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Too Much for Self-Insurance? Asian Foreign Reserves*

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Abstract

This paper attempts to identify whether the recent foreign reserve accumulation in Asian economies has been too extraordinary to recover the moderate level of reserves which depleted at the time of the currency crisis in 1997-1998. First of all, the level of reserves numerated by various economic fundamentals such as broad money, imports and short-term external debt in Asian economies was examined in order to judge whether the level was high enough to weather speculative pressures at the onset of the crisis in 1997. The analysis is based on a Brownian motion model with an absorbing barrier. Although most Asian economies appeared to have larger reserves (reserve indicators) than the estimated threshold at the time of the crisis of 1997, reserves in terms of short-term external debt were apparently not sufficient to avoid speculative attacks. Then, based on the estimated threshold of reserve indicators, the likelihood of a 25% devaluation within three months ahead is calculated. Probabilities of currency devaluation vary from time to time, among countries, and among reserve indicators. The devaluation likelihood was modest in the mid 1990s, but then it showed a big jump in 1997 in Indonesia, Thailand, Korea, and Philippines.

Keywords: foreign reserves, accumulation, Asia, threshold, currency crisis
JEL classifications:

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1. Introduction

Foreign exchange reserve accumulation has risen dramatically over the past years in many parts of the world, and there is as yet no sign that this trend will stop.

For the last decade, there has been a significant increase in the world foreign reserves. In 1995, the foreign reserves were about USD 1.2 trillion. The latest report of the IFS shows that the foreign reserves in the world were about USD 4.98 trillion at the end of November 2006. This huge amount of reserve accumulation just occurred in the past few years. According to ECB (2006), world reserves increased about 90% during 2002-2005, at a pace three times faster than that in 1999-2001. Not only has the speed of accumulation accelerated in recent years, but there are also other significant changes in reserve accumulation around the globe. (See Figure 1, P.13)

The academic interest in foreign reserves can be divided into two types: currency composition and size of reserves.

Currently, two-thirds of the global foreign reserves are held in US dollar denominated assets (IMF, 2005). As a result, the local-currency value of the reserves is sensitive to fluctuation of the US dollar and the US interest rates. However, the introduction of the euro and the increased liquidity of other major currencies have increased the pressure on many central banks to diversify their investments. One method of investment diversification is to focus on the optimal currency shares in foreign reserves (Papaioannou, Portes, and Siourounis 2006). They suggest that the euro shares are still below the optimal level and require a significant increase.

As for the size of reserves, it has been pointed out that many countries, particularly developing countries, are holding excessive reserves. It is also commonly known that among these countries, many Asian economies started accumulating foreign reserves much faster than in the pre-crisis period. Their demand for foreign exchange has increased a lot more than normal economic fundamentals would account for. However, some events must have happened. For example, concerns about sudden reversals of capital flows may have stimulated the reserve accumulation. Whether the Asian countries have accumulated an excessive amount of foreign reserves still remains a question.

Among the top 10 reserve holding accumulating countries in the world, eight are (East) Asian countries. The top two reserve holding countries are Japan and China. Japan had been the top in reserve holdings for a long time, while the amount of reserves in China exceeded that of Japan in August 2006. At the end of November, China had about USD 1 trillion of the reserves, while Japan had about USD 0.9 trillion of the reserves. (See Table 1, P.11)

Apart from the reserve concentration in Asia, it is also pointed out that the oil-exporting countries, whose current account surplus is estimated to have exceeded that of the Asian economies in 2005 due to the oil price hike, have emerged as a new major group of reserve accumulation countries.

In general, there are three main motives for a country to accumulate reserves. One is the self-protection against sudden stops (precautionary reasons, a buffer stock) suggested by Eichengreen and Mathieson (2000) and Aizenman and Lee (2005). The accumulation of reserves in Asian countries especially after 1998 can be thought of as self-insurance behavior against future crisis. In the case of Thailand in 1997, the Bank of Thailand sold foreign reserves and bought domestic assets to prevent currency from

depreciating. When foreign investors feel that the currency is overvalued, they will suddenly change their attitude and expectation toward a currency, and withdraw capital out of the country. Or, in some cases, due to domestic banking fragility, people rush to convert domestic currency deposits and assets into those denominated by US dollars or other currencies. Central banks and monetary authorities with a large amount of reserves can maintain exchange rate stability (by market intervention) and avoid costly liquidation of assets (by providing foreign currency to the private sector). Otherwise, the country will yield to domestic-currency-selling pressure in the market. This is one of the reasons why many emerging market economies began to accumulate reserves in the aftermath of the currency crises in the 1990s and early 2000s.

The other reason, particularly prominent in Asian countries in the aftermath of the crisis of 1997, is that the reserve accumulation is a result of export-led growth strategy. (Aizenman and Lee, 2005). During the strong depreciation period and the following recovery period, the crisis-hit Asian economies pursued export-led growth supported by exchange rate regimes anchoring their currency to the US dollar, although with a more flexible exchange rate policy. By keeping its currency relatively low, a country can enjoy price competitiveness in exports and can expand exports, leading to a trade surplus. Also, foreign reserves will continue to accumulate while exchange rates are kept undervalued. In other words, as long as foreign reserves continue to accumulate, exchange rates might become more manageable.

The third factor that motivates a country to accumulate reserves is related to the saying, "Keep up with the Jones". Countries accumulate reserves not only because the larger the better, but also because other neighboring countries accumulate reserves. According to Mrs. Machlup's wardrobe hypothesis,[1] Mrs. Machlup feels inferior to her neighbor, Mrs. Jones, because Mrs. Machlup has only 100 dresses whereas Mrs. Jones has 110 dresses. Mrs. Machlup cannot stop buying clothes because she has to keep up with Mrs. Jones for whatever reasons. Talking about reserves, not clothes, there's a rationale for this behavior. A country with a relatively higher stock of reserves than its neighbors is more likely to diffuse the speculative pressure. Also, a large amount of reserves works as a good signal to compete for international capital and FDI in the world. According to Mrs. Machlup's hypothesis, one of the reasons that reserve accumulation has been concentrated in Asia in recent years is because other neighboring Asian countries accumulate reserves.

The recent literature focuses on precautionary reserves; that is, large foreign reserves work as a fire wall against speculative attacks. Usually, developing countries ought to have reserves equivalent to the 3-month trade balance. The fact is that reserves in many countries have exceeded the 3-month imports level since the late 1980s. It is also suggested that the ratio of short-term debt over reserves should be less than one (the "Guidotti Rule"), but this ratio in many developing countries is currently greater than one (Rodrik, 2006). Based on several reserve measures and theoretical models, this research intends to find out whether Asian economies are accumulating too many foreign reserves or not. Not only do we calculate the threshold level of reserves for Asian economies at the onset of the crisis, but we also estimate whether the reserve accumulation behavior in the aftermath of the crisis in 1997 is unique in Asian economies, using several crisis-hit countries such as Argentina, Mexico, and Russia.

