

Illiquidity Component of Credit Risk*

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Abstract

We describe and contrast three different measures of an institution's credit risk. "Asset insolvency risk" is the conditional probability of default due to deterioration of asset quality if there is no run by short term creditors. "Total credit risk" is the unconditional probability of default, either because of a (short term) creditor run or (long run) asset insolvency. "Illiquidity risk" is the difference between the two, i.e., the probability of a default due to a run when the institution would otherwise have been solvent. We discuss the relation between the three measures and how their respective magnitudes depend on balance sheet composition.

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1 Introduction

Credit risk refers to the risk of default by the borrower. In the simplest case where the term of the loan is identical to the term of the project cash flow, credit risk arises from the uncertainty over the outcome of the borrower's project. Stated differently, credit risk is associated with uncertainty governing the asset side of the borrower's balance sheet, and the conventional approaches to bank capital regulation has rested on the premise that the role of capital requirement is to serve as a buffer against the shortfall arising from the asset side of the balance sheet.

However the turmoil in credit markets in the financial crisis of 2008 has highlighted the limitations of focusing just on the asset side of the balance sheet, and have cast doubt on the rationale behind the traditional approach to bank capital regulation. The problem can be posed most starkly for institutions such as Bear Stearns or Lehman Brothers that financed themselves through a combination of short-term and long-term debt, but where the heavy use of short-term debt made the institution vulnerable to a run by the short term creditors.¹ For the holders of the long-term debt issued by Lehman Brothers or Bear Stearns, the fundamental risk associated with the assets held by these investment banks (such as mortgage backed securities) was not the only hazard they faced. They also faced the risk that the bank might fail due to its inability to roll over the short-term funding.

The issue is highlighted in an open letter written by Christopher Cox, the (then) chairman of the US Securities and Exchange Commission explaining the background and circumstances of the run on Bear Stearns in March 2008.²

“[T]he fate of Bear Stearns was the result of a lack of confidence, not a lack of capital. When the tumult began last week, and at all times until its agreement to be acquired by JP Morgan Chase during the weekend, the firm had a capital cushion well above what is required to meet supervisory standards calculated using the Basel II standard.

Specifically, even at the time of its sale on Sunday, Bear Stearns'

¹See Morris and Shin (2008) and the Geneva Report (Brunnermeier et al. (2009)) for a reappraisal of financial regulation in a system context.

²Letter to the Chairman of the Basel Committee on Banking Supervision, dated March 20th 2008, posted on the SEC website on: <http://www.sec.gov/news/press/2008/2008-48.htm>

capital, and its broker-dealers' capital, exceeded supervisory standards. Counterparty withdrawals and credit denials, resulting in a loss of liquidity - not inadequate capital - caused Bear's demise."

Thus, in spite of Bear Stearns meeting the letter of its regulatory capital requirements, it got into trouble because its lenders stopped lending. Put differently, the problem was on the liabilities side of the balance sheet, rather than on the asset side, and the run was liquidity based rather than solvency based. The idea that self-fulfilling bank runs are possible is well established in the banking literature (see Bryant (1980) and Diamond and Dybvig (1983)). To the extent that inefficient outcomes are possible in equilibrium, the then SEC Chairman's letter points to another source of credit risk for the long-term claim holder of institutions such as Bear Stearns – namely, that the may institution fail due to a run when it would have survived in the absence of the run.

But the sharp distinction between solvency and liquidity in the SEC Chairman's letter may not be so easy to draw in practice, even *ex post*. Existing theory does a poor job of outlining the relation between insolvency risk and illiquidity risk. Existing models tend to focus on one or the other and not on the interaction between the two. We regard this division of attention as undesirable. Runs don't happen out of the blue; they tend to occur when there are also concerns about the quality of the assets. It is sometimes difficult to tell (even *ex post*) whether the run merely hastened the failure of a fundamentally insolvent bank, or whether the run was an inefficient outcome for the creditors. Nevertheless, the distinction between fundamental solvency and illiquidity is crucial from a conceptual point of view. They gain meaning because the counterfactual propositions are meaningful – at least hypothetically.

In any case, for the *ex ante* pricing of total credit risk, it is important to take account of the probability of a run. This is both because the occurrence of a run will undermine the debt value, and also that a run will tend to destroy recovery values through disorderly liquidation under distressed circumstances. Merely focusing on the credit risk associated with the fundamentals of the assets will underestimate the total credit risk faced by a long term creditor.

In what follows, we provide a framework can be used to address these questions. A leveraged financial institution funds its assets using short- and long-term debt, as well as its own equity. Short-term debt earns a lower

return, but short-term creditors have the choice not to renew funding at an interim date. We use global game methods³ to solve the outcome of the coordination problem among short term creditors. We solve for the unique equilibrium and quantify the total credit risk. In particular, we are able to decompose total credit risk into two components. First, the eventual asset value realization may be too low to pay off all debt. We dub this risk “asset insolvency risk”. Second, a run by the short-term creditors may precipitate the failure of the institution even though, in the absence of the run, the asset realization would have been high enough to pay all creditors. We refer to this second part as “illiquidity risk”. We demonstrate how total credit risk is the sum of the asset insolvency risk and illiquidity risk.

Our analysis reveals the extent to which asset insolvency risk and illiquidity risk are intertwined. Parameters that determine the riskiness of long-term cash flows matter for illiquidity risk as well as for asset insolvency risk. This is because fundamental asset risk determines the fragility of the bank to runs by its short-term creditors, and in turn influences the actions of the short-term creditors.

Most interestingly, our analysis reveals several insights on how the *composition* of the balance sheet affects the two components of credit risk. The capital buffer of the bank is certainly one determinant of credit risk, but our analysis highlights the importance an *illiquidity index*. The illiquidity index depends on the ratio of total face value of short run debt to liquid assets – including cash holdings. Whereas the capital buffer is just the ratio of equity to total assets (and so a given capital buffer is consistent with a wide range of values of the illiquidity index), the illiquidity index is a measure on the *composition* of the assets. In particular, we examine the comparative statics of both components of credit risk to shifts in (i) capital and (ii) cash holdings. We can characterize when reinforcing the capital buffer is the most effective way to reduce total credit risk, and when it is more effect to reduce the illiquidity index by putting more cash on the balance sheet . We show (in section 3) that liquidity enhancing policies are most effective on the margin - relative to focussing on capital regulation - when (1) the current level of the illiquidity index is high; and (2) when there is significant uncertainty

³The pioneering work on global games is Carlsson and van Damme (1993). Morris and Shin (1998, 2003) discuss how global game methods can be used in a wide range of applied settings to understand how coordination problems are resolved. Morris and Shin (2004) address coordination in pricing debt while Rochet and Vives (2004) and Goldstein and Pauzner (2005) use global game methods to examine banks.

about asset returns.

Thus, in contrast to the Basel approach to capital regulation, our analysis points to the importance of balance sheet composition as an important determinant of credit risk. We have argued elsewhere (Morris and Shin (2008)) that for regulatory purposes, single-minded focus on capital requirements need to be give way to a broader range of balance sheet indicators, including the ratio of liquid assets to total assets and short-term liabilities to total liabilities. Our results provide further theoretical backing to our earlier arguments.

