* + a_2 e_t + b_1[c_0 - c_1 i_t + c_2 e_t + c_3 X_t] - b_2 i_t + v_t$$

Rewrite Eq. (9) in deviation form as:

(11) $$\Delta m_t^s = m_t^s - m_{t-1}^s = \Delta d_t + \Delta r_t$$

Under the assumption that the money market clears continuously, $m_t^d = m_t^s = m_t$ for all t. Using this assumption together with Eqs. (10) and (11) allows money market equilibrium to be expressed in deviation form as:

(12) $$\Delta e_t = \frac{\Delta r_t + (b_1 c_1 + b_2)\Delta i_t + \Delta d_t - a_1 \Delta p_t^* - b_1 c_4 \Delta X_t - u_t}{a_2 + b_1 c_2}$$

Eq. (12) indicates that the change in the value of the exchange rates in the small open economy is given by:

(13) $$\Delta e_t = \beta \Delta r_t + \gamma \Delta i_t + W_t$$

where

$$\beta = 1/[a_2 + b_1 c_2]$$

$$\gamma = [b_1 c_1 + b_2]/[a_2 + b_1 c_2]$$

$$W_t = [\Delta d_t - a_1 \Delta p_t^* - b_1 c_3 \Delta X_t - u_t]/[a_2 + b_1 c_2]$$

The elasticity $\beta = \partial \Delta e_t / \partial \Delta r_t = [a_2 + b_1 c_2]^{-1}$, converts observed reserve changes into equivalent exchange rate units.

The elasticity $\gamma = \partial \Delta e_t / \partial \Delta i_t = [b_1 c_1 + b_2]/[a_2 + b_1 c_2]$, converts observed interest rate changes into equivalent exchange rate units.

Notice that both β and γ are positive. As Δr_t increases, the money supply increases. The domestic currency has to depreciate to boost the domestic price, which in turn, increases domestic money demand. Thus, the money market equilibrium is restored. When domestic interest rates increase, the money demand decreases. The domestic currency has to depreciate to boost the money demand in order to restore money market equilibrium.

The EMP can be defined as:

(14) $EMP_t = \Delta e_t - \beta \Delta r_t + \gamma \Delta i_t$ where β and γ are defined as above.

Under such definition of the EMP, the unity is imposed as the weight for the changes of exchange rates in the index while the weights for changes in reserves and interest rates are governed by the reserve change and interest rate change elasticities of exchange rate fluctuations. In absolute value terms, the larger the elasticities, the bigger the weights. Through β and γ, the percentage changes in reserves and interest rates are converted into equivalent exchange rate changes. This index demonstrates what the exchange rate changes would have been if the authority did not intervene the exchange market or increase the interest rates to defend domestic currency. In particular, the depreciation of domestic currency, loss of international reserves as well as the hikes of domestic interest rates will increase the exchange market pressure.

3.4 Comparative Statics

A careful decomposition of the weights for reserve changes and interest rate changes deserves mentioning:

First, $\partial\beta / \partial a_2 = -[a_2 + b_1 c_2]^{-2} < 0$:The elasticity β has the negative relationship with a_2. a_2 measures how responsive the domestic price in relation to the exchange rates. The higher a_2 leads to the higher price response (Eq. (7)), which is fed into the higher money demand (Eq. (6)). Therefore, less exchange rate changes are needed to correspond to one percentage change of reserves in order to restore money market equilibrium.

Second, $\partial\beta / \partial b_1 = -c_2[a_2 + b_1 c_2]^{-2} < 0$: b_1 gauges how responsive the money demand relative to domestic income. The more responsiveness (higher b_1) leads to less exchange rate changes corresponding to the same magnitude of reserve changes.

Third, $\partial\beta / \partial c_2 = -b_1[a_2 + b_1 c_2]^{-2} < 0$: The higher c_2 transforms the exchange rate changes into higher domestic income, which in turn increases the money demand. Therefore, under the three cases described above, the same percentage of reserve changes would require less changes in exchange rates to restore money market equilibrium.

Fourth, $\partial\gamma / \partial c_1 = b_1 / [a_2 + b_1 c_2] > 0$: c_1 measures the extent to which the domestic income is curtailed due to the hikes of interest rates. The reduced domestic income decreases the money demand, which in turn requires more exchange rate depreciation to restore money market equilibirum.

Fifth, $\partial\gamma / \partial b_2 = 1/[a_2 + b_1 c_2] > 0$: b_2 measures the degree to which the money demand responds to interest rate changes. With the higher b_2, one percentage change in interest rate would reduce more money demand. Thus, the domestic currency should depreciate more to boost money demand in order to restore money market equilibrium.

Sixth, $\partial\gamma / \partial a_2 = -1/[a_2 + b_1c_2]^{-2} < 0$: with a higher a_2, less depreciation would be needed to boost money demand in response to the decreased money demand from one percent hike in interest rates.

Seventh, $\partial\gamma / \partial c_2 = -b_1 /[a_2 + b_1c_2] < 0$: the higher c_2 allows less depreciation needed to boost domestic income, which in turn increases the money demand in response to the decreased money demand from the interest rate hikes.

All comparative studies we show above are based on the assumption that the money market is always in equilibrium.

3.5 The Constraints for the Equal Weighting Scheme

The precision weights scheme disregards the analysis of the weights we just presents. On the contrary, the equal weights scheme might be consistent with the elasticity analysis if certain conditions are met. Making the equal weights consistent with the methodology we describe above, we obtain: $\beta = \gamma = 1$.

