

A Theory of Currency Board with Irrevocable Commitments *

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Abstract

Currency boards are subject to runs if the foreign currency reserve is insufficient to back the convertible money supply. We construct a simple model and show how pre-specified optimal reserve commitments can avert currency board runs. If there exists asymmetric information on the government's resolve, the government can also use commitments as a costly signal to induce a separating equilibrium. The model can be adapted to analyze other hard-fixed exchange rate systems such as dollarizations and monetary unions. We illustrate the implications of our model in terms of the recent success in Hong Kong and possible remedies for Argentina.

1. Introduction

Recent financial crises beleaguering Argentina in 2001-04 and East Asia in 1997-98 have brought to focus issues related to the stability of fixed exchange rate policies. At the same time, however, the world's currency markets are gravitating towards an arrangement dominated by a few pivotal currencies upon which the other currencies can anchor with a formal or informal fixed exchange rate. This is a theme receiving significant attention in the recent academic literature [see, e.g., Miller (1998a, 1998b, 2000) and Mundell (2000)] and international economic forums¹.

A currency board is a specific fixed exchange rate arrangement whereby the monetary authority issues domestic currency whose value is linked to a reserve currency. It passively stands ready to exchange the linked reserve currency with the domestic currency at the official "hard-fixed" exchange rate in response to the requests of (foreign and domestic) currency holders. A currency board arrangement was adopted by Hong Kong to stabilize its currency in 1983 and by Argentina in 1991 to tame its runaway hyperinflation (about 5,000 percent in 1989 and 1,300 percent in 1990). It has also been adopted by emerging economies like Estonia, Lithuania and Bulgaria, and under considerations by others [see Hanke (2002a)]. The recent dollarization programs adopted by Panama, El Salvador and Ecuador are equivalent to (except for seigniorage) a perfectly run currency board. Furthermore, a monetary union can also be viewed as a variation of the same general concept of a "hard-fixed" exchange rate system.²

Almost all currency boards are successful, with one exception. Despite its initial success of bringing to Argentina one of the world's highest real growth rates in the period 1991-97 and fending off currency speculations against Argentina in 1995 during the Mexican peso crisis, the *modified* Argentine currency board collapsed in 2001-02. This is in contrast with the Hong Kong currency board which has always been successful in defending its currency, especially

¹ See, e.g., IMF Economic Forum "One World, One Currency: Destination or Delusion?" November 2000, discussion by Maurice Obstfeld, Paul Masson and Robert Mundell. (www.imf.org/external/np/tr/2000/TR001108.htm).

² Many of the same issues common to "hard-fixed" exchange rate systems, such as a currency board, a gold standard, a dollarization program or a monetary union, are discussed in the seminal paper by Mundell (1961) on optimal currency areas. These are collectively referred to as "currency board systems" (see footnote 1). See also a book on monetary integration by De Grauwe (1997). We would like to thank Juha Tarkka, chief economist at the Bank of Finland, for in-depth discussions of the similarities and the differences among the various systems. Documentations on the technical details of the European monetary union are available at the European Central Bank website (www.ecb.int). For a thorough discussion on currency boards, see Hanke, Jonung and Schuler (1993).

during the 1997-98 East Asian and Russian financial crises. This paper presents a theoretical model for analyzing the stability of this monetary system. Within this theoretical framework, we analyze a foreign reserve commitment policy proposed by Miller (1998a) and Chan and Chen (1999) [thereafter CCM] for enhancing the stability of a currency board.

The stability of fixed exchange rate systems has been the subject of investigation using different exchange rate crisis models. The first group of crisis models (see Krugman [1979]) assumes that a government is taking a passive role in using foreign currency reserves to defend speculations on the fixed exchange rate. But due to inconsistencies in the fundamentals for monetary, fiscal and exchange rate policies, the reserve level drops below a critical minimum level and the fixed exchange rate system collapses.

The second group of models is often labeled as the “New Crisis Model” by Krugman (1996) and others. These models assume that apart from defending the fixed exchange rate system, governments have other objectives such as unemployment rates and production outputs of the economy. In defending the exchange rate, the government has to solve an optimization problem between the costs and benefits of defending the exchange rate (see, e.g., Obstfeld [1996], Bensaïd and Jeanne [1997] and others in the context of multiple rational expectations equilibria). Both Obstfeld (1996) and Bensaïd and Jeanne (1997) find that, given the incentives of the government to devalue, the belief of the speculators generates a self-fulfilling currency crisis in a fixed exchange rate system (e.g., the collapse of the European “Exchange Rate Mechanism,” ERM, in 1993).

Despite periodic collapses of fixed exchange rate systems, many countries are still moving towards such an arrangement (e.g., the Euro zone). The costs and benefits of a fixed exchange rate system are thoroughly analyzed in the literature (see the review paper by Mundell[2000]). An economy with wage, price and employment inflexibilities would be more inclined to adopt a floating exchange rate, even with all its volatilities and uncertainties, than a fixed exchange rate that might induce socially intolerable price and employment adjustment pains in response to external shocks. These conflicting social costs often lead to currency crises. On the other hand, a flexible and open economy such as that of Hong Kong is well suited to adopt a monetary union or a fixed exchange rate with its major trading partner because the benefits of a stable currency outweigh the costs. This latter case is the focus of our analysis.

The existing literature for currency crisis models is mostly limited to actively managed fixed exchange rate systems. Few of them investigate a passive “hard-fixed” exchange rate arrangement such as a currency board. Apart from the similar objective of maintaining a stable exchange rate, there are two major differences between a currency board arrangement and an actively managed exchange rate system. First, governments with an actively managed fixed exchange rate system may directly intervene in foreign exchange market, drain liquidity from the domestic money market and lift interest rates in order to raise the cost to speculators, while a currency board arrangement is a passive monetary system without discretion. *The lack of discretion is what gives a currency board its credibility.* This is reflected in the predominantly successful history of currency boards. In contrast, an actively managed fixed exchange rate system fails very often (e.g., in recent history, the ERM, Mexico, East Asian countries, Russia, Brazil, Turkey and others). Second, a government adopting a currency board arrangement gives up its monetary policy and it is taking a passive role in the creation process of money supply. Any change in the domestic money supply corresponds to a change in foreign reserve holding of the currency board. On the other hand, governments adopting an actively managed fixed exchange rate system often retain some discretion over their monetary policies. Thus, the dynamics are quite different between the two systems.

This paper develops a formal theoretical model for analyzing the stability of a currency board arrangement for a government with a limited amount of foreign reserve, which is not enough to fully back the domestic money supply (including notes and coins and bank deposits that are readily convertible in the foreign exchange market) at the pre-specified linked exchange rate. As such, the stability of the currency board depends critically on the public confidence. CCM argue that a government can enhance public confidence through the issuance of a limited amount of currency put option or exchange rate insurance policy.³ This reserve commitment can both solve a time-inconsistency problem of the government’s link/delink decision and signal the true resolve of the government in maintaining the existing currency board.

³ The Chan-Chen put option scheme was formulated in a proposal to the Financial Secretary of Hong Kong in November 1997 and analyzed in Chan and Chen (1999). A related scheme was proposed by Merton Miller to the Premier of China in 1998. See also Miller (1998a) and Culp, Hanke and Miller (1999). These schemes were reported in international media, such as *The Economist*, *Business Week*, *Financial Times*, *Fortune*, *Risk*, *Wall Street Journal*, *CNN* and others during the Asian Financial Crisis in 1998.

The commitment to back the currency board with an explicit amount of reserves solves a time-inconsistency problem because it binds the government to honor the linked exchange rate (up to the commitment level) even in some future states in which the government would have strategically allowed the currency board to collapse. Governments with sufficient reserves would find such a commitment ex-ante optimal because it decreases the future delink probability and pushes the current market equilibrium away from an immediate run against the currency board (analogous to a bank run triggered by private individual incentives).

Furthermore, especially in times of uncertainty, the public might be unsure of the resolve of the government in maintaining the currency board. The reserve commitment can serve as a costly signal to reveal the resolve (which is unobservable) of the government to the public. The public can then infer the resolve of their government from the signal, which would then induce a separating equilibrium. We examine the potential benefits of this commitment policy in enhancing the stability of a currency board and determine what the optimal reserve commitment level should be.

As a historical note, although our model was motivated by the East Asian financial crises in 1997-98, the recent collapse of the Argentina currency board served as an out-of-sample example. The Argentine and the Hong Kong economies were very different during their crises. Argentina was plagued with an inflexible labor market, unsustainable fiscal policies and a prolonged divergence between the US and Argentine economies (often cited as a major danger to sustaining a monetary union) while Hong Kong has always had a flexible labor market and a huge government surplus. In June 2001, the Argentine government, rather than enduring the political pain arising from the implicit price and wage structure adjustments necessary under a currency board, decided to tamper with the currency board by creating a dual exchange rate and moving the currency anchor (see Hanke [2002b]). A major uncertainty arose later in the year when it was learnt that the IMF might decide to withhold further installments of a loan to Argentina. The people of Argentina grew worried and started a run on its banking system. The government imposed a partial bank freeze on December 1 (instead of making a commitment for the currency board as analyzed in this paper) and later an extended banking holiday that halted most banking and exchange transactions that culminated in the collapse of its *modified* currency board. This is in stark contrast to the Hong Kong experience. After the Russia defaulted in 1998 and the world markets faced increasing uncertainty, the Hong Kong Monetary Authority adopted

an equivalent version of the CCM proposal in September 1998 with an explicit reserve commitment backing the linked exchange rate to stop the exodus of capital from Hong Kong [see Chen (2001)]. In the end, the Hong Kong dollar was one of the few freely traded hard currencies that did not depreciate against the US dollar during the financial crisis of 1997-98.

The outline of this paper is as follows. Section 2 describes a simple model of a currency board with limited foreign reserves (insufficient to back the convertible money supply at the official linked exchange rate). Section 3 models a reserve commitment for enhancing the stability of currency boards. Section 4 looks at the multiple equilibria where there is asymmetric information between the government and the currency holders, and examines the signaling role of commitments. We calibrate our model using Hong Kong and Argentina as examples and discuss the implications and possible remedies suggested by the model. Section 5 concludes the paper.

2. The Model

We consider a small open economy adopting a currency board arrangement to link its currency with a major foreign currency. Without loss of generality, we assume that the official linked exchange rate of the domestic currency in terms of the foreign currency is one.

2.1 The Autopilot of a Currency Board and its Reserve-backing Requirement

A currency board stands ready to exchange the linked foreign reserve currency with the domestic currency at the official pre-specified exchange rate. Under this arrangement, not only the exchange rate and the interest rate of the domestic currency are linked to those of the reserve currency, but the creation of domestic currency is also linked to the flow of the reserve currency. An increase in the demand for domestic currency will create an upward pressure on the domestic interest rate and an appreciation pressure on the exchange rate. This will induce an inflow of the reserve currency to the currency board and create an expansion of the domestic money supply. Hence, both the domestic money supply and the foreign reserve holding rise and the market exchange rate will stabilize at the linked exchange rate level. On the other hand, a decrease in demand for domestic currency works in exactly the opposite way and it will induce an outflow of the reserve currency from the currency board and a contraction of domestic currency supply. Consequently, both of the domestic money supply and foreign reserve holding drop and the

market exchange rate will again stabilize at the linked exchange rate level. This equilibrating process is commonly known as the “autopilot” of a currency board. *For the autopilot to function properly, it is critical that the public believes that the currency board will persist at its current linked exchange rate.*

When the currency board is on autopilot, any change in the foreign reserve holding of government will lead to a corresponding change in money supply,

$$\Delta M = \Delta R$$

where ΔM is the change in money supply of domestic currency and ΔR is the change in foreign reserve holding of government. This is the reserve-backing requirement of a currency board.

2.2 *Government’s Ability and Determination*

A government’s ability and determination are the two major determinants for the persistence of a currency board arrangement. The ability is reflected in the level of foreign reserve holding. Although a government adopting a currency board arrangement has to follow the reserve-backing requirement for any new money creation, it does not mean that a government would have enough foreign reserve to back the existing domestic money supply at the pre-specified exchange rate. In reality, the foreign reserve holding of a government is generally not sufficient to back the convertible domestic money supply. Hence, we assume that $R < M$, where R is total foreign reserve level and M is the domestic money supply convertible to the reserve currency. Due to this inequality, if the capital outflow is significant, the currency board may not have enough foreign currency reserve to support the redemption of the domestic currency at the official linked exchange rate. In this case, the government is forced to abandon the currency board system due to lacking in its ability.⁴

Apart from the level of reserve currency holding, a government’s determination is another determinant for the persistence of a currency board system. For example, a currency board usually comes under pressure when there is a significant capital outflow. Since downward

⁴ This condition abstracts away from the possibility that the country would be bailed out by multilateral organizations like IMF. An equivalent condition for a country adopting dollarization would be for the capital outflow to exceed the reserves. A similar crisis would arise for a country in a monetary union experiencing “asymmetric shocks” (relative to other members of the monetary union) when its financial systems get into troubles (similar to those of Argentina in 2001) because the country loses control over its monetary policy and faces restrictions in its fiscal policy in a monetary union, especially if something like the “no-bail-out” clause in the Maastricht Treaty is meant to be serious. In December 2001, Argentina went into a full-fledged financial crisis after IMF refused to bail them out for missing the fiscal target imposed by IMF.

movements in the wage and price structures tend to be sticky, maintaining the linked exchange rate often means slower economic growth and higher unemployment rate until the domestic price structure adjusts appropriately. A government's determination is reflected in the level of political pain it is willing to endure for maintaining the currency board. A government with strong ability (sufficient foreign reserve to support the demand for the redemption of the domestic currency) may voluntarily abandon the currency board if its determination to maintain the currency board is weak. It is a policy decision of the government to maintain or abandon the currency board after considering the costs and benefits. A high determination to maintain the currency board is in a sense equivalent to a high abandonment cost. Hence, government's determination is a key factor for the decision of voluntary abandonment.

To model the abandonment decision, we need to take into account of how the currency board arrangement and the level of reserve benefit the economy. There are at least two important motivations for maintaining a currency board: (i) to eliminate unnecessary volatility of the external value of the domestic currency (as volatility induces risk premiums) and (ii) to inherit the credibility and stability of the reserve currency's inflation policy since a runaway inflation is often considered to be harmful to the economy. For countries that set up a currency board, it must be the case that the value of the aggregate "domestic economic fundamental" is higher when the currency board is maintained. We model this by assuming that the domestic fundamental is f_L when the domestic currency is linked by the currency board and f_D when it is delinked and the currency board is abandoned.

Furthermore, we assume that the value of the economy is affected by the foreign currency reserve level, R , of the country. There are numerous reasons why the government of an open economy wants to maintain a foreign currency reserve. A large enough foreign currency reserve, with or without a currency board, can absorb unnecessary volatility in the exchange value of the domestic currency due to temporary liquidity shocks and disruptions in the foreign exchange market, thereby reducing capital flow risks for domestic and international investors⁵.

⁵ We thank Juha Tarkka and his colleagues for sharing their extensive study at the Bank of Finland on foreign currency reserve policies of small and medium size open economies. Cross-sectionally, the most important variable explaining the size of a country's the foreign currency reserve is its international trade (import+export). Based on the recent experience in the East Asian financial crises, the perceived international value of the economy was indeed related to the size of a country's foreign currency reserve. Using the US dollar as the unit to measure the ratio of the international value of an economy before and after the crisis, those countries with large reserves have a much higher ratio than those without (after taking into account of the foreign currency reserve itself whose world price is not much affected).

Thus, we assume that the value of the economy, F , is an increasing function of the reserve:

$$F = \begin{cases} f_L + g(R) & \text{if the currency board is maintained} \\ f_D + g(R) & \text{if the currency board is abandoned} \end{cases} \quad (1)$$

where $0 \leq f_D \leq f_L$ and $g(R)$ is an increasing function of R , and R is the level of foreign currency reserve. The penalty for losing foreign currency reserve is reflected in $g(R)$.

All economic fundamental values are assumed to be denominated in the reserve currency and, without loss of generality, the interest rate for the reserve currency is assumed to be zero, so there is no time value effect on the fundamental values.

2.3 *Change in Money Supply*

After adopting a currency board, the government has no direct control over the domestic money supply. In our model, we assume the change in the supply of the domestic currency is composed of two parts. The first one is a change in the supply of the domestic currency because of a capital inflow or outflow. The second is a panic selling of the domestic currency from the public because of the possibility of a devaluation in the future.