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[1] Machlup (1966). See also Cheung and Qian (2006) for details.

The paper is organized as follows. In section 2, we give a brief description of foreign reserves in Asian countries. In section 3, a theoretical model to estimate the threshold of reserves is illustrated. In section 4, we review the foreign reserve accumulation in recent years and compare the behavior of reserves before and after the crisis. The final section concludes the paper.

2. Foreign Reserves around the World

As explained in the previous section, the amount of foreign reserves accumulated by Asian countries in recent years is huge. In China, foreign reserves have sharply increased and reached almost USD 1 trillion by mid-2006. Many Asian countries have suffered from the Asian currency crisis in 1997-1998 and sharply reduced foreign reserves. These countries had to make up the loss and accumulated more reserves after 1998. Although the timing of the turnaround and pace of recovery are different for each country, the reserve accumulation accelerated after 2000. The reserve accumulation is partly due to the current account surplus among most of the East Asian countries, where the exchange rate is more or less "managed" (e.g., China is the largest trade partner with the US).[2]

Accumulation of foreign reserves from various point of views such as the recovery from the crisis, precautionary motive to avoid a next crisis, and other reasons are examined by several scholars.[3]

Even though a larger amount of reserves is effective in avoiding speculative pressure and in signaling the robustness of the country's economy, there are *pros* and *cons* in holding a large amount of reserves, which works as self insurance and contributes to the stability of exchange rates. In addition, if domestic interest rates are lower than US or other foreign interest rates, reserve accumulating countries can earn some profit (income gain). On the other hand, if domestic interest rates are higher than US (or foreign) interest rates, central banks lose the opportunity cost in managing foreign reserve: Central banks invest in domestic currency which is equivalent to foreign reserve holdings, and they could have earned higher profits with a higher domestic interest rate. Or, if central banks issue domestic (public) bonds to finance and purchase foreign debt (most of foreign reserves are US TB and), central banks incur losses because payment for a higher interest rate on domestic bonds is greater than earnings from lower US (foreign) interest rates. These are categorized as quasi fiscal costs. In addition to income loss and quasi fiscal costs, a country incurs capital loss if domestic currency appreciates.

Hence, part of foreign reserves, that is, beyond a certain minimum level, is unnecessary and potentially costly. There are several popular indicators that measure the adequate level of foreign reserves.[4]

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[2] The current account deficit in (and the capital flows to) the US can be said to be financed by these reserve accumulating countries. Capital flows into the United States, in terms of purchases of US government bonds, from the rest of the world, most notably from East Asia and recently from oil producing nations. The reserves accumulation, in line with intervention to sell own currencies in exchange for foreign assets, is mostly by dollar-denominated assets and has helped capital inflow to the US.

[3] See, for example, Aizenman and Marion (2003), Genberg, McCauley, Park and Persaud (2005).

[4] These indicators are often cited as early warning signals. For literature of early warning signals, see, for example, Kaminsky, Lizondo and Reinhart(1998).

One of the popular measures is the ratio of broad money to reserves. This reflects the potential for resident-based capital flight from the domestic currency. When capital inflows suffer a reversal, holders of liquid domestic liabilities may try to convert them into foreign currencies. Therefore, foreign reserves are required to cover some proportion of M2 in order to cushion the adverse impacts from the capital flight.

If the M2 to reserves ratio is more than one, broad money will exceed foreign reserves significantly. In the presence of an exchange rate peg, the higher the increase in monetary aggregates relative to the stock of foreign reserves, the higher the probability of capital flight in the event of both external and internal shocks to the foreign exchange market.

As seen in Figure 2.1, the ratio was high up to the early 1990s. Even after some decline in the ratio, these Asian economies show a relatively high ratio of around 2-8 until 1997. After the currency crisis in 1997, most of the Asian economies show some decreasing trend in the ratio.

The second measure is the ratio of imports to reserves. This ratio represents the number of months for which a country could support its current level of imports if all other capital flows were to stop. As a rule of thumb, countries should hold foreign reserves in order to cover their imports for three to four months.

As shown in Figure 2.2, most of the Asian countries appeared to have reserves exceeding the three-month import coverage. As of the end of 1996, the imports to reserves ratio was around 0.2-0.3, varying from 0.14 (Thailand) to 0.35(Korea), which means these economies had reserves equal to or more than three months of imports. Thailand had reserves equivalent to seven months of imports, and Korea was the only country which did not meet the three-month imports criteria as of the end of 1996. In 1997, many countries appeared to show an increase, indicating the depletion of reserves during the speculative attacks. Since 1998, the indicator has decreased significantly. The indicator of most of the countries lies below 0.2, meaning that these economies are able to finance imports for more than five months with the existing stock of foreign reserves.

The third indicator for the adequacy of foreign reserves is the ratio of short-term external debt to reserves. This indicator is known as the Guidotti rule. This ratio reflects a country's ability to service its existing short-term external debt, maturing within one year, in the event of deterioration in the external financing conditions, such as a sudden stop of capital inflows and difficulty in debt payment. Typically, a country is considered prudent if the ratio equals or lies below one: a country holds, at least, foreign reserves in the amount of its total external debt maturing within one year.

As shown in Figure 2.3, many of the Asian countries had huge short-term external debt before 1997. The indicator was well above one in many countries. Malaysia was the only country with short-term external debt to reserves ratio less than one. The ratio became less than one in Philippines after 1991. Thailand had a relatively small ratio throughout the 1980s, but the number exceeded one in 1994 and continued rising afterwards. In some countries, the ratio increased during the course of 1997, due to the decline in reserves. Since 1998, all of these countries have improved their positions in terms of reserves to short-term debt.

In the following section, we first estimate the threshold of reserves, considered as the least amount of reserves required to weather speculative pressure in the foreign exchange market. Using various measures of reserves (M2/reserves ratio, import/reserves ratio, short-term external debt/reserves ratio), we examine whether the Asian countries had enough reserves to escape from the currency crisis of 1997.

3. Asian Foreign Reserves before Crisis Period

This section describes the theoretical model in order to estimate the "threshold" level of reserves that would avoid speculative attacks in the foreign exchange market. The model follows the methodology of the stochastic process model, in which the future devaluation probability of the exchange rate depends on the behavior of the foreign reserves. If the level of reserves at the time of crisis in 1997 was well below the estimated threshold, it is interpreted that the country had too little reserves and was vulnerable to speculative pressure in the foreign exchange market.