If $\beta = 1/[a_2 + b_1c_2] = 1$, and $\gamma = [b_1c_1 + b_2]/[a_2 + b_1c_2] = 1$, then

(15) $a_2 + b_1c_2 = 1$

(16) $a_2 + b_1c_2 = b_1c_1 + b_2$

Eq. (15) describes the constraint with which the one percentage change of reserves enters the EMP equally with the same percentage of exchange rates. Eq. (16) shows the conditions under which the one percentage changes of interest rates would have the same impact on the EMP as the one percentage changes of exchange rates. As noticed in Nitithanprapas and Willett (2000), equal weighting scheme might be a second-best choice if we cannot easily apply the elasticity approach to a large set of countries. As long as the constraints (15) and (16) hold, the equal weighting scheme is consistent with the approach we just presented.

The interpretations of the two constraints in Eq. (15) and (16) can be easily made from a rearrangement of Eq. (10):

(17) $$m_t^d = (a_2 + b_1 c_2)e_t - (b_2 + b_1 c_1)i_t + [a_0 + a_1 p_t^* + b_1(c_0 + c_3 X_t) + v_t]$$

$(a_2 + b_1 c_2)$ is the coefficient of domestic exchange rates in money demand function. It measures the extent to which the domestic money demand responds to exchange rates. Eq. (6) shows that there are two channels through which the exchange rates have an impact on the money demand. One is the domestic price and the other is domestic income. a_2 captures the effect of exchange rates through the first channel. $b_1 c_2$ gauges the effect through the second channel. If the combining effects are equal to unity, then β, as the inverse of the total effects, equals to one too. Alternatively speaking, if a unit increase in e_t boosts the domestic money demand by exactly one unit, then the reserves elasticity of exchange rates β equals to one as well.

In Eq. (17), $(b_1 c_1 + b_2)$ is the absolute value of the coefficient of i_t, which picks up the total effects on money demand from interest rates. There are also two ways for interest rates to affect domestic money demand: direct one and indirect one. Interest rates enter the money demand function directly with the magnitude of marginal effect: b_2.

They can also have an impact on money demand through the channel of domestic income y_t. The magnitude is $b_1 c_1$.

Notice that if Eq. (15) and (16) hold for equal weighting scheme, the money demand function (Eq. (17)) will show a very unique structure:

(18) $$m_t^d = e_t - i_t + [a_0 + a_1 p_t^* + b_1 (c_0 + c_3 X_t) + v_t]$$

Eq. (18) equalizes the total effects on the domestic money demand from exchange rates with the total effects from interest rates. It defines a very special case which justifies the use of equal weights in the EMP.

Combining Eq. (15) with (16), we can derive the condition under which the weights assigned to each component in the EMP are equal:

(19) $$a_2 + b_1 c_2 = b_1 c_1 + b_2 = 1$$

Eq. (19) ensures that the money market disequilibrium from one percentage changes in exchange rates can be eliminated from either one percentage changes in reserves or one percentage changes in interest rates. We should admit that the Eq. (19) is a very strong assumption for applying equal weights to constructing the EMP. We will not argue that the use of equal weight scheme is preferred to other weighting schemes. The whole point we are making in this study is that the equal weight scheme might be consistent with the elasticity approach under certain situations, like the one defined as the Eq. (19).

Basically, the observed combination of exchange rate changes, reserve changes and interest rate changes describes the policy response function of a monetary authority.

Depending on the unique structure of its economy, each country has its own sensitivities of exchange rate changes with respect to the other two. The same weights should not be imposed to the different countries to measure the EMP. Even for the same country, the sensitivity might be time-varying as well. This is one of the fundamental problems the precision weights scheme has. We will discuss the problems of the precision weights scheme in next section.

4 Precision Weights and Their Problems

Eichengreen et al (1994, 1995)[3] proposed using the inverse of each component's variance as the its weight. Their proposal was based on an observation that the conditional volatility of percentage changes in reserves is several times the percentage changes in the exchange rates, which is several times the percentage changes in the interest rate differential. The precision weights were designed to equalize the weights of the three components so that no one component would dominate the movement of the EMP. Therefore, if a component has higher variance, a lower weight would be assigned to it. In the meantime, a component with a lower variance would gain a higher weight.

As noted in Willett et al (2005), this way of weighting is correct for building a composite variable with variables freely determined in markets such as stock prices or

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[3] After their proposal, the use of the precision weights scheme has been dominating the currency crisis literature. See also Kaminsky and Reinhart (1999), Bubula and Otker-Robe (2003), Bordo, et al. (2001), Edison (2003), Kamin, et al. (2001), Glick and Hutchison (2001), Hutchison and Noy (2002), Berg and Pattillo (1999), Aziz, et al. (2000) and IMF (1998), Bussière and Fratzscher (2002), Galindo and Maloney (2002), Sachs, et al. (1996), Bussière and Mulder (1999), for it applications.

bond yields. However, in constructing the exchange market pressure index, all three components are considered policy variables whose volatilities are reflecting the authority's preference at choosing policy tools. Thus, the greater variance of reserves might reflect the fact that the monetary authority tends to intervene more in the exchange market by buying or selling reserves instead of letting the exchange rate float. It is therefore inappropriate to discount reserve changes more than exchange rate changes in constructing the EMP. Otherwise, the exchange market pressure picked by the changes of reserves would be underestimated[4]. Based on the elasticity we compute in last section, we can convert the reserve volatility into the equivalent percentage changes of exchange rates which will be added up to the original percentage changes in exchange rates to get the EMP.

As noted in the previous section of this essay, reserve changes are better regarded as an intervention policy tool, especially in a pegged exchange rate regime. There is a widely known consensus of "fear of floating" which describes the situation of avoiding excessive exchange rate fluctuations by intervening in exchange markets. In this respect, the greater variability of reserve changes reflects the authority's preference in using reserves to maintain the stableness of exchange rates. Thus, the correct EMP should not discount the role of reserve changes by imposing a smaller weight to it. In fact, in a complete fixed regime, more weight should be given to reserve changes to measure the

[4] Under a flexible regime, there should not be any volatility in reserves. All the surpluses and deficits in the balance of payment would be eliminated by instantaneous exchange rate movement. However, the exchange rate response to the BOP is delayed in reality so that the monetary authority has to maintain some position of reserves.