2.3.1 *Public's Panic Selling of the Domestic Currency Due to Potential Devaluation*

The public understands that the domestic currency may fluctuate in value relative to the reserve currency if the currency board is abandoned. If the probability of devaluation is sufficiently small, the convenience yield of holding the domestic currency (for the purpose of conducting all domestic transactions, given that foreign exchange transactions are not costless) together with possibly a small domestic interest rate premium⁶ exceed the small expected loss from devaluation. There will not be any panic and the money supply will not be much affected. If the threat of devaluation is substantial, the public would be tempted to convert their domestic

⁶ In the Hong Kong experience, however, this premium is typically very small (a few basis points) and it fluctuates around zero between positive and negative regions in normal times. During the Asian currency crisis of 1997-98, the premium remained small but positive for most of that period (see Morgan Stanley (1998)), with the exception of the times when the Hong Kong Monetary Authority (HKMA) intentionally drained liquidity and squeezed interest rates to "punish" the speculators [see Chen (2001)]. After the HKMA reformed its currency board in September 1998 to conform more to that of a classical currency board, the interest rate differential between the domestic and reserve currency rates returned to just a few basis points around zero. This was in contrast with the Argentine experience in 2001 when the domestic interest rates were significantly above the US rates because of the significant probability of default (similar to those of US junk bonds), whereas the Hong Kong government bonds have almost zero probability of default because of the huge cumulative government surplus.

currency holdings to the reserve currency to protect their value. As the probability of devaluation reaches some critical level, there will be enough of a critical mass of domestic currency holders wanting to convert to set off a run against the currency board (analogous to a bank run) as in the sequence of events leading to the collapse of the Argentine currency board in 2001.⁷

To keep the model simple, we assume that there are two outcomes: a good outcome where there is no panic selling and a bad outcome with panic selling (currency board runs) that causes the currency board to fail⁸. The two outcomes are separated by a critical probability of devaluation, p^* , which can be interpreted as the public's tolerance level of the exchange rate risk⁹. The probability of delink at $t=1$, p , takes into account of the strategic policy decision of the government. Thus, in our model, we assume that the panic selling quantity Q is given as

$$Q(p) = \begin{cases} Q^* & \text{if } p > p^* \\ 0 & \text{otherwise} \end{cases}$$

where $R < Q^* \leq M$.

2.3.2 Changes in Domestic Money Supply in Response to an External Capital Outflow Shock

The possibility of delink can also arise from a capital outflow shock, S , at $t=1$. A currency board system is fundamentally different from a central bank trying to maintain a fixed exchange rate. A currency board, once installed, cannot create or destroy money by itself. The change in its domestic money supply is isomorphic to the net external capital flow¹⁰ and it is

⁷ On December 1, 2001 (Saturday), faced with an exodus of capital from its own citizens, Argentina placed restrictions on bank deposit withdrawal and convertibility to stop the run against the banks and its currency board. "The draconian measures came after Argentines lined up at the banks on Friday (November 30, 2001) to withdraw their savings." (*Financial Times*, December 3, 2001) The official abandonment of the Argentine currency board came in January 2002.

⁸ In this aspect, many of the issues considered here resemble those of bank runs. See, e.g., Diamond and Dybvig (1983). The main reason of modeling the collapse of a currency board as bank runs is that it corresponds to most cases of fixed exchange rate collapses in the recent currency crises. The most direct causes for the collapse were that local people and businesses lost confidence in the government's resolves to maintain the fixed exchange rate and they started to exchange in the spot market and hedge in the forward market. [See, for example, Miller (1998), IMF reports on the East Asian Crisis and the reports on the collapse of the Argentine currency board.]

⁹ At a low enough probability of delink, domestic currency holders would gladly hold the domestic currency for its convenience yield (and possibly higher interest rates, see footnote 7). As the probability of delink increases beyond some critical point, there are enough domestic currency holders who want to convert their life savings into the reserve currency to preserve their values and set off a run against the currency board. As in a bank run, once it starts, it will snowball as it is in the interest of everyone to convert. In this paper, we take this stylized fact as an assumption without explicitly modeling it to streamline our analysis.

¹⁰ A currency board cannot create money and, therefore, to a good first order approximation, the change in the domestic money supply is about the same as the capital flow (at least in the short run) under a currency board. If there were a multiplier effect, we only need to re-scale the variable S and all the results continue to apply.

regulated by the “autopilot” of the currency board to smooth out any mismatch in the demand and supply of the domestic currency in normal times. This property of a currency board is well understood and the self-adjustment mechanism has never caused any currency board to fail and it is not what we are trying to address here. Instead, we abstract away from this mundane function of a currency board to focus on the more interesting question of what would happen when, in times of uncertainty, the global capital flows are often triggered by events unrelated to the domestic economy (see section 2.5 below). A sudden significant capital outflow could induce huge losses in reserves and currency board runs.

It is helpful to think of capital flows as the sum of two components: an expected component related to the underlying economy and a random noise term. In normal times, the noise component is small and the autopilot behaves properly in regulating the capital flows corresponding to both components. But, in times of uncertainty when the sentiment is fragile, the noise component could cause a crisis in confidence that sets off punishing capital outflows and currency board runs with massive production shocks. *Those volatile capital flows are the main risks to a currency board.* These stylized facts and their implications are the foci of what we are trying to model in this paper.

Therefore, the main exogenous variable in our model is the volatile external capital outflow shock, S . The distribution of S is assumed to be public information at the present time at $t=0$. At $t=0$, given the distribution of S , the government may want to signal its commitment to the currency board;¹¹ and then, the domestic currency holders assess the probability of delink and decide whether to run the currency board. We assume that S has a simple uniform distribution at $t=1$ (conditional on no panic selling at $t=0$) as follows:

$$P\{S \geq s\} = \left[\frac{(\alpha + \beta) \times M - s}{2\beta M} \right], \quad \text{for all } s \in [(\alpha \times M - \beta \times M), (\alpha \times M + \beta \times M)] \quad (2)$$

where α reflects the expected capital outflow and β is a measure of the uncertainty of the capital outflow shock S relative to the money supply, M . The parameter α is not really necessary as it can be folded into M next period, but it is included here for the convenience of comparing across

¹¹ The commitment policy is mathematically equivalent to a put option. From the put-call parity as applied to currency options, the put option is equivalent to a call and a forward. The availability of the put option does not give speculators new instruments for speculation [see Chan and Chen (1999)]. An implication of the result of this paper is that if the monetary authority acts optimally on the commitment policy, the commitment policy itself will not induce speculation.

different economies. For $\alpha = 0$, the shock has a range from $(-\beta \times M)$ to $(+\beta \times M)$. In normal times, β is small and the currency board functions properly. But, in times of uncertainty, β could be large and this is the situation of concern in this paper.

To restrict the size of the outflow to be less than the total money supply, we have $-1 < \alpha < 1$, $0 < \beta \leq 1$, and $|\alpha| + |\beta| \leq 1$. For ease of exposition, we impose the additional restrictions on α and β such that $(\alpha - \beta) < 0$ and $(\beta + \alpha) > 0$ (i.e., the range of shock realizations includes both capital inflows and capital outflows, respectively), to streamline the analysis.¹²

After knowing the realized shock, S , the government will determine whether to maintain or (*strategically / involuntarily*) abandon the currency board at $t=1$. The time line for this model is shown in Figure 1.

Figure 1 about here

If the shock is negative, ($S < 0$), to keep the story simple, we assume that the government will always maintain the currency board under an inflow of foreign reserve¹³. On the other hand, if the shock is positive, the government may maintain or abandon the currency board in accordance with its objective function and the size of the shock.

2.4 Decision of Government

If the government perceives that it cannot prevent public's panic selling at $t=0$ (even with commitments and the possibility of signaling its resolves), the government will abandon the currency board immediately to preserve the foreign reserves currency. If the realization of the capital outflow shock at $t=1$ is larger than the reserve level, rendering the currency board unsustainable, the government will also delink immediately.

If the capital outflow shock is less than or equal to R , then whether to uphold the currency board system is a policy decision of the government that takes into account of the tradeoff between the maintaining cost and the abandonment cost. The government's decision is to minimize the social loss function. If the link is maintained, any capital outflow will be absorbed by the foreign reserve holdings of the government, $\Delta R = -S$. The social loss from the

¹² These restrictions are not critical to the main points of the paper, but they significantly simplify the analysis as we do not need to break up the proofs into many sub-cases that do not add to the intuition of the model.

¹³ The flow of foreign reserve is assumed to be publicly observable (e.g., from the website of central banks).

point of view of the government is the pain necessary to maintain the currency board in response to an external capital outflow: $L^L = a(S)$ for $S > 0$, where $a(S)$ is an increasing function of S .

Among other things, $a(S)$ reflects the respondent decrease (to the contraction in money supply) in production and increase in unemployment, plus the loss in economic value associated with a lower reserve level after the shock. It also captures many other relevant features of the underlying economy, including the possibilities of fiscal policy responses and the flexibility of the wage-price structures. A country adopting a currency board loses control over its monetary policy and exchange rate and thus it must rely on the flexibility of its wage and price structures and its ability to use fiscal policies to absorb economic shocks. Take Argentina and Hong Kong as examples. Hong Kong has a flexible economy and labor market, and a huge government surplus. When the neighboring countries were devaluing their currencies in 1997-98, prices and wages in Hong Kong fell and the government was able to spend part of its huge surplus to absorb some of the shocks. In this sense, the $a(S)$ for Hong Kong would be relatively small. On the other hand, after the devaluations of the Mexican peso in 1995 and the Brazilian real in 1999, the wage and price structures in Argentina remained rigid and increasingly uncompetitive. Argentina had one of the largest emerging market debts and ran fiscal deficits aggravated by political bickering — international investors were increasingly reluctant to keep lending to Argentina for its fiscal spending (“impaired debt capacity”). The Argentine currency board prevented Argentina from financing fiscal deficits with printing money. Consequently, Argentina went into a recession with unemployment skyrocketed to more than 18 percent and ultimately led to deadly riots in December 2001. In our model, the $a(S)$ for Argentina would be larger than that for Hong Kong for the same S .

It is clear that the social loss function of a country, $a(S)$, is necessarily a complicated function that depends on the peculiar features of the underlying economy. The only obvious common property is that $a(S)$ should be increasing in S . To keep the main thrust of our analysis straightforward, we assume a simple linear form for $a(S)$ for the derivation of the analytical solutions. We then use simulations to examine the robustness. The simulation results suggest

that the main intuition from the linear model is rather robust with respect to other specifications of a government's loss function.¹⁴

Thus, for our analytical derivations, we assume

$$L^L = a \times S \quad \text{for } S > 0 \quad (3)$$

where $a > 0$ is a country-dependent constant depending on the particular economy. In this setting, we would expect a high a for Argentina and a low a for Hong Kong to reflect the structural differences between them.

Alternatively, the government may decide to abandon the currency board in response to the capital outflow shock. In this case, the social cost of abandoning the arrangement includes a renege cost, X , and a decrease of $(f_L - f_D)$ in the value of the economy [see Equation (1)] when the currency is delinked:¹⁵

$$L^D = X + (f_L - f_D) \quad (4)$$

The renege cost can be interpreted as a perceived cost arising from losing future credibility of the government and losing the credibility of any future fixed exchange rate commitments that may be necessary to guarantee domestic price stability. In addition, the government may also lose future access to the international capital markets. The renege cost includes also the damage to the country's financial system when a currency board collapses. The Argentine government obviously did not take the renege cost lightly as it risked mounting social unrest to continue its currency board until late in 2001. We can interpret the parameter X as a reflection of the determination of government in maintaining the existing currency board system.

Therefore, the government will trade off the maintaining cost (higher unemployment, lower production, loss of reserve) against the abandonment cost (increase in exchange rate volatility and investment risk premium, loss of credibility, ensuring financial chaos, loss in the domestic economic fundamental after delink) in deciding whether to voluntarily abandon the

¹⁴ There are other popular function forms used in the literature. For example, Barro and Gordon (1983) "assume a simple quadratic form" in their loss function consisting of a sum of the square deviations from their target unemployment and inflation rates in analyzing a policymaker's decision. See also Obstfeld (1996). Their quadratic form is expedient in their case for analyzing the tradeoff between production and inflation. In our case, it is simpler to assume a linear loss function in the contraction of the money supply in deriving our analytical results. From our simulations, we can see that non-linearity would affect the ranges of the different regimes but not the main intuition of the analytical results.

¹⁵ Without loss in generality, we can assume in Equation (4) that any economic loss (linear in S) arising from the capital outflow S is folded into Equation (3) because we will be measuring the difference between (3) and (4) in our analysis.

currency board. A government with a high X is the one who values the credibility and stability of its financial system. It would want to maintain the currency board even at a high political cost.

2.5 *A Historical Note on the Model Assumptions*

The crucial assumptions in our model are those in equations (2), (3) and (4) and these are assumptions central to all currency boards. When the Hong Kong currency board was repeatedly tested during the financial crises that spread from East Asia to Russia to Latin America in 1997-98, these were also the main concerns deliberated in the numerous Hong Kong Monetary Authority meetings.

Equation (2) reflects the shocks corresponding to the global capital flows that were often triggered by events exogenous to the domestic economy in times of uncertainty. During the 1997-98 crises, Hong Kong had ample of reserves, a strong and well-regulated banking system and benefited (and continued to benefit) from a strong Chinese economy, and yet Hong Kong experienced many positive and negative shocks. The biggest one was triggered by the Russian default in the summer of 1998, even though the Russian economy was small and had almost zero impact on the Hong Kong economy. The episode occurred more than one month before the world was even aware of the near collapse of LTCM. The massive domestic money supply contraction (corresponding to the capital outflow shock) almost wrecked the Hong Kong economy. In times of uncertainty, the potential dangers of these external shocks in setting off currency board runs were the main relevant risks facing the currency board.

There were three other major considerations of the currency board at that time. (i) The political pain on the government is increasing with the domestic money supply contraction (corresponding to the capital outflow shock) when the exchange rate is fixed by the currency board [Equation (3)]. (ii) There would be a cost to the underlying economy if the currency were delinked. This is just the selection bias: those economies that would not benefit from a currency board system would not set up a currency board. Furthermore, if the currency board were abandoned, there would be a renege cost to the government. These are captured in Equation (4). (iii) A final major concern was the potential loss in the reserves. Such loss was considered to be detrimental to the underlying economy and we capture that in Equation (7) later.

In all these equations, we approximate the relevant considerations with the simplest functional form to keep the model more tractable and the conclusions less susceptible to certain

twists in the functions. Different currency boards might have different objectives requiring more complicated loss functions to be analyzed with simulations. But, as long as these (possibly nonlinear) functions are monotonic and smooth in the same underlying variables, the main intuitions of the model are unlikely to be much different from those derived from our simple working approximations. In this paper, we first examine the equilibria given these assumptions and then use simulations to address the robustness.

2.6 *Maximum Level of Shock Realization a Government is Willing to Absorb*

At $t=0$, to deduce the probability of devaluation at $t=1$, we must first analyze the strategic decision of the government at $t=1$ (i.e., if S is less than the foreign reserve level R , the government has a choice to abandon the currency board or not.) Given the total available foreign reserve R , a government cannot absorb any shock larger than R . Since we assume that the maximum size of the shock is $(\alpha + \beta) \times M$, the upper bound of the maximum level of shock realization a government is able to and willing to absorb without delinking is,

$$\bar{Z} = \min\{R, (\alpha + \beta) \times M\}.$$

If $a \times \bar{Z} \leq (f_L - f_D)$ (i.e., the abandonment cost is greater than or equal to the maintaining cost even when $X=0$), all governments, regardless of X , will not *voluntarily* abandon the currency board. As such, the problem becomes trivial because p^* , R and the distribution of S completely determine whether there is a panic run against the currency board at $t=0$.

The more interesting case is when $a \times \bar{Z} > (f_L - f_D)$. In this case, a government may *voluntarily* abandon the currency board even though it has enough ability (foreign reserve) to maintain it. Our remaining analysis will concentrate on this more interesting case.

Let z^* be the maximum level of shock realization the government is able and willing to absorb without delinking, thus $0 \leq z^* \leq \bar{Z}$ ($\bar{Z} = \min\{R, (\alpha + \beta) \times M\}$) because z^* cannot be greater than the total available foreign reserve and the maximum size of the shock.

Proposition (I)

With perfect information about X , there exists a critical value for X , call it \bar{X} , such that z^* is given as follows:

Case [1]: If $0 \leq X \leq \bar{X}$,

$$z^* = \left(\frac{X + (f_L - f_D)}{a} \right)$$

where $\bar{X} = [a \times \bar{Z} - (f_L - f_D)]$.

Case [2]: If $\bar{X} < X$, $z^* = \bar{Z}$. Hence, a government with determination higher than \bar{X} will never *voluntarily* delink.

Proof: See Appendix A.1.

Given z^* , we can write down the probability of delink at $t=1, p$, as

$$p = P\{S > z^*\} = \left[\frac{(\alpha + \beta) \times M - z^*}{2\beta M} \right] \quad (5)$$

where
$$z^* = \begin{cases} \left[\frac{X + (f_L - f_D)}{a} \right] & \text{if } \left[\frac{X + (f_L - f_D)}{a} \right] \leq \bar{Z} \\ \bar{Z} & \text{otherwise} \end{cases}$$

We can now derive the critical point ($X_{Safe}^{p^*}$) defined as the minimum level of government determination (given p^*) which will not induce a run against the currency board at $t=0$,

Figure 2 about here

To derive the critical value $X_{Safe}^{p^*}$, we consider the following three possible cases:

[a] If $p^* < \left[\frac{(\alpha + \beta) \times M - \bar{Z}}{2\beta M} \right]$,

the currency board will collapse immediately because even if the government is willing to exhaust all its reserves to support the currency board, the probability of delink is still too high.

[b] If $\left[\frac{a \times (\alpha + \beta) \times M - (f_L - f_D)}{2a\beta M} \right] \leq p^*$,

there is no panic run against the currency board for any government (because the shock is expected to be small and the cost of absorbing the shock is expected to be small relative to the benefit of keeping the link; the critical point is found by solving for p at $X=0$).

$$[c] \quad \text{If} \quad \left[\frac{(\alpha + \beta) \times M - \bar{Z}}{2\beta M} \right] \leq p^* < \left[\frac{a \times (\alpha + \beta) \times M - (f_L - f_D)}{2a\beta M} \right],$$

we can solve for $X_{Safe}^{p^*}$. Let $p = p^*$, where p is given in the Equation (5). We have

$$X_{Safe}^{p^*} = \left\{ aM \times [\beta \times (1 - 2p^*) + \alpha] - (f_L - f_D) \right\}$$

- (i) For a government with X higher than or equal to $X_{Safe}^{p^*}$, the public will realize that $p \leq p^*$. Hence, there is no panic selling.
- (ii) For a government with X lower than $X_{Safe}^{p^*}$, the public will realize that $p > p^*$. Hence, the public will run the currency board and the currency board collapses at $t=0$. In this case, it may be in the interest of the government to use a foreign reserve commitment policy (discussed in next section) to reduce its delink probability and avert the public's panic run against the currency board.

