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Liquidity and Transparency in Bank Risk Management

Lev Ratnovski

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Prepared by Lev Ratnovski[1]

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Abstract

Banks may be unable to refinance short-term liabilities in case of solvency concerns. To manage this risk, banks can accumulate a buffer of liquid assets, or strengthen transparency to communicate solvency. While a liquidity buffer provides complete insurance against small shocks, transparency covers also large shocks but imperfectly. Due to leverage, an unregulated bank may choose insufficient liquidity buffers and transparency. The regulatory response is constained: while liquidity buffers can be imposed, transparency is not verifiable. Moreover, liquidity requirements can compromise banks' transparency choices, and increase refinancing risk. To be effective, liquidity requirements should be complemented by measures that increase bank incentives to adopt transparency.

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Author's E-Mail Address: LRatnovski@imf.org

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1 Introduction

Banks use short-term debt to invest in long-term assets (Diamond and Dybvig, 1983). This creates liquidity risk: a bank unable to roll over maturing debt can fail despite being solvent. A majority of recent bank liquidity crises in developed economies were caused by increased uncertainty over a bank's solvency and played out primarily in wholesale funding markets (Gatev and Strahan, 2006, Shin, 2008, Yorulmazer, 2008, Huang and Ratnovski, 2011).[1] The new Basel III accord aims to address liquidity risk in banks through the Liquidity Coverage Ratio (a liquidity requirement) and the Net Stable Funding Ratio (a restriction on maturity mismatch that limits the volume of refinancing coming due each period; see Basel Committee, 2010).

The purpose of this paper is to offer a model of bank liquidity risk driven by solvency concerns and to study its regulatory implications. In particular, we want to understand the interaction between liquidity requirements, access to refinancing (which we link to bank transparency), and liquidity risk.

We model liquidity risk driven by a sudden increase of uncertainty over the bank's solvency. A bank has a valuable long-term project, which with a small probability can turn out to be of zero value. Because the risk is small, it does not prevent initial funding. At the intermediate date, the bank needs to refinance an exogenous random withdrawal. Yet its ability to do so can be compromised by informational frictions. In most states of the world, the bank is solvent, and refinancing is available. Yet, with some probability, the world is in a "bad" state, where the posterior probability of insolvency is high (but less than one). Then, investors may become unwilling to lend to the bank, creating liquidity risk and the possibility of a failure of a potentially solvent institution.

[1] Some notable examples include: Citibank and Standard Chartered in Hong Kong in 1991 (rumors of technical insolvency), Lehman Brothers in 1998 (rumors of severe losses in emerging markets), and Commerzbank in 2002 (rumors of large trading losses). In the recent crisis: Northern Rock and Countrywide in 2007 and IndyMac in 2008 (concerns about mortgage exposures), Bear Stearns in 2008 (concerns about CDS exposures). Note that in most of these cases the solvency (hypothetical long-term viability) of a bank was still uncertain at the time of the crisis. Yet a banks' inability to refinance prompted distressed liquidations and was a proximate cause of the collapse. The bankruptcy of Lehman Brothers in 2008 led to endemic counterparty solvency concerns, and an inability to refinance in a large number of institutions.

We observe that a bank can hedge liquidity risk in two ways. One, traditional, is to accumulate a precautionary buffer of easily tradeable assets: a liquidity buffer. In a liquidity crisis, a bank can dispose of such assets and cover the refinancing needs internally. Another, less conventional, is to enhance the ability to communicate solvency information to outsiders. A bank that can "prove" its solvency will be able to attract external refinancing. We label the mechanisms by which a bank can establish effective communication "transparency". We take the standard corporate governance view on transparency (Doidge, 2003, Leuz et al., 2003, Anderson et al., 2009), formalized by two assumptions: (*i*) banks can choose the level of transparency (the amount of information available to outsiders), and (*ii*) higher transparency reduces the owner-manager's private benefits of control.

Liquidity buffers and transparency are complements, yet strategic substitutes. They are complements because they hedge the same risk with different imperfections. A liquidity buffer can only cover small refinancing needs because its size is limited. Transparency improves access to external refinancing for liquidity needs of any size, but is only effective with a probability. The reason is that transparency relies on *ex-post* communication to market participants, which may sometimes fail, and then refinancing will not be forthcoming. A bank can therefore combine liquidity buffers and transparency in its risk management, to fully hedge small refinancing needs, and partially hedge large ones. Yet liquidity buffers and transparency are strategic substitutes, because for a bank that adopts one hedging instrument, the value of another diminishes.

Liquidity and transparency are costly hedges, and most of their cost is borne by the bank's shareholders. Holding liquidity buffers is costly because their maintenance requires effort from bank managers (or other administrative cost); the cost of effort cannot be compensated by a low return on highly liquid assets. With transparency, the owner-manager sacrifices private benefits. Yet some of the benefits of hedging accrue to creditors in the form of lower risk and are not internalized by shareholders (Jensen and Meckling, 1976). As a result, a leveraged bank may under-invest in liquidity buffers and transparency.

