A Measure of Optimal Foreign Currency Reserves Holdings of the Bank of Jamaica

Kamara Gibson[1,*], Brian Langrin[2] and Jide Lewis[2]

[1]Tax Policy Unit
Ministry of Finance, Kingston, Jamaica

[2] Bank of Jamaica, Kingston Jamaica

July 2005

Abstract

This study aims to compute the optimal level of foreign currency reserve holdings of the Bank of Jamaica. A logit model consisting of panel data for the Caribbean and Latin America countries was used to calculate the probability of a crisis. Results indicate that a lower reserve to short-term debt ratio is significant in reducing the probability of a currency crisis. The probability estimate was then utilized in calculating the level of optimal reserves. A cost-benefit approach was taken, where the monetary authorities minimize a loss function subject to a wealth constraint. Based on the estimates derived, it can be concluded that the Bank of Jamaica is holding less reserves than is necessary to curtail a currency crisis with an assumed cost of 40.0 per cent of GDP.

* Corresponding author: Kamara Gibson, Tax Policy Unit, Ministry of Finance, Kingston, Jamaica. E-mail: kamaragibson@gmail.com.

1. Introduction

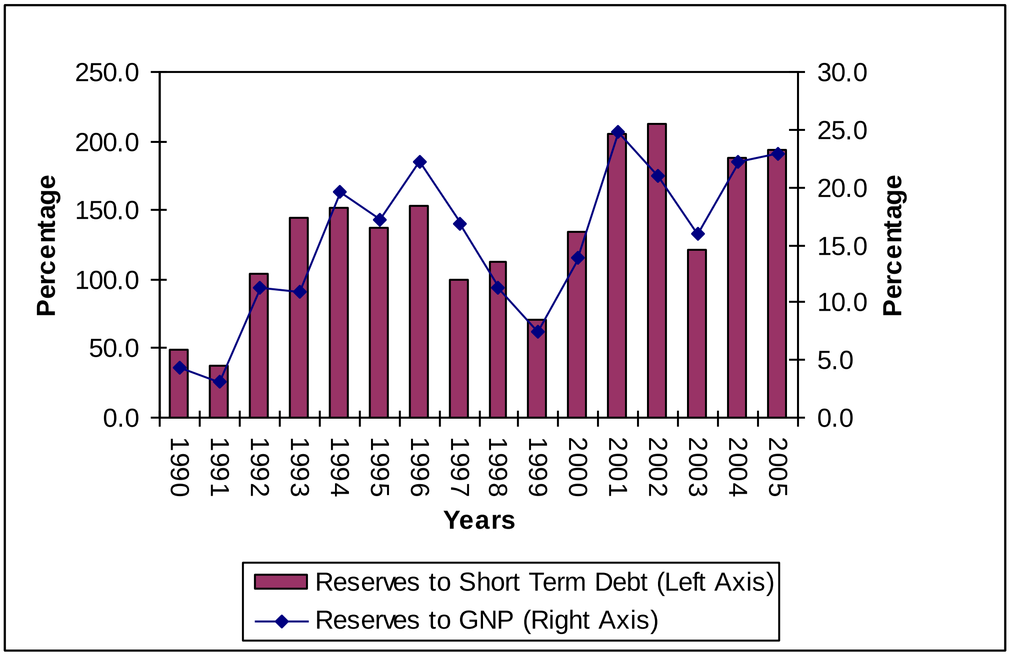
Early currency crisis literature has stressed the import role of foreign currency reserves in maintaining stability in the foreign exchange market and stimulating investor confidence. This literature has emphasized the importance of foreign currency reserve accumulation by the central bank as a mechanism to reduce the incidence of a crisis. Bussiere and Mulder (1999) concluded that reserve holdings should be adjusted according to a one-to-one ratio with the level of short-term debt in order to avoid a contagion related crisis.[1] Early warning Systems (EWS) of currency crises have also received significant attention in the currency crisis literature. The objective of EWS of currency crises is to predict whether a crisis will occur within a specific time period in the future. This allows policy makers to preempt the impact of underlying economic weaknesses and vulnerabilities on the foreign currency market.

Since the period of financial distress in the 1990s, the monetary authorities in Jamaica adopted stringent measures to maintain a tight-hold on the foreign exchange market. This has been achieved for the most part, although bouts of instability associated with a thin foreign exchange market continue to pose a serious challenge to policy makers. The misalignment in foreign currency flows relative to foreign currency demand have made the exchange rate susceptible to speculative attacks, particularly given the exposure of the economy to external shocks. The Bank has, in response, increased reserve holdings in an attempt to safeguard the value of the domestic currency. Since the end of the financial crisis episode in 1999, international reserves as a ratio to debt and GNP[2] have increased, with the exception of 2003 when significant pressures disrupted stability in the foreign currency market. As shown in Figure 1 reserves as a percentage of GNP fell to 16.0 per cent in 2003 from 25.0 per cent in 2001. Reserves to short term debt fell to 121.0 per cent in 2003 from 205.0 per cent in 2001. However, since 2003 the Bank was able to increase net international reserves in the context of strong foreign exchange flows.

[1] Contagion refers to the tendency of an economic crisis to spread from one market to another. For instance in 1997, political instability in Indonesia caused high volatility in their domestic currency, the Rupiah. The contagion then spread to other Asian emerging currencies and then to Latin America. This contagion episode is commonly referred to as the 'Asian Contagion' or the 'Asian Flu.'

[2] Due to data availability, GNP was used instead of GDP.

Figure 1: Reserves in Jamaica



Why is it necessary to ascertain a measure of the optimal level of reserves? Reserves matter because they are a key determinant of a country's ability to avoid a currency crisis. However due to the opportunity cost associated with hoarding reserves it is necessary to calculate that level which is considered as being optimal. Hence calculation of the optimal level of reserves is a critical policy instrument for the Bank of Jamaica and the central focus of this paper.