To summarize, in the case of symmetric information (between the government and the public) about the government's determination, X , and no explicit reserve commitment by the government to back the currency board, the public assesses the devaluation probability conditional on the distribution of S and X . If $p > p^*$, the public will (uncoordinatedly, as in a bank run) panic-sell to protect itself. Realizing the currency board is unsustainable, the government will abandon the currency board immediately to preserve the foreign currency reserves. On the other hand, if $p \leq p^*$, there will not be a panic run against the currency board at $t=0$.

3. An Irrevocable Foreign Reserve Commitment Policy

CCM propose an *irrevocable* foreign reserve commitment policy to enhance the stability of currency board system. Under the proposed reserve commitment policy, a government must continue to honor any conversion demand for reserve currency for at least up to its commitment level at the pre-specified exchange rate of the currency board no matter whether the government

decides to maintain, or *strategically* or *involuntarily* abandon the currency board. As the reserve commitment policy is a binding contract for the future action of the government, the public understands that the government is less likely to abandon the currency board system after engaging in the commitment and hence the public is less likely to run the currency board at $t=0$. Even though the commitment binds the government to honor the linked exchange rate in some future states that the government (without commitment) would have strategically allowed the currency board to fail, it is ex-ante optimal because the expected loss arising from the commitment is less than the corresponding loss if there were an immediate currency board run.

The irrevocable foreign reserve commitment policy can be implemented in the form of an exchange rate insurance, a typical currency put option (with an independent trustee), or other variations.¹⁶ The commitment policy is not costless in the sense that if the currency board is ultimately abandoned, the reserve level will fall by an amount equal to the commitment level. Given the fact that a government wants to minimize the drain of foreign currency reserves, it will suspend the linked exchange rate immediately after it decides to abandon the currency board (no matter strategically or involuntarily) and limit the loss of foreign reserves only to its committed level.

Figure 3 about here

Let us now analyze the case where the government makes an irrevocable reserve commitment of C to guarantee the currency board. The social loss functions are as follows. The social loss for maintaining a currency board system (given a commitment of C) remains as

$$L_C^L = a \times S \quad \text{for } S > 0 \tag{6}$$

¹⁶ There are several ways to make the commitment *irrevocable*. One possibility is an exchange rate insurance in a special form of foreign reserve lending facility contained in the proposal to the Hong Kong Financial Secretary on November 14, 1997 and reported in Chan and Chen (1999). In that proposal, licensed banks would be able to borrow a limited amount (equal to the size of the put option) of the reserve currency and have the option to repay in domestic currency (at the linked exchange rate of the currency board). As the put option holders have already received the underlying foreign currency, the government cannot unilaterally default on the put option under this special arrangement. Alternatively, the put option can also be integrated into structured notes as exchange rate insurance, as in Merton Miller's proposal to the Premier of China in 1998 (See *South China Morning Post*, January 20, 1998). The scheme that was finally adopted by the Hong Kong Monetary Authority in September of 1998 was a combination of the last two variations. If the government had merely issued a limited amount of domestic currency put option to the public with an exercise price equal to the official linked exchange rate under the currency board, the arrangement would have a weakness in that a government may default on the put option contract as well (refuses to sell foreign currency at the official linked exchange rate to put option holders) after it defaults on its currency board. To guarantee performance, the monetary authority would have to deposit the guarantee with a third party, as in the case of Brady bonds where the guaranteed principal is deposited with a trustee in the U.S.

On the other hand, the cost of abandoning the currency board arrangement includes a renege cost, X , a decrease in the fundamental value of the economy when the currency is delinked, plus a new cost arising from the decrease in the foreign reserves under the commitment policy. The cost of abandoning the currency board becomes $X + (f_L - f_D) + (g(R) - g(R - C))$, where $g(R)$ is the increasing function reflecting the impact of foreign reserves (R) on the economy and C is the amount of committed foreign reserve, which is the loss in foreign reserve if the currency is delinked. Normally, one would expect $g(R)$ to be a concave function with its slope increasing as R goes to zero. To keep our analysis easy to follow, however, we make a simplifying assumption that $(g(R) - g(R - C))$ is linear in the relevant range and provide simulations to address how the concavity would impact the results.¹⁷ In this case, L_C^D becomes:

$$L_C^D = X + (f_L - f_D) + g \times C \quad (7)$$

where g is a constant with $0 < g < a$.¹⁸

The only difference between Equation (4) and Equation (7) is the additional social loss of $(g \times C)$ if the currency board is abandoned under a reserve commitment policy C . By substituting the value X by $(X + g \times C)$ into the results of Proposition (I), we have the following corollary (I.a). Given a foreign reserve commitment level (C), let z_C^* be the maximum level of shock realization the government is able and willing to absorb without delinking (where $0 \leq z_C^* \leq \bar{Z}$ and $\bar{Z} = \min\{R, (\alpha + \beta) \times M\}$).

Corollary (I.a)

With perfect information and foreign reserve commitment, C , there exists a critical value for X , call it \bar{X}_C , such that z_C^* , is given as follows:

Case [1]: If $0 \leq X \leq \bar{X}_C$,

$$z_C^* = \left(\frac{X + (f_L - f_D) + g \times C}{a} \right)$$

¹⁷ The linearity assumption is not necessary for the main intuition to hold, but it significantly simplifies the proofs. If we keep $g(R)$ as a concave function with its slope increasing as R approaches 0, the main benefit is to make the separating equilibrium in section 4 easier to achieve as the low type would be less willing to mimic the high type.

where $\bar{X}_C = [(a \times \bar{Z} - g \times C) - (f_L - f_D)]$.

Case [2]: If $\bar{X}_C \leq X$,
 $z_C^* = \bar{Z}$

\bar{X}_C is the upper critical value for X under the foreign reserve commitment policy C . A government with reserve commitment C and weak determination (X less than \bar{X}_C) chooses to *strategically* delink after paying off C if the shock is more than z_C^* . On the other hand, a government with commitment C and strong determination (X greater than \bar{X}_C) will never *voluntarily* delink. The upper critical value, \bar{X}_C , is decreasing with C because $\frac{\partial \bar{X}_C}{\partial C} = -g < 0$.

3.1 Conditional Probability of Delink

Conditional on the reserve commitment policy C , let p_C be the conditional probability of delink at $t=1$. We have,

$$p_C = \text{Prob}\{S > z_C^* | \text{commit } C\} = \left[\frac{(\alpha + \beta) \times M - z_C^*}{2\beta M} \right]$$

where $z_C^* = \begin{cases} \left[\frac{X + (f_L - f_D) + g \times C}{a} \right] & \text{if } \left[\frac{X + (f_L - f_D) + g \times C}{a} \right] \leq \bar{Z} \\ \bar{Z} & \text{otherwise} \end{cases}$

In other words, for a given X , the higher the commitment C , the less likely the government will delink *voluntarily* (because z_C^* , the maximum level of shock realization the government is able and willing to absorb without delinking, is higher). At a high enough C , it is possible that the government would never *voluntarily* delink (as the critical value \bar{X}_C decreases with C).

¹⁸ $g < a$ because the government loss function, $\alpha \times S$, in maintaining the currency board includes a loss in the economic value due to a loss in reserves.

3.2 Minimum Reserve Commitment $C^{p^*}(X)$ to Avert Panic Run

Next, we derive the minimum reserve commitment, $C^{p^*}(X)$, such that a government with determination X , which is less than $X_{Safe}^{p^*}$ (and p^* is lying within the relevant range discussed in Section 2.6, case [c]), can avoid a collapse of the currency board at $t=0$ if the government is willing to commit at least $C^{p^*}(X)$. As the committed reserve level must be non-negative and not greater than the available reserve level R , the feasibility of solution for $C^{p^*}(X)$ depends on X , R and other parameters. To derive the function $C^{p^*}(X)$, we consider the following three different cases:

(i) If $X_{Safe}^{p^*} \leq X$, $C^{p^*}(X) = 0$.

This is a result derived in Section 2. When X is high, a public panic run will not happen even if the government does not commit any foreign reserve.

(ii) If $X < X_{Run}^{p^*}$, where $X_{Run}^{p^*} = \{aM \times [\beta \times (1 - 2p^*) + \alpha] - g \times R - (f_L - f_D)\}$, there is no feasible solution for $C^{p^*}(X)$ ¹⁹. When X is too low and R is not sufficient, the currency board would collapse even if the government commits all available foreign reserve.

(iii) If $X_{Run}^{p^*} \leq X < X_{Safe}^{p^*}$, $C^{p^*}(X) = \left\{ \frac{aM \times [\beta \times (1 - 2p^*) + \alpha] - X - (f_L - f_D)}{g} \right\}$.

To avert a public's panic run at the lowest expected social cost, a government would like to commit the minimum level of reserve so that the conditional probability of delink (conditional on commitment C , i.e., p_C) is not larger than the public's maximum

¹⁹ To see that, for $X < X_{Run}^{p^*}$, we can expand the formula of p_C as follows:

$$p_C = \text{Prob}\{S > z_C^* | \text{commit } C\} = \left[\frac{(\alpha + \beta) \times M - z_C^*}{2\beta M} \right]$$

$$\geq \left[\frac{(\alpha + \beta) \times M - \left[\frac{X + (f_L - f_D) + g \times C}{a} \right]}{2\beta M} \right] > \left[\frac{(\alpha + \beta) \times M - \left[\frac{X_{Run}^{p^*} + (f_L - f_D) + g \times C}{a} \right]}{2\beta M} \right] = p^* + \left[\frac{g \times (R - C)}{2a\beta M} \right] \geq p^*$$

for all $C \leq R$.

Hence, $p_C > p^*$ and a public's panic run is unavoidable.

tolerance p^* . It will commit $C^{p^*}(X)$ such that

$$p_{C=C^{p^*}(X)} = \text{Prob}\{S > z_C^* | \text{commit } C = C^{p^*}(X)\} = p^*,$$

which implies that $C^{p^*}(X) = \left\{ \frac{aM \times [\beta \times (1 - 2p^*) + \alpha] - X - (f_L - f_D)}{g} \right\}$

It is straightforward to verify that for all $X_{Run}^{p^*} \leq X < X_{Safe}^{p^*}$, $0 \leq C^{p^*}(X) \leq R$.

Hence, there is a feasible commitment $C^{p^*}(X)$ to avert runs. Furthermore, as a government will minimize the potential social loss through using the minimum level of reserve which can avert runs, the solution of $C^{p^*}(X)$ is also unique.

To summarize, for a government with determination X less than $X_{Run}^{p^*}$, a panic run is unavoidable with any commitment policy given the available foreign reserve level. For a government with determination X higher than $X_{Safe}^{p^*}$, it does not have to commit any foreign reserve and there is no panic run. For a government with X in between $(X_{Run}^{p^*}, X_{Safe}^{p^*})$, the run-averting foreign reserve commitment policy, $C^{p^*}(X)$, is a decreasing function of X . A government with a *higher* determination (X) can use *less* foreign reserve commitment to avert a panic run against the currency board.

The minimum commitment level $C^{p^*}(X)$ to avert the panic run is intuitively linked to the critical probability p^* . If the public's tolerance level for the exchange rate risk, p^* , is high, a government can avert a run by using a low reserve commitment $C^{p^*}(X)$ or even no reserve commitment. In times of uncertainty, however, the public may panic easily and the critical value of the public's tolerance level for exchange rate risk, p^* , is low. A government would have to use a high reserve commitment $C^{p^*}(X)$ to avert a panic run against the currency board. Hence, the role of a reserve commitment policy in restoring public confidence becomes more important in times of crisis.

3.3 Optimal Reserve Commitment $C^{Optimal}(X)$

Next, we have to determine whether it is in the interests of a government to commit $C^{p^*}(X)$ or not. We compare the social loss perceived by a government with X , which is less

than $X_{Safe}^{p^*}$ but not less than $X_{Run}^{p^*}$, between the choice of committing $C^{p^*}(X)$ to avert panic runs at $t=0$ versus the choice of not committing any reserve²⁰.

If committing C can avert runs, the gain to a government with determination X from the commitment policy, $G(X, C)$, is the difference between the social loss from delink under a panic run (the first term below) and the expected social loss under the commitment policy C (the second term below).

$$G(X, C) \tag{8}$$

$$= [X + (f_L - f_D)] - \left\{ p_C \times [X + (f_L - f_D) + g \times C] + (1 - p_C) \times \left[\left(\frac{a}{2 \times [z_C^* - (\alpha - \beta) \times M]} \right) \times (z_C^*)^2 \right] \right\}$$

with $p_C = \left[\frac{(\alpha + \beta) \times M - z_C^*}{2\beta M} \right]$ and $z_C^* = \min \left\{ \left(\frac{X + (f_L - f_D) + g \times C}{a} \right), \bar{Z} \right\}$

It can be shown that $G(X, C = C^{p^*}(X))$ is a strictly increasing function of X , $X_{Run}^{p^*} \leq X < X_{Safe}^{p^*}$, under perfect information (see Appendix A.2). If $G(X, C = C^{p^*}(X)) > 0$, it would be optimal for the government to make an irrevocable commitment of $C^{p^*}(X)$ to avert runs at $t=0$. Otherwise, the optimal commitment is zero. In other words, the government is better off not to commit and just let the currency board collapse immediately (see Figure 4).

Figure 4 about here

For a government with high determination X , using $C^{p^*}(X)$ can reduce its social loss because it can avoid the high perceived renege cost in the event of abandoning the currency board. On the other hand, for a government with very low determination X , it may be better not to commit any reserve to avert a public's panic run because its perceived renege cost from abandoning the currency board is too low relative to the expected social cost arising from the inflexibility in abandoning currency board with the commitment policy.

²⁰ We do not need to consider any other commitment level for determining the optimal level of commitment. It is never optimal for a government to commit any positive amount of reserve less than $C^{p^*}(X)$ because it will only bear the cost of a commitment policy but cannot avert the panic run. On the other hand, it is also never optimal for a government to commit any reserve greater than $C^{p^*}(X)$ because it bears an extra cost of commitment but there is no extra benefit.

Let us define $X_{Indiff}^{p^*}$ as the critical value of determination such that a government with $X_{Indiff}^{p^*}$ is indifferent to abandoning the currency board versus averting the public's panic run by committing $C^{p^*}(X = X_{Indiff}^{p^*})$. Thus, $X_{Indiff}^{p^*}$ is the X -intercept for $G(X, C = C^{p^*}(X))$ [i.e., $G(X = X_{Indiff}^{p^*}, C = C^{p^*}(X = X_{Indiff}^{p^*})) = 0$, see Figure 4]. The existence of such a solution within the relevant range depends on the parameter values of the model. The following are the exhaustive cases: (a) If there exists a solution for $X_{Indiff}^{p^*}$ between $X_{Run}^{p^*}$ and $X_{Safe}^{p^*}$, it is unique (because $\frac{\partial G}{\partial X} > 0$ from Appendix A.2) and a government with X such that $X_{Indiff}^{p^*} \leq X < X_{Safe}^{p^*}$ will commit $C^{p^*}(X)$ while a government with $X_{Run}^{p^*} \leq X < X_{Indiff}^{p^*}$ will abandon the currency board immediately at $t=0$. (b) If $G(X, C = C^{p^*}(X)) > 0$ for all $X_{Run}^{p^*} \leq X < X_{Safe}^{p^*}$, the gain from commitment is positive within the relevant range of X . All governments with X less than $X_{Safe}^{p^*}$ but not less than $X_{Run}^{p^*}$ will commit their respective $C^{p^*}(X)$ to avoid the panic run at $t=0$. Finally, (c) if $G(X, C = C^{p^*}(X)) < 0$ for all $X_{Run}^{p^*} \leq X < X_{Safe}^{p^*}$, no government will commit any reserve, and all governments with X less than $X_{Safe}^{p^*}$ will abandon the currency board at $t=0$.

Thus, given X and other parameters, the government assesses $G(X, C = C^{p^*}(X))$. If $G(X, C = C^{p^*}(X))$ is non-positive, the government would not make any commitment and the currency board collapses immediately. Hence, the optimal reserve commitment level is zero. On the other hand, if $G(X, C = C^{p^*}(X))$ is positive, the government would make the minimum commitment of $C^{p^*}(X)$ to avert a panic run at $t=0$ and the currency board will not collapse. Hence, the optimal reserve commitment level is $C^{p^*}(X)$. Let us denote $C^{Optimal}(X)$ to be the optimal reserve commitment. From the previous analysis, we have the following results for the perfect information case:

$$C^{Optimal}(X) = \begin{cases} 0 & \text{if } X < X_{Run}^{p*} \\ 0 & \text{if } (X_{Run}^{p*} \leq X < X_{Safe}^{p*}) \text{ and } G(X, C = C^{p*}(X)) \leq 0 \\ C^{p*}(X) & \text{if } (X_{Run}^{p*} \leq X < X_{Safe}^{p*}) \text{ and } G(X, C = C^{p*}(X)) > 0 \\ 0 & \text{if } X_{Safe}^{p*} \leq X \end{cases}$$

4. Reserve Commitment under Asymmetric Information

Suppose that the government's determination to maintain the currency board is known to the government but not to the public. If the public underestimates the determination of government, what can the government do to improve its social welfare under this information asymmetry? This section examines how a government can use an explicit reserve commitment policy to signal its true determination to maintain the currency board,²¹ whereby reducing the social loss arising from the information asymmetry between the government and the public.