Our analysis highlights that cash holdings and fundamental asset insolvency risk interact strongly so that total credit risk is affected through two channels. First, the asset insolvency risk enters directly in credit in the conventional way, where the realized value of assets at the terminal date of the project falls short of the notional obligations. However, there is also a second effect that works through the risk of runs. As the fundamentals of the bank weaken, the probability of the failure of the bank through a run by its short-term creditors also increases. In this way, there is an interaction between the asset fundamentals and the risk of a run. Thus, the SEC chairman's distinction between a run and fundamental solvency is not easily drawn. He and Xiong (2009) is a recent paper that addresses similar questions to our paper in a related context where the fundamentals subject to shocks.

Our results have particular significance in the light of two recent trends that played a role in the 2008 credit crisis. The first is the secular decline in the cash holdings by banks over the last thirty or so years, until the outbreak of the recent financial crisis. Figure 1 shows the proportion of cash assets in the total assets of US commercial banks, drawn from the Federal Reserve's H8 series. Even as recently as the early 1980s, cash assets were around 10% of total assets, but that ratio fell below 3% by the eve of the crisis. However, the cash ratio has risen sharply since September 2008 following the failure of Lehman Brothers.

Although there are several special circumstances that surround the events since September 2008 (such as actions of the Federal Reserve to expand its balance sheet), our theory points to the financial stability consequences both of the long, secular decline in cash holdings until 2008, as well as the portfolio choice motives of banks when faced with credit market turmoil. In particular, our theory highlights the vulnerability of leveraged institutions to the combination of low cash ratios and the prevalence of short term debt.

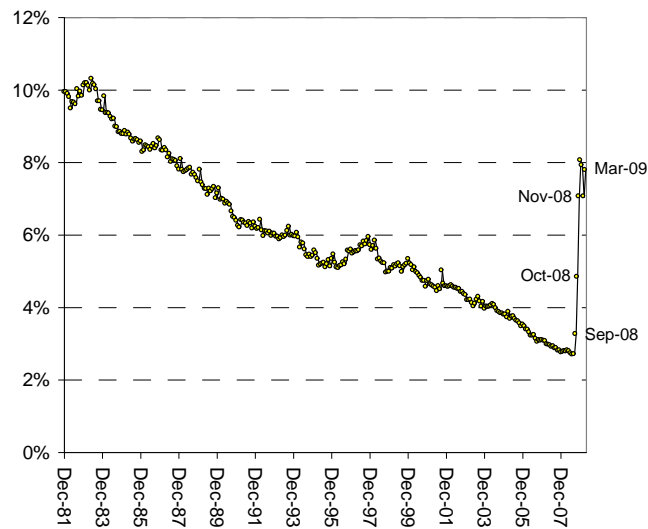


Figure 1: US Commercial Bank Cash Ratio (Source: Federal Reserve H8)

To that extent, the secular decline in the cash ratio in recent years suggests vulnerabilities were increasing in the US banking sector.

The second trend in recent years has been the shortening maturity of bank liabilities, especially for the broker dealer sector of the financial system. The broker-dealer sector is the sector that that included the major Wall Street investment banks.

Figure 2 plots the trend on the composition of liabilities of the banking system comparing the total amount of overnight repurchase agreements with the amount of longer maturity term repo agreements. We can see that the period preceding the current financial crisis saw a dramatic increase in the use of overnight repos, compared to longer maturity term repo agreements (see also Adrian and Shin (2007) and Brunnermeier (2009)).

Our analysis reveals the importance of the maturity of debt through the tradeoffs faced by the short-term creditors. We show in section 4 that when the short-term debt becomes very short term, the illiquidity component of credit risk increases due (paradoxically) to the reduced uncertainty over the short-term as compared to long-term outcomes. The very feature of short-term debt that makes it safe for the creditors (its safety over the short-term)

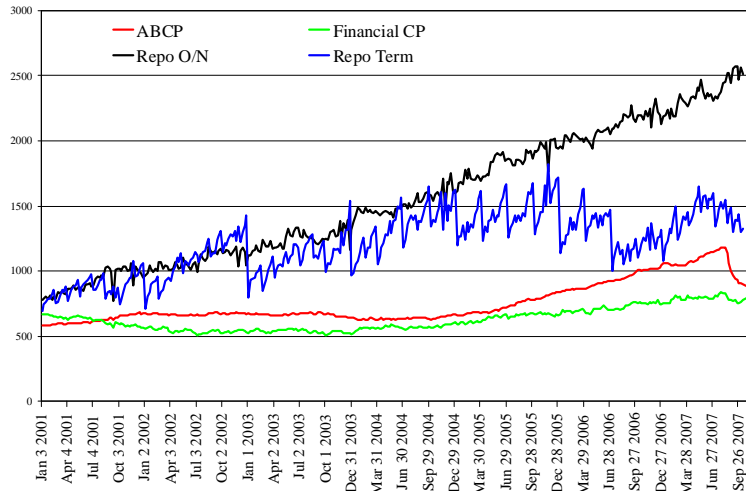


Figure 2: Outstanding Repurchase Agreements of US Primary Dealers (\$ Billion): Source, Adrian and Shin (2008)

makes the bank vulnerable to a run. We explore this feature in more detail below. In the light of our results, the fact that short-term debt becomes *ultra*-short term can be seen as an important consideration when thinking of the fragility of the financial system.

Our results have implications for financial regulation. We discuss these issues in more detail in our Brookings Papers piece on financial regulation (Morris and Shin (2008)). When the spillover effects across financial institutions are taken into account, liquidity requirements take on greater significance as a policy tool. If the debtor bank held more cash in place of illiquid assets, it could meet the withdrawals more easily, thereby lowering the threshold in the coordination game among the creditors to the bank. The cost of miscoordination for the creditor banks could also be reduced if they held more cash, since they would be less vulnerable to a run themselves. A more liquid creditor bank would be less jittery.

The outline of our paper is as follows. We begin in section 2 with a framework where a bank holds several classes of assets (among which is cash) financed through three sources – equity, short-term debt and long-term debt. Short-term debt holders face the choice of rolling over their claims at an interim date. We solve a global game model where the outcome

of the coordination problem faced by the short-term creditors determines the threshold value of the asset realization below which the run outcome takes place. We use the model to define our decomposition of credit risk into insolvency risk and illiquidity risk.

The core of our paper is the comparative statics analysis associated with a closed form solution, under distributional assumptions, of the unique equilibrium in section 3. We explain the importance of balance sheet composition in the determination of overall credit risk. In section 4, we show how these results are robust to the degree of ex ante uncertainty and distributional assumptions. We conclude with some lessons to be drawn from our analysis for financial regulation.

2 A Decomposition of Credit Risk

2.1 The Balance Sheet and the Funding Game

We will analyze the balance sheet of a leveraged financial institution, called a “bank” for convenience, but we have in mind a market-based intermediary such as Bear Stearns or Lehman Brothers that finance themselves with uninsured liabilities. On the asset side, the bank holds assets in $N + 1$ categories indexed by $i \in \{0, 1, \dots, N\}$. We denote by A_i the face value of assets in asset class i . The bank’s assets are financed in three ways – equity, short-term debt and long-term debt. The face value of equity is denoted by E , face value of short-term debt by S and long-term debt by L .