Foreign reserve holdings can be likened to insurance coverage. The cost of holding such reserves therefore can be considered as insurance premium. In this context, the Bank must determine the amount of insurance that the country should have, subject to the requisite cost of having coverage. The adequate level of reserves in its simplest form, is the level of reserves that the public and international investors believe to be sufficient at any given point. For the Central Bank, the adequate level of reserve holdings is dependent on the country's ability to purchase imports, cover short term (and long-term) debt and curtail capital flight.

This paper applies a widely used empirical methodology in establishing the optimal level of reserves holdings of the Bank of Jamaica. This study employs the methodology that was applied by Garcia and Soto (2004). This methodology involves constructing a weighted average of the first differences in real exchange rate and the level of reserves to determine the optimal level of reserves. In this study, changes in the interest rate are included in the calculation of an exchange market pressure (EMP) index . The framework will offer guidance to policy makers in determining the optimal level of reserves.

The remainder of the paper is organized as follows. The proceeding section gives a brief outline of related literature on early warning systems as well as other methods of deriving optimal reserves. Section 3 formally develops the methodology employed in this study, while section 4 gives a detailed description of the dataset. Section 5 presents the results and section 6 gives the conclusion and policy implications.

2. Literature Review

Empirical studies reveal that accumulation of international reserves has a significant impact on the advent of financial crises of countries. Kaminsky, Lizondo and Reinhart (1997) employed a "signals" approach in designing a currency crisis EWS which showed that gross international reserves is a significant variable in signaling a financial crisis. Other studies such as Garcia and Soto (2004), Berg and Pattillo (1999) and Bussiere and Mulder (1999) also pointed to the importance of reserves in anticipating crises in the economy. Bussiere and Fratzcher (2002) highlighted that a shortfall of previous empirical work was that no adjustment was made for the "post-crisis bias". This bias arises if models fail to distinguish between tranquil periods when economic fundamentals are largely sound and sustainable post-crisis/recovery periods, when economic variables go through an adjustment process before reaching a more sustainable level of growth path. To eliminate this bias, they applied a multinomial logit model, which examined the behaviour of a set of indicators before, during and after a crisis. Their study of 32 emerging market economies showed that an increase in the short-term debt to reserve ratio increases the probability of a crisis by almost one unit.

Frankel and Rose (1996) define a currency crash as a depreciation of the nominal exchange rate of at least 25.0 per cent yearly that is also at least a 10.0 per cent increase in the rate of nominal depreciation. This criterion ensures that each depreciation is not registered as an independent crisis episode. Their methodology yielded 117 different crashes[4], which were spread over 105 countries, including Jamaica.[5] Crashes that occurred within three years of each other are excluded to prevent double counting. Their results point to the importance of FDI, reserves, domestic credit growth, interest rates and real exchange rate in explaining the advent of a currency crash.

Garcia and Soto (2004) calculated an exchange market pressure (EMP) index to detect crisis episodes. The EMP index consisted of a weighted average of the first differences in real exchange rate and the level of reserves. A crisis episode was deemed to occur when the EMP index surpassed a computed threshold level. The index was then used as the dependent variable in a logit model to ascertain the probability of a crisis. The independent variables included reserves to short-term debt, total debt to GDP, as well as other relevant macroeconomic variables. Results showed that an increase in reserves to short-term debt ratio reduces the probability of a crisis. The estimate of the probability of a crisis along with the coefficients on the ratio variables was then used to determine the optimal reserves from a cost-benefit perspective. It is assumed that the authorities minimize a cost function subject to a wealth constraint. The first order condition for the minimization problem yielded a non-linear equation for the reserves to GDP ratio. A currency crisis existed if the EMP was two standard deviations or more above the country average EMP.

Frenkel and Jovanovic (1981) applied a buffer (inventory) model for Brazil, where the optimal level of international reserves depends on international transactions. They estimated a log equation using cross-sectional and annual time series data for developed countries over five years. The level of optimal reserves was modeled as a function of the standard deviation in reserves, the cost of reserves, and the cost of external debt finance.

Bassat and Gottlieb (1992) relied on a cost-benefit approach by using a simulation technique to calculate optimal reserves. They combined the standard approach to optimal reserves with a typical country-risk function relating default risk to macroeconomic variables such as the reserves to imports, the external debt to exports

[4] This study recorded 110 number of currency crashes.
[5] Frankel and Rose (1996) reported Jamaica as having a currency crisis in 1978, 1984 and 1991. In this study Jamaica was reported to have a crisis in 1978, 1983 and 1991.

ratio, per capita GNP and the cost of default. Rajan, Siregar and Bird (2003) used regression analysis in calculating optimal reserves. Deflated reserves was specified as a positive function of the population of the country, real per capita GDP, the volatility of real export receipts, the share of imports of goods and services in GDP and the volatility of the nominal effective exchange rate. The in-sample results were in line with apriori expectations while out-of-sample results reveal an under-prediction of reserves for most of the Asian countries.

Li and Rajan (2005) derived a sufficient condition to determine optimal reserves. The risk-averse central bank faces the problem of minimizing total costs of reserves. If the bank fails to hold reserves then it must face the cost of a crisis, while if it chooses to accumulate reserves there is a constant cost that is attached. The cost of the crisis is the expected loss in output between normal times and crisis. The minimization solution resulted in the optimality condition. It stated that a central bank will continue to hold reserves as long as the marginal benefits from doing so exceed the marginal costs. Their research show that if macroeconomic fundamentals are extremely weak, then reserves will not be an effective tool in preventing a crisis. Therefore an optimal reserve level would not exist. However, only if the fundamentals are not very weak can holding increasing amounts of reserves be effective in curbing a crisis.