EMP because it is reserves instead of exchange rates to be allowed to fluctuate.

Two interesting cases have been pointed out aiming at the deficiency of the precision weights. One occurred in Argentina in 1995[5] and the other in Hong Kong in 1998[6]. During the Tequila crisis, Argentina depleted about 20% of its international reserves to defend the currency board adopted in 1991. Even though the speculative attacks were massive at that time, the EMP using precision weights does not show it due to almost zero weight in reserve changes. During the Asian crisis, Hong Kong hiked its interest rates to fight against speculative pressure. The EMP with precision weights underestimates the unsuccessful speculative pressure in the exchange market since the exchange rate changes in Hong Kong have gained entire weight through its currency board regime.

Conceptually, the precision weights are completely inappropriate in constructing the EMP under a pure fixed rate system or a clean float system[7]. Under a fixed rate system, the zero volatility of exchange rates would make the weight assigned to exchange rate changes as infinity and the weight assigned to reserve changes as zero. In a country committed to maintaining its fixed rate regime, the huge reserve loss due to fighting back the speculative attacks would not have any impact on the EMP at all. Therefore, the EMP cannot pick up the market pressure from unsuccessful attacks. In the meantime, under a

[5] See Nitithanprapas and Willett (2000) for detailed discussions.
[6] See Angkinand (2005) for detailed discussions.
[7] Conceptually, there would not be any exchange market pressure if central banks do not intervene the exchange market under a clean float system. "A clean float system" refers to the system under which central banks do not intervene with reserve changes, but could possibly accumulate exchange market pressure by hiking interest rates.

free float system, an EMP index with precision weights would assign entire weight to the changes in international reserves due to its zero volatility. Thus, the speculative pressure absorbed by the exchange rate changes would not be captured by the EMP index.

The following two subsections demonstrate the appropriate combination of the different components in the EMP under a complete fixed rate regime and a float regime respectively.

4.1 The EMP under a Fixed Exchange Rate Regime

Under a complete fixed exchange rate regime, there are no changes in nominal exchange rates. Thus, the number of components in the EMP is naturally reduced from three to two. Notice that one percentage changes in interest rates is not necessarily equivalent to one percentage change in reserves in constructing the two-component EMP as suggested in the equal weights scheme. The real relationship between these two should be traced out by adapting the original model (Eq. (6) – (9)) in section 3 to the case with two components.

Keeping the exchange rate constant, Eq. (7) can be modified as:

(20) $p_t = \hat{a}_0 + a_1 p_t^*$ where $\hat{a}_0 = a_0 + a_2 \bar{e}$

Similarly, Eq. (8) can be rewritten as:

(21) $y_t = \hat{c}_0 - c_1 i_t + c_3 X_t$ where $\hat{c}_0 = c_0 + c_2 \bar{e}$

Therefore, Eqs. (6), (20), (21), and (9) constitute a new system under the fixed rate regime. Following the similar steps described in last section, we should be able to reach

(22) $\Delta r_t = \phi \Delta i_t + Z_t$

where $\phi = b_1 c_1 + b_2 = \gamma / \beta$ and $Z_t = a_1 \Delta p_t^* + b_1 c_3 \Delta X_t - \Delta d_t + \Delta v_t$. β and γ are defined in Eq. (13).

Thus, the revised definition for the EMP is:

(23) $EMP_t = \Delta r_t + \phi \Delta i_t$ where ϕ is defined above.

In Eq. (23), ϕ is the reserve elasticity of interest rates, which measures how many percentage changes of reserves would have been in response to one unit change of interest rates in order to maintain money market equilibrium. By applying ϕ to the weight of the changes in interest rates in the EMP, we can convert the changes of interest rates into the equivalent changes in reserves to keep money market equilibrium. Thus, the EMP is consistently measured in percentage changes in reserve changes only[8]. We surely can do it in the other way by converting reserves changes into the equivalent interest rate changes. But we do not expect a substantial change in the results.

It is worth noticing that ϕ is simply the relative weight of β and γ defined in Eq. (13).

Eq. (23) contrasts with the precision weights scheme in terms of all three weights. Under a pure fixed exchange rate regime, the precision weights scheme imposes entire weight to exchange rate changes while Eq. (23) gives zero weight to exchange rate

[8] Notice that the EMP with three components is measured in the percentage changes in the exchange rates. The reserve changes and interest rate changes are converted into the corresponding exchange rate changes based on the elasticities.

changes. Due to the zero volatility in exchange rates, the weights for reserve changes and interest rate changes approach zero in precision weights scheme, however, the weights are 1 and ϕ respectively in this elasticity approach. This is the reason why the precision-weighted EMP cannot capture the speculative market pressure with unsuccessful attacks in a fixed exchange rate regime. Such EMP underestimates the exchange market pressure substantially. The conceptually correct way to catch the exchange market pressure in fixed regime is to look at the changes in the other two components as suggested in this study.

4.2 The EMP under a Float Exchange Rate Regime

Under a pure float exchange rate system, the monetary authority never intervenes the exchange market with buying or selling reserves, which leaves the reserves unchanged[9]. Leaving out reserve changes, the original three-component EMP is reduced to a new two-component EMP. Eq. (9) should be rewritten as

(24) $$m_t^s = m_{t-1}^s + \Delta d_t$$

Thus, Eq. (6), (7), (8) and (24) constitute a new system of money market equilibrium without changes in reserves. Solving this system will shed light on the exchange rate elasticity of interest rates.

