WP/01/213

IMF Working Paper

A Model of the Joint Distribution of Banking and Exchange-Rate Crises

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INTERNATIONAL MONETARY FUND

 WP/01/213

IMF Working Paper

Research Department

A Model of the Joint Distribution of Banking and Exchange-Rate Crises

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Authorized for distribution by Kenneth Rogoff

December 2001

Abstract

We develop a simple framework for studying the joint distribution of banking and currency crises triggered by real shocks. Our framework illustrates the fact that bank and currency collapses are related but they are not the same thing. Studying currency and bank collapses either in isolation or in perfect correlation with each other is inappropriate, producing biased estimates of the likelihood of crises.

JEL Classification Numbers: F30, F34

Keywords: Currency crisis, bank crisis

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I. Introduction

We develop a framework for studying the joint distribution of banking and currency crises. Previous work has examined these crises either in isolation or in perfect correlation. Our motivation for extending this work is the observation that during the Mexican and Asian financial crises of the 1990s, both fixed exchange rates and banks collapsed, while in other historical periods fixed exchange rates collapsed without bank collapses or banks failed without a simultaneous collapse of the currency. The crises are related, but they are not the same thing. Put differently, the correlation of the two may be positive but it is not necessarily unity. Most importantly, studying these crises either in isolation from each other or without distinction from each other may produce biased estimates of the likelihood of crises.

Our framework builds on the early balance-of-payments crisis models of Krugman (1979) and Flood and Garber (1984) (KFG).[2] Those models developed the private sector's reaction to inconsistent government commitments to both exchange-rate fixing and to financing a primary fiscal deficit. The results of the policy inconsistency are well known. Here we discard the notion that a currency crisis is inevitable because the government finances a persistent deficit. Instead, we add to the fixed exchange-rate promise a second government price-fixing promise involving bank deposits.

Our modeling is shaped by three important features of the Asian crisis. First, commercial banks dominated the financial systems in the Asian crisis countries. In Indonesia, commercial banks accounted for 84 percent of total assets in the financial sector at the end of 1996. In Korea, the figure was 52 percent, while in Thailand it was 64 percent and in the Philippines, 82 percent (Lindgren, et al., 1999)

Second, when there were bank failures, depositors and creditors of financial institutions were paid off at full book value. Governments introduced blanket guarantees

[2] These models build on the gold price-fixing model of Salant and Henderson (1978). We retain the spirit of these models by requiring foreign-currency reserves to be constant after a crisis.

for depositors and creditors of financial institutions shortly after the crisis started.[3] They did so in order to stabilize funding for banks and prevent bank runs.[4]

Third, the estimated fiscal costs of restructuring financial institutions in the Asian countries dwarf the costs associated usually with balance-of-payments crises studied in isolation.[5] According to Lindgren et al., (1999), the gross public sector costs associated with financial-sector restructuring will be over 45 percent of GDP in Indonesia, about 25 percent of GDP in Thailand, 15 percent in Korea and about 10 percent in Malaysia.[6] Initially, the costs were born mainly by central banks in the form of liquidity support to ailing banks.[7] Governments tried to sterilize this liquidity support, and they were largely successful in Korea and Thailand. As the situation stabilized, governments began refinancing the liquidity by issuing domestic government bonds. The full costs to the fiscal authorities will not be known for years, however, and will depend on the amount of additional losses uncovered as well as the proceeds from asset sales and reprivatization.

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[3] Indonesia's blanket guarantee was established after its attempt to provide a limited guarantee failed. Only the Philippines did not see the need to adopt a blanket guarantee, since it already had a well-established limited deposit insurance scheme. For the Asian crisis countries adopting blanket guarantees, the guarantees did not apply to shareholders and holders of subordinated debt. In Indonesia, insider deposits were not covered by the guarantee, while in Thailand, the deposits of directors and related persons were not covered unless they were shown to be at "arms length." (Lindgren, et al., (1999)). The blanket guarantees were announced as temporary, meant to maintain confidence during a period of restructuring. In Korea, the guarantee is expected to expire by the end of the year 2000. No explicit expiration date has been announced in Thailand and Malaysia. In 1999, Indonesia extended the guarantee for at least two more years, with a six-month advance notice promised before the guarantee is lifted. (Lindgren, et al., (1999)).

[4] According to Lindgren et al., (1999), the guarantees were effective in stabilizing banks' domestic funding, although in some cases it took some time to gain credibility, but were less effective in stabilizing banks' foreign funding.

[5] Normally, the main costs associated with balance-of-payments crises are expressed in terms of the capital gain forgone by the government on international reserve losses.

[6] These estimates are projections by national authorities and IMF staff. Merrill Lynch (1999) estimated recapitalization requirements for commercial banks (just one component of gross costs) at 42 percent for Indonesia, 26 percent for Thailand, 10 percent for Korea, and 11 percent for Malaysia.

[7] The initial liquidity support was denominated in domestic currency for all affected countries except Korea, where the Bank of Korea also provided $23.3 billion in foreign-currency support to commercial banks. The amounts of liquidity support were especially large in Thailand and Indonesia, where the stock of support at its peak was 22 percent of GDP in Thailand and 17 percent of GDP in Indonesia. (Lindgren, et al., (1999)).

These three facts about the Asian crisis guide our modeling in straightforward ways. To the KFG framework, we must add commercial banks whose depositors are well-insured. We also need to pay careful attention to the financing of financial restructuring. In the actual crisis these costs were enormous, and we will allow them to dominate our modeling effort.

The results of the modeling effort are appealing and are easily extended. Government guarantees—explicit or implicit—to possibly fragile banks or other firms undermine the fixed exchange rate. All government promises rely in one way or another on the government's ability and willingness to extract resources from the private sector. Each new resource-extracting promise added to previous government commitments affects the government's ability to make good on the old ones. If pay-outs on government promises are positively correlated, then adding an additional promise weakens the government's ability to fulfill the other ones.

Usually, economists have not modeled bank and currency collapses in a single framework. For example, the Chang-Velasco models developed after the Asian crises(1998a,1998b, 1998c) are open-economy versions of the Diamond-Dybvig (1983) bank-run model. The foreign exchange market is left unspecified. The link between bank and currency collapses is inferred rather than modeled. Banks collapse because they face a sudden liquidity problem—unexpectedly heavy deposit withdrawals exceed the fire-sale value of their illiquid assets. If the government injects new liquidity to save the banks, it risks a currency collapse when private agents convert the new liquidity into foreign exchange. If the government chooses not to inject new liquidity, the banks collapse. In the face of a liquidity crisis, it appears that either the banks collapse or the fixed exchange rate does.

In Dooley (1998), the focus is again on banks (and firms), with the foreign-exchange market left unspecified. When banks' foreign-currency liabilities increase to the point where they match the foreign-currency assets backing them, there is a predictable bank run and collapse. Again, the link between bank and currency collapses is inferred. Because the government exhausts its foreign-currency assets to help pay off bank promises, it can no longer support its fixed exchange rate. The presumption is that bank and currency collapses occur together.

Allen and Gale (1999) study bank and currency collapses following a shock to bank asset returns. Again, no foreign exchange market is modeled. In the event of bank collapse, an optimal allocation requires the adoption of a flexible exchange. Thus bank and currency collapses occur together.

Buch and Heinrich (1999) and Burnside, Eichenbaum and Rebelo (2000) depart from previous work by modeling both bank and currency collapses. Buch and Heinrich add a banking sector to the KFG set up. A bad shock to bank asset returns lowers the net worth of banks and increases their cost of foreign borrowing. Since the government is already monetizing a fiscal deficit and losing international reserves, the decline in foreign borrowing speeds up the inevitable collapse of the fixed exchange rate.

Burnside et al. (2000), add a banking sector to a model of a self-fulfilling currency crisis along the lines of Obstfeld (1986). In their model, agents believe that if there is a successful attack on the currency, monetary policy will become more expansionary and validate their beliefs about currency depreciation. So speculators attack, and the monetary expansion does follow because the currency collapse increases the domestic-currency value of banks' foreign liabilities and requires a bank bailout financed partly by money creation. Thus a sudden shift in market expectations triggers both a currency collapse and a bank collapse.