3.1 EWS Methodology

Weak macroeconomic fundamentals in the economy could trigger a currency crisis. In this context, international reserves are used by policy makers to manage the monetary base and foreign currency liquidity. The probability of a crisis is a function of variables measuring liquidity and sovereign solvency along with other macroeconomic variables. Liquidity is measured by the reserve to short term debt ratio and solvency is captured in the debt to GNP ratio.

The probability of a crisis $p_{i,t}$ is defined as:

$$p_{i,t} = \beta_0 \frac{R_{i,t}}{S_{i,t}} + \beta_1 \frac{D_{i,t}}{Y_{i,t}} + Z_{i,t}\gamma - \varepsilon_{i,t} \qquad (1)$$

where

$p_{i,t}$ = probability of a crisis in country I and time t

$\beta_0, \beta_1, Z_{i,t}$ =coefficient estimates

R_{it}/S_{it} = reserve to short term debt

D_{it}/Y_{it} = debt to GNP

γ =

$\varepsilon_{i,t}$ = crisis shock

and the other macroeconomic variables are captured in the vector Z_{it}.

It is expected that the liquidity constraint should have a negative impact on the probability of the crisis. As a country holds more reserves in relation to its debt the probability of a crisis is reduced. However as the debt to GDP ratio increases this can deteriorate the capacity of the economy to meet financial obligations on time.

Other relevant macroeconomic variables are growth in exports, deviation of exchange rate from trend, external debt to GNP, growth in GNP and a dummy capturing the exchange rate regime. Growth in exports should have an inverse relationship with the probability of the crisis. As exports increase they result in an increase in foreign exchange, which will be used to meet any demand for the foreign currency on the market, thus reducing any pressure on the Jamaican Dollar. The debt indicator variables point to the government's ability to repay its debt. A sound economy, which consists of an external debt that is sustainable helps to boost confidence in the domestic currency thereby preventing a high demand for foreign currency.[6] The intuition behind the use of GNP growth in curtailing crisis is also related to consumer and investor confidence. Investors who manage portfolios with foreign denominated assets aim to maximize their

[6] Bassat and Gottlieb (1990) points out that an increase in net external debt may not necessarily increase optimal reserves due to the indirect effect it has on the probability of reserve depletion in the opposite direction. It is however logical to assume a positive relationship between optimal reserves and debt.

return on such portfolios. They therefore consider several factors when deciding in which currency they should place their assets. End-users also take macroeconomic conditions into consideration. An economy with little growth can be characterized by large imports and therefore has greater need for foreign currency. Through the same means increased economic growth would curtail a currency crisis as faster growth in exports reduces the current account deficit.

The exchange rate dummy equals one for the years in which the country has a fixed or managed exchange rate regime and zero otherwise. The expected sign for this variable is uncertain. A fixed exchange rate regime tends to remove the volatility experienced with a fixed exchange rate regime. However arguments have been put forward linking the benefits of a floating exchange rate regime in absorbing shocks or disruptions over time. The rate is therefore able to move towards its natural rate, allowing for a smooth transition of the value of the currency. Under a fixed exchange regime any shocks can result in large shifts since the rate cannot adjust.

The exchange market pressure (EMP) measure, which defines the dependent variable, has been used in several empirical studies as a measure of a crisis episode. It comprises of a weighted average of the rate of depreciation and changes in key policy variables such as interest rates and foreign reserves[7]. The weights are calculated as the inverse of the variance of each variable for all countries over the full sample. The weights are the relative precision of each variable so as to give larger weight to the variable with less volatility. [8] The EMP is defined as:

$$EMP_{i,t} = \omega_{RER}\left(\frac{RER_{i,t} - RER_{i,t-1}}{RER_{i,t-1}}\right) + \omega_r\left(r_{i,t} - r_{i,t-1}\right) - \omega_{FER}\left(\frac{FER_{i,t} - FER_{i,t-1}}{FER_{i,t-1}}\right) \quad (2)$$

where RER is the real exchange rate, r is the real interest rate and FER refers to foreign exchange reserves. Using real values for the exchange rate and interest rate is intended to account for differences in inflation rates across countries over the time horizon. The EMP measures the upward tendency in the demand for foreign exchange. If it is perceived that

[7] The inclusion of interest rates follows Bussiere and Fratzscher (1999). Gracia and Soto (2004) failed to include interest rates because they utilize a long time span. Since annual data was used incorporating interest rate movements would have decreased the data significantly. However, whether interest rates were included or not the number of signals derived in this study did not change.

[8] Weights were used since the variance is not constant.

weak macroeconomic fundamentals exist within the country, investors will seek to purchase foreign exchange therefore putting pressure on the domestic currency. The monetary authorities can respond by either allowing the market to absorb the shock or it can intervene and return the exchange rate to a desirable level by increasing interest rates or reducing their international reserves.

If the EMP surpasses a predetermined threshold value this signals a currency crisis. More specifically a currency crisis occurs if:

$$\left.\begin{array}{r} \mathrm{EMP}_{i,t} > \overline{\mathrm{EMP}_{\mathrm{i}}} + 2\mathrm{SD}(\mathrm{EMP}) \\ \textit{otherwise} \end{array}\right\} \begin{array}{l} y = 1 \\ y = 0 \end{array}$$

where a value of one corresponds to a currency crisis occurring, if for each country the calculated EMP exceeds the three-year average plus two standard deviations of the EMP.[9] A three-year rolling mean and standard deviation was used in this study.