(25) $\Delta e_t = \gamma \Delta i_t + Y_t$ where γ and Y_t are defined as the same as in Eq. (13).

[9] Some reserves changes might be due to the interest earnings from the reserves investment. In doing empirics, we should be careful to filter out the part of reserves changes which is not due to exchange market intervention.

Therefore, the new EMP is defined as

(26) $$EMP_t = \Delta e_t + \gamma \Delta i_t$$

This equation reveals the true definition of the EMP under a free float system. This result contrasts the definition in the precision weights scheme. Under a free float system, the precision weights scheme would give entire weight to reserve changes and ignore the changes in exchange rates and interest rates. But Eq. (26) tells us that the EMP should comprise of only the changes of exchange rates and interest rates and ignore the unchanged reserves.

5 Concluding Remarks

While the precision weights scheme is legitimate to be used for market-determined variables in constructing composite variables, it is conceptually inappropriate to apply to constructing the EMP. The greater variability of reserve changes is due to the monetary authority's preference to use reserves to absorb the speculative pressure. The reluctance to float exchange rates leads to a much smaller variability in exchange rates. Therefore, the different variability in exchange rates and reserves merely reflects the authority's policy response function in relation to the speculative attacks. The greater variability in reserves should register in the higher EMP. We should not discount the reserves changes in constructing the EMP. However, the precision weights scheme implies that zero weight is given to reserve changes in a pure-fixed exchange rate regime and is given to exchange rate changes in a free float regime. This will lead to a downward bias for coding unsuccessful attacks such as the cases in Argentina in 1995 and Hong Kong in 1998.

Under the assumption of money market equilibrium, we derive the percentage changes of exchange rates in response to one percentage changes of reserves and interest rates. These two elasticities demonstrate how much the exchange rates would have changed if there were no exchange market intervention or domestic interest rate hikes, which, in turn, determines the weights of reserve changes and interest rate changes. In addition, we prove that equal weights scheme is one of the special cases derived from our model, which justifies the use of equal weights scheme as used in Girton and Roper (1977) and Nitithanprapas and Willett (2000).

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Annex:

A Comparison among Different Crisis Indices[10]

Even though we derive the two exchange rate elasticities of reserve changes and interest rate changes in section 3, it is still a difficult task to implement in practice. To apply those elasticities to a large sample set would require the assumption that each country should share similar economic structures. Otherwise, different elasticities should be estimated for each country based on its own money demand function. Furthermore, the money demand function for a country may not be stable over a long time span. If the parameters for the function vary over time, the different elasticities should be derived to calculate the EMP. A careful case study using the elasticities proposed in section 3 is worth doing. However, it is almost impractical to apply similar methodology to build the EMP for a large country set over a long time period. Therefore, this section will provide a simple comparison among the results derived from the different conventional ways in literature.

Crisis indices are dummy variables which take the value of one when the EMP is greater than a certain threshold[11]. Any values greater than the specified threshold are considered as the extreme values in the EMP. Any periods, therefore, with the extreme values of the EMP are identified as the crisis periods.

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[10] In this annex, we use the nominal bilateral exchange rates as the first component in the EMP. Differing from Glick and Hutchison (2001) among others to use real exchange rates as the first component, we follow the methodology suggested by Kaminsky and Reinhart (1999) to divide the sample into two sub-samples, the sub-sample with hyperinflation periods and without hyperinflation periods. This is the way to avoid the nominal depreciations caused by hyperinflation. As recognized in Kamin et al (2001), it is not at all clear which rates are superior to the other.

[11] See Ankinand (2005) for a discussion about the arbitrary choices of the thresholds in literature.

A1. Inconsistence among different crisis indices

Table 1 presents the definitions of 30 different crisis indices. Column (2) describes the components of each index. In terms of the components of crisis indices, there is a great deal of disagreement in the literature. Some studies used exchange rates as the single component to capture the "Currency Crash"[12]. Some studies like Glick Moreno (1999) and Bubula et al (2003) argued that the reserves data was very noisy and excluded it in the EMP. Due to lack of reliable market-determined interest rate data, many studies[13] did not include interest rates as a component of the EMP. Without individually justifying the specific use of the components, we try all possible combinations of the three-component, two-component, and single component crisis indices and compare the results across the different indices. This exercise allows us to check the inconsistency among different indices and reminds researchers to test the robustness of any particular index as suggested in Eichengreen et al. (1994), (1995) and Nitithanprapas and Willett (2000).

The first 14 indices are calculated based on the equal weights scheme. The rest of the indices use the individual and pooled precision weights scheme. The individual precision weights scheme means that we take the inverse of the volatilities of the components in each individual country as the weight. Thus, each country has its own

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[12] See Edwards (1989), Frankel and Rose (1996), Rose and Messe (1998), Esquivel and Larrain (1998) and Kumar et al. (1998) for the applications.

[13] See Aziz, et al. (2000), Kaminsky and Reinhart (1999) and Glick and Hutchison (2001)

weights based on the volatilities of three components. The pooled precision weights scheme means that we pool all countries and use the inverse of the components' volatilities as the common weights. Therefore, all countries share the same weights in the case.

The fourth column shows the different thresholds used in identifying the extreme values of the EMP[14]. The observations with extreme values of the EMP are identified as crisis periods.

Table 2 exhibits the numbers and percentages of crisis episodes detected in all 30 indices. Examining across the crisis indices, we can see the great difference among them. Out of 1070 total observations, there is as high as 14.26% being detected as crisis episodes based on ci17. On the contrary, ci9 detects only 4.85% as crisis periods. There is only one component in ci9: reserve changes. This reflects the fact that the large variability of reserve changes makes the extreme values harder to detect. Meanwhile, ci17 consists of only exchange rate changes and interest rate changes, which have less variability.