3.1 Model

In the model, it is assumed that market participants believe at time t that at time $t+k$, either the pegged exchange rates of Asian economies will be maintained, or they will collapse to a new exchange rate level. The conditional exchange rate expectation on whether or not the speculative attack will occur in the future is summarized as follows.

$$ {}_tS_{t+k}=(1-p)S^N_{t+k}+pS^A_{t+k} \tag{1}$$

Here, the expectation at time t of the exchange rate at time $t+k$ is ${}_tS_{t+k}$. S^N_{t+k} and S^A_{t+k} are the expected exchange rates at time $t+k$. S_{t+k} is conditional in that there is no speculative attack (represented as S^N_{t+k}) and on speculative attack (S^A_{t+k}), respectively. p is the probability of speculative attack between time t and $t+k$. In the followings, we treat k-period forward exchange rates as indicators of the expected exchange rate. Thus, the k-period forward premium is an indicator of expected devaluation over the next k periods.

Then, the forward premium, $f_{t,k}$, is expressed as follows.

$$ f_{t,k}= (F_{t,k}-S_t)/S_t + v_{t,k} \tag{2}$$

where $F_{t,k}$ is the $t+k$ forward exchange rate and S_t is the spot exchange rate. An error term, $v_{t,k}$, is assumed to be white noise and $E(v_{t,k})=0$.

If there is no speculative attack between periods t and $t+k$, then $S^N_{t+k}=S_t$. That is, as long as the exchange rate regime is credible, the exchange rate always maintains at S_t. On the other hand, if there is a speculative attack between t and t+k, the expected rate of devaluation is θ, then $(S^A_{t+k} -S_t)/S_t=\theta$. Insert S^N_{t+k} and S^A_{t+k} explained above into equations (1) and (2), then the relationship between speculative attack probability and forward premium is expressed as

$$ f_{t,k}=\theta p+ v_{t,k} \tag{2}'$$

We now turn to the calculation of probability, p. We assume that the reserve indicator (M2 to reserves ratio, imports to reserves ratio, STD to reserves ratio) follows a geometric Brownian motion process. At each time, the reserve indicator is taken to be the realization of a stochastic process, Y_t with an initial value Y_0. We impose an assumption on the mean of the Brownian motion of reserve indicators, Imp/R, M2/R, and STD/R that it depends on the domestic on-shore interest rate. This reflects the fact that high interest rates along with managed exchange rate systems in Asian economies accelerated capital inflows during the 1990s, increasing the pressure for deviation from the existing exchange rate. In the estimation, we use the money market rate as the domestic interest rate.

The probability of a devaluation between time t and $t+k$ is the probability that the reserve indicator first hits the critical level, $\bar{Y}$, during the interval [t, t+k]. This critical level, an absorbing barrier, is thought of as a threshold of foreign reserves.

Suppose the starting point is zero ($t=0$). Then, the probability that the reserve indicator passes through the threshold for the first time within k period from now is given as

$$p_{t,k} = P(Mk \le \bar{Y})$$

$$= \Phi\left(\frac{y-\mu k}{\sigma\sqrt{k}}\right) + \exp\left(\frac{2\mu y}{\sigma^2}\right)\Phi\left(\frac{-y-\mu k}{\sigma\sqrt{k}}\right) \quad (3),$$

where $M_k = \sup [Y_s: 0 \le s \le k]$ and $y = \bar{Y} - Y_0$. μ is the means of the Brownian motion and it takes the form of $\mu = d_0 + d_1 * i_t$, where i_t is the domestic interest rate. Φ is the cumulative standard normal distribution.

In the above equation, the first term is the probability that the increase in the reserve indicator between t and $t+k$ is at least y. In other words, it is the probability that the reserve indicator exceeds the threshold at time $t+k$. The additional terms adjust for the fact that the ratio has already crossed the barrier once and then moved back below the barrier at time $t+k$.

Therefore, we calculate the devaluation probability using this equation (3):

$$f_{t,k} = \theta * [\Phi\left(\frac{y-\mu k}{\sigma\sqrt{k}}\right) + \exp\left(\frac{2\mu y}{\sigma^2}\right)\Phi\left(\frac{-y-\mu k}{\sigma\sqrt{k}}\right)] \quad (4)$$

In calculating the threshold of the reserve of equation (4), we set k=3 months and θ=0.25. That is, the model is to estimate the critical value of reserves that allows a 25% devaluation within three months ahead. For the reserve indicator, we use these three types: imports to reserves ratio, M2 to reserves ratio, and short-term external debt to reserves ratio.

3.2 Results

Estimation results are shown in Table 2. The left column of Table 2 shows the results for threshold level of imports to reserves ratio (Imp/R), and the middle column shows the threshold level of M2 to reserves ratio (M2/R), and right column shows the threshold level of short-term external debt to reserves ratio (STD/R). Since the table shows the imports (M2, STD, respectively) to reserves, the larger the number, the smaller the relative size of reserves.

The estimation period was from the first quarter of 1980 to the end of 1997 for Imp/R and M2/R ratios, and from the last quarter of 1983 (1988 in Korea) to the end of 1997 for STD/R ratio. All countries were estimated based on quarterly data.

Ratio of Imports to Reserves

As seen in the left column of Table 2, the threshold level of M2 to reserves ratio varies from 0.8 (Thailand) to 4.3 (Malaysia), although most of them are estimated insignificantly different from zero. The estimated threshold of reserves indicates that the currency crisis may occur when reserves decline well below about one month of imports (one week of imports in the case of Malaysia). The estimated reserves are fewer than the traditional rule of thumb on reserve holdings accomodatable of three months of imports. Comparing these values with the actual values as of the second quarter of 1997 shown in Table 3, several remarkable findings emerge. Most of these Asian economies had larger amount of reserves, compared to the threshold level. The reserves (relative to M2) were much larger than the threshold levels in Thailand at the onset of the currency crisis of 1997. All other countries are also found to have had enough reserves in terms of months of imports as of the second quarter of 1997.

Ratio of M2 to Reserves

The threshold level of reserves compared to M2 is shown in the middle column of Table 2. Again, the threshold ratio varies from 2.17 (Indonesia) to 29.448 (Korea). Three out of five ratios were significantly estimated: Indonesia, Thailand, and Korea, the three economies that requested the IMF program at the onset of the currency crisis. Comparing these thresholds with the actual values at the second quarter of 1997, the reserves relative to M2 were slightly below the threshold levels in Indonesia and Philippines (although the estimated threshold in Philippines is not significant). These two economies were short of reserves (in terms of M2) before the currency crisis in 1997. Other economies, however, had a larger amount of reserves in terms of M2 compared to the threshold levels.