There are three dates, initial (date 0), interim (date 1) and final (date 2). We write θ_i for the value of fundamentals at date i and assume that

$$\begin{aligned}\theta_1 &= \theta_0 + \sigma_1 \varepsilon_1 \\ \theta_2 &= \theta_1 + \sigma_2 \varepsilon_2\end{aligned}$$

where ε_1 and ε_2 are independently distributed with 0 means and densities f_1 and f_2 respectively. The parameters σ_1 and σ_2 measure the size of interim and final period uncertainty respectively. In our framework, σ_1 and σ_2 can also be given an interpretation as the maturity of the short term debt. If the interim date is close to the initial date but far from the final date, we have small σ_1 but large σ_2 . We will see that the relative size of σ_2 to σ_1 plays an important role in the analysis.

It is convenient to describe the game played by short run creditors from the final period backwards. At the final date 2, the value of asset i will be $\alpha_i + \beta_i \theta_2$, where θ_2 is the final value of fundamentals. We let asset 0 be cash, with $\alpha_0 = 0$ and $\beta_0 = 1$. Note that the returns to all asset categories are thus perfectly correlated. If the bank survives to the final period, then long run debt holders are promised a gross return r_L while short run debt holders are promised a gross return r_S . The bank is *solvent* if asset gross returns cover liabilities, i.e.,

$$\sum_{i=0}^N (\alpha_i + \beta_i \theta_2) A_i \geq Sr_S + Lr_L$$

or, equivalently,

$$\theta_2 \geq \frac{Sr_S + Lr_L - \sum_{i=0}^N \alpha_i A_i}{\sum_{i=0}^N \beta_i A_i} \equiv \theta^*.$$

This *solvency point* θ^* will play a crucial role in our analysis. We assume that if the bank is insolvent in period 2 – i.e., when $\theta_2 < \theta^*$ – then the bank goes into liquidation and (for simplicity) we assume that neither short nor long term debtors receive any return. This assumption is admittedly stark, but we have seen in the current crisis that when a securities firm goes bankrupt, the recovery values tend to be very low. For the long-term creditors of Lehman Brothers, the recovery values have been around 8 cents to the dollar, reflecting the disruptive nature of the failure of a highly leveraged institution with a large derivatives book. In any case, our analysis could easily be extended to encompass positive recovery values at the cost of added complexity.

At the interim date 1, the short run debt holders observe θ_1 and face a decision about whether to roll over their lending. If the positions of short run debt holders are not rolled over, then assets must be liquidated to cover their positions. We assume that the liquidated value of asset i is $\lambda_i (\alpha_i + \beta \theta_0) A_i$, where λ_i represents the fire sale discount. Equivalently, for the purpose of our analysis we can interpret λ_i as one minus the haircut the bank must take in borrowing short term against asset i . We will refer to λ_i as the liquidity of asset i . We will assume that cash is perfectly liquid, so $\lambda_0 = 1$. Now the

total liquidation valuation of the bank's assets is

$$A^* = \sum_{i=0}^n \lambda_i (\alpha_i + \beta \theta_0) A_i.$$

Thus the bank suffers a run if the proportion of short term debt holders not rolling over is more than A^*/S . We assume that if there is a run, all value is destroyed and short term debtors get a return of 0. We assume that if there is not a run, new creditors will eventually be found and the balance sheet reverts to its initial state after the failed run. Finally, we assume that short run debt holders have an alternative investment opportunity in which they can earn gross return r^* .

Throughout the paper, we will assume that

$$q \equiv \frac{r^* S}{r_S A^*} < 1 < \frac{S}{A^*} \quad (1)$$

In other words, the liquidation value A^* is smaller than the face value of short term debt S , and the outside opportunity r^* is small relative to the notional return r_S for short-term debt. The ratio q will also play a crucial role in our analysis. We will be interested in performing comparative statics with the bank's balance sheet at date 0.

2.2 Solving the Coordination Game and Interim Credit Risk

We first describe how we will solve the coordination problem among short run debt holders in the interim period. The interim solvency risk - the probability that the bank will fail *if there is no run* - is

$$\mathcal{INS}_1(\theta_1) = F_2\left(\frac{\theta^* - \theta_1}{\sigma_2}\right) \quad (2)$$

Thus the total expected return to rolling over, conditional on there not being a run, is

$$r_S \left(1 - F_2\left(\frac{\theta^* - \theta_1}{\sigma_2}\right)\right);$$

while return to not rolling over is r^* .

Suppose that instead of perfectly observing θ_1 , each short run creditor observed it with a small amount of noise. Let π be the proportion of short-term creditors who do not roll over their debt. We appeal to the standard result for global games that, in the limiting case as noise goes to zero, and conditional on being at the switching point between rolling over and not rolling over short-term debt, the density over π is the uniform density over $[0, 1]$.⁴ The indifference condition where the payoffs to rolling over and not rolling are set equal each other determines the *run point* θ^{**} of θ . Thus the indifference condition is

$$\frac{A^*}{S} \left(1 - F_2 \left(\frac{\theta^* - \theta^{**}}{\sigma_2} \right) \right) r_S = r^*$$

or, recalling that $q = \frac{r^* S}{r_S A^*}$, we have the following relationship that ties the run point θ^{**} and the solvency point θ^* .

$$\theta^{**} = \theta^* - \sigma_2 F_2^{-1}(1 - q) \quad (3)$$

This equation gives an interpretation to q . The condition states that a run will occur whenever the interim probability of insolvency exceeds q . For this reason, we will label q the *illiquidity index*. Now the interim illiquidity risk (the probability that the bank will fail because of a run, when it would not have been insolvent in the absence of a run) is

$$\mathcal{ILL}_1(\theta_1) = \begin{cases} 1 - F_2 \left(\frac{\theta^* - \theta_1}{\sigma_2} \right), & \text{if } \theta \leq \theta^{**} \\ 0, & \text{if } \theta > \theta^{**} \end{cases} \quad (4)$$

Total interim credit risk is $\mathcal{C}_1(\theta_1) = \mathcal{INS}_1(\theta_1) + \mathcal{ILL}_1(\theta_1)$, so that

$$\mathcal{C}_1(\theta_1) = \begin{cases} 1, & \text{if } \theta \leq \theta^{**} \\ F_2 \left(\frac{\theta^* - \theta_1}{\sigma_2} \right), & \text{if } \theta > \theta^{**} \end{cases} \quad (5)$$

2.3 Three Measures of Ex Ante Credit Risk

We are interested in identifying the ex ante credit risk, i.e., probability of default, for a holder of long-term debt when viewed from the initial date.

⁴See Morris and Shin (2003). In this paper, we take this result as given. In the appendix, we briefly describe how global game techniques allow us to provide micro-foundations for the Laplacian assumption.