In our work, we model both bank and currency collapses but these collapses need not occur together. The range of possible outcomes corresponds more closely to historical experience, where there have been periods characterized only by banking crises, periods with only currency crises, and periods with both occurring together (twin crises). (Bordo and Eichengreen (1999), Kaminsky and Reinhart (1999)). Our framework allows us to calculate the probability of each outcome and identify some factors that influence these probabilities.[8]

The rest of the paper is organized as follows. Section II lays out the model. Section III analyzes the probabilities of various types of collapses using a simple graphical apparatus. Section IV investigates collapse probabilities under an alternative public financing scheme for depositor bailouts. Section V raises some concerns about the way crises are modeled and draws some conclusions.

II. The Model

We study a small, open economy with a fixed exchange rate and a banking system that includes foreign-currency-denominated liabilities. The environment is stochastic and agents have rational expectations. Bank and currency collapses result from current and accumulated bad shocks to fundamentals.[9] There is a single, economy-wide real shock that affects returns on bank assets, the demands for assets and government financing. Following a shock, the economy adjusts to a new equilibrium that is unique except in certain regulatory environments.

What are the conditions that trigger a bank or currency collapse? Our banks fail because they are broke, not because they face a liquidity problem. Banks fail when their liabilities exceed their assets. We call such an outcome a "bank collapse." The fixed exchange rate collapses when currency speculators rush to purchase all the government's

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[8] In future work we plan to calibrate the model to actual crisis countries to determine numerical probabilities.

[9] Bad shocks that led to depositor bailouts in previous periods imply that the economy carries a larger stock of domestic credit or debt in the present and consequently has a more fragile currency peg.

international reserves committed to defense of the fixed rate. Speculators act the moment the shadow exchange rate exceeds the fixed rate, where the shadow rate is the flexible exchange rate that would prevail after the government's committed international reserves are exhausted (Flood and Garber (1984)). We call a successful speculative attack a "currency collapse."

In our small economy banks are regulated strictly and behave mechanically.[10] To start a bank, an agent needs a license. The government distributes these licenses free of charge to favored insiders.[11] There is no requirement for bank owners/managers to capitalize the bank. Furthermore, should the banks go broke, the owners file for bankruptcy, watch as their remaining assets are distributed to creditors and then exit as they arrived—with nothing.[12] Banks play a valuable role in this economy because agents prefer using bank deposits and the attached government-supported clearing mechanism to make transactions. The government stands behind these deposits, pledging to bail out depositors should banks fail.[13] Other roles for banks, such as pooling risks, are not explored here.

We assume also that our small economy is integrated fully into the international capital markets and that integration is invariant to crises.[14] Except for government regulations on banks' foreign-currency-denominated liabilities, there are no government controls on trade in financial assets.

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[10] While there are many ways to extend our model, making the banks less mechanical looks very promising.

[11] We allow bank licenses to be priced and traded in a secondary market. Alternatively, we could have included bank-license sales as a government revenue source. This choice effects our results and we comment on it below.

[12] In the Indonesian crisis, "(t)he president's son, whose Bank Andromeda had been closed on November 1, (1997) was allowed to take over the small Alpha Bank, which was immediately granted a foreign exchange license by Bank Indonesia,..., effectively reopening his former bank under a new name." (Lindgren et al. (1999), p. 59).

[13] The full government bailout of depositors is an extremely important assumption that simplifies the presentation enormously. It also reflects the situation in the Asian crisis, where blanket guarantees to depositors were announced once the severity of the crisis was understood. The full depositor bailout assumption is easily relaxed. Below we will treat the degree of government insurance as a policy. Then the banking-deposit equilibrium is essentially equivalent to the fixed exchange rate equilibrium. Indeed, the bank is treated simply as a semi-private authority that tries to fix the price of its deposits at unity in terms of domestic currency.

[14] Our analysis would be quite different if the country's capital market integration were crisis dependent, e.g., importers could not obtain foreign exchange during a crisis period.

The government's budget constraint is satisfied in one of two ways. In our first example, which is simple but not very realistic, depositor bailouts are financed by domestic credit creation. This case is straightforward because it builds directly on the KFG model. Our second case is more realistic—depositor bailouts are financed by government debt and international reserves. In addition, the government manages the domestic-currency interest rate so as to stabilize money demand absent real shocks to money demand.[15] We start with the first case because it is familiar and it allows us to build quite simply a graphical apparatus appropriate for more complex environments such as the second case.

We now specify the model in greater detail, describing first an economy with a fixed exchange rate where the government monetizes the cost of any depositor bailouts.

A. The Banks

We wish to determine how bad a shock must be to push banks to the break-even point, where bank assets just match bank liabilities. We begin by describing bank balance sheets.

Commercial banks accept domestic-currency deposits whose nominal value in levels is DD. The banks are required to hold a fraction of their demand deposits at the central bank as non-interest-bearing required reserves. Even if there is no reserve requirement, banks choose to hold this fraction of deposits for clearing purposes. Deposit liabilities net of these reserves is γDD, where $0<\gamma<1$.

At the end of time t-1 but before time t shocks are realized, banks take in deposits for time t and transform them net of required (riskless) reserves into risky productive investments, whose nominal value is A_{t-1}.[16] At time t, these investments yield an uncertain return whose value is:

$$R_t = 1 + (1-\beta)r_t + \beta(s_t - \bar{s}) \tag{1}$$

R_t is the gross return, which consists of three components: the first is unity as usual; the second is $(1-\beta)r_t$, with $(1-\beta)$ being the portion of γDD invested in home-currency-return assets and r_t the real shock that drives this model; the third is $\beta(s_t - \bar{s})$, which is

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[15] According to Lindgren, et al. (1999), "(m)onetary policy in all countries focussed on the exchange rate, short-term interest rates and the level of international reserves, rather than on traditional monetary aggregates, which had become unstable."

[16] We call all of the safe assets "reserves." The risky assets will be divided between domestic-currency-denominated investments and foreign-currency-denominated assets (liabilities).

the percentage capital gain (loss) from foreign-currency denominated assets (liabilities). The level exchange rate is S_t. Its log is s_t and $\bar{s}$ is the log of the fixed exchange rate.

Think of a scenario where the bank borrows foreign-currency-denominated bonds at the fixed exchange rate. As an example, suppose they do not cover their exchange-rate risk and that the foreign interest rate is constant and set at zero. The stochastic return on this portfolio is then approximated by (1), with $\beta < 0$. Another example we shall study has the banks covering their foreign-currency exposure in the manner of risk-neutral agents. Then the third term in (1) would be $\beta(s_t - E_{t-1}s_t)$, where $E_{t-1}s_t$ is the time t-1 rational expectation of s_t. Alternatively, if banks were to cover fully their foreign-exchange exposure, such exposure would not be part of the bank return and $\beta = 0$ in (1).

We assume that both β ($\beta \lesseqgtr 0$) and the degree of foreign-currency exposure are regulated exogenously by the government.[17]

At time t-1, the balance sheet of commercial banks is

Assets	Liabilities
A_{t-1}	γDD_{t-1}
	$NW_{t-1} = 0$

(2)

where the absence of capitalization indicates that the banks' net worth, NW, is zero. Productive investments, A_{t-1}, are held in the form of domestic-currency-denominated assets and foreign-currency-denominated assets (liabilities).

At time t, the balance sheet of banks is:

Assets	Liabilities
R_tA_{t-1}	γDD_{t-1}
	NW_t

(3)

[17] In future work we plan to discuss scenarios where the exposure is set optimally by the banks to match their objectives or by government regulators to match their aims.