Ratio of Short-Term External Debt to Reserves

Finally, the right column of Table 2 shows the threshold of short-term external debt (STD) to reserves. Only the estimated threshold of Malaysia is found to meet the Guidotti rule value. All other countries, Indonesia, Philippines, Thailand, and Korea are found to have a larger threshold of STD relative to reserves than one, although the estimated threshold of Philippines is not significantly different from zero.

The actual ratios of all of these economies at the second quarter of 1997 are smaller than the estimated threshold levels. Although the STD-reserve ratio exceeded one, the Guidotti rule value, in most of these countries at the onset of currency crisis of 1997, these countries still had a larger amount of reserves compared with the threshold levels.

Observing each country individually, we find that some countries had not always run short of reserves by all three measures before 1997. Indonesia had run short of reserves in terms of M2, but other economies were found to have a larger amount of reserves than threshold levels. Still, the estimated thresholds of reserves are less than the traditional rule of thumb on reserve holdings of three months imports, or the Guidotti rule of short-term external debt coverage, and actual values of these reserve indicators at the second quarter of 1997 in some countries did not meet the traditional rule or the Greenspan-Guidotti criteria. Therefore, although most economies had larger reserves (in terms of imports, M2, or STD) than the estimated thresholds before the crisis in1997, it is hard to interpret that Asian economies had enough reserves before the crisis of 1997.

4. Probabilities of Crisis

In this section, we calculate probabilities of crisis using thresholds estimated in the previous section. Probabilities are calculated using equation (3) in section 3. The probabilities for the sample period from the end of 1980 to the end of 1997 (the end of 1983 to the end of 1997 for STD/R) are plotted in Figures 3.1 to 3.5.

In Indonesia, the probability of crisis calculated with Imp/R and M2/R is relatively volatile in the early 1980s. Then, the probabilities based on M2/R became almost zero from the end of the 1980s. The calculated expectation for devaluation to take place within three months was around 0.2-0.4 based on the Imp/R and STD/R indicators during the late 1980s and the first half of 1997. In the last half of 1997, the probability of crisis calculated with M2/R jumped to 1, and those calculated with Imp/R and STD/R reached closed to 0.7. The result seems consistent with the story that Indonesia got into crisis due to a contagion from other crisis-hit economies at first and then suffered capital flight and sudden stops.

Probabilities of crisis in Malaysia are shown in Figure 3.2. Overall, the likelihood of a currency crisis was relatively small and stable during the sample period regardless of the indicators.

Figure 3.3 plots the likelihood of a currency devaluation in Philippines. Contrary to the results of Malaysia, probabilities of currency crisis have been quite high for most of the sample period. In particular, probabilities of crisis calculated by M2/R are mostly one during the sample period. After the mid 1990s, probabilities based on Imp/R and/or STD/R becomes very low, almost zero, while probabilities based on M2/R are one. In the second quarter of 1997, the probability calculated by STD/R jumped from zero to one.

Figure 3.4 shows the probabilities of a currency devaluation in Thailand. The probabilities calculated from M2/R were one during the 1980s, while the probabilities based on the other two indicators were much lower. The likelihood of a currency devaluation became low during the early 1990s, around 0-0.4 at the highest, regardless of the indicators. In Thailand, the likelihood of a currency crisis jumped in early 1997 in all three indicators.

The likelihood of a currency devaluation in Korea is plotted in Figure 3.5. Although the probabilities calculated by Imp/R were consistently high, mostly equal to one by the early 1990s, the probabilities based on M2/R and/or STD/R were relatively low and stable. One of the interesting findings is that the likelihood of a large currency devaluation based on STD/R began increasing from the early 1990s whereas the probabilities based on other reserve indicators remained low.

Overall, the estimated likelihood of devaluation was high at some period of time in several countries. For example, the probabilities based on the imports to reserves ratio appeared to be one in Thailand and in Korea for most of the 1980s. The probabilities of devaluation were consistently one in most of the sample period in Philippines. The devaluation likelihood, however, declined to 0.4 or less in many countries in the early 1990s. Then, there was a sharp hike in devaluation probabilities in 1997 in Indonesia, Philippines, Thailand, and Korea. In particular, the likelihood of devaluation based on the STD/R increased significantly in the 1990s in Indonesia, Thailand and Korea. One way to interrupt these results is that, although the actual values of reserve indicators were not that bad in the mid 1990s compared with those in the 1980s, increasing trend in short-term external debt, real exchange rate appreciation, capital market liberalization, and other environmental factors, made the level of reserves temporarily not sufficient to avert speculative attacks.

5. Concluding Remarks

Taking the previous explanation about the accumulation of reserves into account, this paper focuses on the self-insurance motives. By estimating the threshold level of reserve indicators and calculating the likelihood of currency devaluation within three months ahead, we examine whether the Asian countries' foreign reserves were too small to avert speculative attacks in 1997. Our results show that the estimated thresholds of reserves are less than the traditional rule of thumb on reserve holdings of three months imports, or the Guidotti rule of coverage of short-term external debt. Although the actual values of these reserve indicators at the second quarter of 1997 in some countries did not meet the traditional rule or the Guidotti rule criteria, they were larger than the estimated threshold value of reserves. Therefore, Asian countries had not always run short of reserves, but it is hard to interpret that Asian economies had enough reserves before the crisis of 1997. The estimated likelihood of devaluation declined to 0.4 or less in many countries in the early 1990s, but then devaluation probabilities showed a sharp hike in 1997 in Indonesia, Philippines, Thailand, and Korea. Among several factors, increasing trend in short-term external debt, real exchange rate appreciation, capital market liberalization, and financial sector vulnerability made the level of reserves not sufficient to avoid speculative attacks temporarily, and therefore a currency crisis was triggered.

One caveat of the analysis is that part of the assumption in the estimation model is strong. We assume that the exchange rate will not devalue at all if no speculative attack occurs. Exchange rates, however, did change in the Asian economies used in this analysis during the estimation period between 1980 and 1997. It would be better to apply weaker assumptions on exchange rate movements. We also assume that the determinant of drift of the Brownian motion depends on the domestic interest rate. The behavior of foreign reserves (indicators) is affected by, needless to say, many other macroeconomic factors. This remains for future work.