We first identify the ex ante probability of insolvency, that is, the probability that the bank is insolvent in period 2, conditional on there not being a run in period 1. This is given by

$$\mathcal{INS}_0(\theta_0) = \int_{\theta_1=-\infty}^{\infty} F_2\left(\frac{\theta^* - \theta_1}{\sigma_2}\right) \frac{1}{\sigma_1} f_1\left(\frac{\theta_1 - \theta_0}{\sigma_1}\right) d\theta_1. \quad (6)$$

The ex ante probability of illiquidity (a run when it would turn out to be ex post solvent) is then

$$\mathcal{ILL}_0(\theta_0) = \int_{\theta_1=-\infty}^{\theta^* - \sigma_2 F_2^{-1}(1-q)} \left(1 - F_2\left(\frac{\theta^* - \theta_1}{\sigma_2}\right)\right) \frac{1}{\sigma_1} f_1\left(\frac{\theta_1 - \theta_0}{\sigma_1}\right) d\theta_1 \quad (7)$$

Total credit risk is the sum of the two

$$\begin{aligned} \mathcal{C}_0(\theta_0) &= \mathcal{INS}_0(\theta_0) + \mathcal{ILL}_0(\theta_0) \\ &= F_1\left(\frac{\theta^* - \theta_0 - \sigma_2 F_2^{-1}(1-q)}{\sigma_1}\right) \\ &\quad + \int_{\theta_1=\theta^* - \sigma_2 F_2^{-1}(1-q)}^{\infty} F_2\left(\frac{\theta^* - \theta_1}{\sigma_2}\right) \frac{1}{\sigma_1} f_1\left(\frac{\theta_1 - \theta_0}{\sigma_1}\right) d\theta_1 \end{aligned} \quad (8)$$

With the key expressions thus obtained, we now move to our comparative statics analysis.

3 Balance Sheet Composition and Credit Risk

To highlight the effect of balance sheet composition on ex ante credit risk, it is convenient to make assumptions that ensure that we can get closed form solutions to expressions for ex ante credit risk described in equations (6) to (8) above. For this purpose, we first assume that interim and final noise are both uniformly distributed, so that

$$F_1(x) = F_2(x) = \begin{cases} 0, & \text{if } x \leq -\frac{1}{2} \\ x + \frac{1}{2}, & \text{if } -\frac{1}{2} \leq x \leq \frac{1}{2} \\ 1, & \text{if } \frac{1}{2} \leq x \end{cases}$$

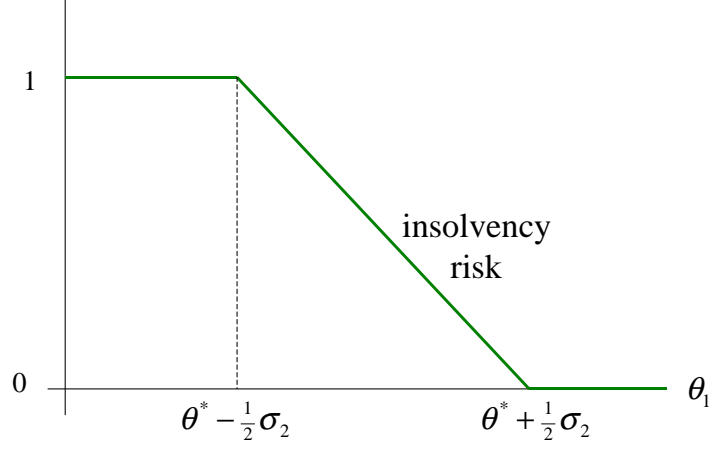


Figure 3: Insolvency risk

In this case, the interim credit risk can be represented as in figure 3. The formal expressions are corresponding to equations (2) - (5) above become:

$$\begin{aligned}
 \mathcal{INS}_1(\theta_1) &= \begin{cases} 1, & \text{if } \theta_1 \leq \theta^* - \frac{1}{2}\sigma_2 \\ \frac{1}{2} + \frac{1}{\sigma_2}(\theta^* - \theta_1), & \text{if } \theta^* - \frac{1}{2}\sigma_2 \leq \theta_1 \leq \theta^* + \frac{1}{2}\sigma_2 \\ 0, & \text{if } \theta^* + \frac{1}{2}\sigma_2 \leq \theta_1 \end{cases} \\
 \theta^{**} &= \theta^* + \sigma_2 \left(q - \frac{1}{2} \right) \\
 \mathcal{ILL}_1(\theta_1) &= \begin{cases} 0, & \text{if } \theta_1 \leq \theta^* - \frac{1}{2}\sigma_2 \\ \frac{1}{2} - \frac{1}{\sigma_2}(\theta^* - \theta_1), & \text{if } \theta^* - \frac{1}{2}\sigma_2 \leq \theta_1 \leq \theta^* + \sigma_2 \left(q - \frac{1}{2} \right) \\ 0, & \text{if } \theta_1 > \theta^* + \sigma_2 \left(q - \frac{1}{2} \right) \end{cases} \\
 \mathcal{C}_1(\theta_1) &= \begin{cases} 1, & \text{if } \theta_1 \leq \theta^* + \sigma_2 \left(q - \frac{1}{2} \right) \\ \frac{1}{2} + \frac{1}{\sigma_2}(\theta^* - \theta_1), & \text{if } \theta^* + \sigma_2 \left(q - \frac{1}{2} \right) \leq \theta_1 \leq \theta^* + \frac{1}{2}\sigma_2 \\ 0, & \text{if } \theta^* + \frac{1}{2}\sigma_2 \leq \theta_1 \end{cases}
 \end{aligned}$$

Figure 4 illustrates the total credit risk $\mathcal{C}_1(\theta_1)$ consisting of the insolvency risk and the illiquidity risk.

To evaluate ex ante credit risk, we want to identify the expectations of these expressions at θ_0 when θ_1 is uniformly distributed around θ_0 . We will assume all values of θ_1 where the insolvency risk is strictly between 0 and 1 are included in the support of the prior distribution (in a later section, we

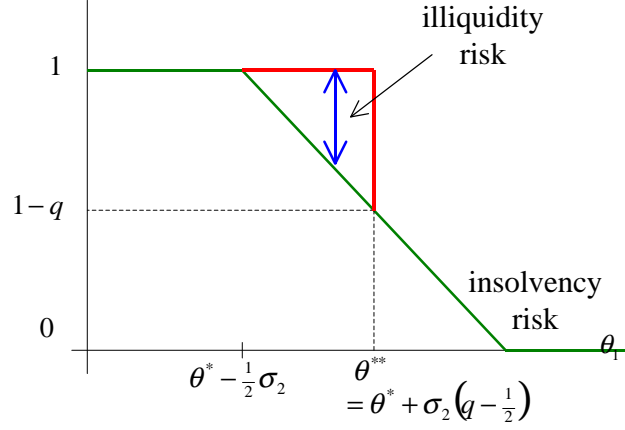


Figure 4: Total Credit Risk

examine the case where this condition does not hold). For now, we assume that the ex ante noise is sufficiently high ($\sigma_1 \geq \sigma_2$) and that θ_0 is not too extreme, i.e.,

$$\theta_0 \in \left[\theta^* - \frac{1}{2} (\sigma_1 - \sigma_2), \theta^* + \frac{1}{2} (\sigma_1 - \sigma_2) \right].$$

The ex ante insolvency risk is then

$$\begin{aligned} \mathcal{INS}_0(\theta_0) &= \int_{\varepsilon=-\frac{1}{2}}^{\frac{1}{2}} \mathcal{INS}_1(\theta_0 + \sigma_1 \varepsilon) \\ &= \frac{1}{\sigma_1} \left[\theta^* - \left(\theta_0 - \frac{1}{2} \sigma_1 \right) \right] \\ &= \frac{1}{2} + \frac{\theta^* - \theta_0}{\sigma_1} \end{aligned}$$