Suboptimal risk management (insufficient hedging) justifies government intervention in the form of bank liquidity regulation. We make two observations. First, while liquidity buffers can be imposed, transparency is not easily verifiable and is harder to regulate. Then, liquidity requirements may have unintended consequences: compromise the bank's endogenous transparency choices. We show that for some parameter values the deterioration of transparency may more than offset the positive effect of larger liquidity buffers, so that liquidity regulation will unintentionally *increase* the overall refinancing risk.

Second, while transparency cannot be regulated directly, the model identifies a number of indirect mechanisms by which policy can address it. One mechanism is to encourage transparency by reducing its alternative cost, the bank owner-manager's private benefits of control. This can be achieved, for example, by stronger corporate governance. Another mechanism is to accept insufficient transparency, but reduce the risk of large refinancing needs that exceed the size of the liquidity buffer. This can be implemented through maturity mismatch limits (such as the Net Stable Funding Ratio of Basel III). These solutions may be essential complements to liquidity requirements.

The paper is organized as follows. Section 2 reviews the literature on bank liquidity risk and on transparency. Section 3 sets up the model. Section 4 describes socially optimal and private risk management choices. Section 5 studies regulatory implications. Section 6 concludes.

2 Related Literature

2.1 Bank Liquidity Risk

The paper relates to the literature on bank liquidity risk and refinancing frictions. Early papers on liquidity risk, such as Diamond and Dybvig (1983) and Chari and Jagannathan (1988), assumed the absence of informed refinancing even for banks with valuable assets. The seminal work of Goodfriend and King (1988) provided a benchmark that banks known to be solvent should be able to refinance themselves in well-functioning interbank markets. Their work implies that, in order to describe modern liquidity risk in banks, models need to demonstrate how market failures may restrict the market-based refinancing of solvent institutions.

One such market failure is informational frictions. In Flannery (1996), potential lenders are uncertain of their screening ability, and restrict refinancing to avoid lemon costs. Rochet and Vives (2004) model a coordination failure among bank creditors, where each withdraws if expects others to do the same. Freixas et al. (2004) consider a solvent bank that seeks refinancing but is indistinguishable from an insolvent one that attracts funds to gamble for resurrection. Huang and Ratnovski (2011) argue that sophisticated lenders may over-react to solvency concerns when they are senior and do not incur the full cost of liquidations. Our paper contributes to this literature with a simple model driven by a basic information friction, where the probability of bank failure is initially low, but its posterior can increase at an intermediate date, exposing affected banks to prohibitive lemon costs.

Another market failure that may restrict refinancing is an increase in moral hazard as in Holmstrom and Tirole (1998, 2011). The key distinction between the Holmstrom and Tirole framework and our approach is that they consider a *net* liquidity need: a bank needs to attract *additional* funds to continue the project, but a moral hazard-related leverage constraint may prevent it from doing so. As a result, such models may be more attuned to the analysis of leverage and capital regulation (cf. Farhi and Tirole, 2012). In contrast, our and similar models consider a *gross* liquidity need: a firm needs to attract funds to *substitute* the outflow. The bank's leverage does not change and its overall borrowing constraint does not become more binding.

Our focus on liquidity buffers and transparency as instruments of liquidity risk management is consistent with the empirical results that both stock liquidity (Paravisini, 2007) and access to external refinancing (Kashyap and Stein, 1990, Holod and Peek, 2004) are important in determining bank financial pressures. There is evidence that banks may be insufficiently liquid (Gatev et al., 2004, Gonzalez-Eiras, 2003) or transparent (Morgan, 2002). The issue of transparency may be most relevant for advanced banking systems (Bennet and Peristiani, 2002, Chaplin et al., 2000), since banks in developing countries (with less deep financial markets) predominantly rely on stock liquidity to manage refinancing risks (Freedman and Click, 2006).

2.2 Bank Transparency

The paper also relates to the literature on bank transparency (or, conversely, opacity). The literature offers two ways to formalize transparency: as the presence of credible communication channels or as asset choice. We focus on the former.

The link between transparency and credible communication has strong foundations in the corporate governance literature. Firms can suppress information and conceal own performance by deliberately maintaining lower levels of disclosure (Anderson et. al., 2009) or through earnings management (Leuz et al., 2003). The key reason for suppressing information is that it enhances insiders' private benefits of control (Doidge, 2003, Leuz et al., 2003, Doidge et al., 2009). The impact of transparency on firm performance is ambiguous.

For banks, the argument that the availability of information on asset returns is endogenous goes back at least to Stanhouse (1986). In addition to the methods available to non-financial firms, banks can conceal information through organizational complexity (Berger et al., 2000) or obfuscation (Carlin, 2009, and Carlin and Manso, 2011). Banks can facilitate information production by maintaining incentives for market participants to specialize in analyzing information about the bank (Calomiris, 1999). The argument that opacity enhances private benefits of control in banks has been articulated by Ostberg (2006) and Wagner (2007).

We follow this literature in interpreting transparency as a set of ex-ante choices that determine the presence of credible communication channels; with the key cost of transparency being lower private benefits of control.