At time t, banks just break even when their net assets (R_tA_{t-1}) equal their deposit liabilities (γDD_{t-1}). Since $A_{t-1} = \gamma DD_{t-1}$ from time t-1, we know that banks are at the break-even point at time t when:[18]

$$R_t = 1, \text{ or} \tag{4}$$

$$0 = (1-\beta)r_t + \beta(s_t - \bar{s})$$

Figure 1 plots equation (4). Define $\tilde{s}$ to be the shadow (log) exchange rate, the value a flexible exchange rate would take if the exchange-rate peg were attacked successfully. If $\tilde{s} < \bar{s}$, speculators take capital losses if they successfully attack the exchange rate, so there is no attack and $s_t = \bar{s}$. If instead $\tilde{s} \geq \bar{s}$, speculators can make capital gains, so they attack and $s_t = \tilde{s}$. Figure 1 plots the break-even points for banks, with r and s on the axes. Either the exchange rate is fixed at $\bar{s}$ or it is variable for values above $\bar{s}$. When $s_t = \bar{s}$ in equation (4), the value of the shock that equates bank assets and liabilities is $r_t = 0$. If the shadow rate should exceed the fixed exchange rate, the fixed exchange rate collapses, and the shadow rate becomes the operative exchange rate. Then $s_t = \tilde{s}_t$ in equation (4) and the shock that drives banks to the break-even point is $r_t = \frac{-\beta(\tilde{s}_t - \bar{s})}{1-\beta}$. The exchange rate that drives banks to the break-even point is $\tilde{s}_t = \bar{s} - \frac{(1-\beta)r_t}{\beta}$.

If R falls below one, the banks collapse and the government fully compensates depositors for the deposits that banks are unable to redeem at par. The depositor bailout is financed by unsterilized credit creation. If $R \geq 1$, banks are solvent and there is no credit creation. Thus:

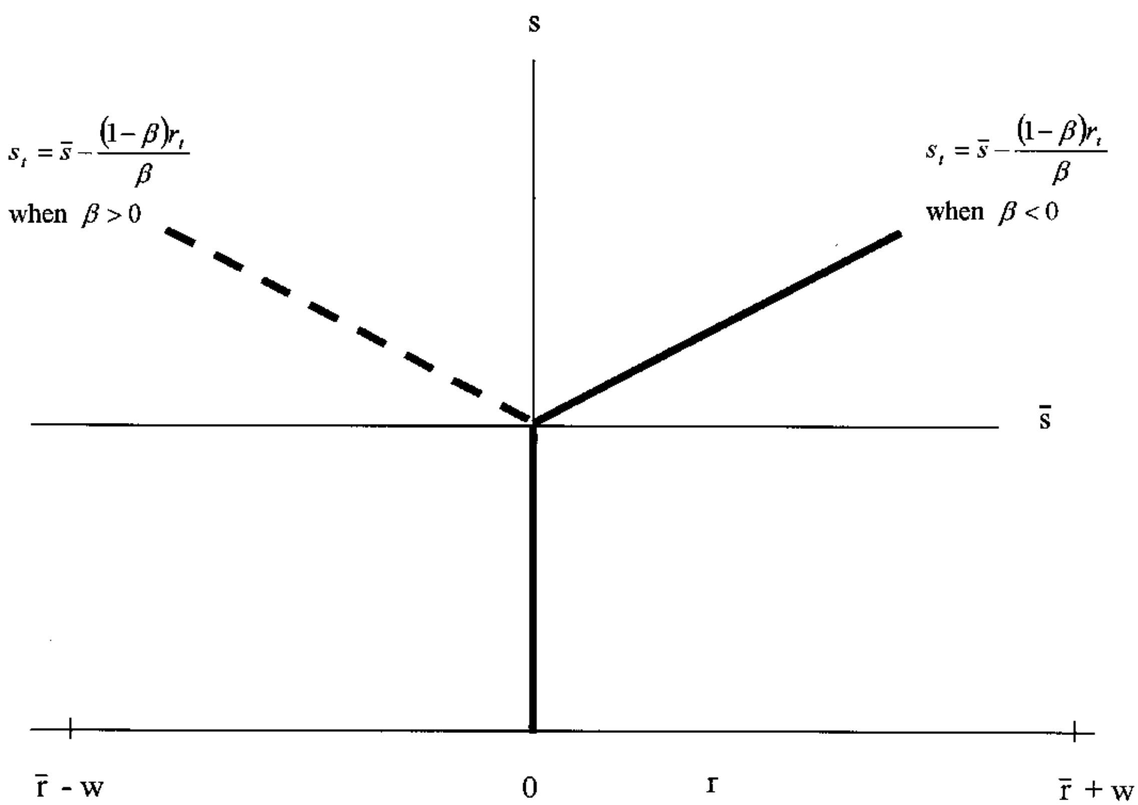
$$D_{t+1} - D_t = (1 - R_t)\gamma DD \qquad \text{if } R<1 \tag{5}$$

$$D_{t+1} - D_t = 0 \qquad \text{if } R \geq 1$$

where D is the level of domestic credit. Defining d as the log of domestic credit, we rewrite equation (5) in logs after substituting equation (4) into equation (5), dividing both sides by D_t and normalizing the money multiplier so that $\gamma DD/D = 1$. Thus:

[18] Naturally, $E_{t-1}NW_t > 0$ due to the bankruptcy provision. We assume that bank licenses trade in a secondary market.

Figure 1. The Break Even Point for Banks



$$d_{t+1} - d_t = -(1-\beta)r_t - \beta(s_t - \bar{s}) \quad \text{if } R<1$$
$$d_{t+1} - d_t = 0 \quad \text{if } R \geq 1 \tag{6}$$

If banks fail, the government bails out depositors and then distributes new bank licenses. Banks are back in business by the end of the period providing deposits to be used in the next period.[19]

To determine whether the fixed exchange rate collapses at time t, we need the value of the shadow exchange rate at time t, because the fixed rate collapses if $\tilde{s}_t \geq \bar{s}$. Recall that the shadow exchange rate is the rate that prevails if the fixed exchange rate is attacked, international reserves are driven to their lower bound, which we assume to be zero, and the exchange rate is allowed to float freely thereafter.

The shadow exchange rate equilibrates the domestic money market *after* the collapse of the fixed exchange rate. We specify this post-collapse money market as:

$$m_t - \tilde{s}_t = -\alpha(E_t\tilde{s}_{t+1} - \tilde{s}_t) + \delta r_t \tag{7}$$

In equation (7), m is the log of the nominal high-powered money supply. The nominal money supply is the sum of international reserves and domestic credit, but since the central bank has completely exhausted its international reserves defending the fixed exchange rate, the nominal money supply equals domestic credit after the exchange-rate collapse ($m_t = d_t$). Nominal money balances are deflated by the domestic price level. Because we assume purchasing power parity, the price level is equal to the post-collapse shadow exchange rate, $\tilde{s}_t$.

The right-hand side of equation (7) is the demand for real money balances. It depends negatively on the domestic interest rate, which in turn equals the expected rate of change of the exchange rate, $E_t\tilde{s}_{t+1} - \tilde{s}_t$, since uncovered interest parity is assumed to hold. In addition, the demand for money depends positively on the real shock, r_t.[20]

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[19] Our model works equally well for any fixed period of bank closing.

[20] If we wanted the real shock to affect firm balance sheets and lead to some of the income effects associated with crises suggested in Krugman (1999), we would model the δ in money demand more carefully.

Since the money market in equation (7) is linear, we propose a linear solution for the shadow exchange rate of the form:

$$\tilde{s}_t = \lambda_0 + \lambda_1 d_t + \lambda_2 r_t \qquad (8)$$

From equation (7), we know that the expected future exchange rate, $E_t \tilde{s}_{t+1}$, affects the shadow exchange rate at time t. Consequently, beliefs about possible future domestic credit growth resulting from future depositor bailouts are important in determining the shadow rate at time t. We use equation (6) to calculate expected domestic credit growth in future periods. We present in the text the simplifying case where banks are required to cover their foreign-currency liabilities (assets) in subsequent periods. The expected rate of domestic credit creation between period t+1 and period t+2 is:

$$E_t(d_{t+2} - d_{t+1}) = -\text{prob}(r_{t+1} < 0)(E_t r_{t+1} \mid r_{t+1} < 0) \qquad (9)$$

In the far future (t+1 and beyond) expected domestic credit growth equals the expected depositor bailout. The expected bailout equals the probability that the disturbance will generate a bank collapse, prob (r_t<0), multiplied by the expected value of the real disturbance conditional on the disturbance generating a bank collapse ($E_t r_{t+1} | r_{t+1} < 0$). We assume the disturbance has a uniform distribution centered on $\bar{r}$, with upper bound $\bar{r} + w$ and lower bound $\bar{r} - w$. Now equation (9) becomes:

$$E_t(d_{t+2} - d_{t+1}) = \frac{(\bar{r} - w)^2}{4w} = \mu \qquad (10)$$

Agents recognize that there may be bank failures in future periods t+1, t+2, and so on, and therefore they expect future domestic credit expansion at rate μ. As a result, they expect the future rate of currency depreciation to be μ as well.