Table 3 provides a comparison of crisis indices across similar definitions. Out of about 1000 observations, only 3 crisis episodes are common across all 30 indices. But the number of total agreement for both non-crisis periods and crisis periods among 30 indices is 578. Since crises are considered as low probability events, it is reasonable to see many

[14] See Hartmann et al. (2003) and Siregar et al. (2005) for discussions about the inappropriate use of conventional ways to identify crisis periods because of non-normality distribution of the EMP. They employed extreme value theory to find crisis episodes.

agreements in non-crisis periods among different indices.

Table 4 shows the statistics comparing the indices with thresholds of two standard deviations and three deviations. As expected, the indices with lower thresholds detect more, about double, the number of crises found with the higher threshold.

Table 5 presents the comparison across different weighting schemes. In terms of the number of crisis episodes detected, the equal weights scheme finds fewer number of crisis episodes than the precision weight schemes.

Table 6 compares the single-component indices and multiple-component indices across different weighting scheme. The results are similar to those in Table 5.

A2 An Analysis of Crisis Indices for Asian Countries

The data analyzed in this section is compiled in Table 7.

A2.1 Hong Kong

Hong Kong has been keeping the currency board system throughout our sample period (1989-2003). The successful sustaining of the hard-peg system in Hong Kong makes it immune from potential currency collapses. However, there were still a great number of attacks on Hong Kong dollar during Asian Financial Crises. The substantial exchange market pressure was not reflected by the changes of nominal exchange rates but the sudden hikes of domestic interest rates in the defense of Hong Kong dollar in 1997 and 1998. Thus, the crisis indices without interest rates component might not be able to capture the exchange market pressure properly. Among the 30 crisis indices for Hong Kong in year 1997 and 1998, all 9 indices (ci1, ci2, ci6, ci8, ci9, ci13, ci22, ci26, and ci30) not detecting crisis included no interest rate component no matter what weighting schemes are. The significant movement of interest rates in year 1998 dominated the crisis indices so that they were not sensitive to the different weighting schemes. All the indices including interest rate component caught the crisis in year 1998.

A2.2 Indonesia

The crisis in Indonesia was so severe that all 30 crisis indices detected the crisis period either in year 1997 or year 1998. All 3 components of the indices displayed the significant fluctuations during the crisis time.

A2.3 Korea

While most of the indices detected the crisis year in Korea as year 1997, the interest rate only index, ci3, showed the crisis period as year 1996. The monetary authority in Korea increased the interest rates significantly one year before the actual hit in 1997.

A2.4 Malaysia

All 30 crisis indices consistently detected the crisis year in Malaysia in year 1997. In year 1992 and 1994, the monetary authority sold a substantial amount of reserves in response to the speculative attacks as recorded in reserves-only indices, ci2, and ci9. Under the equally weighting scheme, both the three-component index (ci7) and the two-component index without interest rates (ci6) detected crises in these two years. But under the individual precision weighting scheme, neither of the two (ci15, ci18) showed the crisis in 1994. In 1992, the three-component index (ci18) did not appear to capture the crisis. Under the pooled precision weighting scheme, neither the three-component nor two-component without interest rates recorded the crisis in 1994. The pooled precision weighting scheme seems not so biased like the individual precision weighting scheme. Both the three-component and two-component indices (ci23, ci26) recorded the crisis in year 1992.

A2.5 Philippines

In 1997, the crisis was detected by exchange rate changes and interest rate changes indices (ci1, ci3) but not by reserve changes indices (ci2). It means that the monetary authority in Philippines did not use the reserves to intervene the exchange market in crisis period. But it did increase the interest rates to strengthen the domestic currency.

A2.6 Singapore

In 1997, all 30 crisis indices detected the crisis in Singapore no matter what the components of the EMP or the weighting schemes were.

In 1991, the exchange rates-only index (ci1) showed the crisis but not the reserves-only or interest rates-only indices. The three-component index with equal weights (ci7) successfully captured the crisis but not the counterpart index with individual precision weights (ci15). It seems that the individual weighting scheme underestimates the EMP from the changes of exchange rates when the exchange rates are relatively flexible.

A3 An Analysis of Crisis Indices in Other Regions

A3.1 Argentina

From the first three single-component crisis indices, we can tell the different timing of the central bank's behavior. At year 2001, the reserves-only index (ci2) detected the crisis. However, the exchange rate-only index (ci1) showed the crisis at year 2002 instead of 2001. The interest rate-only index (ci3) did not display any crisis in this period. The different timings of crisis reflect the fact that the monetary authority in Argentina tried to defend its currency by selling reserves at year 2001, but quitted defending at year 2002. It did not employ interest rate hikes to defend. That is the reason why the two-component index without interest rates (ci6) showed the year 2002 as the crisis year while the three-component index (ci7) with equal weights did not detect any crisis around that period.

Examining the indices using individual precision weights, we can see the dominant effect from the exchange rate movement in the indices. The currency board system in Argentina strictly limited the variability in the exchange rates, which led to the large weights for the exchange rate changes in precision weighting scheme. All the indices with the exchange rate component (ci15, ci17, ci18, ci19, ci21, ci22) showed the crisis at year 2002. The indices with no exchange rates either shows the crisis at year 2001 (ci16) or no crisis at all (ci20).

In the indices with pooled precision weights, the inactivity of interest rates was amplified so that all indices with the interest rate component (ci23, ci24, ci25, ci27, ci28, ci29) did not indicate any crisis in 2001 – 2002 periods. Only two indices without interest rates (ci26, ci30) detected the crisis at year 2002.

The comparison among the three weighting scheme in the case of Argentina in 2001-2002 periods may lead to the following conclusions. First, the individual weighting scheme shows the most upward bias toward the changes in the exchange rates under a fixed rate system. Second, the pooled precision weighting scheme gives the upward bias toward interest rate changes. Third, taking the mean plus 2 or 3 standard deviations might seem to be too strict in defining crisis because even the ci7 does not point to crisis in years of 2001 or 2002.