The ex ante illiquidity risk is

$$\begin{aligned}
\mathcal{ILL}_0(\theta_0) &= \int_{\varepsilon=-\frac{1}{2}}^{\frac{1}{2}} \mathcal{ILL}_1(\theta_0 + \sigma_1\varepsilon) \\
&= \frac{1}{2\sigma_1} \left[\left[\theta^* + \sigma_2 \left(q - \frac{1}{2} \right) \right] - \left[\theta^* - \frac{1}{2}\sigma_2 \right] \right] q \\
&= \frac{\sigma_2}{2\sigma_1} q^2
\end{aligned}$$

The ex ante credit risk is now

$$\begin{aligned}
\mathcal{C}_0(\theta_0) &= \mathcal{INS}_0(\theta_0) + \mathcal{ILL}_0(\theta_0) \\
&= \frac{1}{2} + \frac{\theta^* - \theta_0}{\sigma_1} + \frac{\sigma_2}{2\sigma_1} q^2
\end{aligned} \tag{9}$$

We note the following features of our solution. First, the illiquidity index q plays an important role in determining the size of the ex ante credit risk. The larger is q , the larger is the credit risk ex ante. Second, and perhaps more interestingly, there is an important role for the relative size of σ_2 compared to σ_1 , which interacts with the illiquidity index q . We noted earlier that the relative size of σ_2 to σ_1 can be interpreted as the degree to which the short-term debt is ultra short-term. This is because the shorter is the short-term debt, the smaller is the initial uncertainty versus the uncertainty faced at the interim stage.

Since the third term $\frac{\sigma_2}{2\sigma_1} q^2$ drops out when $q = 0$, we know that the relative size of σ_2 to σ_1 matters because of the interim roll-over stage of the game. We can also see this from our expression for $\mathcal{ILL}_0(\theta_0)$, ex ante illiquidity risk. Our expression 9 for total ex ante credit risk suggests that credit risk arising from the roll-over stage of the game is largest when the short-term debt is ultra-short term - where σ_1 becomes small. The reason lies in the increased fragility of the bank to a run by the short-term creditors, who become much more trigger-happy due to the relative uncertainty of the roll-over decision.

3.1 Balance Sheet Comparative Statics

We now turn our attention to the composition of the balance sheet. We can see that the impact (in increased credit risk) to increasing the solvency point

θ^* is

$$\sigma_1 \frac{d\mathcal{C}_0}{d\theta^*} = 1,$$

while the impact of increasing the illiquidity index q is

$$\sigma_1 \frac{d\mathcal{C}_0}{dq} = \sigma_2 q.$$

Hence, we see that improving the liquidity of the bank's balance sheet may be more effective in mitigating overall credit risk when compared to increasing the capital buffer that does not have an implications of the liquidity. This is so when σ_2 is large (there is more interim uncertainty about the bank's assets, and short-term debt is ultra short-term) and when q is large (the current liquidity of the balance sheet is low).

We can also identify in more detail the effectiveness of holding different assets in reducing credit risk. For any asset i , we can identify its impact on solvency and liquidity. Let us write E_0 for the market value (expected value) of equity at time 0:

$$E_0 = \sum_{i=0}^N A_i (\alpha_i + \beta_i \theta_0) - Sr_S - Lr_L$$

and write

$$V = \sum_{i=0}^N A_i \beta_i$$

for a measure of the variability of the variance of the firm's portfolio. Now observe that the solvency point θ^* can be written as

$$\theta^* = \frac{Sr_S + Lr_L - \sum_{i=0}^N \alpha_i A_i}{\sum_{i=0}^N \beta_i A_i} = \theta_0 - \frac{E_0}{V}$$

Writing $\bar{r}_i = \alpha_i + \beta_i \theta_0$ for the gross expected return of asset i , we have

$$\frac{d\theta^*}{dA_i} = \frac{-\bar{r}_i}{V} + \frac{E_0 \beta_i}{V^2}.$$

Recall that

$$q \equiv \frac{r^* S}{r_S A^*}$$

and $A^* = \sum_{i=0}^n \lambda_i \bar{r}_i A_i.$

Thus

$$\begin{aligned} \frac{dq}{dA_i} &= -\frac{q}{A^*} \frac{dA^*}{dA_i} \\ &= -\frac{q \lambda_i \bar{r}_i}{A^*} \end{aligned}$$

Thus the total impact of asset i on credit risk is

$$\sigma_1 \frac{d\mathcal{C}_0}{dA_i} = -\frac{\bar{r}_i}{V} + \frac{E_0 \beta_i}{V^2} - \frac{\sigma_2 q^2 \lambda_i \bar{r}_i}{A^*}.$$

Thus for asset 0 (i.e. cash) we have

$$\sigma_1 \frac{d\mathcal{C}_0}{dA_0} = -\frac{1}{V} - \sigma_2 \frac{q^2}{A^*}.$$

For a riskless illiquid asset k with gross return R , we have

$$\sigma_1 \frac{d\mathcal{C}_0}{dA_k} = -\frac{R}{V}.$$

The multiplier of cash is

$$\frac{A^* + \sigma_2 V q^2}{A^* R}. \tag{10}$$

We see the importance of the liquidity effect of cash, as compared to the riskless nature of cash. The impact of cash holdings shows through to the final credit risk due to its role in mitigating the illiquidity risk of the bank, rather than the ultimate solvency of its asset book. The multiplier (10) shows the added impact of cash as a *liquid asset* versus cash as a *safe asset*. No doubt, when we delve deeper into the reasons for the liquid nature of cash we will see some connection between the two, but for our comparative statics exercise, it is possible to separate the two attributes of cash - its liquid nature versus its risk-free nature.

4 Robustness

In this section, we verify the robustness of our results to some underlying assumptions.

4.1 The small ex ante uncertainty case

In section 3, we calculated ex ante credit risk and its decomposition into insolvency and illiquidity risk under the assumption that there was a significant amount of ex ante uncertainty (relative to interim uncertainty). In this section, we examine how results would change if there was only a small amount of ex ante uncertainty.

In particular, we see the impact of only a small amount of information being released between times 0 and 1. Thus we assume that

$$\sigma_1 < \sigma_2(1 - q)$$

In this case, we derive simple expressions for ex ante credit risk as follows. Define the following cut-off values of θ_0 .

$$\begin{aligned} a_1 &\equiv \theta^* + \sigma_2 q - \frac{1}{2}\sigma_2 - \frac{1}{2}\sigma_1 \\ a_2 &\equiv \theta^* + \sigma_2 q - \frac{1}{2}\sigma_2 + \frac{1}{2}\sigma_1 \\ a_3 &\equiv \theta^* + \frac{1}{2}\sigma_2 - \frac{1}{2}\sigma_1 \\ a_4 &\equiv \theta^* + \frac{1}{2}\sigma_2 + \frac{1}{2}\sigma_1 \end{aligned}$$

Then we have: $\mathcal{C}_0(\theta_0) =$

$$\begin{cases} 1, & \text{if } \theta_0 \leq a_1 \\ \left(\begin{array}{l} 1 - \frac{1}{\sigma_1} (\theta_0 - \theta^* - \sigma_2 (q - \frac{1}{2}) + \frac{1}{2}\sigma_1) q \\ -\frac{1}{2\sigma_1\sigma_2} (\theta_0 - \theta^* - \sigma_2 (q - \frac{1}{2}) + \frac{1}{2}\sigma_1)^2 \end{array} \right), & \text{if } a_1 \leq \theta_0 \leq a_2 \\ \frac{1}{2} + \frac{1}{\sigma_2} (\theta^* - \theta_0), & \text{if } a_2 \leq \theta_0 \leq a_3 \\ \frac{1}{2\sigma_1\sigma_2} (\theta^* - \theta_0 + \frac{1}{2}\sigma_2 + \frac{1}{2}\sigma_1)^2, & \text{if } a_3 \leq \theta_0 \leq a_4 \\ 0, & \text{if } a_4 \leq \theta_0 \end{cases}$$

Figure 5 plots $\mathcal{C}_0(\theta_0)$ for the case when there is small interim uncertainty.