It is useful to highlight the distinction between transparency and disclosure. First, establishing transparency can involve other corporate actions, such as avoiding complexity. Second, transparency is a strategic *ex-ante* decision, while disclosure is an *ex-post* action (Perotti and Von Thadden, 2003). Unless preconditions are in place, *ad hoc* disclosure may be not credible (Boot and Thakor, 2001), particularly in the context of a liquidity crisis, since a distressed firm has high incentives to manipulate information (Povel et al., 2007, Atanasov et al., 2010).[2] Therefore while the regulation of disclosure may be useful (Admati and Pfleiderer, 2000, Ostberg, 2006), it is not sufficient to achieve transparency when banks can manipulate or obfuscate information.

The final caveat is that we focus on the positive effects of transparency where it enables the refinancing of solvent banks. One can construct opposite examples where transparency has negative unintended consequences. For example, Chen and Hasan (2006) and Huang and Ratnovski (2011) show how transparency renders banks unable to conceal negative but possibly incorrect news about solvency. We abstract from these effects.

An alternative approach to interpreting transparency would be to link it with bank asset choice. Indeed, some bank assets, such as relationship-based loans, are intensive in soft information, and their value is hard to communicate. In contrast, other assets, such as trading assets or securitized loans (e.g. mortgages) rely on hard information that can be more easily communicated (Boot and Thakor, 2000, Berger et al., 2005). While theoretically appealing, the relationship between transparency and asset choice has limited empirical support: Morgan (2002) and Flannery et al. (2010) find no relationship between bank asset class holdings and market-based measures of transparency.

[2] Two illustrations are useful. *The Economist* highlights the difficulty of communicating during a banking crisis: "You know something bad is going to happen... when a bank boss [is] insisting that his institution is completely solid" ("Here We Go Again", October 8, 2011). Griffin and Wallach (1991) offer a historic perspective on the credibility of disclosure: when Citicorp became the first large bank to make provisions against losses from the Latin American debt crisis (in May 1987), it had to make clearly excess, very costly provisions ($3 billion) as a signal of a commitment to draw a line under prior losses.

3 The Model

This section outlines a model of bank liquidity risk driven by solvency concerns.

3.1 Economy and Agents

Consider a risk-neutral economy with three dates $(0, 1, 2)$ and no discounting. The economy is populated by multiple competitive investors and a single owner-managed bank. Investors are endowed with money that they can lend to the bank against a zero expected rate of return.

The bank is endowed with a profitable investment project. The project is fixed in size. It requires an investment of 1 at date 0, and returns at date 2 a high $X > 0$ with probability $1 - s$ or 0 with a small probability s (s stands for solvency risk). In addition to the project's pecuniary returns, the payoff of the bank's owner-manager has two other components. First, she incurs a cost of effort γ per unit of the bank's balance sheet at date 0.[3] Second, she derives non-verifiable private benefits of control B from running the bank. The owner-manager maximizes the sum of profits, costs (taken with a negative sign), and private benefits.

The bank has no initial capital and is financed with debt. Some debt is short-term and has to be refinanced at date 1, as detailed below. The timeline is given in Figure 1.

[3] The parameter γ can be though of as the administrative cost of running the bank. The empirical literature (cf. Berger et al., 1987) showed that the cost function of banks is, in general, U-shaped in bank size, and may depend on product mix. We simplify by using a fixed cost, with the idea that managing any component of the bank's balance sheet is costly. For example, in the case of loans, the bank's owner-manager has to monitor loan officers, and in the case of managing liquidity, she has to monitor bank treasury employees. The fact that the management of bank liquidity is associated with agency costs and requires monitoring is highlighted theoretically by Myers and Rajan (1998) and was recently illustrated by the 2012 losses of \$6.8 billion in the treasury department of JP Morgan on mishandled operations to invest surplus liquidity.

The role of the parameter γ in our model is that it imposes a cost on large bank balance sheets, and hence on holding idle assets – liquidity buffers. An alternative way to model the cost of holding liquidity would have been to use the "pledgeable income" approach of Holmstrom and Tirole (1998, 2011). There, the size of the bank's balance sheet is limited to a multiplier of bank capital by an incentive compatibility constraint. When the incentive compatibility constraint is binding, accumulating additional liquidity buffers has costs: it requires either cutting down on profitable investments or attracting costly capital. The implications of the "pledgeable income" and our "cost of effort" approaches to micro-founding the costs of liquidity are similar.

3.2 Information and Refinancing

Two events happen at date 1. One is a random withdrawal of a part of initial funding. Another is a signal on bank solvency. The two events are independent – withdrawals are made by uninformed depositors or represent maturing term funding, and therefore are not influenced by the solvency signal.

Withdrawals and the refinancing need While the project is long-term, some debt matures earlier and must be refinanced.[4] In reality there may be multiple refinancing events through the course of the project, but for the analysis we collapse them into a single "intermediate" date 1. The share of funds maturing at date 1 – the refinancing need – is random. With probability l, the refinancing need is low: a share $w_L < 1$ of initial funds. With additional probability $1-l$, the refinancing need is high, $w_H = 1$, so that a bank has to refinance all initial funding. If a bank cannot refinance, it fails and has to liquidate the long-term project at zero residual value.

Information and the refinancing risk Because investors always offer an elastic supply of funds (there is no aggregate liquidity shortage in the model), a known solvent bank can refinance any withdrawals by new borrowing. Yet smooth refinancing can be impeded by imperfect information, namely – solvency concerns. That is the origin of liquidity risk in this model.