The probability of a crisis that is derived from equation (1) corresponds to the probability of the dichotomous variable, Y, taking on a value of 1 in the event of a currency crisis and zero, otherwise.

$$\Pr(\mathrm{Y}_{\mathrm{i,t}} = 1) = F\left[\beta_0 \frac{\mathrm{R}_{\mathrm{i,t}}}{\mathrm{S}_{\mathrm{i,t}}} + \beta_1 \frac{\mathrm{D}_{\mathrm{i,t}}}{\mathrm{Y}_{\mathrm{i,t}}} + \mathrm{Z}_{\mathrm{i,t}}\gamma - \varepsilon_t\right]. \tag{4}$$

Empirically equation (4) has been modeled as a logistic function. By applying this particular distribution we define the logit model as:

$$p_{i,t} = \frac{\exp\left(\beta_0 \frac{\mathrm{R}_{\mathrm{i,t}}}{\mathrm{S}_{\mathrm{i,t}}} + \beta_1 \frac{\mathrm{D}_{\mathrm{i,t}}}{\mathrm{Y}_{\mathrm{i,t}}} + \mathrm{Z}_{\mathrm{i,t}}\gamma - \varepsilon\right)}{1 + \exp\left(\beta_0 \frac{\mathrm{R}_{\mathrm{i,t}}}{\mathrm{S}_{\mathrm{i,t}}} + \beta_1 \frac{\mathrm{D}_{\mathrm{i,t}}}{\mathrm{Y}_{\mathrm{i,t}}} + \mathrm{Z}_{\mathrm{i,t}}\gamma - \varepsilon\right)} \tag{5}$$

[9] It may be difficult to always accurately identify the occurrence of a currency crisis since the Central Bank may have intervened in the market and was successful in curtailing the crisis. In addition it may be hard to differentiate between normal instability in the foreign exchange market and conditions that warrant signaling a crisis.

This probability of a crisis is then used in the determination of optimal reserves discussed below.

3.2 Optimal Reserves

It is assumed that policy makers try to minimize losses that can occur subject to a wealth constraint. It is also assumed that if a crisis occurs then losses would increase in terms of GNP. The authorities can safeguard against the occurrence of such a crisis by holding sufficient reserves. However policy makers must face the insurance cost of holding the international reserves. The loss function can be thought of as a weighted cost function where the cost of a crisis is multiplied by its probability and the total cost of holding reserves is associated with the probability of not having a crisis. This function is shown below:

$$\mathrm{L} = \mathrm{p_t} C_t + (1 - \mathrm{p_t})\, \phi\, \mathrm{R_t} \tag{6}$$

where p_t refers to the probability of a crisis that is attained by estimating equation (5), C_t is the cost of the crisis, ϕ is the unit cost or reserves and R_t is the level of reserves. The cost of a crisis is the difference of the output levels between normal time and crises. This study employs Edwards (1985) measure of calculating the opportunity cost of reserves for a borrowing country as the spread between the interest rates on the debt and the reserves. The loss function in (6) is minimized with respect to the following wealth constraint:

$$\mathrm{K_t} - \mathrm{W_t} + \mathrm{R_t} = \mathrm{D_t} \tag{7}$$

where K_t is the capital stock of the economy, W_t refers to total wealth and D_t is total debt which consists of both short-term and long-term debt. Therefore the policy maker's problem may be formulated as follows:

$$\text{Min } \mathrm{L} = \mathrm{p_t} C_t + (1 - \mathrm{p_t})\, \phi\, \mathrm{R_t}$$

$$s.t. \;\; K_t - \mathrm{W_t} + R_t = \mathrm{D_t}$$

The first order condition for equation (6) is:

$$\frac{\partial p_t}{\partial R_t} C_t + p_t \frac{\partial C_t}{\partial R_t} + (1 - p_t)\phi - \frac{\partial p_t}{\partial R_t} \phi R_t = 0, \tag{8}$$

where $\frac{\partial p_t}{\partial R_t} = (1 - p_t) p_t \left(\beta_0 \frac{1}{S_t} + \beta_1 \frac{1}{Y_t} \right)$.

By combining the previous two expressions the following non-linear equation in R_t is obtained:[10]

$$0 = (1 - p_t) pt \left(\beta_0 \left(\frac{S_t}{Y_t} \right)^{-1} + \beta_1 \right) \left(\frac{C_t}{Y_t} - \phi \frac{R_t}{Y_t} \right) + p_t \eta \left(\frac{S_t}{Y_t} \right)^{-1} + (1 - p_t)\phi \tag{9}$$

where $\eta = \partial C / \partial (R_t / S_t)$ corresponds to the change in the cost of a crisis associated with a change in the reserves to short-term debt. If there is an increase in the cost of a crisis or a reduction in the cost of reserves then optimal reserve should rise. A currency crisis typically follows a banking crisis.[15] The estimate of the 1996-1998 financial crisis in Jamaica of 40.0 per cent of GDP was used as the upper limit for the ratio of cost of a crisis to GNP.

4. Data

The variables used in this study to calculate the EMP index were real reserves, real interest rate and real exchange rate. Nominal reserves were divided by the consumer prices for the respective years in order to attain the real reserves. Data was attained from Global Development Finance (2000 and 2005) on CD-ROM. The interest rate and exchange rate were attained from the IFS CD-ROM. The deposit interest rate is used as a proxy in the analysis due to the unavailability of a complete time series data set for Treasury bill yields. Before deciding on the use of this proxy however graphical techniques were used to ensure that all the rates followed a similar trend. Due to the presence of varying exchange rate regimes in the respective countries, the market, official and principal exchange rates were included in the dataset. Market rates describe an

---

[10] For derivation of first order condition see Appendix 4

[15] See, for example, Kaminsky, Lizondo and Reinhart (1998).

exchange rate determined by market forces, while the authorities set the official rate. Principal rates apply to countries that maintain multiple exchange arrangements.

In running the logit model the following independent variables were used: reserve to short term debt ratio, long term external debt to GNP, real exchange rate, real growth in exports and GNP growth. These additional variables were also attained from the Global Development Finance CD-ROM. Short-term debt refers to debt that has an original maturity of one year or less, while long-term debt has an original extended maturity of more than one year. Calculation of the export variable included income and worker remittances received. All the variables used in this study were end of period values.