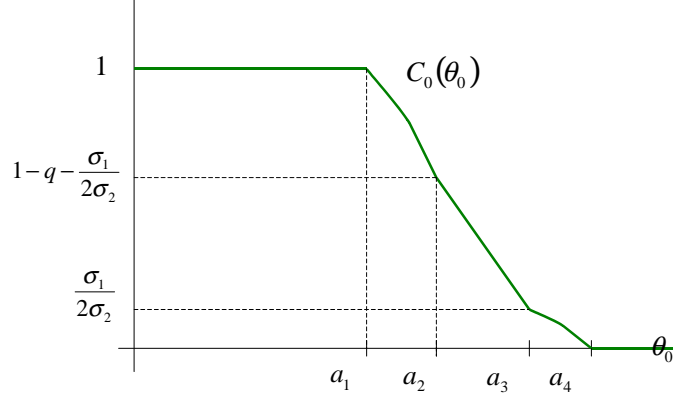


Figure 5: Total credit risk with small interim uncertainty

Thus

$$\sigma_1 \frac{dC_0}{d\theta^*}(\theta_0) = \begin{cases} 0, & \text{if } \theta_0 \leq a_1 \\ q + \frac{1}{\sigma_2} (\theta_0 - \theta^* - \sigma_2 (q - \frac{1}{2}) + \frac{1}{2}\sigma_1), & \text{if } a_1 \leq \theta_0 \leq a_2 \\ \frac{\sigma_1}{\sigma_2}, & \text{if } a_2 \leq \theta_0 \leq a_3 \\ \frac{1}{\sigma_2} (\theta^* - \theta_0 + \frac{1}{2}\sigma_2 + \frac{1}{2}\sigma_1), & \text{if } a_3 \leq \theta_0 \leq a_4 \\ 0, & \text{if } a_4 \leq \theta_0 \end{cases}$$

and

$$\sigma_1 \frac{dC_0}{dq}(\theta_0) = \begin{cases} 0, & \text{if } \theta_0 \leq a_1 \\ \sigma_2 q, & \text{if } a_1 \leq \theta_0 \leq a_2 \\ 0, & \text{if } a_2 \leq \theta_0 \end{cases}$$

These expressions are illustrated in figure 6. Now the impact of the solvency point and illiquidity index on ex ante credit risk is extremely sensitivity to the initial value of θ_0 . In fact, we see that the illiquidity index will have no impact except in the range $\theta_0 \in [\theta^* + \sigma_2 q - \frac{1}{2}\sigma_2 - \frac{1}{2}\sigma_1, \theta^* + \sigma_2 q - \frac{1}{2}\sigma_2 + \frac{1}{2}\sigma_1]$ and, in the limit, the solvency will have most of its impact in that range. In that range, it remains the case that the illiquidity index has a relatively large impact if σ_2 is large. In particular,

$$\sigma_1 \frac{dC}{d\theta^*} \rightarrow \begin{cases} 0, & \text{if } \theta_0 \leq a_1 \\ q, & \text{if } a_1 \leq \theta_0 \leq a_2 \\ 0, & \text{if } a_2 \leq \theta_0 \end{cases}$$

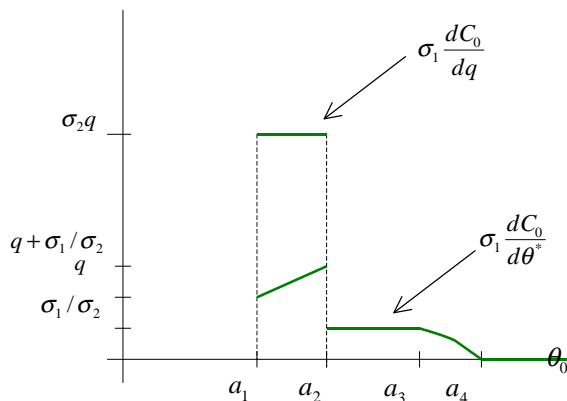


Figure 6: $\sigma_1 \frac{dC_0}{dq}$ and $\sigma_1 \frac{dC_0}{d\theta^*}$

4.2 General Distributions

Recall that - in section 3 - we showed that with uniform distributions and sufficiently large σ_1 , we had:

1. $\mathcal{INS}_0(\theta_0) = \frac{1}{2} + \frac{\theta^* - \theta_0}{\sigma_1}$, and thus independent of q
2. $\mathcal{ILL}_0(\theta_0) = \frac{\sigma_2}{2\sigma_1} q^2$, and thus independent of θ^*
3. $\sigma_1 \frac{d\mathcal{INS}_0}{d\theta^*} = 1$
4. $\sigma_1 \frac{d\mathcal{ILL}_0}{dq} = \sigma_2 q$

Here we note that qualitatively similar results hold with general distributions.

Definition 1 *Distribution h satisfies a non-decreasing (increasing) monotone hazard ratio condition if $\frac{f_2(x)}{1-F_2(x)}$ is non-decreasing (increasing) in x ; it has thin tails if $\frac{f_2(x)}{1-F_2(x)} \rightarrow \infty$ as $x \rightarrow \infty$.*

Proposition 1. With general distributions, $\mathcal{INS}_0(\theta_0)$ is independent of q

1. as $\sigma_1 \rightarrow \infty$, $\sigma_1 \mathcal{ILL}_0(\theta_0)$ becomes independent of θ^*

2. as $\sigma_1 \rightarrow \infty$, $\sigma_1 \frac{d\mathcal{I}NS_0}{d\theta^*}$ becomes constant (i.e., independent of θ^*)
3. as $\sigma_1 \rightarrow \infty$, $\sigma_1 \frac{d\mathcal{I}LL_0}{d\theta^*}$..
 - (a) becomes linear in σ_0 ;
 - (b) tends to infinite as $q \rightarrow 1$;
 - (c) becomes non-decreasing (increasing) if f_2 has non-decreasing (increasing) hazard ratio;
 - (d) tends to 0 as $q \rightarrow 0$ if f_2 has thin tails

Thus all the qualitative properties of the uniform case survive, with the sensitivity of $\sigma_1 \frac{d\mathcal{I}LL_0}{d\theta^*}$ to the illiquidity index being even higher when the level of illiquidity is high. The proof is in the appendix.