In year 1995, Argentina got hit by the crisis originated from Mexico if measured by the reserves-only indices (ci2, ci9). This observation may support the way to define currency crises in Zhang (2001). Zhang (2001) proposed that the periods with either large depreciations OR large reserve loss could indicate crisis.

A3.2 Brazil

The Brazilian responses to the speculative attacks in periods of years 1998-1999 were similar as the Argentinean in years 2001-2002. In year 1998, the central bank sold a significant share of its reserve holding in order to defend of its currency. Therefore, the reserves-only indices (ci2, ci9) were coded as 1 in year 1998. The next year, the authority caved to the speculative attacks and let its currency depreciate. This event was captured by the exchange rates-only indices (ci1, ci8). The authority did not employ interest rate policy to defend as the interest rates-only indices (ci3, ci10) indicated no crisis.

Under pooled precision weighting scheme, each component across countries shares the same weight. We should expect the coding for Brazil in years 1998 and 1999 similar to the coding for Argentina in years 2001 and 2002. Due to the exaggerated effect of interest rates' inactivity, only the indices (ci26, ci30) without interest rates detect crisis for this period.

A3.3 Mexico

The year 1994 in Mexico was coded as the crisis period from all crisis indices except the interest rate-only indices (ci3, ci10). The currency depreciation and reserve loss in the Tequila Crisis were so severe that the different weighting schemes made no difference in determining the crisis periods.

In year 1990, the monetary authority intervened the exchange market by selling a large amount of reserves. The reserves-only indices (ci2, ci9) detected the crisis, but not exchange rates-only (ci1, ci8) or interest rate-only indices (ci3, ci10). The reserve loss in

1990 was so substantial that even the three component index with equal weights (ci7) detected crisis as well. But the massive speculative attacks were not recorded in the index with individual precision weights (ci15). This is directly due to the small weight attached to reserve changes from individual weighting scheme. It is worth noticing that the three component index with pooled precision weights (ci23) successfully captures the crisis in 1990. We may be able to draw the conclusion that the pooled precision weighting scheme tends to give less bias at estimating the exchange change market pressure from reserve loss.

A3.4 Russia

While the EMP without interest rates might underestimate the magnitude of speculative attacks when the monetary authority increases the interest rates significantly to defend its currency. However, the EMP with interest rates might show a downward bias when the authority employs only reserves to intervene.

In year 1995 in Russia, the reserves-only indices (ci2, ci9) detected crisis but not the exchange rates-only or interest rates-only indices. Most of the two-component indices without interest rates (ci6, ci13, ci18, ci22, ci26) signaled the crisis while none of the three-component indices does that. This reflects the tradeoff of adding interest rates in the indices. If the monetary authority uses only reserves to defend, then the more components are in the EMP, the less impact the intervention would have on the whole EMP.

A3.5 Turkey

In year 1991, the reserves-only indices (ci2, ci9) detected the crisis. But in all the multiple-component indices, only the two-component index without interest rates (ci6) successfully captured that. This is an equally weighted index. The observation confirms that the precision weighting scheme discounts the impact of reserve movement with an inappropriate degree. This is another example to see the costs of adding interest rates into the EMP since the three-component index (ci7) did not show the crisis.

A4. Conclusions

From the simple exercises above, we can draw some conclusions regarding the coding of crisis indices and the weights of the EMP.

First, the different crisis indices based on the different definitions vary substantially.

Second, under a fixed exchange rate regime, the indices with the precision weighting scheme underestimate the impact of reserves movement in the EMP. The individual precision weighting scheme is more biased than the pooled precision weighting scheme.

Third, the pooled precision weighting scheme seems to overestimate the EMP when the interest rates changes persist.

Fourth, the individual precision weighting scheme tends to underestimate the EMP from exchange rate changes when the exchange rate regime of a country is relatively more flexible.

Fifth, using different components in the EMP might lead to different timing of crisis. Monetary authorities tend to intervene the exchange market by selling reserves first, which is followed by depreciating their currencies.

Sixth, while the three-component indices with interest rates may be able to pick up the exchange market pressure from interest rate hikes, they might miss the crisis periods when authorities intervenes the market with reserves only. In terms of picking up the mild EMP from selling reserves, the two-component indices without interest rates seem to be superior to the three-component indices.

Seventh, even the mean plus 2 standard deviations might seem to be too strict to pick up some mild currency crises.

Last, but not the least, there is no universal standard to define currency crisis that could perfectly capture all the crises. In order to get a better measure of currency crisis, we may have to adopt different ways based on various behaviors of each component.