4.1 Optimal Reserve Commitment under Information Asymmetry

Suppose there are two types of governments, L and H, and let X_L and X_H denote their respective values of the government's determination to maintain the currency board, where $X_L < X_H$. The government knows that it is an H-type, but the public underestimates the government's determination and believes that it is an L-type²². Both the government and the public know the two possible levels; however, only the government knows that its true value is X_H . Furthermore, to look at only the non-trivial cases, we consider that (1) $X_L < X_{Safe}^{p*}$ ²³, which means that the currency board will collapse if the government does not commit any foreign

²¹ A government can also signal its private information on the magnitude of negative impact on economic fundamental from delink, $(f_L - f_D)$, if this is not public information. Information asymmetries on $(f_L - f_D)$ and X are mathematically isomorphic because the government loss function contains the sum of $(f_L - f_D)$ and X .

²² It is trivial to consider the case when the market overestimates the determination of the government to maintain the currency board. If the market overestimates the government's determination value X_{HH} , which is larger than the actual determination value X_H , the government with determination X_H can simply use $C^{p*}(X_{HH})$, which is not greater than $C^{p*}(X_H)$, to avert the public's panic runs.

²³ It is trivial to consider $X_L \geq X_{Safe}^{p*}$ because both the government with X_H and the government with X_L can avoid the public's panic run without any reserve commitment.

reserve and the public believe its determination value to be X_L ; (2) $X_H \geq X_{Run}^{p*}$ ²⁴ and $X_H > X_{Indiff}^{p*}$ ²⁵, which means that X_H may reduce its social loss if it could reveal its true determination to the public and implement commitment policy to avoid the panic run. Under what conditions can a government with X_H signal to the public by a reserve commitment policy to avoid an immediate collapse of the currency board and what should the optimal reserve commitment level be?

Consider a government with X_H who wants to use a reserve commitment policy to avert a public's panic run. The minimum commitment level for X_H to avert a panic run under asymmetric information cannot be less than $C_H^{p*} = C^{p*}(X_H)$, which is the minimum reserve commitment for X_H to avert a panic run under perfect information. In other words, C_H^{p*} is the lower bound of minimum reserve commitment for X_H to avert a panic run under imperfect information (with $X_L < X_H$ and $X_L < X_{Safe}^{p*}$). If the lower bound of reserve commitment, C_H^{p*} , can effectively change the public's pessimistic estimate of the government's determination from X_L to X_H , it means that a government with X_L committing C_H^{p*} will incur a higher expected social loss than not committing any reserve (i.e. $C=0$). To analyze whether a government with X_L will imitate the government with X_H through committing C_H^{p*} , we have to examine its benefit from imitation.

The gain for X_L to imitate X_H can be written as $G(X = X_L, C = C^{p*}(X_H))$ using Equation (8) in Section 3.3. The following proposition shows that for a sufficiently small X_L , the L-type will not mimic the H-type.

²⁴ It is trivial to consider $X_H < X_{Run}^{p*}$ because both the government with X_H and the government with X_L cannot avoid the public's panic run by commitment policy.

²⁵ It is trivial to consider $X_H \leq X_{Indiff}^{p*}$ because even under perfect information the government with X_H will not use commitment policy to avert the public's panic run. It is obvious that the government will not use any commitment policy under asymmetric information that the public underestimates its determination to maintain the currency board.

Proposition (II): Reserve Commitment C_H^{p*} with Separating Equilibrium

There exists $X^\#$ such that for any $X_L < X^\#$, a government with X_H can use the reserve commitment policy C_H^{p*} to signal its true type to the public and reduce its social loss; where C_H^{p*} is the optimal reserve commitment of X_H to avert a panic run under perfect information; and $X^\#$ is the highest value of X_L such that a government with X_L will not imitate X_H by committing C_H^{p*} . The critical value, $X^\#$, is the *unique* solution of Equation (9) if a solution exists for $0 \leq X^\# < X_H$.

$$G(X = X^\#, C = C^{p*}(X_H)) = 0 \quad (9)$$

Otherwise, $G(X = X_L, C = C^{p*}(X_H)) > 0$ for all X_L , $0 \leq X_L < X_H$ ²⁶. In this case, define $X^\# = 0$. It means that X_H cannot generate any separating equilibrium by committing just C_H^{p*} .

For an H-type to separate from the L-type, the H-type must commit more than C_H^{p*} .

Proof: Appendix A.3.

Thus, for the case where $X_L < X^\#$ and $X_H > X_{Indiff}^{p*}$, a government with X_H would make the minimum commitment of C_H^{p*} to avert a panic run at $t=0$ (see Section 3.3) and the currency board would not collapse. Hence, the optimal reserve commitment level is C_H^{p*} (see Figure 5).

Figure 5 about here

On the other hand, for any $X_L \geq X^\#$, a government with X_H cannot simply use the reserve commitment policy, C_H^{p*} , to separate itself from a government with X_L . In this case, X_H would have to commit more to avert a run against its currency board. Let us define C_L^{Indiff} to be the maximum reserve commitment such that X_L is willing to commit if such commitment will avert a public panic run. The value of C_L^{Indiff} can be solved from

$$G(X = X_L, C = C_L^{Indiff}) = 0 \quad (10)$$

²⁶ $G(X = X_L, C = C^{p*}(X_H))$ cannot be negative for all X_L , $0 \leq X_L < X_H$ because $X_H > X_{Indiff}^{p*}$.

If the solution of C_L^{Indiff} in Equation (10) is between 0 and R , it is feasible²⁷. Otherwise²⁸, $G(X = X_L, C) > 0$ for all $0 \leq C \leq R$. It means that a government with X_L has an incentive to avoid a collapse of its currency board even by committing all reserve R . In this case, we define $C_L^{Indiff} = \infty$ for the purpose of Proposition III below.

Similarly, we define C_H^{Indiff} to be the maximum reserve that a government with X_H is willing to commit if such commitment will avert a public panic run. The value of C_H^{Indiff} can also be solved from the commitment level inducing a zero gain in the function G of Equation (8) with $(X = X_H, C = C_H^{Indiff})$. If the solution of C_H^{Indiff} is between 0 and R , it is feasible²⁹. Otherwise³⁰, $G(X = X_H, C) > 0$ for all $0 \leq C \leq R$. It means that a government with X_H has an incentive to avert panic runs even by committing all reserve R . In this case, we define $C_H^{Indiff} = \infty$ for the purpose of Proposition III below.

Finally, define $C_L^{p*} = C^{p*}(X = X_L)$ (see Section 3.2). C_L^{p*} has the interpretation that it is the minimum reserve commitment of a government with X_L that would avert runs under perfect information. If $C_L^{p*} > R$, it is not a feasible commitment and we define $C_L^{p*} = \infty$. This value of C_L^{p*} is still useful for delineating the cases in the propositions below. The following propositions list all the possible equilibria.

Proposition (III.a): Separating Equilibrium with Reserve Commitment C_L^{Indiff}

For any $X_L \geq X^\#$, if $\min\{C_L^{p*}, C_L^{Indiff}\} \leq \min\{R, C_H^{Indiff}\}$ and $C_L^{Indiff} < C_L^{p*}$, a government with X_H can adopt the optimal reserve commitment policy C_L^{Indiff} to separate itself from X_L and

²⁷ The feasibility of solution of C_L^{Indiff} implies its uniqueness unless $z_{C=C_L^{Indiff}}^* = (\alpha + \beta) \times M$ which means the delink probability is zero. See Appendix A.4.

²⁸ As we are considering $X_L \geq X^\#$, it is impossible that $G(X = X_L, C) < 0$ for all $0 \leq C \leq R$ because (1)

$$G(X = X^\#, C = C_H^{p*}) = 0 \text{ and (2) } \frac{\partial G}{\partial X} > 0 \text{ (see Appendix A.5).}$$

²⁹ The feasibility of solution of C_H^{Indiff} implies its uniqueness unless $z_{C=C_H^{Indiff}}^* = (\alpha + \beta) \times M$ which means the delink probability is zero. See Appendix A.4.

reduce its social loss. A separating equilibrium is reached such that the public's estimate of its determination is upgraded and there is no panic run.

Proof: When an H-type commits any amount above C_L^{Indiff} , the L-type will rather allow its currency board to collapse than to mimic (from the definition of C_L^{Indiff}). Thus there is a separating equilibrium.

Proposition (III.b): Good Pooling Equilibrium with Reserve Commitment C_L^{p*}

For any $X_L \geq X^\#$, if $\min\{C_L^{p*}, C_L^{Indiff}\} \leq \min\{R, C_H^{Indiff}\}$ and $C_L^{p*} \leq C_L^{Indiff}$, a government with X_H can adopt the optimal reserve commitment policy C_L^{p*} to reduce its social loss. A good pooling equilibrium is reached where there is no panic run, even though the public cannot tell whether the government is of L-type or H-type.

Proof: As $C_L^{p*} \leq C_L^{Indiff}$, a L-type is willing to commit C_L^{p*} to avert runs. As

$$C_L^{p*} \leq \min\{R, C_H^{Indiff}\}, \text{ the H-type is willing and able to commit } C_L^{p*} \text{ to avert run also.}$$

Note: In this case, the H-type may still be able to induce a separating equilibrium by committing more, but this would not be in its interest as the H-type can commit a lower amount, pool with the L-type and can still avert a run.

Proposition (III.c): Bad Pooling Equilibrium with No Reserve Commitment

For any $X_L \geq X^\#$, if $\min\{C_L^{p*}, C_L^{Indiff}\} > \min\{R, C_H^{Indiff}\}$, a government with X_H cannot adopt any feasible reserve commitment policy to credibly distinguish itself from X_L and a government with X_L is unable to avert a run. Hence, the government will not commit any reserve and the currency board collapses immediately.³¹

³⁰ As we are considering $X_H > X_L \geq X^\#$, it is impossible that $G(X = X_H, C) < 0$ for all $0 \leq C \leq R$ because (1)

$$G(X = X^\#, C = C_H^{p*}) = 0 \text{ and (2) } \frac{\partial G}{\partial X} > 0 \text{ (see Appendix A.5).}$$

³¹ The implicit assumption is that the market expects the government to be definitely an L-type (an "Enron") unless the government can credibly signal that it is not. This assumption approximates the market sentiment in times of uncertainty when people are eager to protect the value of their life savings from devaluations. It is possible to impose a more complicated set of assumptions in our model, such as market prior expectations on the types (H and L) and posterior updates based on commitments, but we believe that our simple model provides an adequate representation of the relevant market conditions.

Proof: If C_L^{Indiff} were feasible (i.e., $0 \leq C_L^{Indiff} \leq R$), $C_H^{Indiff} > C_L^{Indiff}$ (see Appendix A.5) $> \min\{R, C_H^{Indiff}\}$. Therefore $\min\{R, C_H^{Indiff}\} = R$. Hence, $C_L^{Indiff} > R$ which is a contradiction. As C_L^{Indiff} must be outside of the feasible range $[0, R]$, so is C_H^{Indiff} (see also Appendix A.5). Hence, $C_H^{Indiff} = \infty$. We have $\min\{R, C_H^{Indiff}\} = R$ and $C_L^{p*} > R$. As $C_L^{p*} > R$, it implies the L-type cannot avert runs and its currency board would collapse. At the same time, $C_L^{Indiff} > R$ and therefore H does not have enough reserves (to commit more than C_L^{Indiff}) to credibly separate itself from L. Consequently, we have a bad pooling equilibrium resulting in the immediate collapse of the currency board. *QED*

Proposition III illustrates that there are different equilibria depending on the market perception of the government's resolves and the penalty for losing reserves. Consistent with simple economic intuition, if the market perception (X_L) is close enough to the true government's resolves (X_H) and the penalty for losing reserves is small, there is going to be a pooling equilibrium, as the government would not be able to use commitments as signals to distinguish itself from the market misperception. On the other hand, if there is significant difference between the perceived and the true resolves of the government, it is possible to induce a separating equilibrium and convince the market with reserve commitments.

To summarize the results under asymmetric information, the optimal reserve commitment for X_H is as follows (see examples in Figures 6 and 7 below):

$$C^{Optimal}(X_H) \tag{11}$$

$$= \begin{cases} 0 & \text{if } (X_H \leq X_{Indiff}^{p*}) \\ \text{otherwise,} \\ C_H^{p*} & \text{if } (X_L < X^\#) \\ C_L^{Indiff} & \text{if } (X_L \geq X^\#), \min\{C_L^{p*}, C_L^{Indiff}\} \leq \min\{R, C_H^{Indiff}\} \text{ and } (C_L^{Indiff} < C_L^{p*}) \\ C_L^{p*} & \text{if } (X_L \geq X^\#), \min\{C_L^{p*}, C_L^{Indiff}\} \leq \min\{R, C_H^{Indiff}\} \text{ and } (C_L^{Indiff} \geq C_L^{p*}) \\ 0 & \text{if } (X_L \geq X^\#) \text{ and } \min\{C_L^{p*}, C_L^{Indiff}\} > \min\{R, C_H^{Indiff}\} \end{cases}$$

In the next section we will illustrate these implications from Proposition III with examples pertaining to Hong Kong and Argentina.

4.2 *Simulations and Implications*

It would be interesting to simulate our model with the approximate economic environment of the Hong Kong currency board during the East Asian and Russian financial crisis and the Argentine currency board just before it collapsed.

4.2.1 *The Hong Kong Example*

At the end of the summer of 1997, Hong Kong had about US\$86 billion in reserves and an M3 in Hong Kong dollar that was equivalent to US\$210 billion³². Accordingly, we set $M=20$ and $R=8$ in all the Hong Kong simulations below. During the crisis years of 1997-98, there were periods when Hong Kong actually experienced some capital inflows as Hong Kong was considered (relatively speaking) a safe haven when international investors moved their money out of the other neighboring countries ravaged by financial crises; and there were periods when the market sentiments in Hong Kong were fragile (e.g., after the Russian default) and the capital outflows from Hong Kong were significant. In the simulations below, we set $\alpha = 0.05$ and $\beta = 0.4$. We pick a reasonable $(f_L - f_D) = 1$ and leave the important variations to X (see footnote 21). We set the critical delink probability $p^* = 0.1$, which implies that the local people will start a run against the currency board (in a manner resembling the case of Argentina in November 2001) if the perceived delink probability is higher than 0.1.

In Figure 6, we set $g=0.35$, which implies a moderate loss to the economic fundamental in response to losses in reserves. We set $a = 0.5$, a relatively low a as Hong Kong's economy and labor market are quite flexible. The economy can easily adjust with some transitional pain in response to outside shocks. Finally, we set a high $X_H = 3$ as the government's perceived damage of reneging on the currency board commitment. This parameter can be interpreted as the government's determination in maintaining the currency board as the government would tradeoff this perceived renege cost against the political cost of recession and unemployment when it maintains the currency board.

³² Data is available from the *Monthly Statistical Bulletin* or web site (<http://www.info.gov.hk/hkma/index.htm>) of the Hong Kong Monetary Authority.

Given those parameters, the optimal commitment for the H-type is zero if there is no asymmetric information (Figure 6). If the market misinterprets the government as an L-type, the optimal response for an H-type government depends on the market perception of X_L . For X_L small enough, there is a separating equilibrium. In particular, if X_L is smaller than X_{sep}^{p*} , an H-type would simply commit a bit more than C_L^{Indiff} to induce a separating equilibrium. For X_L larger than X_{sep}^{p*} , the H-type can still separate itself from L-type by committing C_L^{Indiff} , but it is not in the interest of H-type to do so. Thus, the H-type will simply commit C_L^{p*} (to take the L-type's commitment that will avert a collapse of the currency board at $t=0$) and pool itself with the L-type. But this is a good pooling equilibrium, as the currency board will not collapse.

The situation portrayed in Figure 6 resembles that of the Hong Kong experience in the summer of 1998. After the Russian default, there was an exodus of capital from Hong Kong as the market was unsure of the determination of the Hong Kong Monetary Authority to maintain the currency board. In September, the Hong Kong Monetary Authority announced a reserve commitment backing its currency board and the exodus stopped.

Figure 6 about here

4.2.2 *The Argentina Examples*

At the end of November 2001, Argentina had about \$16 billion in liquid reserves and an M3 in peso of about \$32 billion³³. Thus, we set $M=20$ and $R=10$. Based on these numbers, the reserves to M3 ratio (assuming that the reserves were unencumbered by off-balance sheet obligations³⁴) for Argentina was actually more favorable than that of Hong Kong. We keep all

³³ Data is available from the *Daily Monetary Report* of the Central Bank of Argentina from the web site (<http://www.bcra.gov.ar/English/default.asp>).