Recall that a bank is solvent (yields X at date 2) with probability $1-s$ and insolvent with probability s. Assume that, at date 1, investors receive a *noisy* signal refining the posterior of bank solvency. With probability $1-(s+q)$ there is a "positive" signal, conditional on which a bank is always solvent and yields X with certainty. Then, a bank can refinance itself at a risk-free rate. However, with a residual probability $s+q$, there is a "negative" signal when the probability of insolvency is high. The negative

[4] We do not explicitly model why the bank has short-term debt. The reliance of banks on short-term debt is an established stylized fact. It also has numerous explanations in the literature. One explanation is that short-term debt is a mechanism by which banks offer liquidity insurance to customers, as in Diamond and Dybvig (1983). Another explanation is that short-term debt is a device for disciplining banks (Calomiris and Kahn, 1991, Diamond and Rajan, 2001).

signal is received by all insolvent banks and by some solvent banks. The posterior probability of insolvency under a "negative" signal is then $s/(s+q)$, higher than the date 0 prior probability, s. A solvent bank affected by a negative signal is thus pooled with a large number of insolvent banks, which can render it unable to refinance due to increased solvency risk. Such a set-up, while stylized, is descriptive of many real-world liquidity crises. The information structure is illustrated in Figure 2.[5]

The model allows different interpretations of the availability of solvency information to the bank's owner-manager. The only requirement is that all banks should have incentives to seek refinancing. This is natural in the model. Indeed, for the manager, there is an upside to seeking refinancing if there is some chance that the bank is solvent. And even if the manager knows that the bank is insolvent, there is no cost to seeking refinancing (so we can assume that, on the margin, the manager prefers to seek refinancing).

We impose two restrictions. The first restriction is that a bank can always obtain initial funding at date 0, and the owner-manager's return is positive:

$$X > \frac{1}{1-(s+q)} + \frac{\gamma}{1-(s+q)}. \tag{1}$$

On the left hand side of (1), X is the return in case of success. The first term on the right hand side is the repayment that a bank has to offer to investors if it always failed upon a "negative" signal at date 1. The second term is the compensation for the owner-manager's cost of effort (for an initial balance sheet size of 1, corresponding to the size of the investment project).

The second restriction is that under a negative signal at date 1 a bank cannot obtain

[5] The signal can also be interpreted as a state of the world. In a "good" state, such as an economic expansion, all banks are solvent. In a "bad" state, such as a recession, some solvent banks may start looking insolvent.

Note that in this model a solvent bank cannot signal its quality (or the state of the world) since it are not known to the owner-manager *ex-ante* (cf. Stein, 1998). Also, liquidity risk insurance (along the lines of Perotti and Suarez, 2009, or similar) can be ruled out. Since the insurer is unable to distinguish illiquid from insolvent banks, any insurance will cover insolvent banks too.

refinancing even for a low refinancing need:

$$X < (1 - w_L) + w_L \cdot \frac{s+q}{q}. \tag{2}$$

This is a sufficient condition, where on the right hand side the funds that are not withdrawn $(1 - w_L)$ carry a risk-free interest rate, while the funds which the bank has to refinance w_L carry a rate adjusted for the posterior probability of solvency, $q/(s+q)$. Clearly, this implies that a bank faced with a more significant withdrawal w_H is also unable to refinance.

We can now formulate the following result on the existence of liquidity risk.

Lemma 1 *There exist parameter values such that a bank can attract initial funding at date* 0*, but cannot refinance in case of solvency concerns (a negative signal) at date* 1*. In that case, some solvent banks are liquidated.*

The parameter values under which Lemma 1 holds are given by (1) and (2). The two inequalities are satisfied simultaneously, for example, for $s+q << 1$, $q << s$ (where "<<" stands for "much smaller"), and a w_L that is not too close to zero.

To streamline exposition, in the main model we assume that the date 0 initial funding is attracted at the risk-free interest rate of 0, as in the case of not priced deposit insurance. To model refinancing frictions, we maintain that the date 1 refinancing is not covered by deposit insurance and is risk-sensitive. This corresponds to the practice where banks use market-based wholesale funding to manage intermediate liquidity needs, such as deposit outflows. This assumption does not affect the properties of the model; in fact, it makes our results weaker. The key friction of the model is that the bank's owner-manager chooses insufficient hedging because she does not internalize the part of the benefits of success that accrues to the bank's creditors. When bank funding is risk-sensitive, it is attracted at a higher interest rate. The bank owes more to the creditors, making the owner-manager's decisions more distorted. To verify this, in Appendix A, we present a version of the model that incorporates risk-sensitive debt.

3.3 Risk Management Tools

The bank has two instruments of liquidity risk management.

Liquidity buffer First, a bank can *accumulate a liquidity buffer.* A bank can attract additional funds at date 0 and invest them in short-term assets, such as cash or easily tradeable securities that can be liquidated at any time, but produce a return of 0. Holding liquidity is costly, since the bank incurs a per-unit cost of effort γ to maintain a larger balance sheet.

The size of the liquidity buffer a required to cover a refinancing need w_L is given by:

$$(1+a) \cdot w_L = a, \tag{3}$$

where the left-hand side is the refinancing need (1 is the funding for the investment project, and a is the funding for the liquidity buffer), and the right-hand side is the size of the liquidity buffer. This makes:

$$a = \frac{w_L}{1 - w_L}. \tag{4}$$

Accordingly, the cost of maintaining a liquidity buffer to cover small refinancing needs is $a\gamma$.