Figure 1

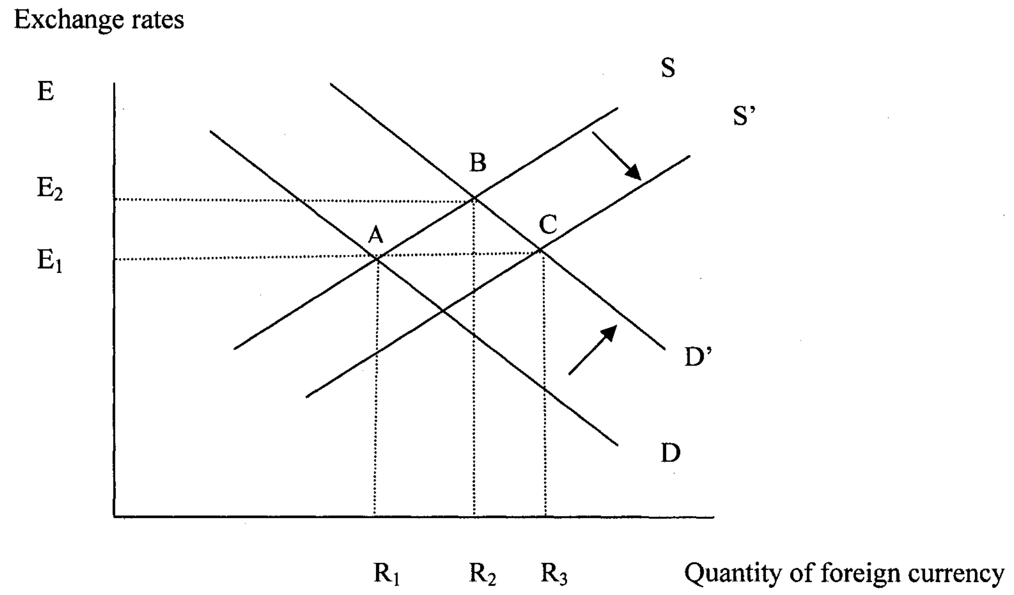
Exchange rates
E
E2
E1
S
S'
B
A
C
D'
D
R1
R2
R3
Quantity of foreign currency