³⁴ In the simulations below, we assume that there is a separation between the national bank (currency board) and the government in the sense that the national bank does not have the additional obligations to pay government debts and bail out the banking system if the banks mismanage their currency risks. Such separation is essential to the credibility of hard-fixed exchange rate systems (e.g., the European monetary union). If the reserves are encumbered to pay government debts, our model is flexible enough to accommodate that by either reducing R by the encumbered amount or increasing α , whichever is more appropriate to the actual scenario. Furthermore, there could be some externalities arising from the weight of government debts to the credibility of a fixed exchange rate. When Argentina suspended debt payment on December 24, 2001, even though it simultaneously pledged to keep its currency board (*Reuters*), the damaged credibility finally forced Argentina to abandon its currency board in January. In our model, we would assign a higher X before the debt moratorium than after the debt moratorium. We would assign a lower “ a ” for the Argentine currency board if the government had a smaller amount of debt or a greater credible debt capacity. At the end of 2001, the debt to GDP(2000) ratio for Argentina was 44 percent,

other parameters for Argentina the same as those in Figure 6, including the government's determination,³⁵ except α and a . For Argentina, we set a higher capital outflow parameter, $\alpha=0.1$, because the Argentine economy was mired in a four-year old recession at the end of 2001 with disillusioned investors investing their money elsewhere, as compared to the Hong Kong's economy which continued to be a beneficiary of the robust Chinese economy during the East Asian financial crisis. We also set a higher economic pain parameter (see section 2.4), $a=1$, for Argentina as Argentina has a much more rigid economy and labor market, and a large public debt. After the devaluation of the Mexican peso and the Brazilian real, the domestic price structure adjustment was slow and painful and Argentina went into a deepening recession with unemployment rate reaching more than 18 percent. The government was caught between the IMF that required them to exercise fiscal disciplines and the Argentines who wanted more government spending to bail the country out of a recession, which ultimately culminated in widespread protests and deadly riots.

Figures 7a-c plot several scenarios corresponding to different parameters (a, X_H) with the values of X_L on the X-axis. In Figure 7a, the commitment C has to be more than 12 to avert runs but the government has only $R=10$ in reserves. Given these simulation parameters, the linked exchange rate will collapse with runs against the currency board (via the banking system as in Argentina in December 2001).

Figure 7a about here

Could the outcomes be different under some other parameter values? Figure 7b and Figure 7c illustrate two possible scenarios with positive outcomes. In Figure 7b, we assume that X_H is 4 (rather than 3 in Figure 7a). At this higher level of determination, it is possible to avert runs against its currency board if the government is willing to guarantee the currency board with an irrevocable commitment (i.e., with no default possibility, see footnote 16). To translate this to the Argentine scenario, the government would have to (i) stop tinkering with the hard-fixed exchange rate of its currency board with exit strategies (as it did in June 2000), (ii) convince the market that its perceived renege cost is very high and it is willing to withstand even deadly riots

which was actually lower than that of each of the G7 country (Britain 47 percent, US 57 percent, Germany 58 percent, France 63 percent, Canada 106 percent, Japan 109 percent and Italy 110 percent. Source: *Economists*)

to continue its currency board and service its international debts [as Argentina was actually doing even in the week of December 17 (*Reuters, December 20, 2001*) before the president resigned] and, to further convince the market, (iii) makes an irrevocable commitment of C_H^{D*} (which, according to Figure 7b, is almost the entire reserves) to guarantee the currency board.

Figure 7b about here

Alternatively, in Figure 7c, we keep $X_H = 3$ but lower a to 0.5 (so that the economy would be as flexible as Hong Kong). In this case, the government can easily avert runs with a small irrevocable commitment. Thus, if the Argentine politicians could convince the people to readily accept a flexible wage and price structure in response to the currency devaluations of its competing economies or Argentina could convince the IMF for emergency loans to cover its relief fiscal spending,³⁶ the adjustment pain (“social loss”) to the government for sticking to the currency board would have been low. When this is combined with an irrevocable commitment to signal its resolves, the currency board would have survived.

Figure 7c about here

4.2.3 Robustness Checks and Policy Tools

We derive the results so far with the simplifying assumptions that the impact of reserve losses and the impact from external shocks (Equation (6) and Equation (7)) are linear. We want to confirm by simulations that the equilibria remain qualitatively the same even when the linearity assumptions are relaxed. In those simulations, we let $g(R)$, the economic benefit of

³⁵ It took deadly riots and five presidents in two weeks to finally bring down the currency board in Argentina. It would seem reasonable to assume that the determinations of Hong Kong and Argentina were both high in preserving the currency board.

³⁶ The parameter “ a ” would be lower if multilateral organizations like the IMF can be relied upon to provide emergency relief for extra fiscal spending to ease the adjustment pains. This is similar in spirit to a provision in the European monetary union that allows member countries affected by negative shocks to violate fiscal restrictions without penalties. The IMF is particularly well suited for providing this type of emergence loans to carry a country over an economic shock. Indeed, in December 2000, the IMF (and the US Treasury), in taking the leadership in putting together a package of \$20 billion emergency loans to Argentina, believed that the package “should improve the investment climate and, together with enhanced domestic and external confidence, lay the ground for sustained economic growth in Argentina (*Financial Times*, December 19, 2000).” In August 2001, the IMF offered another \$8 billion in aids. But, in December 2001, the IMF finally got impatient with Argentina’s fiscal deficits (perpetuated by local politics) and withheld the anticipated aid. The action weakened the already fragile confidence in Argentina and eventually led to a full-blown crisis.

having reserves, be concave in the level of reserves: $g(R) = g_0 \times R^{\hat{g}}$, where $0 < \hat{g} < 1$ and $0 < g_0$.

We also relax the linearity in $a(S)$ by replacing $a \times S$ (in Equation (6)) by a general quadratic equation $a(S)$ ³⁷:

$$a(S) = [g(\bar{R}) - g(\bar{R} - S)] + a_0 \times S + a_1 \times S^2, \quad \text{for } S > 0$$

where \bar{R} is the initial reserve level; $0 < a_0$ and a_1 .

Figure 8 illustrates a typical simulation with these non-linear loss functions. Though the exact ranges defining the different regimes depend on the specific parameters, the general picture remains the same as those in Figure 6 and Figure 7.

Figure 8 about here

The simulations in Figure 6 to Figure 8 illustrate how the role of an irrevocable reserve commitment and other parameters in our currency board model interact to determine the viability of a currency board. It is easy to infer from these simulations about the importance of economic flexibility and reserve commitments to the survival of a hard-fixed exchange rate system. Although the analytical results are derived with many simplifying assumptions, the main implications are robust to minor modifications to the model, such as changing the statistical distribution of the shock or replacing the loss function with another smooth monotonic function. The ranges of the different equilibria might be dependent on the specific functions, but the main economic scenarios will remain the same.

The simulations also highlight the impact of the changes in parameter value on the model implications. *The differences in the simulation input values are not intended to be taken literally, but rather as an illustration of how they can influence the outcomes.* To turn the model into an actual policy tool, one would have to substitute into the model the appropriate parameters corresponding to the problem at hand. In this sense, our model can be viewed as a general framework upon which government policy makers can put in their own favorite social loss functions and their estimated shock distribution function to simulate the relevant scenarios. From

³⁷ Barro and Gordon (1983) and Obstfeld (1996) and others use a quadratic social loss function for the convenience of trading off deviations from target inflation and employment rates. Our motivation here of a nonlinear loss function is to reflect a reasonable assumption that these abilities to absorb the shock are limited, and the pain on the economy could rise sharply as the size of the shock increases. We will see how this non-linearity affects the range of the different regimes in the equilibrium.

the results of those sensitivity analyses, they can then design the appropriate policy remedies if necessary.

5. Conclusion

This paper provides a simple theoretical framework for analyzing the stability of a currency board system in times of uncertainty. Within this framework, we investigate the role of an irrevocable commitment for enhancing the stability of a currency board. Our results highlight the important functions of foreign currency reserves in a currency board system. In the traditional thinking of a currency board arrangement, foreign currency reserves are considered only as a shock absorber for the capital outflow. In this paper, we show that the foreign reserve can be used, perhaps more importantly, both as a commitment to solve a time-inconsistence problem in averting an immediate currency board run and a costly signal to induce a separating equilibrium. Both of these functions can further enhance the stability of a currency board system.

We illustrate the implications of our model by calibrating it with the financial crisis environments facing Argentina in 2001 and Hong Kong in 1997-98. In the Argentina case, we show that the runs against its currency board would be unavoidable given certain parameter values reflecting the rigidity of its economy and labor market in response to currency devaluations of its competing economies. Our model also suggests that a combination of policy remedies together with an irrevocable reserves commitment backing the currency board could possibly have saved the Argentine currency board from its collapse and the Argentine economy from its ensuing turmoil.

Perhaps more importantly, if Argentina (or any other country) wants to enter into a fixed exchange rate arrangement again in the future to win back the credibility of its monetary and fiscal policies, the relevant economic environment can be analyzed with our framework to assess how an irrevocable commitment can be combined with other policy remedies to stabilize the fixed exchange rate arrangement. Although our analysis is based on a currency board arrangement, which is just one variation of a variety of “hard-fixed” exchange rate arrangements, our model can be easily adapted to analyze financial crises arising in other variations (see footnote 4), such as dollarizations or monetary unions, and suggest possible remedies if necessary.

The Hong Kong currency board was also under tremendous pressure during the 1997-98 Asian financial crisis. After Russia defaulted in the summer of 1998 and the Hong Kong government intervened massively in the stock market in August 1998, the market sentiment was extremely fragile. People were unsure of the government's resolves to preserve the currency board and there was great uncertainty in the market. In the morning of September 14, 1998, the banks in Hong Kong were selling Hong Kong dollars aggressively to the Hong Kong Monetary Authority (HKMA, the currency board) upon the rumor that the prevailing exchange rate for the "Convertibility Undertaking Arrangement" would be adjusted imminently. At 2:00pm, in desperation, the HKMA announced that the conversion of government bills via the banking system's discount window and the currency board into U.S. dollars would be honored at the prevailing exchange rate for the next six months. The announcement effectively adopted the CCM recommendation by attaching a six-month domestic currency put option onto the outstanding bills, representing a reserve commitment of about US\$8 billions backing the currency board.

The empirical support for the benefit of commitment was immediate and compelling. Within the next three days, all the capital that flowed out of Hong Kong in the morning of September 14, 1998 flowed back to Hong Kong plus a little more [see Morgan Stanley (1998)]. The Hong Kong market did not even shake in the following week when a major shock hit the world markets with the near collapse of LTCM. In the end, the Hong Kong economy emerged mostly unscathed after some adjustment pains and the Hong Kong dollar was one of the few freely traded hard currencies in the world that did not depreciate against the U.S. dollar during the crisis period of 1997-98.

Appendix: Mathematical Proofs

A.1 Proof of Proposition (I)

We can solve z^* such that the government is indifferent to link or delink when $S = z^*$.

$$L^L|z^* = L^D|z^*$$

$$a \times z^* = X + (f_L - f_D)$$

$$z^* = \left[\frac{X + (f_L - f_D)}{a} \right]$$

Since the government has foreign reserve holdings, R , and the maximum level of shock realization is $(\alpha + \beta) \times M$, the value of z^* must be in-between $[0, \bar{Z}]$, where

$$\bar{Z} = \min\{R, (\alpha + \beta) \times M\}. \text{ If } \left[\frac{X + (f_L - f_D)}{a} \right] \geq \bar{Z} \text{ then } z^* = \bar{Z}. \text{ It means that the government}$$

will never *voluntarily* delink. It is straightforward to derive the upper critical value, \bar{X} , for the government's determination in maintaining the currency board, X .

- End of Proof -

A.2 Proof that $G(X, C = C^{p^*}(X))$ is a strictly increasing function of X for

$$X_{Run}^{p^*} \leq X < X_{Safe}^{p^*}$$

Given that there is a public's panic run if a government chooses not to commit any reserve, the social loss is

$$\begin{aligned} & E[L/C = 0, \text{ with Public's Panic Run}] \\ & = \left[X + (f_L - f_D) \right] \end{aligned}$$

On the other hand, if a government with determination X , $X_{Run}^{p^*} \leq X < X_{Safe}^{p^*}$, chooses to commit $C^{p^*}(X)$, then $p_{C=C^{p^*}(X)} = p^*$ (by the definition of $C^{p^*}(X)$) and there will be no panic run.

Hence, the expected social loss is

$$\begin{aligned}
& E[L | C = C^{p^*}(X), \text{No Public's Panic Run}] \\
&= p_{C=C^{p^*}(X)} \times E[L | C = C^{p^*}(X), \text{No Public's Panic Run}, (z_{C^{p^*}(X)}^* < S)] \\
&\quad + \left(1 - p_{C=C^{p^*}(X)}\right) \times E[L | C = C^{p^*}(X), \text{No Public's Panic Run}, (-M \leq S \leq z_{C^{p^*}(X)}^*)] \\
&= \left[p^* \times L_{C^{p^*}(X)}^D + (1 - p^*) \times E[L_{C^{p^*}(X)}^L] \right]
\end{aligned}$$

where

$$p_C = \text{Conditional Probability of Delink at } (t = 1) = \left[\frac{(\alpha + \beta) \times M - z_C^*}{2\beta M} \right]. \text{ When}$$

$$C = C^{p^*}(X), \text{ we have } p_{C=C^{p^*}(X)} = p^* \text{ and let } z_{C^{p^*}(X)}^* = z_{C=C^{p^*}(X)}^*.$$

$$L_{C^{p^*}(X)}^D = \text{Social Loss from Delink,}$$

$$\begin{aligned}
& \text{given that (i) } C = C^{p^*}(X) \text{ and (ii) No Public's Panic Run} \\
&= E[L | C = C^{p^*}(X), \text{No Public's Panic Run}, (z_{C^{p^*}(X)}^* < S)] \\
&= \left[X + (f_L - f_D) + g \times C^{p^*}(X) \right]
\end{aligned}$$

$$E[L_{C^{p^*}(X)}^L] = \text{Expected Social Loss from Maintaining the Link,}$$

$$\begin{aligned}
& \text{given that (i) } C = C^{p^*}(X), \text{ and (ii) No Public's Panic Run} \\
&= E[L | C = C^{p^*}(X), \text{No Public's Panic Run}, (\alpha - \beta) \times M \leq S \leq z_{C^{p^*}(X)}^*] \\
&= \left[\left(\frac{a}{2 \times \left[z_{C^{p^*}(X)}^* - (\alpha - \beta) \times M \right]} \right) \times \left(z_{C^{p^*}(X)}^* \right)^2 \right]
\end{aligned}$$

Note: We assume the social loss from maintaining the link is zero if the external shock is a capital inflow.

The gain from using reserve commitment $C^{p^*}(X)$ to avert the public's panic run for a government with determination X , $X_{Run}^{p^*} \leq X < X_{Safe}^{p^*}$ is³⁸:

$$\begin{aligned}
& G(X, C = C^{p^*}(X)) \\
&= E[L | C = 0, \text{with Public's Panic Run}] - E[L | C = C^{p^*}(X), \text{No Public's Panic Run}]
\end{aligned}$$

³⁸ As all social losses are denominated in the foreign currency and interest rate for foreign currency is assumed to be zero, there is no time value effect on the future value of social loss.

It is obvious that $\left(\frac{\partial E[L | C = 0, \text{with Public's Panic Run}]}{\partial X}\right) = 1$. With some algebraic manipulations, it can be shown that $\left(\frac{\partial E[L | C = C^{p^*}(X), \text{No Public's Panic Run}]}{\partial X}\right) = 0$. This comes from the optimality of $C^{p^*}(X)$.

Thus,

$$\frac{\partial G}{\partial X} = \left[\left(\frac{\partial E[L | C = 0, \text{with Public's Panic Run}]}{\partial X} \right) - \left(\frac{\partial E[L | C = C^{p^*}(X), \text{No Public's Panic Run}]}{\partial X} \right) \right] > 0$$

Hence, $G(X, C^{p^*}(X))$, is a strictly increasing function of X .

- End of Proof -

A.3 Proof of Proposition (II)

We want to show that if a solution $X^\#$ exists, that it is unique. Let us consider only the relevant situations that $X_L < X_H$, $X_L < X_{Safe}^{p^*}$, $X_H \geq X_{Run}^{p^*}$, and $X_H > X_{Indiff}^{p^*}$. Within this parameter range, we want to show that the function of $G(X = X_L, C = C^{p^*}(X_H))$, the gain of a government of L-type from imitating the H-type by committing $C_H^{p^*}$, is strictly increasing with X_L . If so, $X^\#$ is unique if a solution exists for $0 < X^\# < X_H$. Among other things, this would imply that all governments with sufficiently low X_L (less than $X^\#$) would choose not to commit any reserve (to avert the public's run against the currency board).

Let $z_{C_H^{p^*}}^L$ denote the maximum level of shock realization the government (with X_L and reserve commitment $C_H^{p^*}$) is able and willing to absorb without delinking.