5 Implicit Cost of Reserve Holdings

An alternative way of evaluating reserve adequacy consists of determining the implicit cost of a crisis. That is the level of insurance being procured by holding a given level of international reserves. This was derived by solving equation (9) for the cost of a crisis as a per cent of GNP (see Table 1). The composite interest rate spread of the US and Euro was used to measure the opportunity cost of holding reserves. The assumption is made that η = -0.0025 which is the change in the cost of a crisis associated with a change in the reserves and is the value estimated by De Gregorio and Lee (2004). The equation estimated is as follows[13]

$$\frac{C_t}{Y_t} = \frac{-p_t \eta \left(\frac{S_t}{Y_t}\right)^{-1} - (1-p_t)\phi}{(1-p_t)p_t\left(\beta_0\left(\frac{S_t}{Y_t}\right)^{-1} + \beta_1\right)} + \phi\frac{R_t}{Y_t} \tag{10}$$

[13]For algebraic manipulation see Appendix 4

Table1: Implicit Cost of a Crisis and Crisis Probability

Year	Actual Reserves US $mn	Actual Reserves per cent GNP	Cost of Reserve (b.p.)	Crisis Probability per cent	Short Term Debt per cent of GNP	Implicit Cost per cent GNP
2000	1054.0	13.8	639.3	11.6	10.3	84.0
2001	1901.0	24.8	537.5	11.3	12.1	68.0
2002	1645.0	21.0	512.3	11.2	9.9	73.0
2003	1195.0	15.9	499.8	11.6	13.0	58.0
2004	1846.0	22.3	299.1	9.6	11.3	40.0
Mar-05	1902.0	22.8	235.5	9.6	11.3	32.0

. Despite reductions in reserve holdings and the implicit cost of a crisis in 2003, the cost of reserves along with the probability of the crisis increased. This was due to the increase in short-term debt for the period. From this period onward, however, the crisis cost along with the probability of a crisis has declined, which speaks to the improvement in macro-economic fundamentals. The cost of a crisis that would justify the amount of reserves held was estimated at approximately 40.0 per cent of GNP for 2004 and 32.0 per cent of GNP for March of 2005. The results highlight the sensitivity of the cost to the level of short-term debt and reserves in the economy.

5.1 Results of the Probability of a Crisis

Table 2 (in Appendix 1) displays the results from estimating various specifications of the probability of crisis equation. The results from the logit model highlight the importance of increasing export growth and keeping sufficient reserves relative to short-term debt in reducing the probability of a crisis. It should be noted however that although the magnitudes are statistically significant they are not large. Table 2 in the Appendix shows that reserves to short-term debt is statistically significant. An increase in the debt to GNP ratio was expected *a priori* to increases the probability of a currency crisis in the economy. However, total debt as a per cent of GNP was not statistically significant in any of the regressions. Export growth was found to be a statistically significant indicator of a currency crisis and the sign on its coefficient was consistent with *apriori* expectations. Economic growth and the exchange rate regime variables were not statistically significant.

5.2 Optimal Reserves

As shown in Table 3, over the period 2000 to 2003, reserves were both above and below its optimal level.[15] Based on these results, the actual amount of reserves held by the Bank during 2004 of 22.0 per cent of GNP was close to the optimal target of 23.0 per cent of GNP. For March 2005, reserve holdings should have been US$323 000.0 more when compared to the optimal level.

Table 3: Actual and Optimal Reserves. Crisis is 40% of GNP

	PER CENTAGE OF GNP		US$MN		PER CENTAGE	
Year	Actual	Optimal	Actual	Optimal	Growth rate of Actual Reserve	Growth rate of Optimal Reserve
2000	14	18	1,054	1,378	90	3
2001	25	19	1,901	1,428	80	4
2002	21	20	1,645	1,582	-13	11
2003	16	18	1,195	1,387	-27	-12
2004	22	23	1,859	1,953	56	41
Mar-05	23	27	1,902	2,225	2	14

The deviation of reserves from its optimal level was large for the 2000 to 2001 periods but has been narrowing due to the changes in the growth rates. The growth rates of optimal reserves suggest that for 2005 there should be a slower growth rate of reserves.

Estimates of the optimal level of reserves were also conducted for lower possible crisis costs: 10.0 per cent GNP, 20.0 per cent GNP and 30.0 per cent of GNP[16]. Figure 2 shows for 2004, as the cost of the crisis increases from 10.0 per cent to 30.0 per cent, the actual level of reserves is above the optimal level. Only when the crisis cost is 40.0 per cent of GNP is the actual holdings of international reserves below the optimal amount.

[15] Bassat and Gottlieb (1999) concluded that Malaysia, Thailand and Korea were not holding reserves above their optimal level as at 2003. However Chile had actual reserves above the optimal level. The crisis costs used were 5%GDP, 10%GDP and 15% GDP.

[16] The IMF (1998) reported the average cost of a currency crisis, a currency crash, and a banking crisis in emerging markets as 7.6 percent of GDP, 10.7 percent of GDP, and 14 percent of GDP. This was calculated by taking the differences between trend growth and output growth after the crisis occurred.