Note that, since we took $w_H = 1$, no liquidity buffer can cover a large refinancing need: all funding has to be refinanced, so the bank would need to have only liquid assets.[6] Finally, we assume that if a bank is liquidated at date 1, or if it does not use

[6] The fact that liquidity buffers cannot be used to cover large refinancing needs is consistent with practice. For example, the Basel III Liquidity Coverage Ratio requires banks to hold sufficient liquidity to cover outflows only over a relatively short period of 30 days. This acknowledges that the use of liquidity buffers to insure larger refinancing needs is not optimal.

We model the fact that liquidity buffers cannot be used to cover large outflows by assuming that in the case of large outflows the bank has to refinance all initial funding: $w_H = 1$. To manage such outflows internally, all bank funding should be put into liquid assets. This corresponds to practitioners' arguments that large liquidity buffers "crowd out" the bank's core business – their economic role, maturity transformation. An alternative setup would have been to keep $w_H < 1$ but impose a condition that the cost of maintaining a liquidity buffer necessary to cover such outflows, $(w_H/(1 - w_H)) \cdot \gamma$, is so high that it makes bank profit negative. This would correspond to another practitioners' notion, that large liquidity buffers are "too costly".

the liquidity buffer, the bank returns the liquidity buffer to creditors in its entirety at date 1.

Transparency Second, a bank can *adopt transparency.* Transparency is an ex-ante (date 0) decision that enables a more effective communication of bank asset values to outsiders (see Section 2). In case of a negative signal at date 1, a transparent solvent bank can communicate its solvency to investors (and obtain funding) with probability t. With probability $1-t$, the bank is still unable to "prove" solvency and cannot obtain refinancing. The imperfect, probabilistic nature of transparency is driven by the fact that it relies on *ex-post* communication. Even for a bank that has put in place all the necessary preconditions, the communication may sometimes be ineffective, and then the refinancing will not be forthcoming. The cost of transparency is that the bank's owner-manager loses private benefits of control B.

For certainty we impose that, on the margin, the bank prefers hedging to no hedging, and liquidity buffers to transparency.

4 Liquidity risk management

We now derive the first best and the bank's private choices of liquidity buffers and transparency.

4.1 First best

In the first best, the bank's risk management strategy maximizes the social welfare, defined as the joint surplus of the bank's owner-manager and creditors (and equivalent to the NPV of the bank). The bank chooses between four strategies. The first strategy is to do nothing. The second strategy is to accumulate a liquidity buffer a. It will protect a solvent bank in a liquidity crisis with probability l (if the refinancing need is small). The third strategy is to adopt transparency. It will protect a solvent bank in a liquidity crisis with probability t (when *ex-post* communication is effective). The final strategy is to adopt both a liquidity buffer and transparency.

Payoffs We derive the social welfare W under different hedging strategies. When a bank does not hedge liquidity risk (no liquidity buffer and no transparency), the social welfare is:

$$W_N = (1 - (s + q))\, X - \gamma + B, \tag{5}$$

where the first term on the right hand side is the probability of success times the payoff in success, γ is the cost of effort for an initial balance sheet of size 1, and B are the private benefits.

When a bank has a liquidity buffer only, the social welfare is:

$$W_L = (1 - (s + q) + ql)\, X - \gamma - a\gamma + B. \tag{6}$$

Note the changes in the right hand side compared to (5). The probability of success increases by ql: the risk of an incorrect negative signal on solvency q times the probability that the withdrawals are low l (so that the liquidity buffer is sufficient to cover the refinancing need). The additional term $-a\gamma$ is the cost of effort associated with holding the liquidity buffer.

When a bank is transparent only, the social welfare is:

$$W_T = (1 - (s + q) + qt)\, X - \gamma. \tag{7}$$

The probability of success now increases by qt where t is the probability that *ex-post* communication is effective. Compared to (5), the right hand side misses the private benefits B, reflecting the cost of transparency.

When a bank is both liquid and transparent, the social welfare is:

$$W_{LT} = (1 - (s + q) + q\,(l + t - lt))\, X - \gamma - a\gamma. \tag{8}$$

This is a combination of the costs and benefits of (6) and (7). In the probability of success, the term $-qtl$ represents a probability that a bank experiences a small refinancing need (which can be covered from a liquidity buffer) at the time as when transparency is effective and enables external refinancing. Then, one of the two bank's hedges is redundant *ex-post*.

Preferences We can now derive the first best hedging strategy. The social preferences are determined on the balance between the costs and benefits of hedging. It is optimal, for a bank without a hedge, to be liquid when $W_N \leq W_L$, giving:

$$a\gamma \leq qlX, \tag{9}$$

where the left hand side is the cost of holding a liquidity buffer, and the right hand side is the payoff from a higher probability of success.

Similarly, it is optimal, for a bank without a hedge, to be transparent when $W_N \leq W_T$, giving:

$$B \leq qtX. \tag{10}$$

In the choice between the two single hedges, a liquidity buffer is preferred to transparency for $W_L \geq W_T$, giving:

$$a\gamma - B \leq q(l-t)X, \tag{11}$$

where the left hand side is the difference in cost, and the right hand side is the difference in the probabilities of success times the payoff in success.