Under perfect information, if a government with X_H commits more than

$$\left(\frac{a \times \bar{Z} - [X_H + (f_L - f_D)]}{g} \right),$$

it will only incur more cost but cannot further increase z_C^* as

$z_C^* = \bar{Z}$, where $\bar{Z} = \min\{R, (\alpha + \beta) \times M\}$. Hence, $C_H^{p^*}$, the minimum reserve commitment for

X_H to avert panic run under perfect information situation, must be equal to or less than

$$\left(\frac{a \times \bar{Z} - [X_H + (f_L - f_D)]}{g} \right), \text{ i.e. } C_H^{p^*} \leq \left(\frac{a \times \bar{Z} - [X_H + (f_L - f_D)]}{g} \right).$$

By the definition, $z_{C_H^{p^*}}^L = \min \left\{ \left(\frac{X_L + (f_L - f_D) + g \times C_H^{p^*}}{a} \right), \bar{Z} \right\}$, and

$$\begin{aligned} & \left(\frac{X_L + (f_L - f_D) + g \times C_H^{p^*}}{a} \right) \\ & \leq \left(\frac{a \times \bar{Z} - (X_H - X_L)}{a} \right) && \text{because } C_H^{p^*} \leq \left(\frac{a \times \bar{Z} - [X_H + (f_L - f_D)]}{g} \right) \\ & < \bar{Z} && \text{because } X_L < X_H, \end{aligned}$$

$$\text{thus } z_{C_H^{p^*}}^L = \left(\frac{X_L + (f_L - f_D) + g \times C_H^{p^*}}{a} \right).$$

Next, let $p_{C_H^{p^*}}^L$ denote the probability of delink at $t=1$ if a government with determination

X_L commits foreign reserve $C_H^{p^*}$ (to mimic X_H), and there is no panic run. Hence,

$$\begin{aligned} & p_{C_H^{p^*}}^L \\ & = \text{Prob}\{\text{Delink} \mid X = X_L, C = C_H^{p^*}, \text{No Public's Panic Run}\} \\ & = \text{Prob}\{S > z_{C_H^{p^*}}^L \mid X = X_L, C = C_H^{p^*}, \text{No Public's Panic Run}\} \end{aligned}$$

As $z_{C_H^{p^*}}^L = \left(\frac{X_L + (f_L - f_D) + g \times C_H^{p^*}}{a} \right)$, we have

$$p_{C_H^{p^*}}^L = \left[\frac{(\alpha + \beta) \times M - z_{C_H^{p^*}}^L}{2\beta M} \right] = (2\beta M)^{-1} \times \left[(\alpha + \beta)M - \left(\frac{X_L + (f_L - f_D) + g \times C_H^{p^*}}{a} \right) \right].$$

Since $X_L < X_{Safe}^{p^*}$ and the public believes that a government with X_H commits $C_H^{p^*}$, there must be a public's panic run if a government with X_L does not commit any reserve. The social loss of a government with X_L with no reserve commitment is

$$\begin{aligned} & E[L \mid X = X_L, C = 0, \text{with Public's Panic Run}] \\ & = [X_L + (f_L - f_D)] \end{aligned}$$

On the other hand, if mimicking X_H can avert a panic run, the expected social loss of a government with X_L with reserve commitment $C_H^{p^*}$ is

$$\begin{aligned}
& E[L | X = X_L, C = C_H^{p^*}, \text{No Public's Panic Run}] \\
&= p_{C_H^{p^*}}^L \times E[L | X = X_L, C = C_H^{p^*}, \text{No Public's Panic Run}, (z_{C_H^{p^*}}^L < S)] \\
&\quad + \left(1 - p_{C_H^{p^*}}^L\right) \times E[L | X = X_L, C = C_H^{p^*}, \text{No Public's Panic Run}, (\alpha - \beta)M \leq S \leq z_{C_H^{p^*}}^L] \\
&= \left[p_{C_H^{p^*}}^L \times L_{X_L, C_H^{p^*}}^D + \left(1 - p_{C_H^{p^*}}^L\right) \times E[L_{X_L, C_H^{p^*}}^L] \right]
\end{aligned}$$

where

$p_{C_H^{p^*}}^L$ = Probability of Delink,

given that (i) $X = X_L$, (ii) $C = C_H^{p^*}$, and (iii) No Public's Panic Run

$$= \left[\frac{(\alpha + \beta) \times M - z_{C_H^{p^*}}^L}{2\beta M} \right]$$

$L_{X_L, C_H^{p^*}}^D$ = Social Loss from Delink,

given that (i) $X = X_L$, (ii) $C = C_H^{p^*}$, and (iii) No Public's Panic Run

$$\begin{aligned}
&= E[L | X = X_L, C = C_H^{p^*}, \text{No Public's Panic Run}, (z_{C_H^{p^*}}^L < S)] \\
&= \left[X_L + (f_L - f_D) + g \times C_H^{p^*} \right]
\end{aligned}$$

$E[L_{X_L, C_H^{p^*}}^L]$ = Expected Social Loss from Maintaining the Link,

given that (i) $X = X_L$, (ii) $C = C_H^{p^*}$, and (iii) No Public's Panic Run

$= E[L | X = X_L, C = C_H^{p^*}, \text{No Public's Panic Run}, (\alpha - \beta)M \leq S \leq z_{C_H^{p^*}}^L]$

$$= \left[\left(\frac{a}{2 \times \left[z_{C_H^{p^*}}^L - (\alpha - \beta) \times M \right]} \right) \times \left(z_{C_H^{p^*}}^L \right)^2 \right]$$

Note: We assume the social loss from maintaining the link is zero if the shock is a capital inflow.

First, it is obvious that $\left(\frac{\partial E[L | X = X_L, C = 0, \text{with Public's Panic Run}]}{\partial X_L} \right) = 1$. Second, it

is easily to show that

$$\frac{\partial C_H^{p^*}}{\partial X_L} = 0, \quad \frac{\partial z_{C_H^{p^*}}^L}{\partial X_L} = \left(\frac{1}{a} \right), \quad \frac{\partial p_{C_H^{p^*}}^L}{\partial X_L} = \left(\frac{-1}{2a\beta M} \right), \quad \frac{\partial L_{X_L, C_H^{p^*}}^D}{\partial X_L} = 1, \text{ and}$$

$$\begin{aligned}
\frac{\partial E[L_{X_L, C_H^{p^*}}^L]}{\partial X_L} &= \left(\frac{-a}{2 \times [z_{C_H^{p^*}}^L - (\alpha - \beta) \times M]^2} \right) \times \frac{\partial z_{C_H^{p^*}}^L}{\partial X_L} \times (z_{C_H^{p^*}}^L)^2 \\
&+ \left(\frac{a}{2 \times [z_{C_H^{p^*}}^L - (\alpha - \beta) \times M]} \right) \times 2 \times z_{C_H^{p^*}}^L \times \frac{\partial z_{C_H^{p^*}}^L}{\partial X_L} \\
&= \left(\frac{z_{C_H^{p^*}}^L}{[z_{C_H^{p^*}}^L - (\alpha - \beta) \times M]} \right) \times \left(1 - \frac{1}{2} \times \left(\frac{z_{C_H^{p^*}}^L}{[z_{C_H^{p^*}}^L - (\alpha - \beta) \times M]} \right) \right)
\end{aligned}$$

Hence,

$$\begin{aligned}
&\frac{\partial E[L | X = X_L, C = C_H^{p^*}, \text{No Public's Panic Run}]}{\partial X_L} \\
&= \left[\frac{\partial p_{C_H^{p^*}}^L}{\partial X_L} \times L_{X_L, C_H^{p^*}}^D + p_{C_H^{p^*}}^L \times \frac{\partial L_{X_L, C_H^{p^*}}^D}{\partial X_L} + \frac{\partial (1 - p_{C_H^{p^*}}^L)}{\partial X_L} \times E[L_{X_L, C_H^{p^*}}^L] + (1 - p_{C_H^{p^*}}^L) \times \frac{\partial E[L_{X_L, C_H^{p^*}}^L]}{\partial X_L} \right] \\
&= \left[\frac{(\alpha + \beta) \times M - z_{C_H^{p^*}}^L}{2\beta M} \right]
\end{aligned}$$

Finally, let us examine the gain of a government with X_L from imitating a government with X_H .

$$\begin{aligned}
&\text{Gain for } X_L \text{ to Imitate } X_H \text{ by Committing } C_H^{p^*} \\
&= G(X = X_L, C = C^{p^*}(X_H)) \\
&= E[L | X = X_L, C = 0, \text{with Public's Panic Run}] - E[L | X = X_L, C = C_H^{p^*}, \text{No Public's Panic Run}]
\end{aligned}$$

It is obvious that

$$\begin{aligned}
&\frac{\partial G(X = X_L, C = C^{p^*}(X_H))}{\partial X_L} \\
&= \left\{ \frac{\partial E[L | X = X_L, C = 0, \text{with Public's Panic Run}]}{\partial X_L} - \frac{\partial E[L | X = X_L, C = C_H^{p^*}, \text{No Public's Panic Run}]}{\partial X_L} \right\} \\
&= \left[\frac{z_{C_H^{p^*}}^L - (\alpha - \beta) \times M}{2\beta M} \right] \\
&> 0
\end{aligned}$$

because $(\alpha - \beta) < 0$ and $0 \leq z_{C_H^{p^*}}^L \leq \bar{Z}$

- End of Proof -

A.4 Proof that $G(X, C)$ is a Decreasing Function of C

To show that conditional on no public panic run, the gain $G(X, C)$ is a decreasing function of C , we consider the following two exhaustive cases:

$$G(X, C) = [X + (f_L - f_D)] - \left\{ \begin{array}{l} p_C \times [X + (f_L - f_D) + g \times C] \\ + (1 - p_C) \times \left[\left(\frac{a}{2 \times [z_C^* - (\alpha - \beta) \times M]} \right) \times (z_C^*)^2 \right] \end{array} \right\}$$

Case 1: $z_C^* = \left(\frac{X + (f_L - f_D) + g \times C}{a} \right) < \bar{Z}$, where $\bar{Z} = \min\{R, (\alpha + \beta) \times M\}$.

$$C = \left[\frac{a \times z_C^* - (X + (f_L - f_D))}{g} \right], \quad p_C = \left[\frac{(\alpha + \beta) \times M - z_C^*}{2\beta M} \right] \quad \text{and}$$

$$1 - p_C = \left[\frac{z_C^* - (\alpha - \beta) \times M}{2\beta M} \right]$$

$$G(X, C) = \left\{ [X + (f_L - f_D)] - \left[\frac{a \times (\alpha + \beta)}{2\beta} \right] \times z_C^* + \left(\frac{a}{4\beta M} \right) \times (z_C^*)^2 \right\}$$

$$\begin{aligned} \frac{\partial G}{\partial C} &= \frac{\partial G}{\partial z_C^*} \times \frac{\partial z_C^*}{\partial C} \\ &= \frac{g}{2\beta} \times \left[\frac{z_C^*}{M} - (\alpha + \beta) \right] \\ &= - \left[\frac{(\alpha + \beta) \times M - z_C^*}{2\beta M} \right] \times g \\ &< 0 \end{aligned}$$

because $0 \leq z_C^* < \bar{Z} \leq (\alpha + \beta) \times M$.

Case 2: $z_C^* = \bar{Z}$

$$p_C = \left[\frac{(\alpha + \beta) \times M - \bar{Z}}{2\beta M} \right] \quad \text{and} \quad 1 - p_C = \left[\frac{\bar{Z} - (\alpha - \beta) \times M}{2\beta M} \right]$$

$$G(X, C) = \left[X + (f_L - f_D) \right] - \left\{ \begin{aligned} & \left[\frac{(\alpha + \beta) \times M - \bar{Z}}{2\beta M} \right] \times \left[X + (f_L - f_D) + g \times C \right] \\ & + \left[\frac{\bar{Z} - (\alpha - \beta) \times M}{2\beta M} \right] \times \left[\left(\frac{a}{2 \times [\bar{Z} - (\alpha - \beta) \times M]} \right) \times \bar{Z}^2 \right] \end{aligned} \right\}$$

$$\frac{\partial G}{\partial C} = - \left[\frac{(\alpha + \beta) \times M - \bar{Z}}{2\beta M} \right] \times g$$

Hence, $\frac{\partial G}{\partial C}$ is $\begin{cases} \text{less than zero} & \text{if } R < (\alpha + \beta) \times M \\ \text{equal to zero} & \text{if } R \geq (\alpha + \beta) \times M \end{cases}$ because

$$\bar{Z} = \min\{R, (\alpha + \beta) \times M\}.$$

In conclusion, $\frac{\partial G}{\partial C} \leq 0$ for all X , given that $0 \leq C \leq R$. Furthermore, $G(X, C)$ is a strictly

decreasing function of C (i.e. $\frac{\partial G}{\partial C} < 0$) unless $z_C^* = (\alpha + \beta) \times M$, which means the delink

probability under commitment policy C is zero. Hence, the existence of solution of C^{Indiff}

implies its uniqueness unless $z_{C=C^{Indiff}}^* = (\alpha + \beta) \times M$.

- End of Proof -

A.5 Proof that $C_L^{Indiff} < C_H^{Indiff}$ if C_L^{Indiff} is Feasible; Otherwise, Both C_L^{Indiff} and C_H^{Indiff} Are Outside of the Feasible Range $[0, R]$

First of all, let us prove the fact that $G(X, C)$ in Equation (8) of Section 3.3 is a strictly increasing function of X for any given C . We consider the following two exhaustive cases:

Case 1: $z_C^* = \left(\frac{X + (f_L - f_D) + g \times C}{a} \right) < \bar{Z}$

$$p_C = \left[\frac{(\alpha + \beta) \times M - z_C^*}{2\beta M} \right] \quad \text{and} \quad 1 - p_C = \left[\frac{z_C^* - (\alpha - \beta) \times M}{2\beta M} \right]$$

$$\frac{\partial z_C^*}{\partial X} = \frac{1}{a}, \quad \frac{\partial p_C}{\partial X} = \frac{\partial p_C}{\partial z_C^*} \times \frac{\partial z_C^*}{\partial X} = \frac{-1}{2\beta M} \times \frac{1}{a} = \left(\frac{-1}{2a\beta M} \right)$$

$$\text{Let } \Delta = \left[\left(\frac{a}{2 \times [z_C^* - (\alpha - \beta) \times M]} \right) \times (z_C^*)^2 \right]$$

$$\begin{aligned} \frac{\partial \Delta}{\partial z_C^*} &= \frac{a}{2} \times \left[-1 \times [z_C^* - (\alpha - \beta) \times M]^{-2} \times (z_C^*)^2 + 2 \times [z_C^* - (\alpha - \beta) \times M]^{-1} \times z_C^* \right] \\ &= \frac{a}{2 \times [z_C^* - (\alpha - \beta) \times M]^2} \times \left[(z_C^*)^2 - 2 \times (\alpha - \beta) \times M \times z_C^* \right] \end{aligned}$$

$$\begin{aligned} \frac{\partial \Delta}{\partial X} &= \frac{\partial \Delta}{\partial z_C^*} \times \frac{\partial z_C^*}{\partial X} = \left(\frac{a}{2 \times [z_C^* - (\alpha - \beta) \times M]^2} \times \left[(z_C^*)^2 - 2 \times (\alpha - \beta) \times M \times z_C^* \right] \right) \times \left(\frac{1}{a} \right) \\ &= \frac{1}{2 \times [z_C^* - (\alpha - \beta) \times M]^2} \times \left[(z_C^*)^2 - 2 \times (\alpha - \beta) \times M \times z_C^* \right] \end{aligned}$$

Hence,

$$\frac{\partial G}{\partial X} = 1 - \left[\frac{\partial p_C}{\partial X} \times [X + (f_L - f_D) + g \times C] + p_C \right] - \left[\frac{\partial(1 - p_C)}{\partial X} \times \Delta + (1 - p_C) \times \frac{\partial \Delta}{\partial X} \right]$$

It can be simplified that

$$\frac{\partial G}{\partial X} = \left[\frac{(\beta - \alpha) \times M + z_C^*}{2\beta M} \right] > 0 \quad \text{because} \quad \alpha < \beta \quad \text{and} \quad 0 \leq z_C^* < \bar{Z} .$$

Case 2: $z_C^* = \bar{Z}$

$$p_C = \left[\frac{(\alpha + \beta) \times M - \bar{Z}}{2\beta M} \right] \quad \text{and} \quad 1 - p_C = \left[\frac{\bar{Z} - (\alpha - \beta) \times M}{2\beta M} \right]$$

$G(X, C)$

$$= [X + (f_L - f_D)] - \left\{ \begin{aligned} &\left[\frac{(\alpha + \beta) \times M - \bar{Z}}{2\beta M} \right] \times [X + (f_L - f_D) + g \times C] \\ &+ \left[\frac{\bar{Z} - (\alpha - \beta) \times M}{2\beta M} \right] \times \left[\left(\frac{a}{2 \times [\bar{Z} - (\alpha - \beta) \times M]} \right) \times \bar{Z}^2 \right] \end{aligned} \right\}$$

$$\frac{\partial G}{\partial X} = \left[\frac{(\beta - \alpha) \times M + \bar{Z}}{2\beta M} \right] > 0 \quad \text{because} \quad \alpha < \beta \quad \text{and} \quad 0 \leq \bar{Z} .$$

Hence, $\frac{\partial G}{\partial X} > 0$ for all X , given that $\alpha < \beta$ and $0 \leq z_C^* \leq \bar{Z} \leq R$.

Given that $G(X, C)$ is a strictly increasing function of X , it is easy to prove (see below) that $C_L^{Indiff} < C_H^{Indiff}$ if C_L^{Indiff} is feasible; (i.e., $G(X = X_L, C = C_L^{Indiff}) = 0$, $0 \leq C_L^{Indiff} \leq R$). In this case, $G(X = X_H, C = C_L^{Indiff}) > 0$ because $\frac{\partial G}{\partial X} > 0$. Furthermore, according to Appendix A.4, $\frac{\partial G}{\partial C} \leq 0$. Hence, if $G(X = X_H, C = C_H^{Indiff}) = 0$, we must have $C_L^{Indiff} < C_H^{Indiff}$. On the other hand, if C_L^{Indiff} is outside of the feasible range $[0, R]$ (i.e., $G(X = X_L, C) > 0$ for any $0 \leq C \leq R$), $G(X = X_H, C) > 0$ for any $0 \leq C \leq R$ because $\frac{\partial G}{\partial X} > 0$. Hence, C_H^{Indiff} is also outside of the feasible range.