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Table 1. Total Reserves Minus Gold, billions of USD, 1990-2006

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
China	29.59	43.67	20.62	22.39	52.91	75.38	107.04	142.76	149.19	157.73	168.28	215.60	291.13	408.15	614.50	821.51	1068.49
Japan	78.50	72.06	71.62	98.52	125.86	183.25	216.65	219.65	215.47	286.92	354.90	395.15	461.19	663.29	833.89	834.27	879.68
Russia				5.84	3.98	14.38	11.28	12.89	7.80	8.46	24.26	32.54	44.05	73.17	120.81	175.89	295.57
Taiwan	72.44	82.41	82.31	83.57	92.45	90.31	88.04	83.50	90.34	106.20	106.74	122.21	161.66	206.63	241.74	253.29	266.15
Korea	14.79	13.70	17.12	20.23	25.64	32.68	34.04	20.37	51.97	73.99	96.13	102.75	121.35	155.28	199.00	210.32	238.88
India	1.52	3.63	5.76	10.20	19.70	17.92	20.17	24.69	27.34	32.67	37.90	45.87	67.67	98.94	126.59	131.92	170.74
Singapore	27.79	34.19	39.94	48.42	58.30	68.82	76.96	71.39	75.08	77.05	80.17	75.68	82.22	96.25	112.58	116.17	136.26
Hong Kong	24.57	28.81	35.17	42.99	49.25	55.40	63.81	92.80	89.65	96.24	107.54	111.16	111.90	118.36	123.54	124.24	133.17
Brazil	7.44	8.03	22.52	30.60	37.07	49.71	58.32	50.83	42.58	34.80	32.49	35.74	37.68	49.11	52.74	53.57	85.56
Malaysia	9.75	10.89	17.23	27.25	25.42	23.77	27.01	20.79	25.56	30.59	28.33	29.52	33.36	43.82	65.88	69.85	82.13
Algeria	0.72	1.49	1.46	1.47	2.67	2.01	4.24	8.05	6.85	4.53	12.02	18.08	23.24	33.13	43.25	56.30	77.91
Mexico	9.86	17.73	18.94	25.11	6.28	16.85	19.43	28.80	31.80	31.78	35.51	44.74	50.59	58.96	64.14	74.05	76.27
Thailand	13.31	17.52	20.36	24.47	29.33	35.98	37.73	26.18	28.83	34.06	32.02	32.35	38.05	41.08	48.66	50.69	65.29
Turkey	6.05	5.14	6.16	6.27	7.17	12.44	16.44	18.66	19.49	23.35	22.49	18.88	27.07	33.99	35.67	50.58	61.07
Libya	5.84	5.70	6.18						7.27	7.28	12.46	14.80	14.31	19.58	25.69	39.51	59.29
Norway	15.33	13.23	11.94	19.62	19.03	22.52	26.52	23.40	19.05	23.81	27.60	23.28	32.00	37.22	44.31	46.99	56.84
USA	72.26	66.66	60.27	62.35	63.28	74.78	64.04	58.91	70.71	60.50	56.60	57.63	67.96	74.89	75.89	54.08	54.85
Australia	16.26	16.53	11.21	11.10	11.29	11.90	14.48	16.85	14.64	21.21	18.12	17.96	20.69	32.19	35.80	41.94	53.45
Poland	4.49	3.63	4.10	4.09	5.84	14.77	17.84	20.41	27.33	26.35	26.56	25.65	28.65	32.58	35.32	40.86	46.37
France	36.78	31.28	27.03	22.65	26.26	26.85	26.80	30.93	44.31	39.70	37.04	31.75	28.37	30.19	35.31	27.75	42.65
World	934.64	993.77	1003.65	1107.94	1264.29	1476.09	1651.71	1708.70	1759.54	1886.41	2026.35	2148.59	2527.70	3156.51	3868.70	4246.50	5095.93

Source: International Financial Statistics

Table 2. Threshold of Reserve Indicators

	Import to reserves	Money to reserves	Short-term debt to reserves
Indonesia	0.913	2.174 ***	3.645 *
s.e.	1.39	0.820	2.849
Malaysia	4.284	9.441	0.997 *
s.e.	538.85	36.207	0.827
Philippines	1.575	4.034	1.209
s.e.	6.35	54.347	3.083
Thailand	0.812 ***	6.440 ***	3.182 ***
s.e.	0.30	2.105	1.104
Korea	1.358	29.448 *	2.431 ***
s.e.	20.30	23.785	0.202

Table 3. Actual Values of Reserve Indicators

	Import to reserves			Money to reserves			Short-term debt to reserves		
	97Q2	01Q4	05Q4	97Q2	01Q4	05Q4	97Q2	01Q4	05Q4
Indonesia	0.205	0.111	0.161	6.214	3.056	3.702	1.705	0.622	0.542
Malaysia	0.807	0.628	0.432	3.877	3.231	2.334	0.611	0.264	0.223
Philippines	0.970	0.560	0.780	4.932	3.088	3.387	0.900	0.492	0.645
Thailand	0.160	0.134	0.173	4.894	3.665	3.096	1.453	0.319	0.220
Korea	1.097	0.334	0.336	6.206	3.464	2.664	2.081	0.301	0.250

Source: Author's calculation

Figure 1. Total International Reserves Minus Gold in the World, millions of USD, 1980-2006