The expected future exchange rate can now be determined by examining the money market at t+1, one period after the collapse of the fixed exchange rate:

$$d_{t+1} - \tilde{s}_{t+1} = -\alpha\mu + \delta r_{t+1} \qquad (11)$$

Rearranging terms in equation (11), we find that the future exchange rate is $\tilde{s}_{t+1} = \alpha\mu + d_{t+1} - \delta r_{t+1}$ and its expected value at time t is $E_t \tilde{s}_{t+1} = \alpha\mu + d_{t+1} - \delta\bar{r}$. Substituting our expression for the expected future exchange rate into the money market equation (7) yields:

$$d_t - \tilde{s}_t = -\alpha[\alpha\mu + d_{t+1} - \delta\bar{r} - \tilde{s}_t] + \delta\bar{r}_t \qquad (12)$$

where $d_{t+1} = d_t - (1-\beta)r_t - \beta(\tilde{s}_t - \bar{s}) \mid R < 1$ and $d_{t+1} = d_t \mid R \geq 1$

We now solve for two possible shadow exchange rates at time t, one conditional on bank collapse (R<1) and the other conditional on no bank collapse (R≥ 1).

When the banks collapse at time t, the solution for the shadow rate is:

$$\tilde{s}_t = \lambda_{10} + \lambda_{11}d_t + \lambda_{12}r_t$$

where

$$\begin{aligned} \lambda_{10} &= \frac{(\alpha^2\mu - \alpha\delta\bar{r} + \alpha\beta\bar{s})}{(1+\alpha+\alpha\beta)} \\ \lambda_{11} &= \frac{(1+\alpha)}{(1+\alpha+\alpha\beta)} \\ \lambda_{12} &= -\frac{[\alpha(1-\beta)+\delta]}{(1+\alpha+\alpha\beta)} \end{aligned} \qquad (13)$$

When banks are solvent at time t, the solution for the shadow rate is:

$$\tilde{s}_t = \lambda_{20} + \lambda_{21}d_t + \lambda_{22}r_t$$

where

$$\begin{aligned} \lambda_{20} &= \frac{\alpha^2\mu - \alpha\delta\bar{r}}{(1+\alpha)} \\ \lambda_{21} &= 1 \\ \lambda_{22} &= -\frac{\delta}{(1+\alpha)} \end{aligned} \qquad (14)$$

III. Collapse Probabilities: A Graphical Representation

The two shadow exchange rate solutions, along with the break-even line for banks having net foreign liabilities, are graphed in a set of three figures, Figures 2-4. The figures can be used to illustrate the various possibilities for currency and bank collapse. First, notice there is a range of shock values for which there is no currency or bank collapse (labeled a in all figures), a range where there can be a currency collapse without a bank collapse (labeled b in Figure 2), a range where there can be a bank collapse without a currency collapse (labeled b' in Figure 3), and a range of shocks that bring about the simultaneous collapse of the currency and the banks (labeled c in all figures). Second, given our assumption of a uniformly-distributed real shock, we can use the figures to calculate the probability of the economy being in any particular range. Moreover, we can determine the factors that influence the probabilities of joint collapses, no collapses, and so on.

Before we analyze these probabilities, it is helpful to mention several things about the way the figures are constructed. First, the two shadow exchange rate lines in each figure are drawn for a given value of domestic credit. An increase in domestic credit shifts up the two lines, but by different amounts if bank returns are affected by exchange-rate changes (if $\beta \neq 0$). Second, the slope of the shadow rate line conditional on bank collapse is steeper than the slope of the shadow rate line conditional on no bank collapse. Third, there is a discontinuity between the two shadow rate lines at the break-even point.

We can now calculate the probabilities of the various possible outcomes and observe the factors that influence these probabilities. We consider the case where banks have net foreign liabilities ($\beta<0$). In Figure 2, let r_a be the value of the shock where the shadow exchange rate conditional on no bank collapse just equals the exchange rate where banks break even. Let r_b be the value of the shock where the shadow exchange rate conditional on no bank collapse just equals the fixed exchange rate. Relying on our earlier assumption that the shock has a uniform distribution with $r_t \sim (\bar{r}, w)$, the probability of no collapses is $\frac{\bar{r} + w - r_b}{2w}$ where $r_b = \frac{(c_t^1 - \bar{s})(1+\alpha)}{\delta}$ and $c_t^1 = d_t + \frac{\alpha^2 \mu - \alpha\delta\bar{r}}{1+\alpha}$. Not surprisingly, a higher level of domestic credit (d_t) or a higher expected rate of domestic credit expansion in the future to finance depositor bailouts (μ) reduces the probability of no collapses. The more favorable on average is the shock ($\bar{r}$), the greater the probability of no collapses.

In Figure 2, the probability of being in the range where there is a currency collapse but no bank collapse, is $\frac{r_b - r_a}{2w}$ where $r_a = \frac{c_t^1 - \bar{s}}{\frac{\delta}{1+\alpha} - \frac{(1-\beta)}{\beta}}$ and r_b and c_t^1 were defined previously. For banks with net foreign liabilities, a greater sensitivity of bank returns to exchange-rate changes (a more negative β) rotates down the positively-sloped