Finally, it is optimal for a bank to be both liquid and transparent for $W_L \leq W_{LT}$ and $W_T \leq W_{LT}$, corresponding to:

$$\begin{cases} a\gamma \leq ql(1-t)X \\ B \leq q(1-l)tX \end{cases}. \tag{12}$$

The right-hand sides show the marginal benefit of an additional hedge for a bank that already has another hedge. Note that the marginal benefit of the second hedge (in (12)) is lower than that of the first hedge (on the right-hand side in (9) and (10)). This means that the two hedges are strategic substitutes: when one hedge is already in place, the additional value of another diminishes. This is because of the probability qtl that one of the two hedges is redundant *ex-post* (see (8)).

Taking the above inequalities together allows us to describe the bank's first best hedging strategy, shown in Figure 3. In the figure, the horizontal axis measures the cost of maintaining the liquidity buffer, $a\gamma$, and the vertical axis – the cost of transparency, B. There are four areas. When the costs of liquidity buffers and transparency are high, it is optimal that a bank does not hedge: the area N, with the boundary given by (9) and (10). When the costs of hedging are intermediate, it is optimal that a bank uses either a liquidity buffer or transparency to hedge liquidity risk; the choice between the two is determined by (11). When the costs are low enough, it is optimal that a bank uses both hedges: area LT, with the boundary given by (12).

Proposition 1 *Both liquidity buffers and transparency can be socially desirable components of bank liquidity risk management. When the costs of liquidity buffers and transparency are low enough, it is optimal that a bank combines them in its liquidity risk management.*

Proposition 1 establishes that, in the first best, a bank may combine liquidity buffers and transparency in its risk management. Liquidity buffers fully insure small refinancing needs, while transparency provides a partial hedge for large withdrawals.

4.2 Private Risk Management Choices

We can now analyze private risk management choices.

Payoffs The bank owner-manager's payoffs Π are similar to the corresponding levels of social welfare, with the difference that the owner-manager only internalizes the cost of bank funding in case of success. This is a standard effect driven by limited liability.

When a bank does not hedge liquidity risk, the owner-manager's payoff is:

$$\Pi_N = (1 - (s + q))\,(X - 1) - \gamma + B. \tag{13}$$

Note how compared to (5) the owner-manager's payoff in success is reduced by the cost of funding: the multiplier to the probability of success is $(X - 1)$ instead of X. The same difference will appear in the rest of private payoffs (as compared to (6)-(8)).

When a bank has a liquidity buffer, the payoff is:

$$\Pi_L = (1 - (s + q) + ql)\,(X - 1) - \gamma - a\gamma + B. \tag{14}$$

When a bank is transparent, the payoff is:

$$\Pi_T = (1 - (s + q) + qt)\,(X - 1) - \gamma. \tag{15}$$

When a bank is both liquid and transparent, the owner-manager's payoff is:

$$\Pi_{LT} = (1 - (s + q) + q\,(l + t - lt))\,(X - 1) - \gamma - a\gamma. \tag{16}$$

Preferences As with the social preferences, the banker's preferences are determined on the balance between the costs and benefits of hedging. The difference, however, is that the bank's owner-manager does not internalize the full benefit of hedging since a part of that benefit accrues to the bank's creditors in the form of safer claims.

The bank's owner-manager prefers that a bank is at least liquid for $\Pi_N \leq \Pi_L$, giving:

$$a\gamma \leq ql\,(X - 1)\,. \tag{17}$$

The left-hand side is the cost of holding a liquidity buffer. It is the same as in (9), implying that the cost is fully internalized by the bank's owner-manager. The right-hand side is the benefit of hedging for the bank's owner manager. Note that it is lower than the social benefit of hedging in (9): the owner-manager internalizes only her own payoff in case of success $(X-1)$, not the full social payoff X that includes benefits that accrue to creditors. This means that the owner-manager disregards the positive effect of hedging on creditors' claims, and will only choose to hold a liquidity buffer for a lower cost of hedging. The same holds for the rest of hedging decisions.

The bank's owner-manager prefers that a bank is at least transparent for $\Pi_N \leq \Pi_T$, giving:

$$B \leq qt\,(X-1)\,. \tag{18}$$

The bank's owner-manager prefers liquidity over transparency for $\Pi_L \geq \Pi_T$, giving:

$$a\gamma - B \leq q(l-t)\,(X-1)\,. \tag{19}$$

And the bank's owner-manager prefers to have both transparency and liquidity for $\Pi_L \leq \Pi_{LT}$ and $\Pi_T \leq \Pi_{LT}$, corresponding to:

$$\begin{cases} a\gamma \leq ql(1-t)\,(X-1) \\ B \leq q(1-l)t\,(X-1) \end{cases}. \tag{20}$$

Figure 4 depicts the private risk management choices and compares them to the first best. Note that the threshold lines separating private hedging choices are below and to the left of the respective lines for the first best hedging choices. This implies that a bank can choose insufficient hedging. In particular, there exist parameter values (represented by an area in light gray) such that the bank privately chooses to use only one hedge (a liquidity buffer or transparency), while it is socially optimal that the bank is both liquid and transparent.