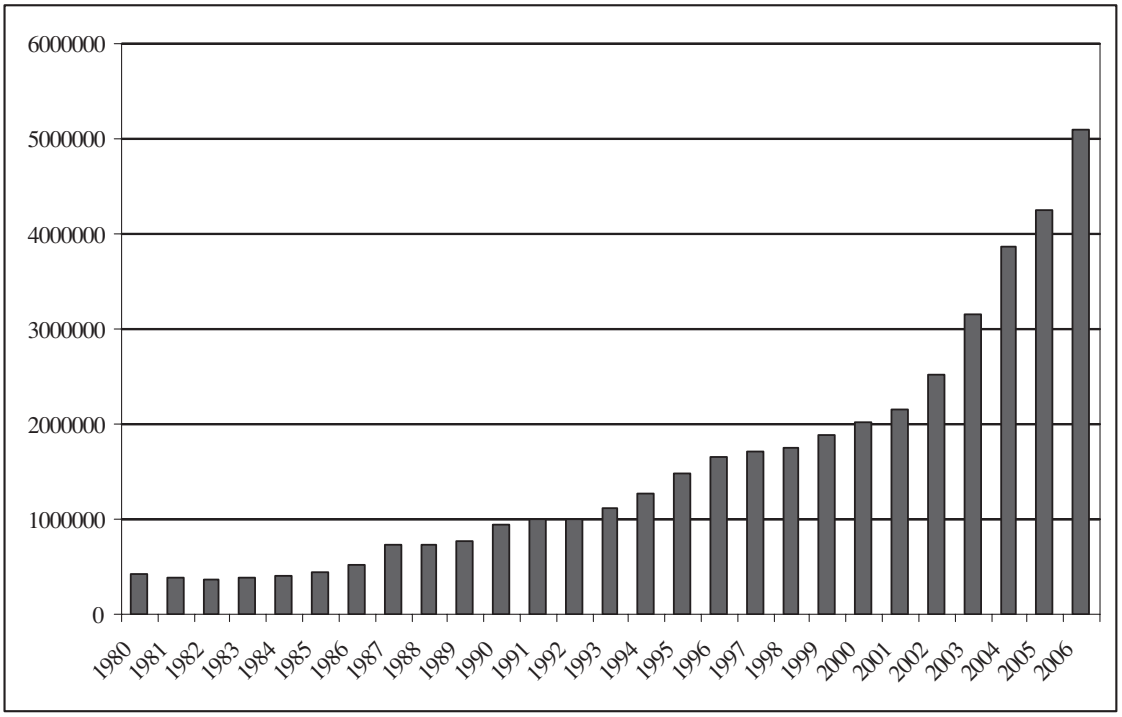
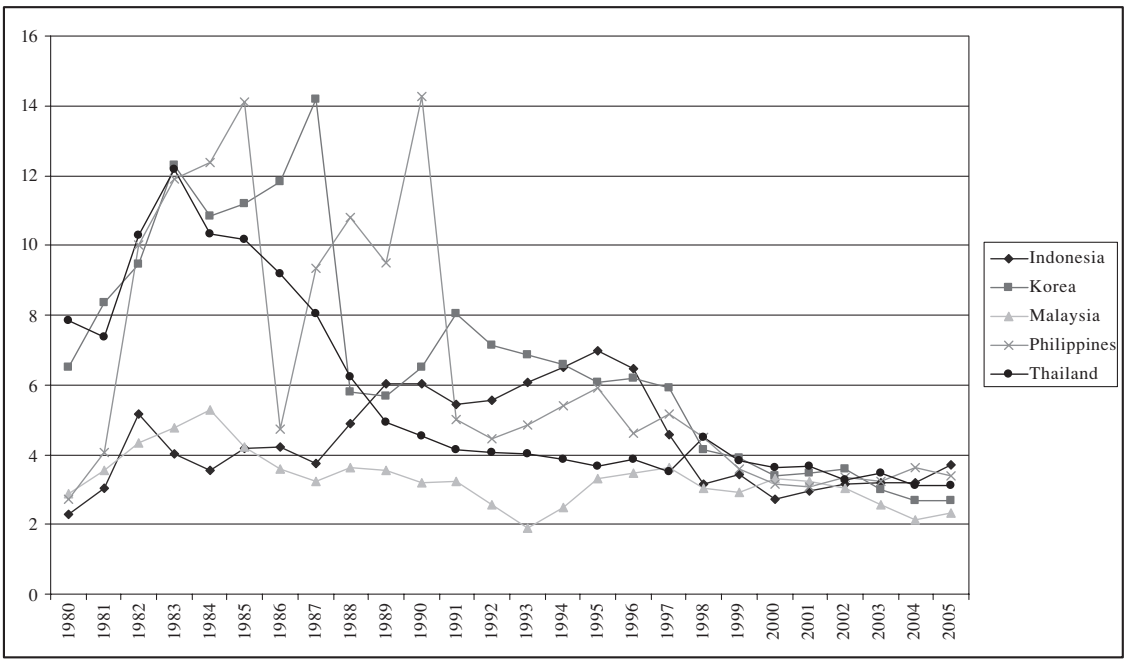
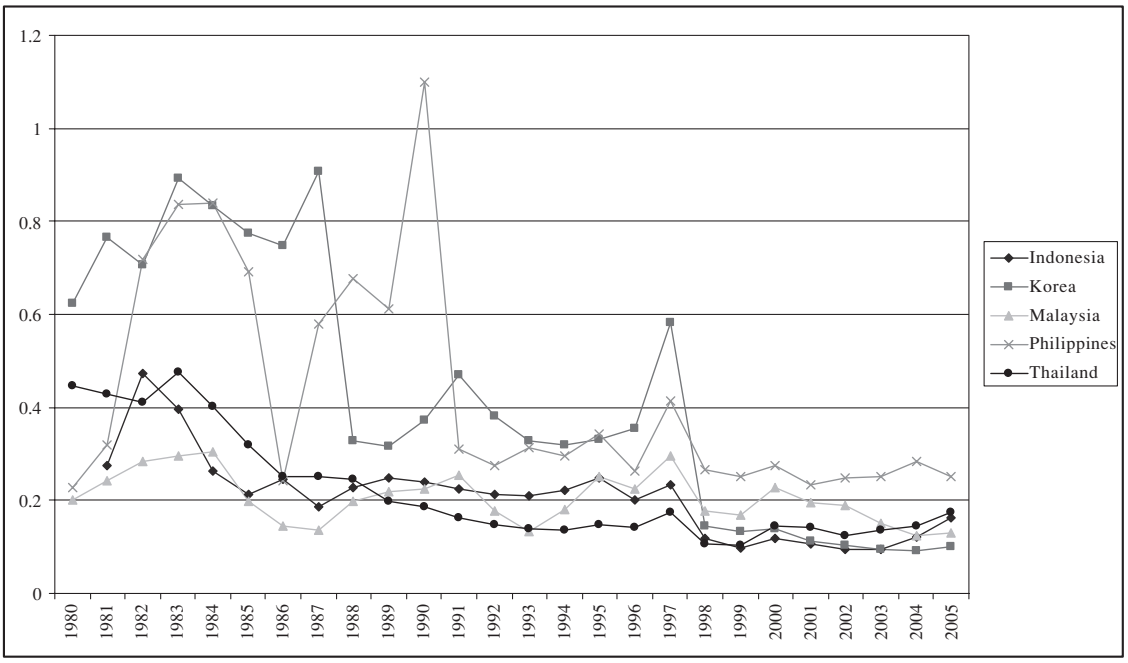