Figure 2

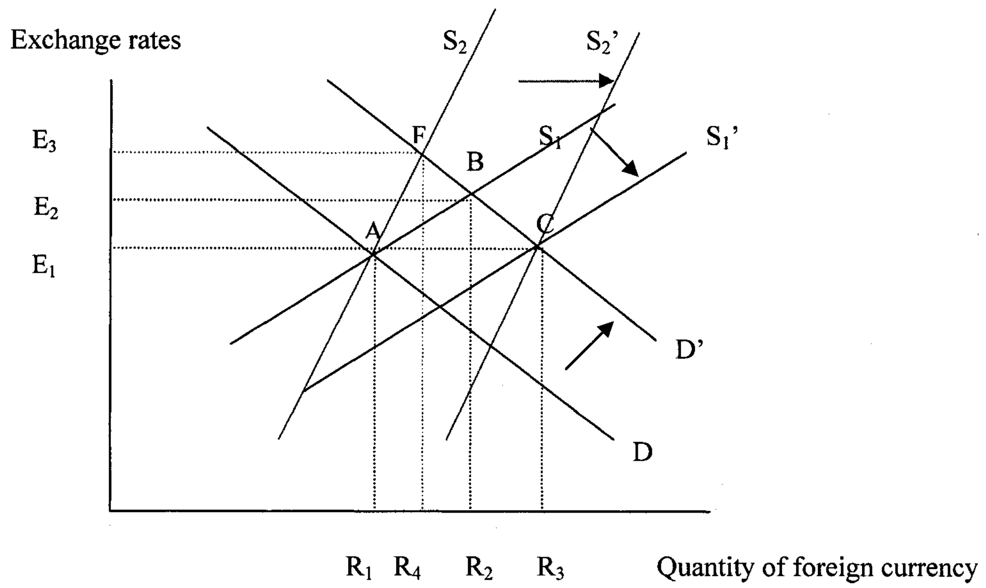

Figure 3

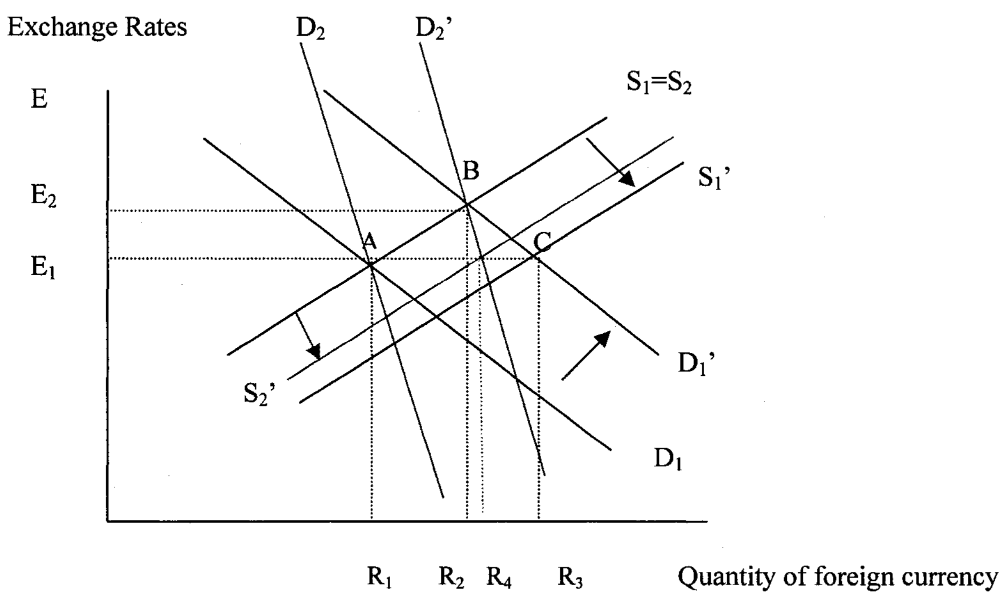

Table 1: The Definitions of All Crisis Indices*

(1)	(2)	(3)	(4)
Crisis Indices	Components**	Weighting Schemes	Std. Dev.
ci1	E	Equal Weights	2
ci2	R	Equal Weights	2
ci3	I	Equal Weights	2
ci4	R+I	Equal Weights	2
ci5	E+I	Equal Weights	2
ci6	E+R	Equal Weights	2
ci7	E+R+I	Equal Weights	2
ci8	E	Equal Weights	3
ci9	R	Equal Weights	3
ci10	I	Equal Weights	3
ci11	R+I	Equal Weights	3
ci12	E+I	Equal Weights	3
ci13	E+R	Equal Weights	3
ci14	E+R+I	Equal Weights	3
ci15	E+R+I	Indi. Prec. Weights	2
ci16	R+I	Indi. Prec. Weights	2
ci17	E+I	Indi. Prec. Weights	2
ci18	E+R	Indi. Prec. Weights	2
ci19	E+R+I	Indi. Prec. Weights	3
ci20	R+I	Indi. Prec. Weights	3
ci21	E+I	Indi. Prec. Weights	3
ci22	E+R	Indi. Prec. Weights	3
ci23	E+R+I	Pooled Prec. Weights	2
ci24	R+I	Pooled Prec. Weights	2
ci25	E+I	Pooled Prec. Weights	2
ci26	E+R	Pooled Prec. Weights	2
ci27	E+R+I	Pooled Prec. Weights	3
ci28	R+I	Pooled Prec. Weights	3
ci29	E+I	Pooled Prec. Weights	3
ci30	E+R	Pooled Prec. Weights	3

*: The crisis window is 24 months. Once the first crisis is detected, the crises in the following 23 months will be regarded as the continuation of the same crisis as the first one.

**: E = exchange rate fluctuations; R = reserves changes; I = interest rate differentials

Table 2:

(1)	(2)	(3)	(4)
Crisis Index	# of Crisis Episodes	# of Obs. Available	Percentage of Crisis Episodes
ci1	158	1159	13.63%
ci2	145	1134	12.79%
ci3	127	1040	12.21%
ci4	119	982	12.12%
ci5	147	1017	14.45%
ci6	133	1085	12.26%
ci7	119	960	12.40%
ci8	102	1159	8.80%
ci9	55	1135	4.85%
ci10	85	1040	8.17%
ci11	56	982	5.70%
ci12	94	1018	9.23%
ci13	61	1086	5.62%
ci14	57	960	5.94%
ci15	134	962	13.93%
ci16	139	984	14.13%
ci17	144	1010	14.26%
ci18	145	1086	13.35%
ci19	81	962	8.42%
ci20	72	984	7.32%
ci21	90	1010	8.91%
ci22	80	1085	7.37%
ci23	144	1087	13.25%
ci24	59	962	6.13%
ci25	133	960	13.85%
ci26	63	960	6.56%
ci27	179	1086	16.48%
ci28	74	1086	6.81%
ci29	161	960	16.77%
ci30	63	960	6.56%

Table 3: Comparison of Crisis Index across Similar Definitions

# of Agreement on Crisis Episodes among All Indices
3
# of Agreement among All Indices
578
# of Agreement on Crisis Episodes among ci1 ~ ci3
16
# of Agreement on Crisis Episodes among ci4 ~ ci6
38
# of Agreement on Crisis Episodes among ci8 ~ ci10
4
# of Agreement on Crisis Episodes among ci11 ~ ci13
19
# of Agreement on Crisis Episodes among ci16 ~ ci18
31
# of Agreement on Crisis Episodes among ci20 ~ ci22
18

Table 4: 2 Std Deviation VS. 3 Std Deviation

	2 STD	3 STD
Averaged # of Crisis Episodes across All Indices	142	73
Averaged # of Crisis Episodes across Indices with single Component	143	81
Averaged # of Crisis Episodes across Indices with Two Components	144	73
Averaged # of Crisis Episodes across Indices with Three Components	137	66

Table 5: Comparison across Different Weighting Schemes

	Equal Weights	Individual Precision Weights	Pooled Precision Weights
Averaged # of Crisis Episodes across Indies with Two Components	107	112	114
Averaged # of Crisis Episodes across Indices with Three Components	88	108	105

Table 6: Comparison Single-Element Indices and Multiple-Element Indices with 2-STD

	Equal Weights	Individual Precision Weights	Pooled Precision Weights
Averaged # of Crisis Episodes across Indices with Single Component	143	143	143
Averaged # of Crisis Episodes across Indices with Two Components	133	143	162
Averaged # of Crisis Episodes across Indices with Three Components	119	134	147

Table 7: Currency Crisis Indices

Ctry	Yr	ci1	ci2	ci3	ci4	ci5	ci6	ci7	ci8	ci9	ci10	ci11	ci12	ci13	ci14	ci15	ci16	ci17	ci18	ci19	ci20	ci21	ci22	ci23	ci24	ci25	ci26	ci27	ci28	ci29	ci30
Arg	95	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Arg	01	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Arg	02	1	0	0	0	0	1	0	1	0	0	0	0	1	0	1	0	1	1	1	0	1	1	0	0	0	1	0	0	0	1
Brz	98	0	1	0	0	0	1	0	0	1	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Brz	99	1	0	0	0	0	0	0	1	0	0	0	0	1	0	1	0	1	0	1	0	1	1	0	0	0	1	0	0	0	1
HK	97	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
HK	98	0	0	1	1	1	0	1	0	0	1	1	1	0	1	1	1	1	0	1	1	1	0	1	1	1	0	1	1	1	0
Ind	97	1	1	1	1	1	1	1	0	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0
Ind	98	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Kr	96	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Kr	97	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Mal	92	0	1	0	1	0	1	1	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	1	1	0	1	0	0	0	0
Mal	94	0	1	0	1	0	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Mal	97	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Mal	98	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mex	90	0	1	0	1	0	1	1	0	1	0	1	0	0	0	0	1	0	1	0	0	0	0	1	1	0	1	0	0	0	0
Mex	94	1	1	0	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Phil	97	1	0	1	1	1	1	1	1	0	1	0	1	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	0
Rs	95	0	1	0	0	0	1	0	0	1	0	0	0	1	0	0	0	0	1	0	0	0	1	0	0	0	1	0	0	0	0
Sing	91	1	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	1	1	0	0	0	0
Sing	97	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Turk	91	0	1	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0