Figure 3: Actual and Optimal Reserves at varying cost of crisis at 2004

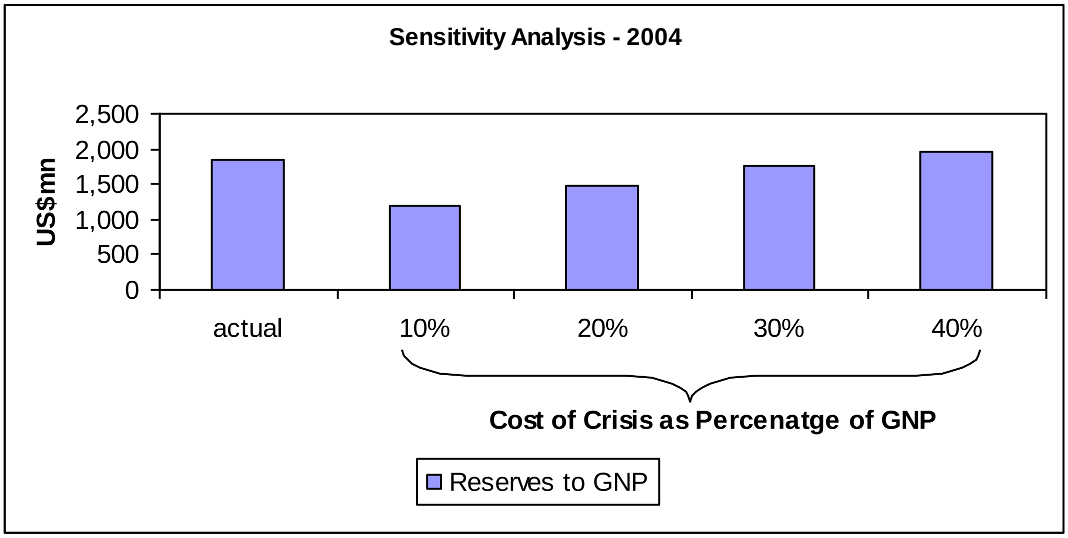
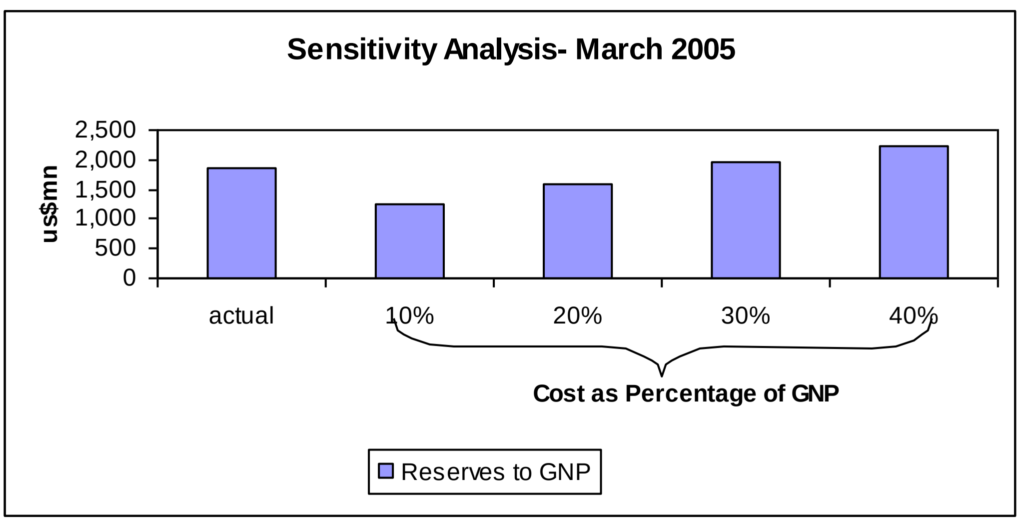


Figure 3 shows a slightly different analysis for the March 2005 period. Above a crisis cost of 20.0 per cent of GNP, the actual level of reserves is less than optimal. Overall, the actual holdings of reserves have been closer to the Bank holding insurance coverage against a 30.0 per cent cost of a crisis.

Figure 3: Actual and Optimal Reserves at varying cost of crisis at 2005



6. Conclusion

The results justify recent increases in reserve holdings by the Central Bank in the context of protecting the foreign exchange market against speculative attacks. A sufficient level of reserves engenders investor confidence since it is an indicator of the county's ability to repay its debt. On the other hand, accumulation of large amounts of international reserves above the optimal level can be counterproductive due to the high associated insurance costs. The results show that a 1.0 per cent increase in the holding of international reserves reduces the probability of a crisis by 0.04 points. Although reserves are important in controlling a crisis it is necessary to find the optimal level that will prevent the occurrence of a crisis. This study underscores the importance for the Bank to monitor its accumulation of foreign currency reserves against the optimal computed reserves for a given crisis cost. This was done using a cost benefit analysis. The results for March 2005 show that more reserves should be held by the Central Bank in protecting the economy against a crisis, assuming a crisis cost of above 30.0 per cent of GNP.

Policy makers can use certain levers to affect the level of optimal reserves. Reserves can be built up by borrowing funds on the international market. However, increasing the short-term debt for a given level of reserves will actually increase the probability of a currency crisis. Policy makers can also reduce the level of optimal reserves by reducing the cost of a crisis through the proper regulation and supervision of the financial system. Banks should hold enough foreign exchange assets so as to back their liabilities. In so doing they will be better able to hedge their foreign exchange positions in the event of a speculative attack. An increase in the probability of a crisis will necessitate an increase in reserve holdings but as the analysis has shown, reducing short-term debt and increasing exports and total external debt can reduce this probability, ceteris paribus. In this light the economy should continue to foster growth in foreign exchange earning sectors of the economy along with a consistent reduction in short-term debt holdings.

Bibliography

Berg, Andrew and Catherine Patillo (1999b). "Predicting Currency Crises: The Indicators Approach and an Alternative," *Journal of International Money and Finance; 18(4), August 1999, pp. 561-86.*

Bussiere, Matthieu and C. Mulder (1999). "External Vulnerability in Emerging Market Economies: How High Liquidity Can Offset Weak Fundamentals and the Effect of Contagion." *IMF Working Paper* 99/88.

Bussiere, Matthieu and Marcel Fratzscher (2002). "Towards a New Early Warning System of Financial Crises." *European Central Bank Working Paper,* No. 145 May 2002.

De Gregio, J. and J. Lee (2003). "Growth and Adjustment in East Asia and Latin America", *Central Bank of Chile Working Papers* 245.