Figure 2. Collapses, Including Currency Collapse Without Bank Collapse

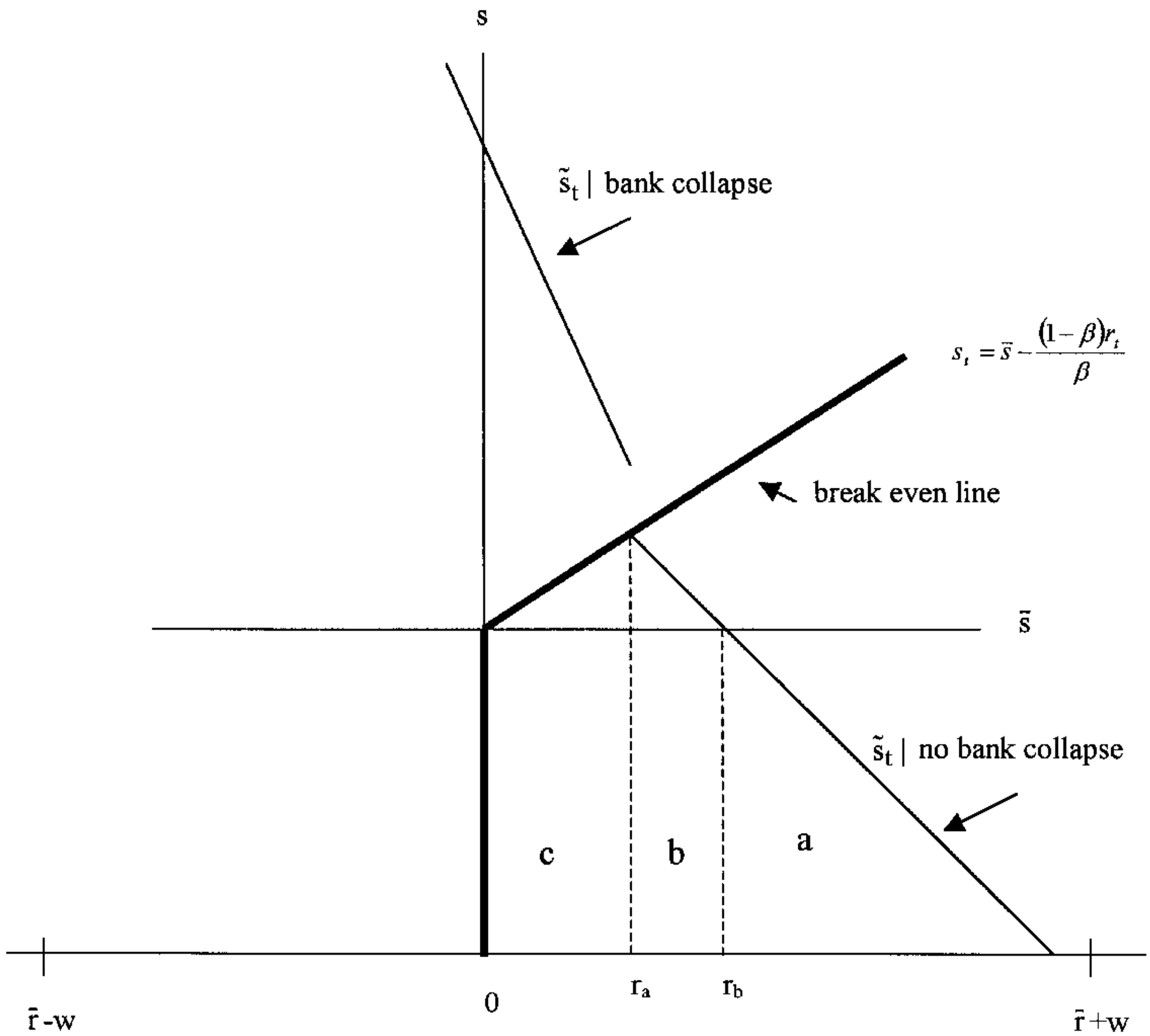


Figure 3. Collapses, Including Bank Collapses Without Currency Collapse

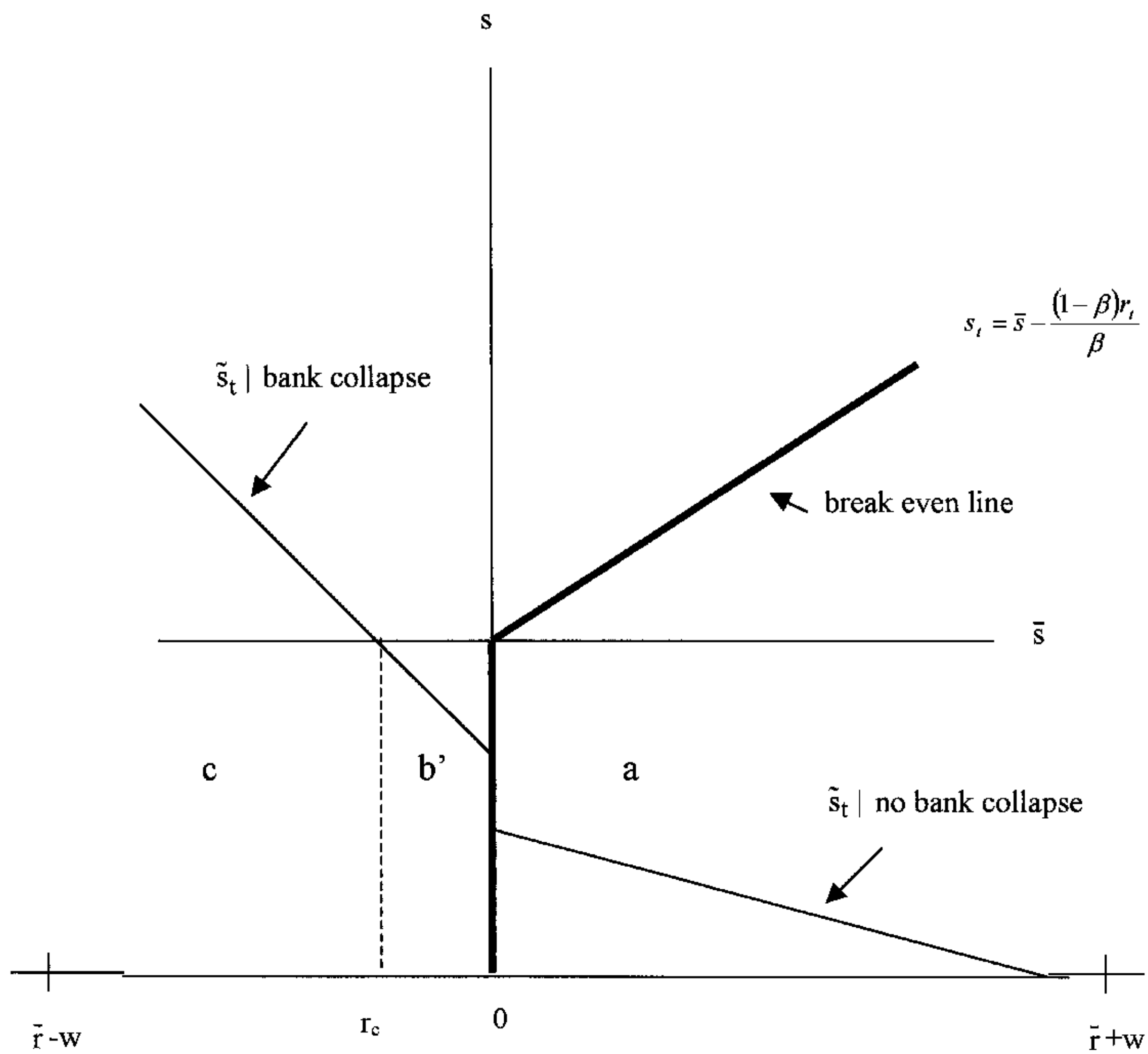
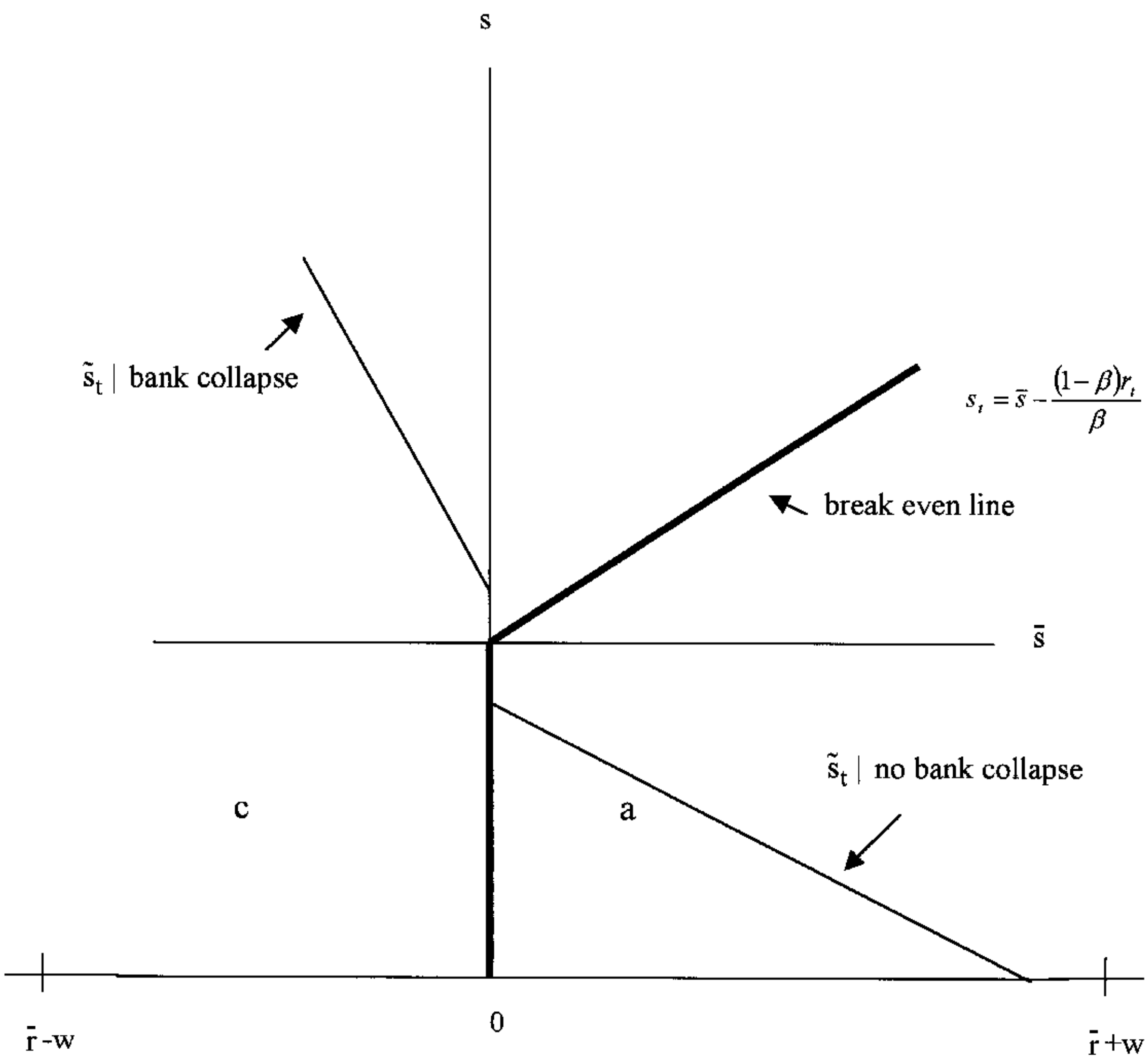


Figure 4. Joint Collapses or No Collapses



segment of the break-even line, increases the value of r_a, and reduces the probability of a currency collapse without a bank collapse.