We can also provide results for general distributions and small ex ante noise:

Proposition 2.

$$\sigma_1 \frac{d\mathcal{C}_0}{dq} = \frac{\sigma_2 q f_1 \left(\frac{\theta^* - \theta_0 - \sigma_2 F_2^{-1}(1-q)}{\sigma_1} \right)}{f_2 \left(F_2^{-1}(1-q) \right)}$$

and, as $\sigma_1 \rightarrow 0$,

$$\sigma_1 \frac{d\mathcal{C}_0}{d\theta^*} \rightarrow q f_1 \left(\frac{\theta^* - \theta_0 - \sigma_2 F_2^{-1}(1-q)}{\sigma_1} \right)$$

and thus

$$\frac{\frac{d\mathcal{C}_0}{dq}}{\frac{d\mathcal{C}_0}{d\theta^*}} \rightarrow \frac{\sigma_2 q}{f_2 \left(F_2^{-1}(1-q) \right)}$$

The proof is in the appendix.

5 Concluding Remarks

Our results highlight two trends in banking that are likely to have increased the sensitivity of overall credit risk to run outcomes. The first is the secular decline in the cash holdings by commercial banks over the last thirty or so years, until the outbreak of the recent financial crisis. As discussed earlier, even as recently as the early 1980s, cash assets of US commercial banks were

around 10% of total assets, but that ratio fell to around 2.5% in recent years, before jumping up sharply with the onset of the financial crisis of 2008. Our theory has highlighted the vulnerability of banks to low cash ratios.

The second trend in recent years has been the shortening maturity of short-term bank liabilities, with the increased use of overnight repos over term repos. When viewed through the lens of our theory, this trend toward the shortening of maturities for short-term liabilities can be seen as a factor that increased fragility. The fact that short-term debt becomes *ultra*-short term is an important factor in increasing the illiquidity component of credit risk.

Our results hold implications for financial regulation, and give theoretical support to two ideas - a cash requirement for banks, and the importance of keeping track of ultra-short term liabilities. Our theory suggests that the interactions are subtle and depend on the interactions of illiquidity risk and fundamental insolvency risk. More research beckons in exploring further the themes outlined in this paper.

Appendix

Global Game Foundations for the Laplacian Rule

We first present the argument for Laplacian beliefs for the Gaussian case. Let player i 's private signal be given by

$$x_i = \theta + \varepsilon_i$$

where θ is a Gaussian random variable with mean y and variance $1/\alpha$, and ε_i is Gaussian with mean zero and variance $1/\beta$. The random variables $\{\varepsilon_i\}$ are mutually independent, and independent of θ . Denote by $\pi(x)$ the proportion of players whose signal is x or less. Then, $\pi(x)$ is a random variable with realizations in the unit interval, and which is a function of the random variables $\{\theta, \varepsilon_i\}_{i \in [0,1]}$ and the threshold x . We derive the density function of $\pi(x_i)$ conditional on x_i . Let

$$G(z|x_i) \tag{11}$$

be the cumulative distribution function of $\pi(x_i)$ conditional on x_i , evaluated at z . In other words,

$$G(z|x_i) = \Pr(\pi(x_i) \leq z|x_i) \tag{12}$$

so that, $G(z|x_i)$ is the probability that the proportion of players with signal lower than x_i is z or less, conditional on x_i . Figure 7 illustrates the derivation of $G(z|x_i)$.

Given θ , the proportion of players who have signal below x_i is

$$\Phi\left(\sqrt{\beta}(x_i - \theta)\right) \tag{13}$$

where $\Phi(\cdot)$ is the cumulative distribution function for the standard normal. Let $\hat{\theta}$ be the realization of θ at which this proportion is exactly z . In other words,

$$\hat{\theta} = x_i - \frac{\Phi^{-1}(z)}{\sqrt{\beta}} \tag{14}$$

The top panel of figure 7 illustrates $\hat{\theta}$. When $\theta \geq \hat{\theta}$, the proportion of players that have signal below x_i is z or less. In other words, $\pi(x_i) \leq z$ whenever $\theta \geq \hat{\theta}$. Hence, $G(z|x_i)$ is the probability of $\{\theta|\theta \geq \hat{\theta}\}$ conditional on x_i .

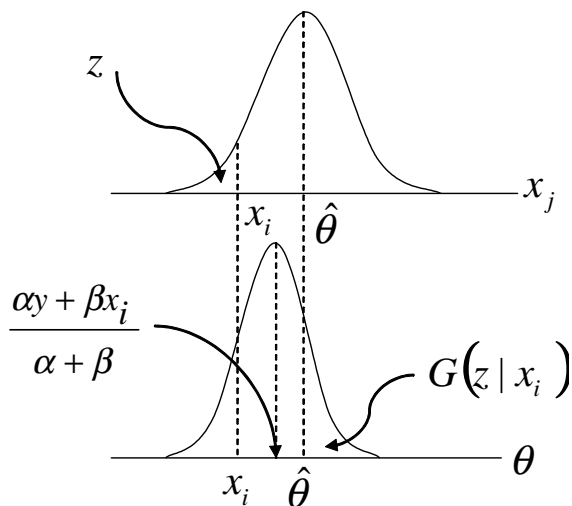


Figure 7: Deriving $G(z|x_i)$

The bottom panel of figure 7 illustrates the argument. Conditional on x_i , the density over θ is normal with mean

$$\frac{\alpha y + \beta x_i}{\alpha + \beta} \quad (15)$$

and precision $\alpha + \beta$. The probability that $\theta \geq \hat{\theta}$ is the area under this density to the right of $\hat{\theta}$, namely

$$1 - \Phi\left(\sqrt{\alpha + \beta}\left(\hat{\theta} - \frac{\alpha y + \beta x_i}{\alpha + \beta}\right)\right) \quad (16)$$

This expression gives $G(z|x)$. Substituting out $\hat{\theta}$ by using (14) and rearranging, we can re-write (16) to give:

$$G(z|x_i) = \Phi\left(\frac{\alpha}{\sqrt{\alpha + \beta}}(y - x_i) + \sqrt{\frac{\alpha + \beta}{\beta}}\Phi^{-1}(z)\right) \quad (17)$$

In the special case when $\beta \rightarrow \infty$, the private signal becomes infinitely precise. In this limit,

$$G(z|x) \rightarrow \Phi(\Phi^{-1}(z)) = z$$

so that G is the identity function. In other words, the c.d.f. of $\pi(x_i)$ is the 45 degree line, and hence the density over $\pi(x_i)$ is uniform. Thus, in this

limit, player i believes that he is “typical” in quite a strong sense, in that he puts equal weight on every realization of $\pi(x_i)$.

Morris and Shin (2003) show that the above argument is valid for general densities provided that some mild regularity conditions on the smoothness of densities are preserved. We refer the reader to that discussion for the full argument.