- End of Proof -

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Figure 1

Time Line for the One-Period Model



Given the foreign reserve level (R), fundamental values (F_D, F_L), the government's determination (X) and other parameters, the public will panic run (sell Q^* of domestic currency) if the implied delink probability p is higher than the threshold p^* .

If there is a panic run against the currency board, the government has no choice but to abandon the currency board *involuntarily*.

If there is no panic run at $t=0$, the decision for the abandonment of currency board will be made at time $t=1$.

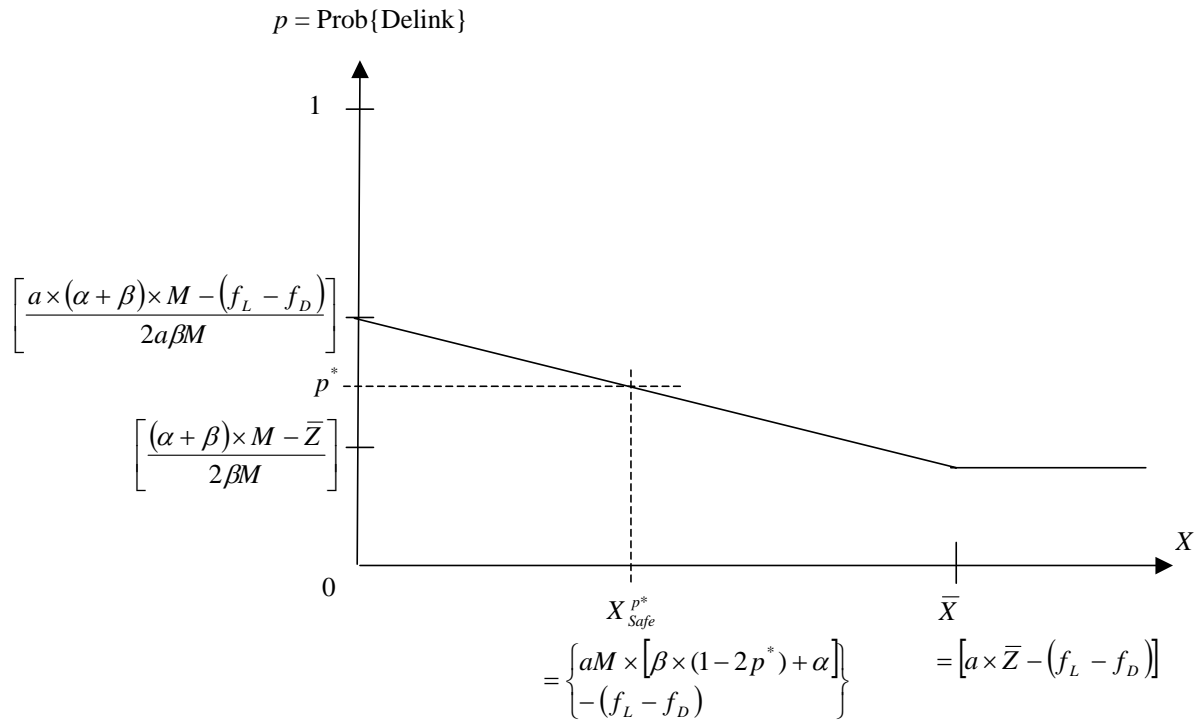
The realization of capital outflow shock (S) is publicly observable.

If the capital outflow shock is larger than the foreign reserve holding, the government will abandon the currency board *involuntarily*.

Otherwise, the government can decide whether to maintain or *voluntarily* abandon the currency board in accordance with its social loss function.

Figure 2

Threshold Probability (p^* , the Public's Risk Tolerance) and the Implied Delink Probability at $t=1$ as a Function of the Government's Determination X



A government with low X may use commitment policy (C) to avert public's panic runs.

where $\bar{Z} = \min\{R, (\alpha + \beta) \times M\}$

Figure 3

Realization of Capital Outflow Shock and Government's Decision
Conditional on a Foreign Reserve Commitment Policy (C)

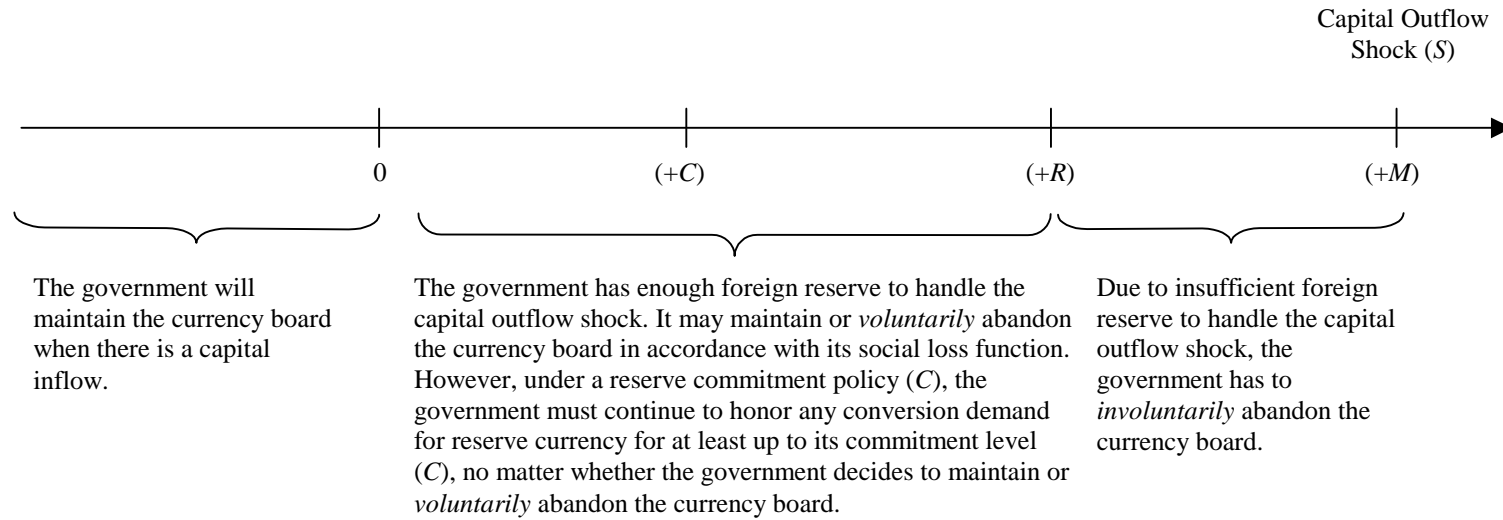


Figure 4

Gain from Using $C^{p^*}(X)$ to Avert Public's Panic Selling

With perfect information on X , the gain of a government with determination X (value on the X-axis) from using reserve commitment $C^{p^*}(X)$ to avert a public's panic run is $G(X, C = C^{p^*}(X))$, which is the difference between the expected social loss with a panic run, $E[L | C = 0, \text{with Panic Run}]$, and the expected social loss under reserve commitment policy $C^{p^*}(X)$ and no panic run, $E[L | C = C^{p^*}(X), \text{without Panic Run}]$. The $X_{Indiff}^{p^*}$, the X-intercept for $G(X, C = C^{p^*}(X))$, is the critical value of determination such that a government with $X_{Indiff}^{p^*}$ is indifferent to abandoning the currency board versus averting panic run by committing $C^{p^*}(X)$.

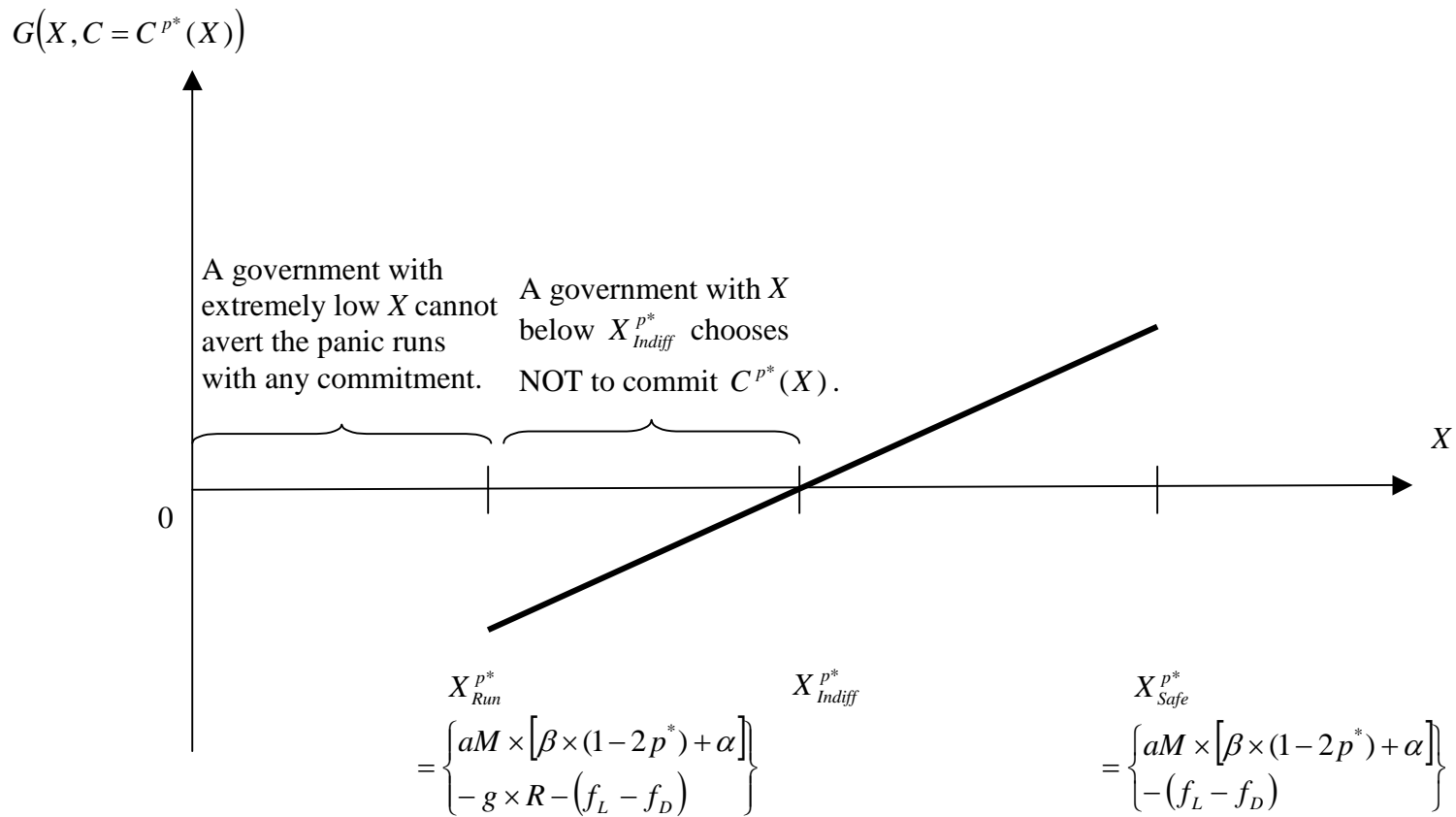


Figure 5

Gain to a Government with X_L from Imitation if a Government with X_H Commits $C_H^{p^*}$

With asymmetric information on the government's determination X , the imitation gain of a government with a low determination X_L (value on the X-axis) from using reserve commitment $C_H^{p^*}$ to imitate a government with high determination X_H , is $G(X = X_L, C = C_H^{p^*})$, which is the difference between the expected social loss to X_L with a panic run, $E[L | X = X_L, C = 0, \text{with Panic Run}]$, and the expected social loss under reserve commitment policy $C_H^{p^*}$ and no panic run, $E[L | X = X_L, C = C_H^{p^*}, \text{without Panic Run}]$. The $X^\#$, the X-intercept for $G(X = X_L, C = C_H^{p^*})$, is the critical value of determination such that a government with $X^\#$ is indifferent to imitating the X_H with committing $C_H^{p^*}$ versus not committing.

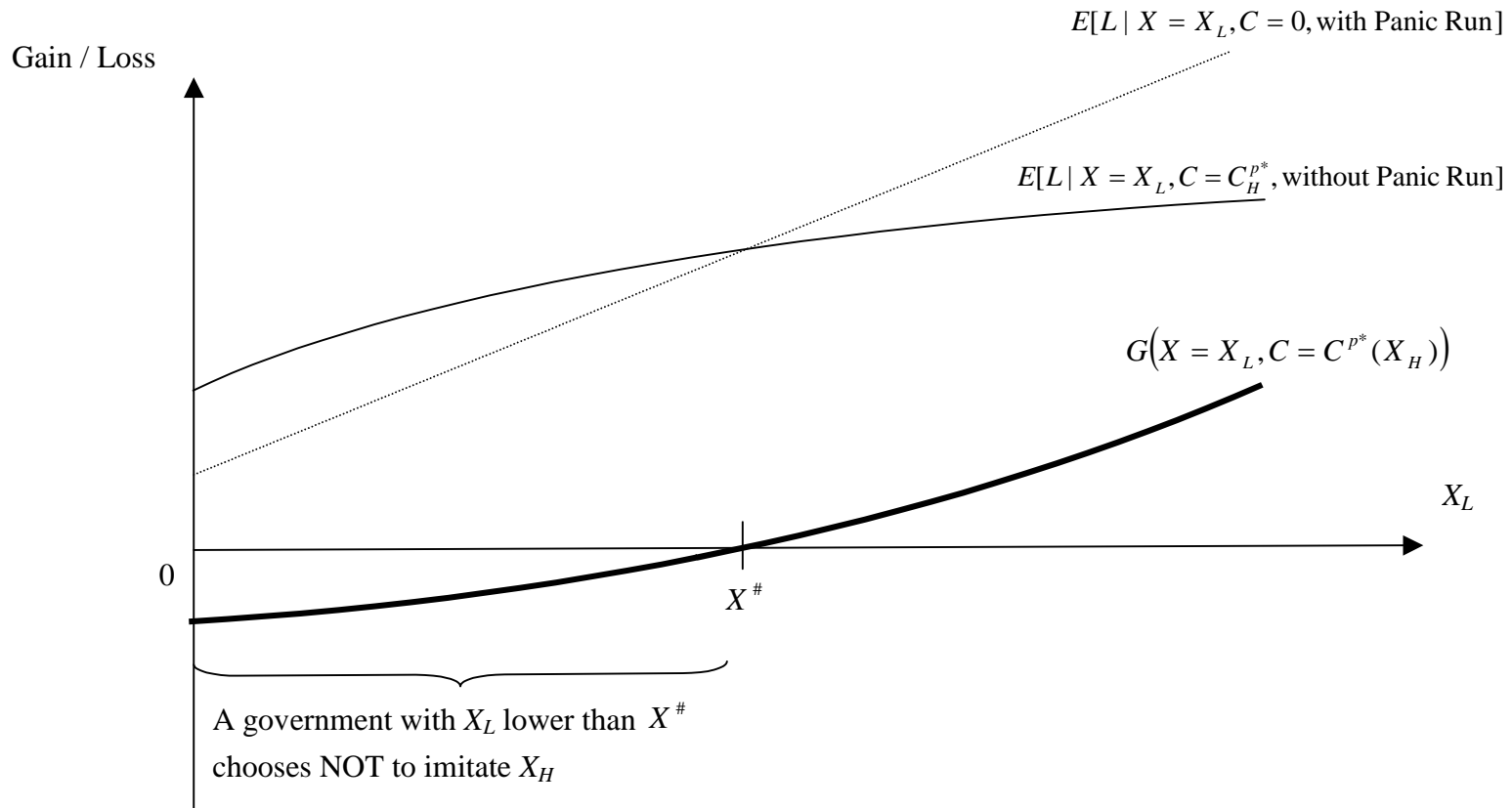


Figure 6

Hong Kong's Simulation: Optimal Reserve Commitment for a Large X_H ($X_H = 3 > X_{Safe}^{p*}$)

Given that $a=0.5$, $(f_L-f_D)=1$, $g=0.35$, $p^*=0.1$, $M=20$, $\alpha=0.05$, $\beta=0.4$, $R=8$, and $X_H=3$ ($X_H > X_{Safe}^{p*}$), with perfect information, a government with X_H will not face any panic run. With asymmetric information on the government's determination X , if the public underestimates its determination to be X_L (value on the X-axis), the government may have to commit some reserves to avert panic runs in accordance with the public's estimate X_L . Case (i): if $X_L < X_{Sep}^{p*}$, the government will commit C_L^{Indiff} , which is the reserve commitment such that X_L is indifferent to imitating X_H (separating equilibrium). Case (ii): if $X_{Sep}^{p*} \leq X_L < X_{Safe}^{p*}$, the government will commit C_L^{p*} (good pooling equilibrium). Case (iii): if $X_{Safe}^{p*} \leq X_L$, the government does not need to commit any reserve (good pooling equilibrium).