The probability of joint collapses is $\frac{-\bar{r}+w+r_a}{2w}$. The probability of joint collapses increases when the average shock is less favorable or has a higher variance, when the sensitivity of bank returns to exchange-rate changes is high, and when the future rate of domestic credit tied to depositor bailouts is high. The probability of joint collapses is also higher the greater is the stock of domestic credit in the economy. We leave the calculations of the various probabilities of collapse in Figures 3 and 4 to the interested reader.[21]

Our analysis is conducted on the assumption that the possibility of bank collapse is fully taken into account by agents. Ignoring the possibility of bank collapse biases the probability estimates. Graphically, ignoring the possibility of bank collapses shifts the two shadow rate lines down and eliminates any distinction between them. Consequently, it biases upward the probability estimate of no collapses by failing to account for the monetary (or fiscal) consequences of depositor bailouts.

The framework above can be used to investigate the outcome when banks hedge their foreign-currency liabilities. Suppose, for example, that banks undertake risk-neutral hedging. They obtain insurance so that in period t they will receive domestic currency whose spot foreign-currency equivalent covers their expected foreign-currency liabilities. On average, insurance allows the banks to avoid net gains or losses on their foreign-currency liabilities. Nevertheless, in periods where the spot rate exceeds what was expected, banks receive less domestic currency than they need to pay off their foreign-currency liabilities.

Since bank returns are reduced when the spot exchange rate exceeds its expected value, the break-even point for banks using risk-neutral hedging is:

$$R_t = 1 \tag{15}$$

where $R_t = 1 + (1-\beta)r_t + \beta(s_t - E_{t-1}s_t)$

In order to calculate the value of the shock that now drives banks to the break-even point, we must obtain an expression for the expected spot exchange rate in equation (15) and then solve equation (15) for r_t. We obtain our expression for the expected spot rate by considering the case described by Figure 2. In that figure, the

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[21] We have ignored the effects of domestic interest rates on bank returns. We could easily incorporate this effect by adding a term ζi to the right-hand side of equation (4). The sign of ζ is ambiguous; a higher interest rate could increase asset returns directly but could also produce more non-performing loans, thereby worsening bank returns.

expected spot exchange rate at time t is a weighted average of the fixed exchange rate, the expected shadow exchange rate conditional on currency collapse but no bank collapse, and the expected shadow exchange rate conditional on currency collapse and bank collapse:

$$E_{t-1}s_t = \pi_1 \bar{s} + \pi_2 (E_{t-1}s_t \mid r_a < r_t < r_b) + (1 - \pi_1 - \pi_2)(E_{t-1}s_t \mid r_t < r_a) \tag{16}$$

with probability weights $\pi_1 = \frac{(\bar{r} + w) - r_b}{2w}$, $\pi_2 = \frac{r_b - r_a}{2w}$, $\pi_3 = \frac{r_a - (\bar{r} - w)}{2w}$.

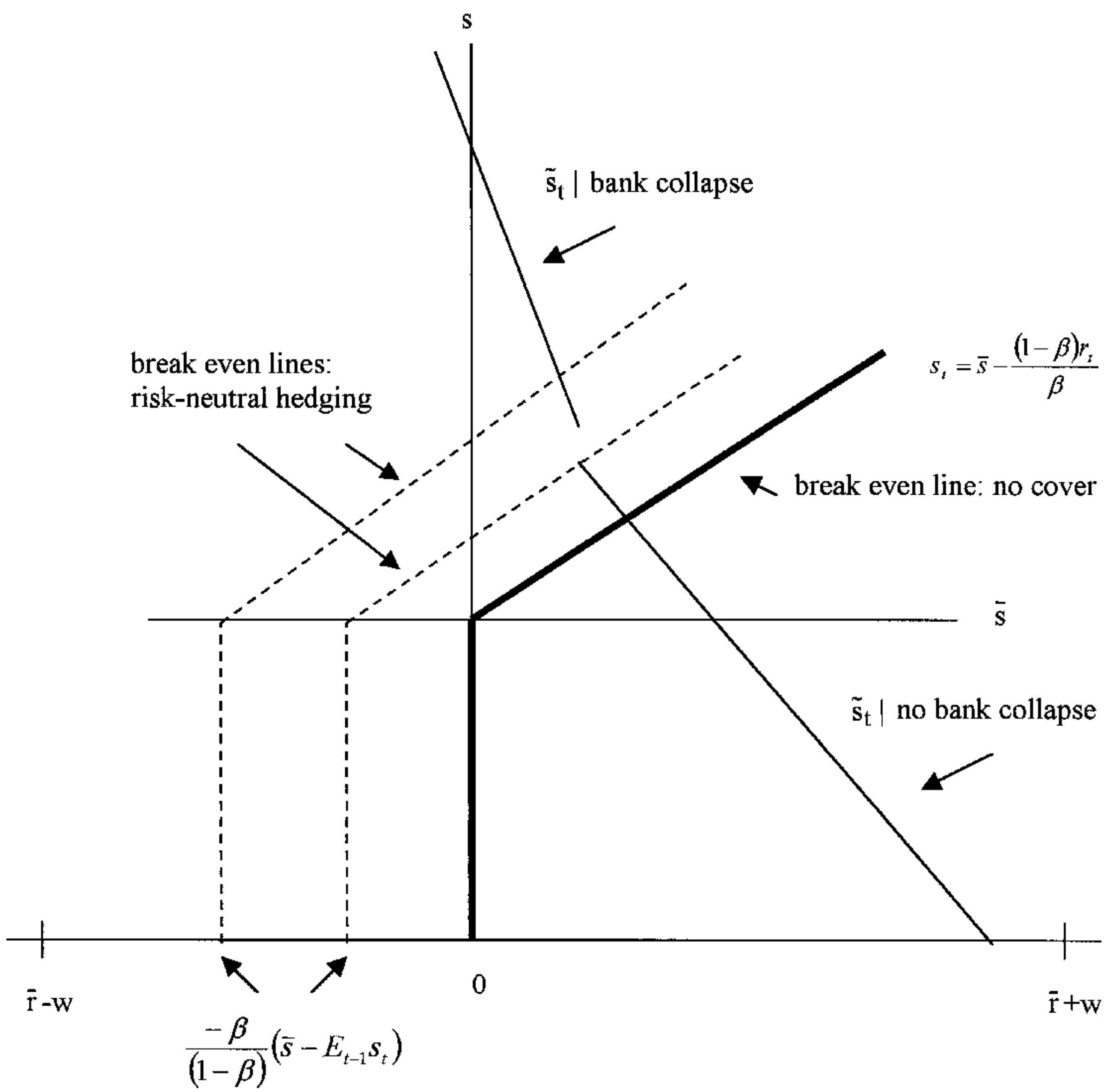
Risk-neutral hedging alters the analysis in two fundamental ways. First, the adoption of risk-neutral hedging shifts the break-even line in Figure 2 to the left. When banks are covered against expected exchange-rate depreciation, it takes a more adverse shock to drive them to the break-even point. Second, the adoption of risk-neutral hedging raises the possibility of two feasible break-even lines. There can be two break-even lines because there are two possible values for the expected spot rate at time t.[22] If the economy settles on the higher expected spot rate and hedges on this basis, say by choosing a higher forward rate, then the economy will be hedged over a greater range of hock values. Consequently, the relevant break-even line is the one on the left in Figure 5 and a more adverse shock is required to drive banks to the break-even point. If the economy settles on the lower expected spot rate and hedges on this basis, the relevant break-even line is the one on the right and the banks are more vulnerable to bad shocks.