Proofs for the General Distribution Case

PROOF OF PROPOSITION 1. Recall that the ex ante insolvency risk is

$$\mathcal{INS}_0(\theta_0) = \int_{\theta_1=-\infty}^{\infty} F_2\left(\frac{\theta^* - \theta_1}{\sigma_2}\right) \frac{1}{\sigma_1} f_1\left(\frac{\theta_1 - \theta_0}{\sigma_1}\right) d\theta_1,$$

which is obviously independent of q . So as $\sigma_1 \rightarrow \infty$

$$\begin{aligned} \sigma_1 \frac{d\mathcal{INS}_0}{d\theta^*} &\rightarrow \int_{\theta_1=-\infty}^{\infty} \frac{1}{\sigma_2} f_2\left(\frac{\theta^* - \theta_1}{\sigma_2}\right) f_1(0) d\theta_1 \\ &= f_1(0) \end{aligned}$$

The ex ante illiquidity risk is

$$\mathcal{ILL}_0(\theta_0) = \int_{\theta_1=-\infty}^{\theta^* - \sigma_2 F_2^{-1}(1-q)} \left(1 - F_2\left(\frac{\theta^* - \theta_1}{\sigma_2}\right)\right) \frac{1}{\sigma_1} f_1\left(\frac{\theta_1 - \theta_0}{\sigma_1}\right) d\theta_1$$

By the change of variables

$$r = 1 - F_2\left(\frac{\theta^* - \theta_1}{\sigma_2}\right),$$

we can re-write the above expression for liquidity risk as

$$\sigma_1 \mathcal{ILL}_0(\theta_0) = \int_{r=0}^q r f_1\left(\frac{\theta^* - \theta_0 - F_2^{-1}(1-r)}{\sigma_1}\right) \frac{\sigma_2}{f_2(F_2^{-1}(1-r))} dr.$$

As $\sigma_1 \rightarrow \infty$,

$$\sigma_1 \mathcal{ILL}_0(\theta_0) = \int_{r=0}^q f_1(0) \frac{\sigma_2 r}{f_2(F_2^{-1}(1-r))} dr.$$

This is independent of θ^* . Now as $\sigma_1 \rightarrow \infty$,

$$\sigma_1 \frac{d\mathcal{I}\mathcal{L}\mathcal{L}_0(\theta_0)}{dq} \rightarrow \frac{\sigma_2 q f_1(0)}{f_2(F_2^{-1}(1-q))}$$

This expression is linear in σ_2 . It depends on q through $\frac{q}{f_2(F_2^{-1}(1-q))}$. Setting $x = F_2^{-1}(1-q)$, this equals $\frac{1-F_2(x)}{f_2(x)}$. Thus the thin tails property implies $\frac{q}{f_2(F_2^{-1}(1-q))} \rightarrow 0$ as $q \rightarrow 0$; the non-decreasing (increasing) hazard ratio condition implies $\frac{q}{f_2(F_2^{-1}(1-q))}$ is (non-decreasing) increasing; and $\frac{q}{f_2(F_2^{-1}(1-q))} \rightarrow \infty$ as $q \rightarrow 1$.

PROOF OF PROPOSITION 2. Differentiating (8) with respect to q gives

$$\begin{aligned} \mathcal{C}_0(\theta_0) &= \mathcal{I}\mathcal{N}\mathcal{S}_0(\theta_0) + \mathcal{I}\mathcal{L}\mathcal{L}_0(\theta_0) & (18) \\ &= F_1\left(\frac{\theta^* - \theta_0 - \sigma_2 F_2^{-1}(1-q)}{\sigma_1}\right) + \int_{\theta_1 = \theta^* - \sigma_2 F_2^{-1}(1-q)}^{\infty} F_2\left(\frac{\theta^* - \theta_1}{\sigma_2}\right) \frac{1}{\sigma_1} f_1\left(\frac{\theta_1 - \theta_0}{\sigma_1}\right) d\theta_1 \\ \sigma_1 \frac{d\mathcal{C}_0}{dq} &= \frac{\sigma_2 q f_1\left(\frac{\theta^* - \theta_0 - \sigma_2 F_2^{-1}(1-q)}{\sigma_1}\right)}{f_2(F_2^{-1}(1-q))}. \end{aligned}$$

Differentiating (8) with respect to θ^* gives

$$\sigma_1 \frac{d\mathcal{C}_0}{d\theta^*} = \left\{ \begin{array}{l} f_1\left(\frac{\theta^* - \theta_0 - \sigma_2 F_2^{-1}(1-q)}{\sigma_1}\right) \\ - (1-q) f_1\left(\frac{\theta^* - \theta_0 - \sigma_2 F_2^{-1}(1-q)}{\sigma_1}\right) \\ + \int_{\theta_1 = \theta^* - \sigma_2 F_2^{-1}(1-q)}^{\infty} \frac{1}{\sigma_2} f_2\left(\frac{\theta^* - \theta_1}{\sigma_2}\right) f_1\left(\frac{\theta_1 - \theta_0}{\sigma_1}\right) d\theta_1 \end{array} \right\}.$$

As $\sigma_1 \rightarrow 0$, the last expression tends to 0 and thus

$$\sigma_1 \frac{d\mathcal{C}_0}{d\theta^*} \rightarrow q f_1\left(\frac{\theta^* - \theta_0 - \sigma_2 F_2^{-1}(1-q)}{\sigma_1}\right).$$

References

- [1] Adrian, Tobias and Hyun Song Shin (2007) “Liquidity and Leverage” forthcoming in the *Journal of Financial Intermediation*.
- [2] Adrian, Tobias and Hyun Song Shin (2008) “Liquidity and Financial Contagion” *Financial Stability Review*, Banque de France, February 2008
- [3] Brunnermeier, Markus (2009) “Deciphering the Liquidity and Credit Crisis of 2007-8” *Journal of Economic Perspectives* 2009, 23(1), 77-10
- [4] Brunnermeier, Markus, Andrew Crockett, Charles Goodhart, Avi Persaud and Hyun Song Shin (2009) “The Fundamental Principles of Financial Regulation” Geneva Report on the World Economy 11.
- [5] Bryant, J. (1980). ”A model of reserves, bank runs, and deposit insurance,” *Journal of Banking & Finance* 4, 335-344.
- [6] Diamond, D. and P. Dybvig (1983). ”Bank Runs, Deposit Insurance, and Liquidity,” *Journal of Political Economy* 91, 401-419,.
- [7] Carlsson, H. and E. van Damme (1993). ”Global Games and Equilibrium Selection,” *Econometrica* 61, 989-1018.
- [8] Goldstein, I. and A. Pauzner (2005). “Demand Deposit Contracts and the Probability of Bank Runs,” *Journal of Finance* 60, 1293-1328.
- [9] Guimaeres, B. (2006). ”Dynamics of Currency Crises with Asset Market Frictions,” *Journal of International Economics* 68, 141-158.
- [10] He, Z. and W. Xiong (2008). ”Dynamic Bank Runs.”
- [11] Morris, S. and H. S. Shin (1998). ”Unique Equilibrium in a Model of Self-Fulfilling Currency Attacks,” *American Economic Review* 88, 587-597.
- [12] ——— (2003). ”Global Games: Theory and Applications,” in *Advances in Economics and Econometrics (Proceedings of the Eighth World Congress of the Econometric Society)*, edited by M. Dewatripont, L. Hansen and S. Turnovsky. Cambridge, England: Cambridge University Press (2003), 56-114.

- [13] ——— (2004). "Coordination Risk and the Price of Debt," *European Economic Review* 48, 133-153.
- [14] ——— (2008). "Financial Regulation in a System Context," forthcoming in *Brookings Papers on Economic Activity*.
- [15] Rochet, J-C. and X. Vives (2004). "Coordination Failures and the Lender of Last Resort: Was Bagehot Right After All?" *Journal of the European Economic Association* 2, 1116-1147.