Proposition 2 *A bank's owner-manager may choose a level of liquidity risk hedging* *that is insufficient from the social welfare perspective. There exist parameter values such that it is socially optimal that a bank adopts both liquidity buffers and transparency, while it privately chooses to have only one or the other.*

From (9)-(12) and (17)-(20), the bank is only liquid, while it is socially optimal that it both liquid and transparent for:

$$\begin{cases} q(1-l)t\,(X-1) < B \leq q(1-l)tX \\ a\gamma \leq ql(1-t)X \\ a\gamma - B \leq q(l-t)\,(X-1) \end{cases}, \tag{21}$$

and the bank is only transparent, while it is socially optimal that it both liquid and transparent for:

$$\begin{cases} ql(1-t)\,(X-1) < a\gamma \leq ql(1-t)X \\ B \leq q(1-l)tX \\ a\gamma - B > q(l-t)\,(X-1) \end{cases}. \tag{22}$$

The reason why a bank under-insures against liquidity risk is that, under limited liability, the owner-manager does not internalize the full benefit of hedging (Jensen and Meckling, 1976).[7] Having established the market failure, we can now proceed to the analysis of regulation.

5 Regulation

Suboptimal hedging justifies policy intervention. This section studies the implications of our model for the optimal regulatory design. We start by observing that regulation can directly affect bank liquidity buffers (through liquidity requirements). However regulation cannot directly affect bank transparency choices because transparency is not verifiable. Indeed, while some components of transparency are amenable to regulation

[7] There may be more reasons for banks to be insufficiently insured: banks may not internalize the systemic externalities of failure (Acharya and Yorulmazer, 2007) or expect a bailout in case of distress (Mailath and Mester, 1994, Ratnovski, 2008).

(e.g. formal disclosure), others are not (the credibility of disclosure, the endogenous production of information, the choice of the organizational structure; see Section 2). Regulating only the verifiable components of transparency may be insufficient (as there are non-verifiable determinants too) and ineffective (e.g. a bank may manipulate information, making formal disclosure not credible). Hence, transparency is largely an endogenous decision of a bank.

We proceed in steps. We first establish what happens if the regulator only regulates liquidity buffers, and then discuss ways of influencing the bank's choice of transparency.

5.1 The Unintended Effects of Liquidity Requirements

Consider the case where authorities can regulate only one dimension of bank liquidity risk management, liquidity buffers, while also another dimension, transparency, is important for hedging liquidity risk. Section 4 showed that liquidity buffers and transparency are strategic substitutes: a bank with one hedge has lower incentives to adopt another. This brings a question of whether liquidity requirements may have an unintended effect of compromising bank transparency choices.

To study this, consider a set of parameter values that satisfies (22). For such parameters, a bank chooses to be transparent, but to have no liquidity buffers. At the same time, in the first best the bank should have both liquidity buffers and transparency. We ask what are the consequences of introducing liquidity requirements (compulsory liquidity buffers) on such a bank.

There can be two outcomes, depicted in Figure 5. For a low cost of transparency (point A') such that:

$$B \leq qt(1-l)\left(X-1\right), \tag{23}$$

corresponding to the second condition in (20), the bank will choose to maintain transparency. Liquidity requirements will ensure the presence of liquidity buffers and the bank's liquidity risk management will become socially optimal.

However for a higher cost of transparency (point A) such that:

$$B > qt(1-l)\,(X-1)\,, \tag{24}$$

the bank will choose to forego transparency in response to liquidity requirements. The reason is that an exogenously imposed liquidity buffer protects the bank against small refinancing shocks. Then the value of maintaining transparency as an additional hedge against large shocks diminishes compared to the conditions when the bank used transparency to respond to both large and small refinancing needs. Note that the bank's shift from transparency to liquidity buffers is detrimental to social welfare. Indeed, point A is below the social welfare indifference line between liquidity buffers and transparency (11), suggesting that transparency was a more cost-effective hedge. Moreover, for $t > l$, the shift from transparency to liquidity also represents an increase in bank refinancing risk in response to liquidity requirements.

Proposition 3 *There exist parameter values such that a transparent bank responds to liquidity requirements by abandoning transparency. This reduces social welfare, and represents an unintended effect of liquidity requirements.*

The proposition establishes the key policy-relevant result of the paper. While liquidity requirements may be desirable due to banks' insufficient hedging of liquidity risk, they may have unintended consequences: compromise bank transparency choices.

A natural question may arise as to how likely this problem is to appear in practice. A reduced form model such as ours is not well-suited to provide a general answer to this question. However, in Appendix B, we offer a quantitative example with a set of plausible parameter values for which the results of the model hold: banks choose suboptimal liquidity risk management (only transparency), and liquidity requirements compromise bank transparency choices. In fact, the range of parameters for which liquidity requirements compromise bank transparency choices appears to be wider than the range of parameters for which they do not. This suggests that the effects described in the model are plausible and reasonably likely.

5.2 Addressing Bank Transparency

While transparency cannot be regulated directly, the government may attempt to influence the bank's endogenous choices, or to mitigate the effects of insufficient transparency.