Regardless of which expected spot rate the economy uses to form a risk-neutral hedge, hedging always makes banks less vulnerable to bad shocks than not covering at all. How does risk-neutral cover compare with full cover? When banks cover fully, exchange-rate changes do not affect bank returns and the break-even line is the vertical line at r=0 in Figure 5. Risk-neutral cover provides greater bank protection from bad shocks than full cover only when the spot rate does not exceed its expected value for that period.

How do the various hedging strategies affect the probabilities of no collapse, a single collapse or joint collapses? As can be seen from Figure 5, the various hedging strategies do not alter the probability of no collapses. However, they can affect the probability of currency collapse and the probability of joint collapses. Compared with not covering foreign liabilities, risk-neutral hedging increases the range of shocks for which

[22] Using equation (16) to calculate the expected spot rate, we observe that r_a is in the expression for the probability weight π_2 and it is also in the expected value of the shadow rate conditional on currency collapse but no bank collapse. Additionally, r_a is in the probability weight π_3 as well as in the expected value of the shadow rate conditional on both currency and bank collapses. Therefore the expected spot rate is a quadratic function of r_a and can take on two possible values.

Figure 5. Collapses with Risk-Neutral Hedging



currency collapse can occur without bank collapse. It also reduces the range of bad shocks for which both the currency and banks collapse.[23]

So far we have identified factors that influence the joint probability distribution of currency and bank collapses on the assumption that a government finances depositor bailouts with domestic credit creation. This financing assumption is a familiar one from the KFG set up and it gives simple analytical solutions. However, it is unsatisfying since governments generally try to sterilize the liquidity support provided for bailouts and later resort to bond financing and ultimately to tax increases. Our first example also ignores any attempt by the government to actively manage the domestic interest rate.

We next study a model with more realistic features. The good news is that the figures developed previously are invariant—in broad outline—to the adoption of a more realistic model. Thus the basic insights obtained from our earlier analysis carry over to a more realistic set up. Of course, the probabilities of various collapse outcomes are affected by model-specific factors.

IV. A Variation on Government Financing

The government's budget constraint is now expressed (in levels) as:

$$N_{t+1} - N_t = i(N_t - D_t) - S_t i^* V_t - S_t \tau_t + \Omega_t$$

$$\Omega_t \begin{cases} 0 & \text{if no depositor bailout} \\ (1 - R_t)\gamma DD_t & \text{if full depositor bailout} \end{cases} \qquad (17)$$

The government's net deficit determines the evolution of the total stock of outstanding government nominal debt, N. The government must make interest payments equal to i(N-D) on the portion of government debt not held by the central bank as domestic credit. The government receives interest payments on international reserve holdings equal to Si*V, where i* is the interest rate earned on foreign-currency reserve holdings, V, and the price level is equal to the spot exchange rate S assuming purchasing power parity. The government also receives tax payments net of expenditure, $S\tau$, where τ is the real primary surplus. We assume that real taxes depend on the real shock. Finally,

[23] Our discussion ignores any cost of obtaining cover and the possible gain/loss that might arise from risk-neutral hedging when calculating the break-even point for banks. It also ignores the possibility that risk-neutral hedging may have affected bank demand for foreign-currency liabilities.

the government may be required to spend (1-R)γDD to bail out depositors should the banks collapse.

The interest parity condition reflects the notion that domestic and foreign bonds are imperfect substitutes:

$$i = i^* + \frac{E_t S_{t+1} - S_t}{S_t} + \theta[\frac{B_t}{S_t}], \tag{18}$$

where $B_t = N_t - D_t$ is the quantity of domestic bonds held privately. The domestic interest rate must compensate international investors not only for expected depreciation of the home currency but also for risk that increases with the quantity of domestic bonds in investors' portfolios. We assume that θ is a positive parameter.[24] The domestic interest rate is managed actively by the government. We consider it an exogenous variable.

We log-linearize equation (17) and equation (18) in the appendix and solve them for the (log) shadow exchange rate conditional on no bank collapse and the (log) shadow rate conditional on bank collapse. These shadow exchange rate solutions take the form:

$$\tilde{s}_t = \gamma_0 + \gamma_1 n_t + \gamma_2 r_t \tag{19}$$

where n is the log of nominal government debt and the γ_i coefficients differ across the two solutions.

Our specification for the banks' break-even point is the same as it was in our first model specification.

The two shadow exchange rates, as well as banks' break-even point are shown graphically using the same set of figures as before. The two shadow rate lines are drawn for a given stock of outstanding government debt, and an increase in that debt will shift

[24] Our justification for a wedge in UIP is the assumption that domestic and foreign–currency bonds are imperfect substitutes in agents' portfolios. At a deeper level, imperfect substitution may reflect a utility-based bias toward own-currency assets that could be derived from those assets having a *liquidity* advantage over foreign-currency assets (see Lahiri and Végh (1999)). The wedge could equally well result from increasing marginal domestic-currency borrowing costs (see Drazen (1999)). The function we use here is derived from risk aversion in Jeanne and Rose (1999). Flood and Marion (2000) derive a wedge proportional to the ratio of domestic bonds to foreign bonds in investors' portfolio

up both lines, though not by the same amounts.[25] Our earlier Figures 2-4 can again be used to illustrate the various possible outcomes for the case where banks do not cover their foreign liabilities. Figure 5 can again be used to illustrate a possible outcome when banks engage in risk-neutral hedging. Of course, since our model specification is now different, different factors will affect the probabilities of collapse.

For example, if the economy is characterized by Figure 2, the probability of no collapses is once again $\frac{(\bar{r}+w)-r_b}{2w}$, where r_b is the value of the shock where the shadow rate conditional on no bank collapse equals the fixed exchange rate, so $r_b = \frac{\bar{s}-\gamma_0-\gamma_1 n_t}{\gamma_2}$. Now the probability of no collapse depends on such factors as tax policy, interest-rate policy, the risk premium (component θ), the stock of nominal government debt, the share of government debt held by the central bank, the value of the fixed exchange rate, and the size of future bailouts., and the mean value of the shock and its variance.

For example, larger tax revenues are associated with a higher probability of no collapses. Larger tax revenues reduce the amount of needed bond financing, thereby reducing the value of the shadow exchange rate. A higher foreign interest rate reduces the probability of no collapse since it makes foreign assets more attractive to hold and thereby increases the value of the shadow exchange rate. An increase in the domestic interest rate has an ambiguous effect on the shadow exchange rate. It makes domestic assets more attractive to hold but it also requires the government to issue more bonds to cover its increased interest payments on the debt. Moreover, if interest rates are allowed to influence bank fragility, a change in domestic interest rates can shift the break-even line.

V. Conclusion

We present a simple graphical framework that allows us to calculate the joint probability of bank and currency collapses triggered by real shocks. Our framework illustrates the fact that bank and currency collapses are related but they are not the same thing. Studying currency and bank collapses either in isolation or in perfect correlation with each other is inappropriate because it produces biased estimates of the likelihood of crises.

Everyone involved in policy work believes that central bank reserves are very important in delaying or preventing crises. One troubling feature of our model is that

[25] If the government had auctioned bank licenses instead of giving them away, the added government revenues would mean less bond financing. As a result, the shadow exchange rate lines would shift down, increasing the chance of avoiding collapses.

central bank reserves, or access to additional IMF credits for that matter, play no important role in reducing the likelihood of crises. The shadow exchange rates are determined conditional on central bank reserves being drawn down to some fixed lower bound. The break-even point for banks is independent of the size of central bank reserves. Reserves just do not enter as a state variable in our model.

To the extent that reserves represent net wealth, then other things equal, more reserves are preferable. If a government were "given" additional reserves, then it would have additional resources for potential future bailouts and that would lessen the pressure to issue domestic credit or domestic debt or raise taxes to finance bailouts. The result of such a windfall gain in government assets would be to shift down the shadow exchange rate lines and increase the range of real shocks over which there is no probability of collapses. Drawing on an IMF credit facility, however, does not provide the government with free reserves. The IMF funds are loans. Alternatively, if a country were to accumulate foreign reserves through private capital inflows, sterilizing through open market sales, the government would be accumulating reserve assets that pay a lower return than the borrowing cost of the debt it issued. It is not a fiscally sensible policy.