Figure 2.1 M2 to International Reserves Ratio for Selected Asian Economies



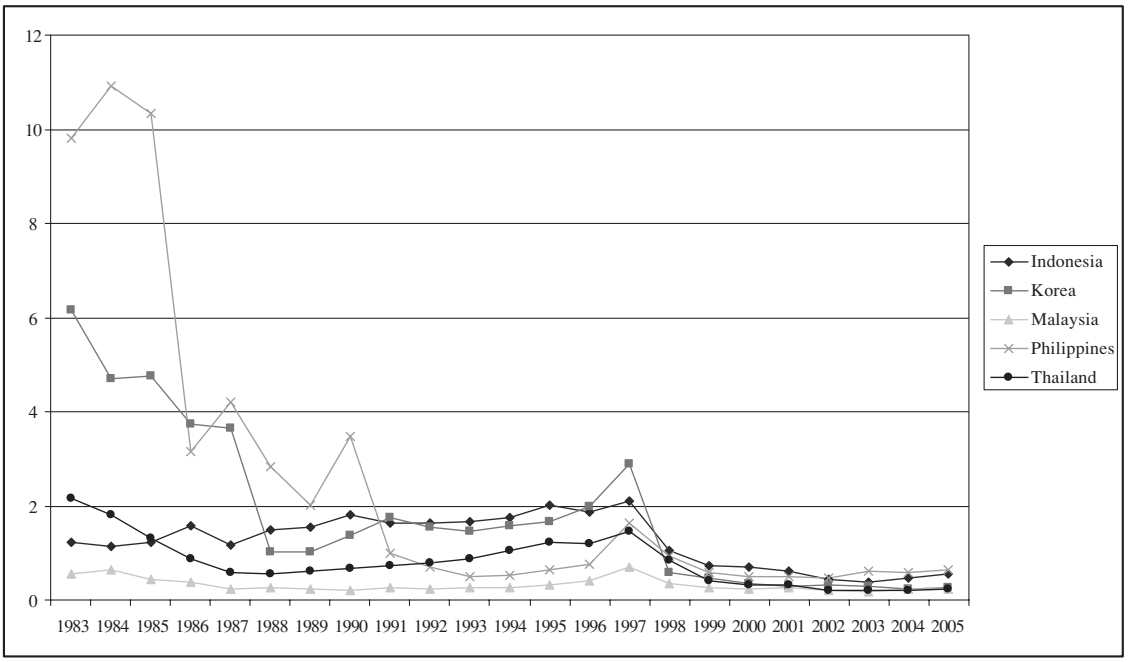
Source: International Financial Statistics

Figure 2.2 Imports to International Reserves Ratio for Selected Asian Economies



Source: International Financial Statistics

Figure 2.3 Short-Term External Debts to Reserves Ratio for Selected Asian Economies



Source: International Financial Statistics, Bank for International Settlements

Figure 3.1 Devaluation Probabilities (Indonesia)

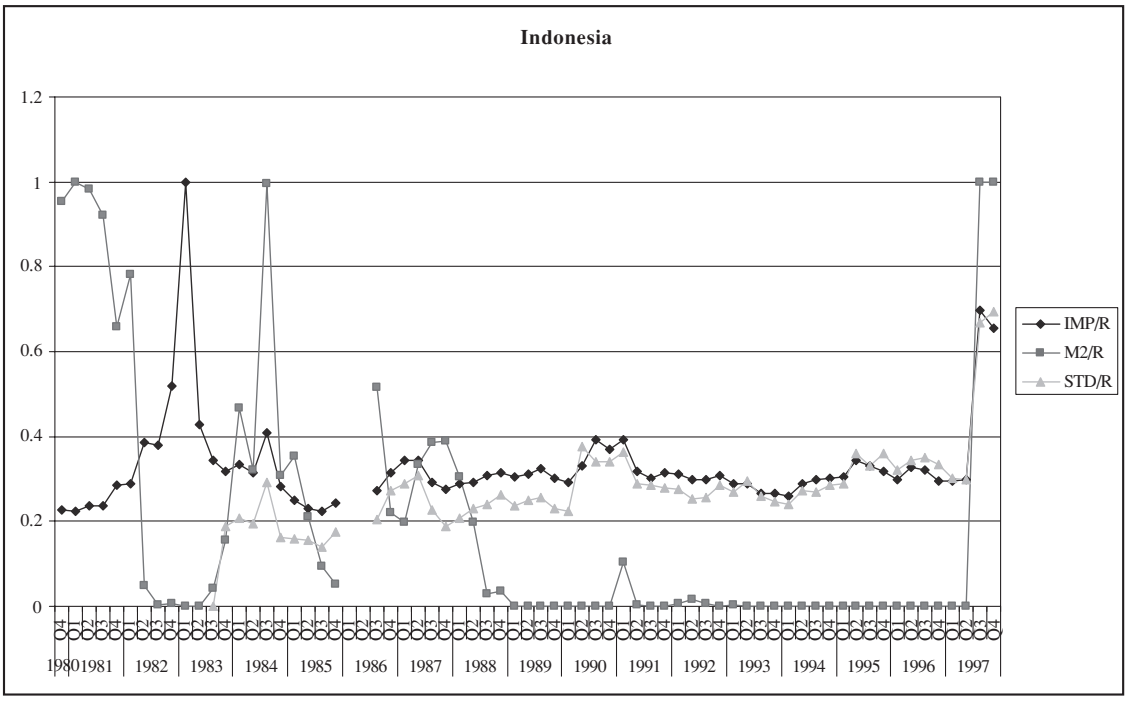


Figure 3.2 Devaluation Probabilities (Malaysia)