Edwards. S. (1985). "On the interest-rate elasticity of the demand fro international reserves: Some evidence from developing countries", *Journal of International Money and Finanace*, 4, pp287-295.

Frankel, J. and Andrew Rose (1996). "Curreny Crashes in Emerging Markets: An Empirical Treatment", *International Finance Discussion Papers*. No.534.

Frenkel, J. and B. Jovanovic (1981). "Optimal International Reserves: A Stochastic Framework", *Economic Journal*, 91, pp.507-41.

Garcia, Pablo and Claudio Soto, 2004, "Large Hoardings of International Reserves: Are They Worth It?" *Central Bank of Chile Working Papers* No. 299.

IMF (1998). "Financial Crises: Causes and indicators", *World Economic Outlook*, May.

Kaminsky, Graciela L., Saul Lizondo and Carmen M. Reinhart (1998). "Leading Indicators of Currency Crises," *IMF Staff Papers*, 45, No. 1, pp. 1-48.

Reinhart, C. M. and Kenneth Rogoff (2002). "The Modern History of Exchange Rate Arrangements: A Reinterpretation", *NBER working Paper* 8963.

Appendix 1

Table 2: Estimation of Crisis Probability

	(1)	(6)	(3)	(5)	(7)
EX MIS	-0.007	-0.009	-0.007	-0.009	-0.009
	(-1.628)	(-1.835)*	(-1.632)	(-1.837)*	(-1.854)*
RES/STD	-0.043	-0.037	-0.043	-0.044	-0.044
	(-1.66)*	(-1.464)	(-1.657)*	(-1.663)*	(-1.665)*
TD/GNP	0.038		0.039	0.018	0.021
	(0.393)		-0.403	(-0.177)	(0.208)
RES/TD		-0.277			
		(0.819)			
GNP GROWTH			0.033		0.096
			-0.155		(0.511)
EXPORTS		-1.645		-1.647	-1.665
		(-3.654)**		(-3.664)**	(-3.689)**
FIXED	-0.158	0.144	-0.157	0.107	0.117
	(-0.489)	(0.418)	(-0.484)	(0.311)	(0.339)
MANAGED	-0.020	0.107	-0.019	0.093	0.101
	(-0.064)	(0.335)	(-0.061)	(0.292)	(0.315)
Constant	-1.833	-2.024	-1.838	-2.078	-2.098
	(-6.524)**	(-6.745)**	(-6.492)**	(-6.847)**	(-6.824)**
Observations	925	925	925	925	925
McFadden R2	0.02	0.04	0.01	0.04	0.04
N Crisis	110	110	110	110	110

*significant at 10%; **significant at 1%

Value of z statistics in parenthesis.

Appendix 2: Variable Definition

EX MIS	2^{nd} lag of real exchange rate deviation from Hodrick- Prescott tendency
RES/STD	Real Reserves to Real Short Term Debt
RES/TD	Real reserves to Real Total Debt
TD/GNP	Real Total Debt to Real GNP
GNP	Real GNP growth
EXPORTS	Real exports growth
INTEREST	Real Interest Rate
Δ INTEREST	Change in Real Exchange rate from previous year
FIX	Corresponds to years of a Fixed Exchange Rate Regime
MANAGE	Corresponds to years of a Managed Exchange Rate Regime

Appendix 3: Logit Models

When there exists a binary dependent variable with continuous variables on the right hand side applying a logit model will provide a better framework. We have N countries $\mathrm{i}=\{1,2,\ldots\mathrm{N}\}$ that we observe during T periods $\mathrm{t}=\{1,2,\ldots T\}$. For each country and for each year observation is made on the binary dependent variable Y:

$$\mathrm{Y}_{\mathrm{i,t}} = \begin{cases} 1 & \text{with probability } \Pr(\mathrm{Y}=1)=\mathrm{P} \\ 0 & \text{with probability } \Pr(\mathrm{Y}=0)=1-\mathrm{P} \end{cases} \tag{1}$$

The crisis index Y is explained by a set of K independent variables X. Therefore X is a KN*T matrix of observations. The model is designed to estimate the effect of the indicators X on the probability P of experiencing a crisis. The vector of K marginal effects is denoted as γ:

$$\gamma = \frac{d\mathrm{P}}{d\mathrm{X}'} \tag{2}$$

In the logit model the probability of a crisis is a non-linear function of the indicators:

$$\Pr(Y=1) = F(X\beta) \tag{3}$$

Using a logistic distribution defines the logit model:

$$\Pr(Y=1) = F(X\beta) = \frac{e^{X\beta}}{1+e^{X\beta}} \tag{4}$$

Equation (4) can be manipulated to get the effect of the indicators on the odds as follows:

(5)

$$P = \frac{e^{X\beta}}{1+e^{X\beta}}$$

$$P\left(1+e^{X\beta}\right) = e^{X\beta}$$

$$P + Pe^{X\beta} = e^{X\beta}$$

$$P = e^{X\beta} - Pe^{X\beta}$$

$$P = \left(1-P\right)e^{X\beta}$$

$$\Omega(Y=1/X)=\frac{\mathrm{P}}{1-\mathrm{P}}=e^{X\beta}$$

The effect of the indicators on the odds ratio, given two realizations of X, e.g. X_1 and X_0 is:

$$\frac{\Omega(Y=1/X_1)}{\Omega(Y=1/X_0)}=e^{(X_1-X_2)\beta} \qquad (6)$$

The odds ratio shows how the odds of observing Y=1 change when X moves from X_1 to X_0.