All modern crisis models are based on convertibility. During a crisis, the government (and the private sector) can exchange home currency for foreign currency at some exchange rate. With full convertibility, as assumed in this paper, there is no role for international reserves regardless of the state. Now suppose that the home currency is actually inconvertible during a crisis. Then domestic agents (including the government) cannot get foreign currency at all. If the government is worried about inconvertibility during a crisis, then it might have a precautionary demand for foreign reserves to insure against future inconvertibility that comes with a crisis. Foreign reserves would have an insurance value and there would be some positive social return to holding them. In future work, we hope to identify a market breakdown or a need for insurance that would provide a sensible demand for foreign reserves and relate central bank reserves to the likelihood of crises.

Interest Rate Policy

In the second version of the model, depositor bailouts are financed by government debt. The government also manages the interest rate. In this appendix, we specify the equations of the model, linearize them, and derive the solutions for the shadow exchange rate conditional on no bank collapse and the shadow rate conditional on bank collapse.

The government budget constraint, equation (17) in the text, is:

$$N_{t+1} - N_t = i(N_t - D_t) - S_t i^* V_t - S_t \tau_t + \Omega \tag{20}$$

$$\Omega = \begin{cases} 0 & \text{if no depositor bailout} \\ (1-R_t)\gamma DD_t & \text{if full depositor bailout} \end{cases}$$

The variables in equation (20) are defined in the text. Dividing both sides of equation (20) by N_t gives:

$$\frac{N_{t+1} - N_t}{N_t} = i(1 - \frac{D_t}{N_t}) - \frac{S_t i^* V_t}{N_t} - \frac{S_t \tau_t}{N_t} + \frac{\Omega}{N} \tag{21}$$

We now linearize equation (21). Let lower-case letters (except for interest rates) represent logs, so $n_t = \ln N_t$. Then the left-hand side of equation (21) is

$$\frac{N_{t+1} - N_t}{N_t} = n_{t+1} - n_t \tag{22}$$

Let $X_t \approx a + bx$, where x=lnX. Then

$$\frac{D_t}{N_t} = f_0 + f_1(d_t - n_t) \tag{23}$$

where $f_0 = (\frac{\overline{D}}{\overline{N}})[1 - \ln(\frac{\overline{D}}{\overline{N}})]$, $f_1 = \frac{\overline{D}}{\overline{N}}$, and a bar over a variable indicates its average value.

After the fixed exchange-rate collapses, the government does not receive interest on central bank foreign reserve holdings since reserves have been depleted defending the fixed exchange rate. The second term on the right-hand side of equation (21) is therefore zero.

We assume that the ratio of nominal taxes to nominal debt is a linear function of the real shock, r. Tax revenues increase (decrease) when the real shock is more (less) favorable than its average value. Thus the third term on the right-hand side of equation (21) is:

$$\frac{S_t \tau_t}{N_t} = T_0 + T_1(r_t - \bar{r}) \tag{24}$$

where T_0 is the average value of nominal taxes relative to nominal debt.
Recognizing that $XY = \bar{X}Y + \bar{Y}X - \overline{XY}$, we can linearize the bailout term in equation (21) as:

$$\frac{(1-R_t)\gamma DD_t}{N_t} = \frac{\overline{\gamma DD}}{N}(1-R_t) + (\overline{1-R})\gamma \frac{DD_t}{N_t} - \frac{\overline{\gamma DD}}{N}(\overline{1-R}). \tag{25}$$

Further, let $\ln(\frac{DD_t}{N_t}) = s_t + dd_t - n_t$, where DD is the (level) value of nominal demand deposits and dd is the log of real demand deposits. Thus the linearization of the bailout term in equation (25) is:

$$\frac{(1-R_t)\gamma DD_t}{N_t} = \beta_0 + \beta_1[s_t + dd_t - n_t] + \beta_2(1-R_t) \tag{26}$$

where $\beta_0 = \frac{-\overline{\gamma DD}}{N}(\overline{1-R})$, $\beta_1 = (\overline{1-R})\gamma$, $\beta_2 = \frac{\overline{\gamma DD}}{N}$, and bank returns are $R_t = 1 + (1-\beta)r_t + \beta(s_t - \bar{s})$ when banks do not cover their foreign-currency exposure.

Substituting equations (22)-(24) and equation (26) into equation (21) and recalling that international reserves are depleted once the fixed exchange rate collapses, the linearized version of the government budget constraint in equation (21) becomes:

$$n_{t+1} - n_t = i[1 - f_0 - f_1(d_t - n_t)] - T_0 - T_1(r_t - \bar{r}) \tag{27}$$

$$+ \begin{cases} 0 & \text{if no bailout} \\ \beta_0 + \beta_1[s_t + dd_t - n_t] + \beta_2(1-R_t) & \text{if full bailout} \end{cases}$$

The portfolio equation, equation (18) in the text, is:

$$i = i^* + \frac{E_t S_{t+1} - S_t}{S_t} + \theta[\frac{N_t - D_t}{S_t}] \tag{28}$$

To linearize the third term on the right-hand side of equation (28), we first convert [N_t-D_t] to $(1+\delta)n_t - \delta d_t$, with $0 < \delta < 1$. Since $X \approx a + bx$, the linearization of the third term is:

$$\frac{N_t - D_t}{S_t} = f_2 + f_3[(1+\delta)n_t - \delta d_t - s_t] \tag{29}$$

In addition, the linearization of the second term on the right-hand side of equation (28) is:

$$\frac{E_t S_{t+1} - S_t}{S_t} = E_t s_{t+1} - s_t \tag{30}$$

Substituting equation (29) and equation (30) into equation (28) yields:

$$i = i^* + E_t s_{t+1} - s_t + \theta[f_2 + f_3\{(1+\delta)n_t - \delta d_t - s_t\}] \tag{31}$$

Further, after the depletion of foreign reserves and an exchange-rate collapse, domestic credit equals the sum of demand deposits and currency, which we specify as:

$$d_{t+1} = s_{t+1} + \alpha_0 - \alpha_1 i + \alpha_2 r_{t+1} \tag{32}$$

We conjecture that the shadow exchange rate at time t+1 takes the form:

$$\tilde{s}_{t+1} = \lambda_0 + \lambda_1 n_{t+1} + \lambda_2 r_{t+1} + \lambda_3 \hat{u}_{t+1} \tag{33}$$

where $\hat{u}_{t+1}$ is the part of the depositor bailout made at time t+1 that is unexpected at time t. We also conjecture that the shadow exchange rate at time t takes the form:

$$\tilde{s}_t = \gamma_0 + \gamma_1 n_t + \gamma_2 r_t \tag{34}$$

Using equations (32)-(34) and solving equation (27) and equation (31), we find that the shadow exchange rate conditional on no bank collapse is:

$$\tilde{s}_t \mid \text{no bank collapse} = \gamma_0 + \gamma_1 n_t + \gamma_2 r_t \tag{35}$$

where

$$\gamma_0 = \frac{\Lambda}{\Gamma}$$

with $\Lambda = i^* - i + \lambda_0 + \lambda_2\bar{r} + \theta f_2 + i(1 - f_0) - T_0 + T_1\bar{r} - [\theta f_3\delta + if_1][\alpha_0 - \alpha_1 i]$

$$\Gamma = 1 + if_1 + \theta f_3(1+\delta)$$
$$\gamma_1 = 1$$

$$\gamma_2 = \frac{-[T_1 + (\theta f_3\delta + if_1)\alpha_2]}{\Gamma}$$

The shadow exchange rate conditional on bank collapse is:

$$\tilde{s}_t \mid \text{bank collapse} = \gamma_0^* + \gamma_1^* n_t + \gamma_2^* r_t \tag{36}$$

where

$$\gamma_0^* = \frac{\Lambda + \beta_0 + \beta_1(\alpha_0 - \alpha_1 i) + \beta_2\beta\bar{s}}{\Gamma - \beta_1 + \beta_2\beta}$$

$$\gamma_1^* = \frac{\Gamma - \beta_1}{\Gamma - \beta_1 + \beta_2\beta}$$

$$\gamma_2^* = \frac{-[T_1 + (\theta f_3\delta + if_1)\alpha_2 + \beta_2(1-\beta)}{\Gamma - \beta_1 + \beta_2\beta}$$

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