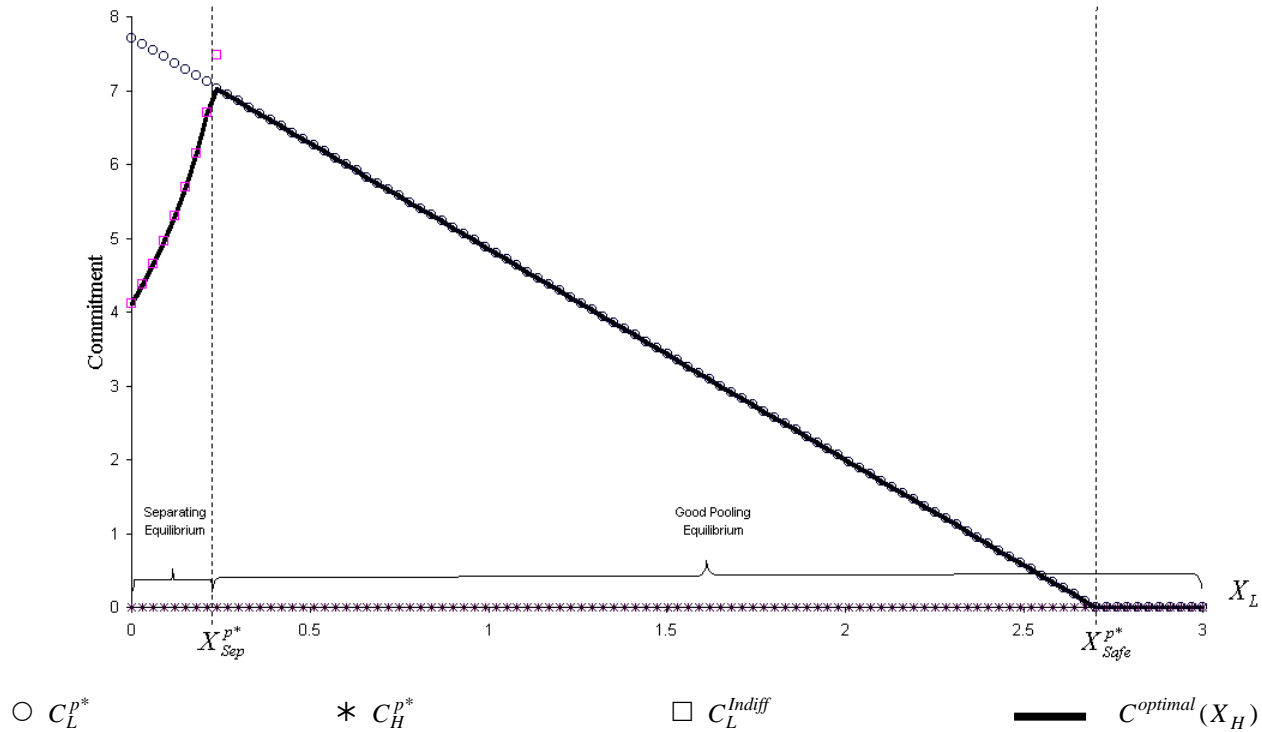


Figure 7a

Argentina's Simulation (a): No Feasible Reserve Commitment to Avert Panic Runs

Given that $a=1$, $(f_L-f_D)=1$, $g=0.35$, $p^*=0.1$, $M=20$, $\alpha=0.1$, $\beta=0.4$, $R=10$, and $X_H=3$ ($X_H < X_{Safe}^{p^*}$), even with perfect information, a panic run is unavoidable because a government with X_H has to commit 12.6 to avert a panic run but the available reserve is only 10. Hence, $C_H^{p^*}$ is outside of the feasible range.

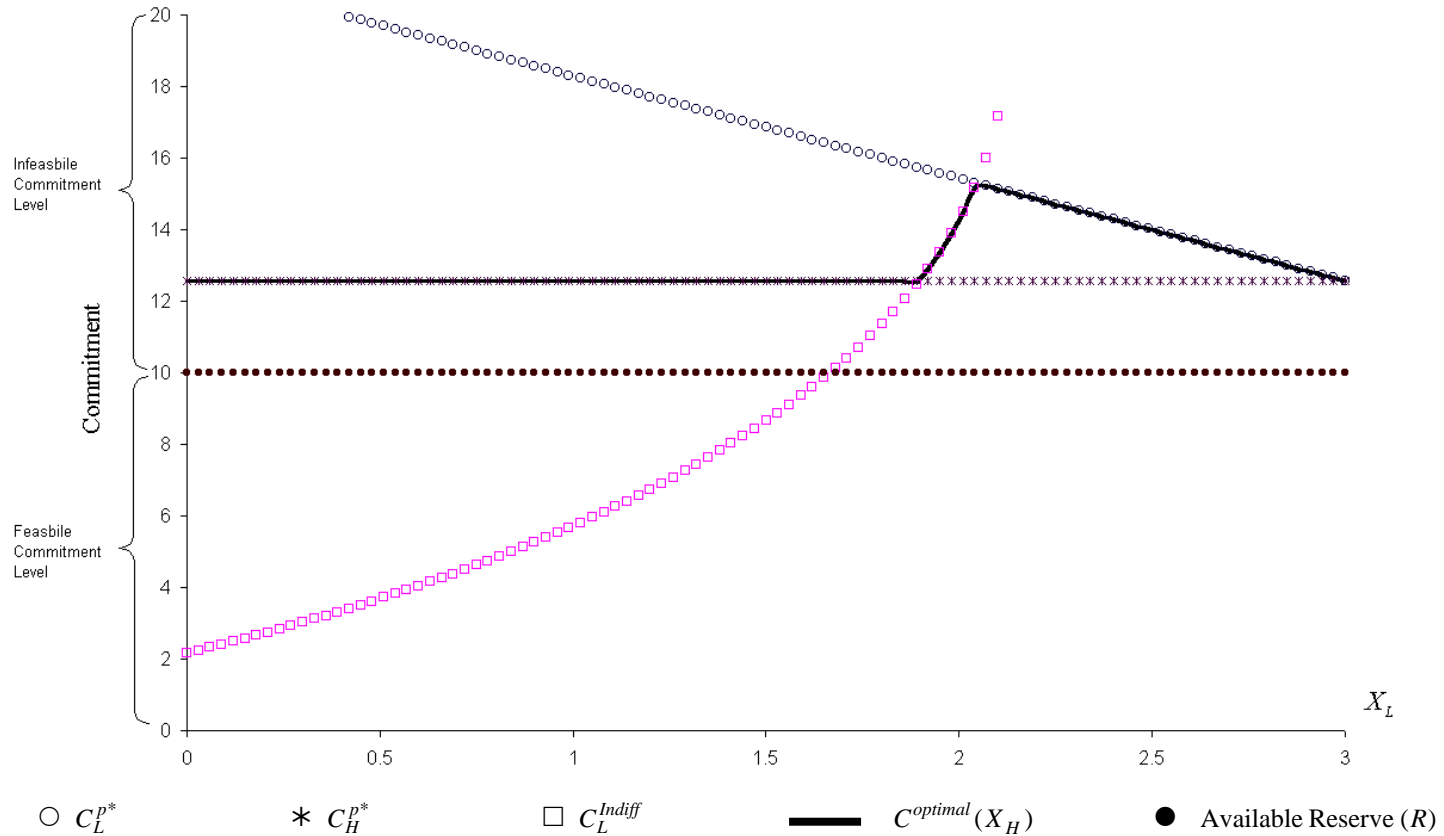


Figure 7b

Argentina's Simulation (b): Existence of Feasible Reserve Commitment to Avert Panic Runs for Larger X_H

Given that $a=1$, $(f_L-f_D)=1$, $g=0.35$, $p^*=0.1$, $M=20$, $\alpha=0.1$, $\beta=0.4$, $R=10$, and $X_H=4$ ($X_H < X_{Safe}^{p^*}$), with perfect information, a government with X_H has to commit $C_H^{p^*} = 9.7$ to avert panic runs. Under asymmetric information on the government's determination X , if the public underestimates its determination to be X_L (value on the X-axis), the government may have to commit more reserves to avert panic runs in accordance with the public's estimate, X_L . Case (i): if $X_L < X_{Sep}^{p^*}$, the government will commit $\max\{C_H^{p^*}, C_L^{Indiff}\}$ (separating equilibrium). Case (ii): if $X_{Run}^{p^*} \leq X_L < X_H$, the government will commit $C_L^{p^*}$ (good pooling equilibrium). Case (iii): if $X_{Sep}^{p^*} \leq X_L < X_{Run}^{p^*}$, due to limited reserves the government cannot commit enough to separate itself from X_L to avert panic runs (bad pooling equilibrium).

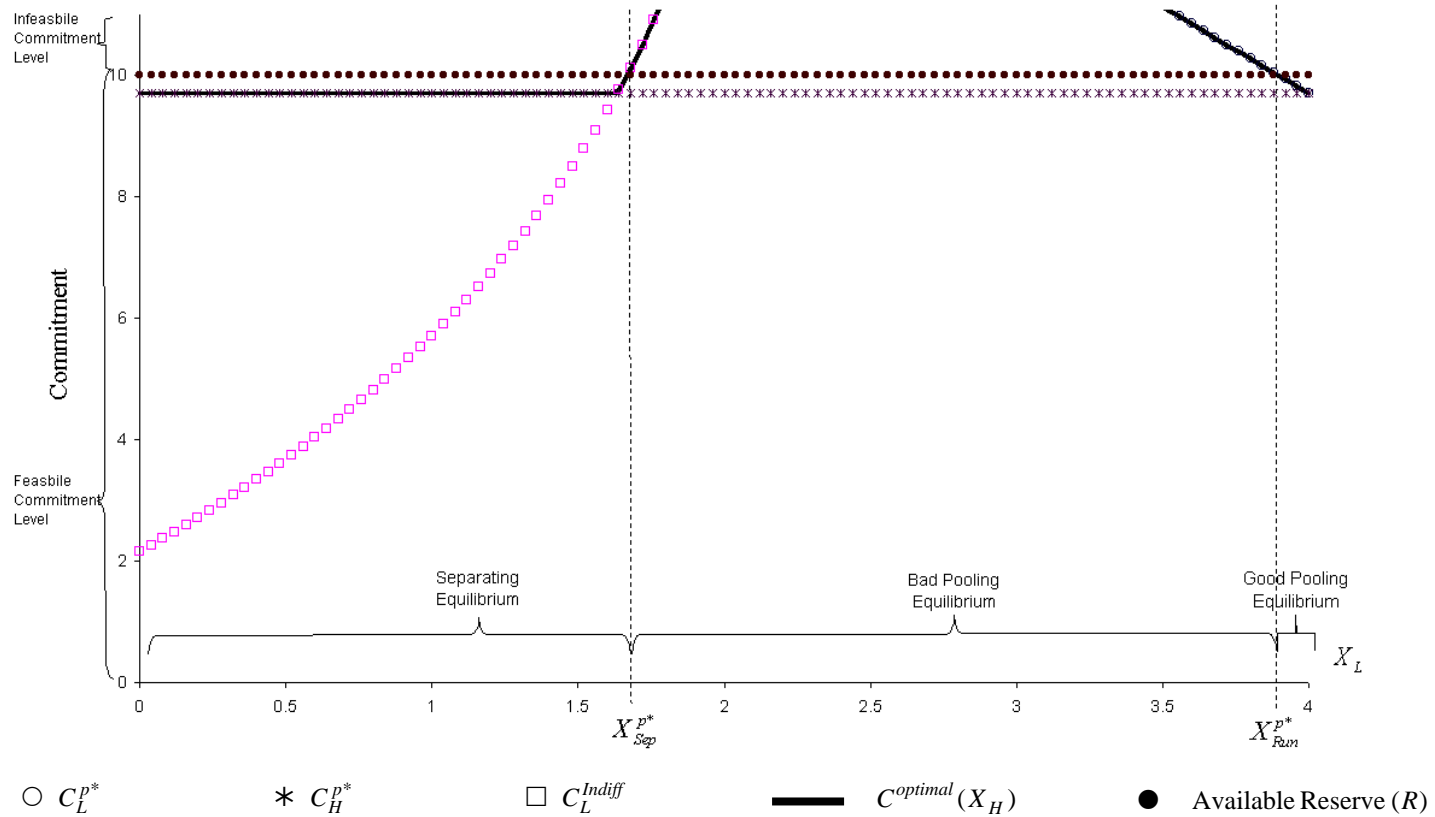


Figure 7c

Argentina's Simulation (c): Existence of Feasible Reserve Commitment to Avert Panic Runs for Large X_H and Small a

Given that $a=0.5$, $(f_L-f_D)=1$, $g=0.35$, $p^*=0.1$, $M=20$, $\alpha=0.1$, $\beta=0.4$, $R=10$, and $X_H=3$ ($X_H < X_{Safe}^{p^*}$), with perfect information, a government with X_H has to commit $C_H^{p^*} = 0.57$ to avert panic runs. With asymmetric information on the government's determination X , if the public underestimates its determination to be X_L (value on the X-axis), the government may have to commit extra reserves to avert a public panic run in accordance with the public's estimate, X_L . Case (i): if $X_L < X_{Sep}^{p^*}$, the government will commit C_L^{Indiff} (separating equilibrium). Case (ii): if $X_{Sep}^{p^*} \leq X_L < X_H$, the government will commit $C_L^{p^*}$ (good pooling equilibrium).

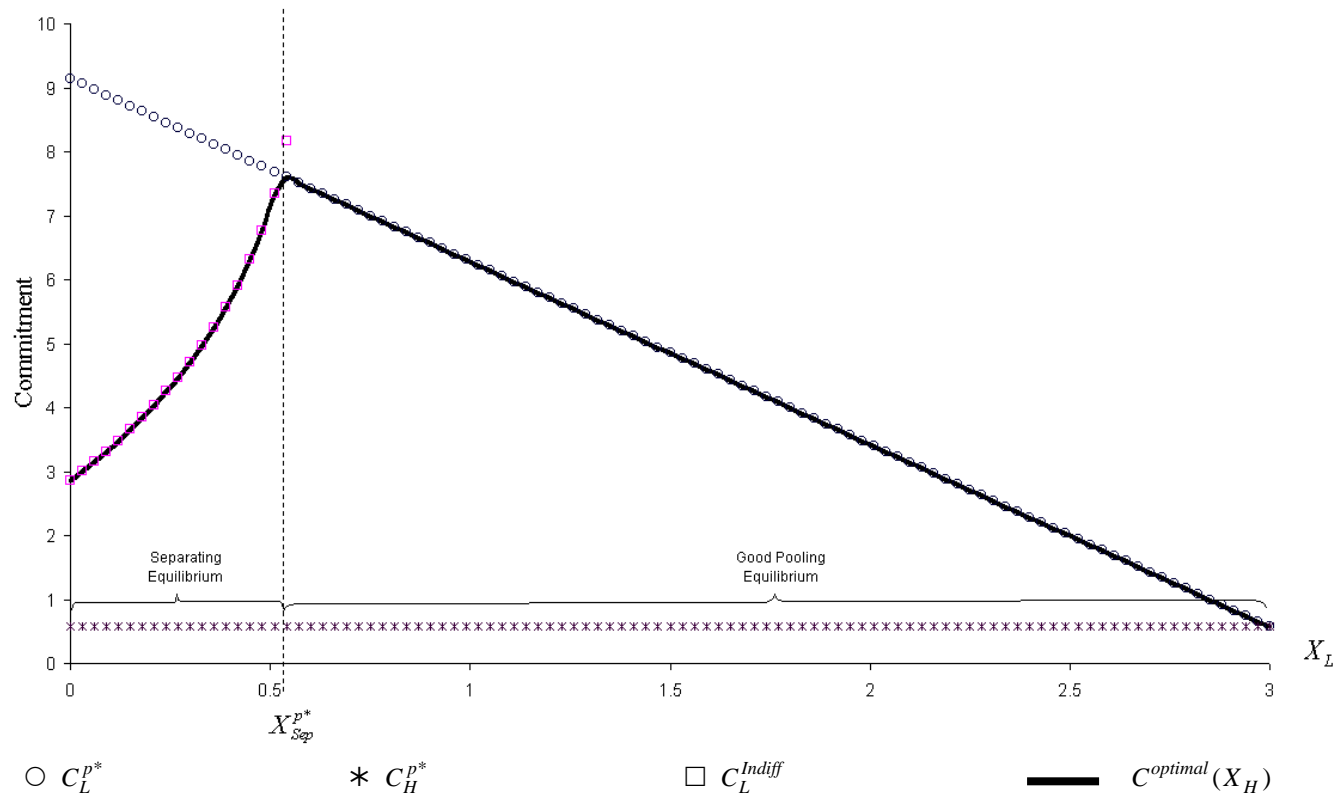


Figure 8

Robustness Simulation (c): Optimal Reserve Commitment for a Concave Function $g(R)$ and a Convex Function of $a(S)$ with a Quadratic Term in S

Given that $g(R) = \bar{R}^{(1-0.15)} \times R^{0.15}$, $a(S) = [g(\bar{R}) - g(\bar{R} - S)] + 0.5 \times S^2$, $(f_L - f_D) = 1$, $p^* = 0.1$, $M = 20$, $\alpha = 0.05$, $\beta = 0.1$, $\bar{R} = 8$, and $X_H = 3$ ($X_H > X_{Safe}^{p^*}$), with perfect information, a government with X_H will not face any panic run. With asymmetric information on the government's determination X , if the public underestimates its determination to be X_L (value on the X-axis), the government may have to commit some reserves to avert panic runs in accordance with the public's estimate X_L . Case (i): if $X_L \leq X_{Sep}^{p^*}$, the government will commit $C_L^{p^*}$ (separating equilibrium). Case (ii): if $X_{Safe}^{p^*} \leq X_L$, the government does not need to commit any reserve (good pooling equilibrium). Case (iii): if $X_{Sep}^{p^*} < X_L < X_{Safe}^{p^*}$, the government will commit $C_L^{p^*}$ (good pooling equilibrium).