Appendix 4: Algebra

1.1 Estimating Optimal Reserves

The authority:

$$\text{Min } \Gamma = \mathrm{p}_{\mathrm{t}} C_t + (1 - p_t)\,\phi\,\mathrm{R}_{\mathrm{t}} \tag{1}$$

$$\text{Subject to } \mathrm{K}_{\mathrm{t}} - W_t + R_t = D_t \tag{2}$$

Reserves not only affect the probability of a crisis but also the cost of a crisis.

$$p_{i,t} = \frac{\exp \beta_0 \frac{\mathrm{R}_{\mathrm{i,t}}}{\mathrm{S}_{\mathrm{i,t}}} + \beta_1 \frac{\mathrm{D}_{\mathrm{i,t}}}{\mathrm{Y}_{\mathrm{i,t}}} + \mathrm{Z}_{\mathrm{i,t}}\gamma - \varepsilon}{1 + \exp \beta_0 \frac{\mathrm{R}_{\mathrm{i,t}}}{\mathrm{S}_{\mathrm{i,t}}} + \beta_1 \frac{\mathrm{D}_{\mathrm{i,t}}}{\mathrm{Y}_{\mathrm{i,t}}} + \mathrm{Z}_{\mathrm{i,t}}\gamma - \varepsilon} \tag{3}$$

$$\frac{C_t}{Y_t} = C\left(\frac{R_t}{S_t}, \ldots\right) \tag{4}$$

The First Order Condition is:

$$\frac{\partial p_t}{\partial R_t} C_t + p_t \frac{\partial C_t}{\partial R_t} + (1 - p_t)\phi - \frac{\partial p_t}{\partial R_t}\phi\, R_t = 0, \tag{5}$$

Factoring out $\frac{\partial p_t}{\partial R_t}$ gives:

$$\frac{\partial \mathrm{p}_{\mathrm{t}}}{\partial \mathrm{R}_{\mathrm{t}}}\left(\frac{C_t}{Y_t} - \partial R_t\right) + \mathrm{p}_{\mathrm{t}} \frac{\partial C_t}{\partial R_t} + (1 - \mathrm{p}_{\mathrm{t}})\phi \tag{6}$$

Where $\frac{\partial p_t}{\partial R_t}$ is given by:

$$\mathrm{p}_{\mathrm{t}} = e^f (1 + e^f)^{-1} \tag{7}$$

Where $f = \beta_0 \frac{R_{i,t}}{S_{i,t}} + \beta_1 \frac{D_{i,t}}{Y_{i,t}} + Z_{i,t}\gamma - \varepsilon$ (8)

$$\frac{\partial p_t}{\partial R_t} = e^f \cdot f \cdot \left(1+e^f\right)^{-1} - e^f \cdot \left(1+e^f\right)^{-2} \cdot f \tag{9}$$

$$\frac{\partial p_t}{\partial R_t} = \frac{e^f}{f\left(1+e^f\right)} \cdot f - \frac{e^f}{\left(1+e^f\right)^2} \cdot f \tag{10}$$

$$\frac{\partial p_t}{\partial R_t} = \left(p_t - p_t^{\,2}\right) \cdot f = (1-p_t)\, p_t \left(\beta_0 \frac{R_{i,t}}{S_{i,t}} + \beta_1 \frac{D_{i,t}}{Y_{i,t}}\right) \tag{11}$$

Substituting into equation (6) gives:

$$0 = (1-p_t)\,pt\left(\beta_0\left(\frac{S_t}{Y_t}\right)^{-1} + \beta_1\right)\left(\frac{C_t}{Y_t} - \phi\frac{R_t}{Y_t}\right) + p_t\eta\left(\frac{S_t}{Y_t}\right)^{-1} + (1-p_t)\phi \tag{12}$$

Solving explicitly for $\frac{R_t}{Y_t}$ gives :

$$\boldsymbol{\frac{R_t}{Y_t} = \frac{1}{\phi}\frac{C_t}{Y_t} + \frac{1}{\phi}\frac{p_t\eta\left(\frac{S_t}{Y_t}\right)^{-1} + (1-p_t)\phi}{(1-p_t)\,p_t\left(\beta_0\left(\frac{S_t}{Y_t}\right)^{-1} + \beta_1\right)}} \tag{13}$$

1.2 Implicit Cost of a Crisis

Equation (13) is manipulated and solved for $\frac{C_t}{Y_t}$

$$\boldsymbol{\frac{C_t}{Y_t} = \phi\frac{R_t}{Y_t} - \frac{p_t\eta\left(\frac{S_t}{Y_t}\right)^{-1} + (1-p_t)\phi}{(1-p_t)\,p_t\left(\beta_0\left(\frac{S_t}{Y_t}\right)^{-1} + \beta_1\right)}} \tag{14}$$

1.3 Optimal Short Term Debt to GNP ratio

From equation (6):

$$0 = (1-\mathrm{p}_t)\mathrm{p}_t\left(\beta_0\left(\frac{S_t}{Y_t}\right)^{-1} + \beta_1\right)\left(\frac{C_t}{Y_t} - \phi\frac{R_t}{Y_t}\right) + \mathrm{p}_t\eta\left(\frac{S_t}{Y_t}\right)^{-1} + (1-\mathrm{p}_t)\phi \qquad (15)$$

$$\frac{\mathbf{S_t}}{\mathbf{Y_t}} = \frac{-\left[(\mathbf{1}-\mathbf{p_t})\mathbf{p_t}\boldsymbol{\beta}_\mathbf{0}\left(\frac{\mathbf{C_t}}{\mathbf{Y_t}} - \boldsymbol{\varphi}\frac{\mathbf{R_t}}{\mathbf{Y_t}}\right) + \mathbf{p_t}\boldsymbol{\eta}\right]}{(\mathbf{1}-\mathbf{p_t})\boldsymbol{\varphi} - \left[(\mathbf{1}-\mathbf{p_t})\mathbf{p_t}\boldsymbol{\beta}_\mathbf{1}\left(\frac{\mathbf{C_t}}{\mathbf{Y_t}} - \boldsymbol{\varphi}\frac{\mathbf{R_t}}{\mathbf{Y_t}}\right)\right]} \qquad (16)$$