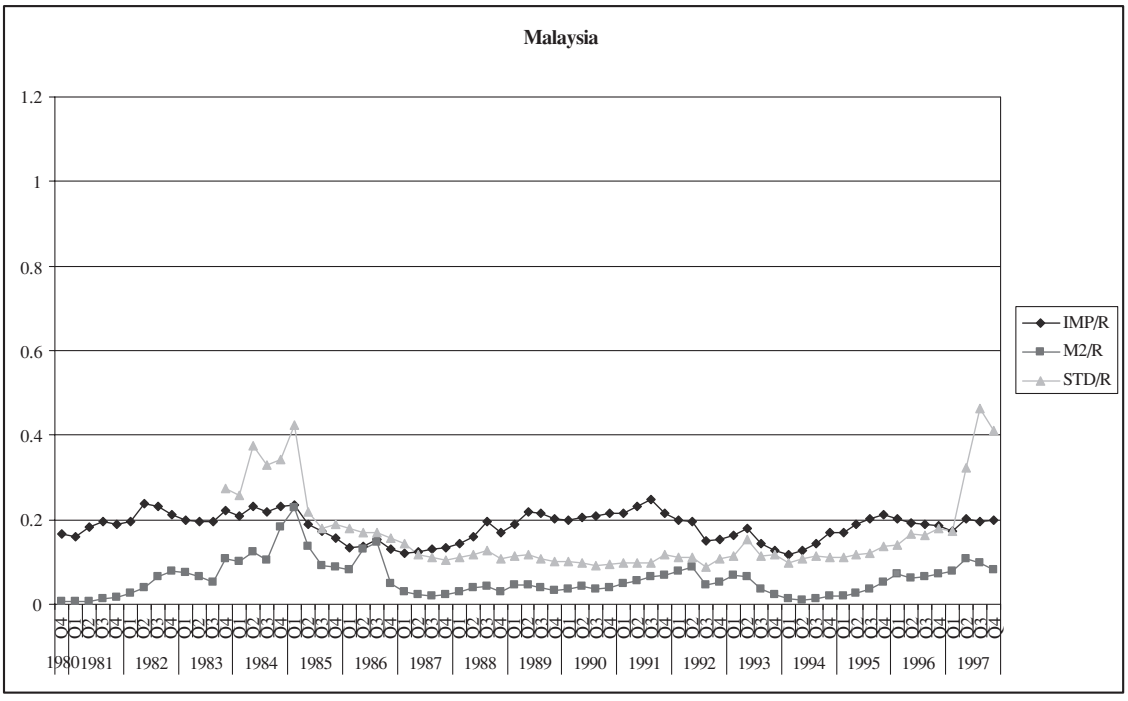


Figure 3.3 Devaluation Probabilities (Philippines)

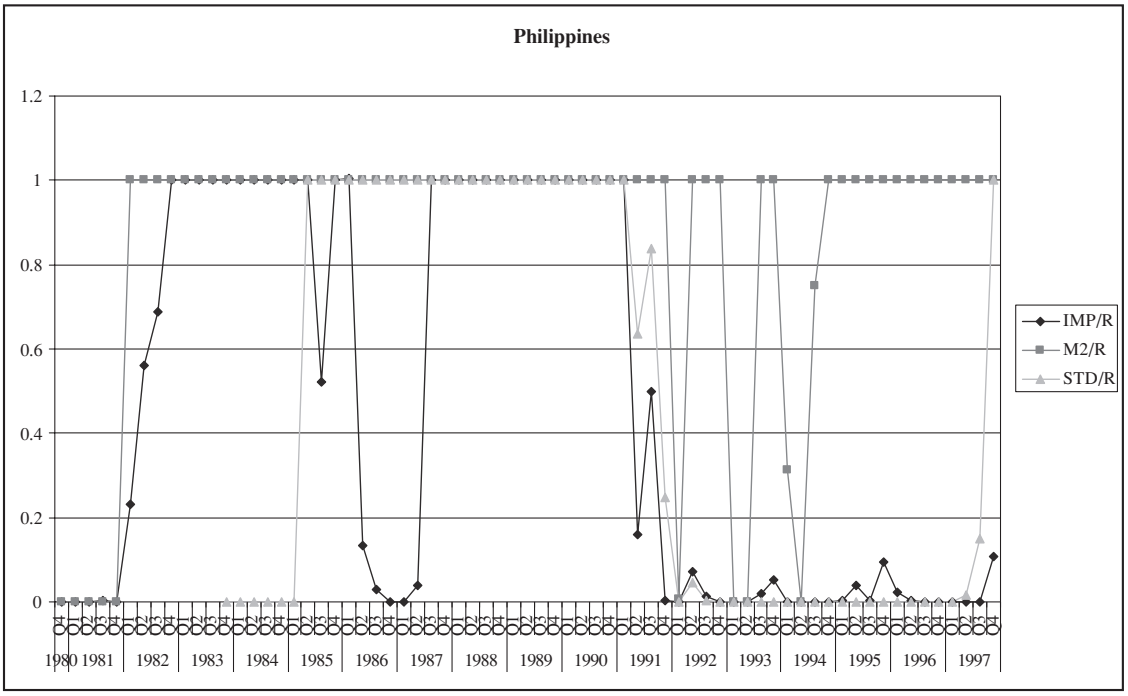


Figure 3.4 Devaluation Probabilities (Thailand)

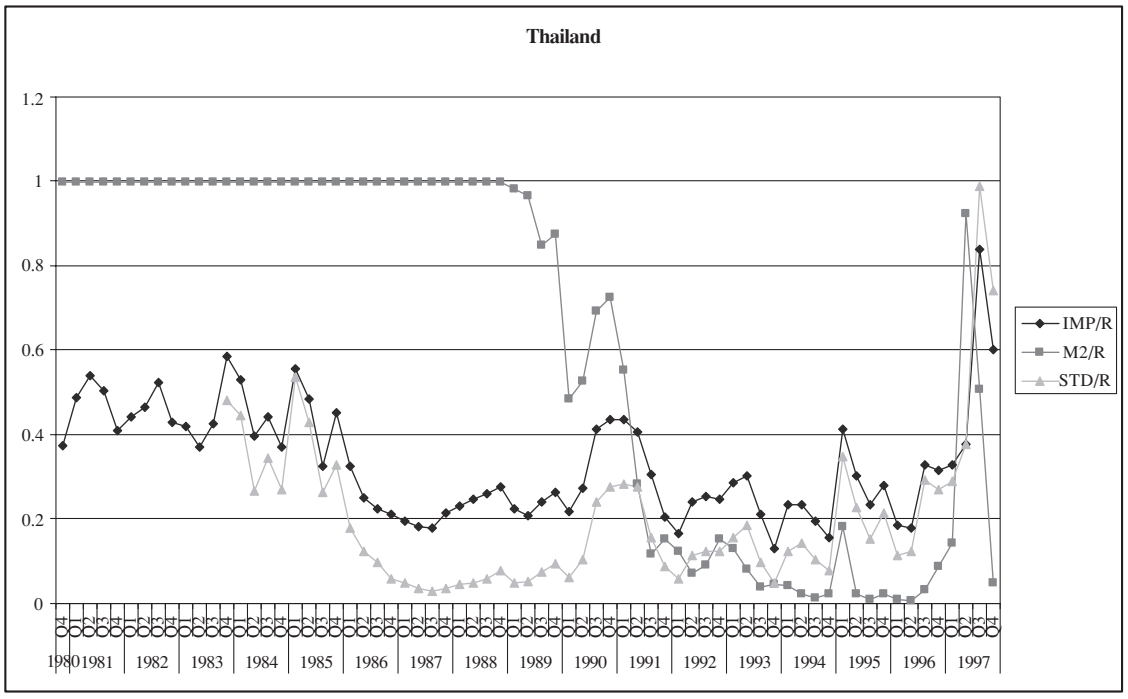


Figure 3.5 Devaluation Probabilities (Korea)