The government can make a bank more likely to adopt transparency by reducing its alternative cost, the bank owner-manager's private benefits of control, B. In practice, private benefits of control can be reduced by improving corporate governance, and/or by encouraging less concentrated ownership of banks (cf. Barclay and Holderness, 1989, and Dyck and Zingales, 2004). If B is reduced sufficiently so that the condition (23) becomes satisfied, liquidity requirements will no longer crowd out bank transparency. The effect of reducing B would produce effects similar to a move from point A to point A' in Figure 5. While in point A, the bank responded to liquidity requirements by abandoning transparency, in point A' the bank will maintain transparency even when it is subject to liquidity requirements. This suggests that measures to improve bank transparency may be a useful (or, indeed, necessary) complement to liquidity requirements.

Alternatively, the government may accept insufficient bank transparency, but minimize its effect on liquidity risk. This can be achieved by influencing bank funding structure so that large refinancing needs become less likely. That would lead to a higher l, making the risk $(1 - l)$ of large refinancing needs (which cannot be covered from the liquidity buffer) lower. This may make transparency not necessary from the social welfare perspective: the second inequality in (12) will cease being satisfied under a high l. Figure 6 illustrates the effects of a higher l as a shift of the bank's risk management choice thresholds downwards and to the right.

In practice, a higher l can be achieved by maturity mismatch limits, such as the Net Stable Funding Ratio of Basel III. Maturity mismatch limits push banks to use more long-term and "stable" funding, which has refinancing events that are more evenly and thinly distributed over the course of a bank's investment project. Our model takes l as exogenous, so we cannot formally study the implications of maturity mismatch limits. Informally however, one could expect that longer-term funding may increase the cost of funds, adding some r per-unit to the cost of the liquidity buffer. In Figure 6, this would imply a shift from point A to A''. In any case, either point lays above the social welfare indifference line for the choice of transparency in the presence of liquidity buffers (given by the second inequality in (12)), so that transparency is no longer required in order to maximize social welfare. Then, liquidity requirements and maturity mismatch limits can ensure that the bank's liquidity risk management choices are socially optimal.[8]

6 Conclusion

The paper emphasized that both liquidity buffers and – in a novel perspective – bank transparency (better communication that enhances access to external refinancing) are important in bank liquidity risk management. In a liquidity event, a liquidity buffer can cover small withdrawals with certainty. Transparency allows the bank to refinance large withdrawals too, but it is not always effective. Banks may choose insufficient liquidity and transparency; the optimal policy response is constrained by the fact that bank transparency is not verifiable.

The paper offers important policy implications, particularly for the ongoing liquidity regulation debate. The results caution that the focus on liquidity requirements needs to be complemented by measures to improve bank transparency and access to market refinancing. Without such measures, liquidity requirements may not achieve the full potential of improvements in social welfare, and under some conditions may have unintended effects. We also highlight the need for better corporate governance as a way to improve bank transparency, and the scope to use net stable funding ratios to increase the effectiveness of liquidity requirements.

[8] Note however that while stable funding ratios may make liquidity requirements more effective (and bank transparency not necessary), their overall welfare effect remains ambiguous. In particular, it may be negative if longer-term bank funding is associated with deadweight costs or is distortive (e.g. makes banks unable to perform their liquidity insurance function, or compromises the monitoring of banks by their creditors – reduces market discipline; see also Footnote 4).

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Appendixes

A A Model Without Deposit Insurance

In the main model, to streamline the exposition, we have assumed that initial bank funding benefits from not priced deposit insurance, making the interest rate on it zero. In this Appendix, we relax that assumption. Note that the interest rate on deposits does not affect the first best risk management choices since they are based on maximizing the joint surplus of the bank's owner-manager and creditors. But the interest rate does affect the private choices of the owner-manager, by increasing the amount that she has to repay depositors in case of success. As a result, as we show here, allowing for risk-sensitive debt increases the wedge between public and private liquidity risk management preferences, strengthening our result that private choices may be suboptimal.

In the absence of deposit insurance, creditors charge a risky bank a positive interest rate to compensate for risk and achieve zero expected return. For simplicity, we assume that the date 0 funding for the investment project is segregated from the funding for the liquidity buffer. Then the funding for the investment project is risky and is charged a gross interest rate $i > 1$. Funding for the liquidity buffer is risk-free. Indeed, the buffer is always repaid if the bank survives the intermediate date, and it is also, by assumption, repaid in liquidations when a liquidity buffer is insufficient to cover a large liquidity need or a bank is insolvent. Recall that, within our model, funding from date 1 to date 2 is either risk-free or is not available.

Under risky funding, there is scope for multiple equilibria (when depositors charge a higher interest rate, the manager may choose a riskier strategy). We assume that, in case of multiple equilibria, depositors charge the lowest rate possible. Also, to simplify the analysis, without a loss of generality, we take $l = t$.

It is useful to start the analysis from the case of most complete hedging. Assume that the creditors expect the bank to be both liquid and transparent. Then they charge the interest rate:

$$i_2 = \frac{1}{1-(s+q)+q\,(l+t-lt)}, \tag{25}$$

where on the right hand side in the denominator is the probability of bank success. Under the interest rate i_2, the bank's owner-manager will choose to be liquid and transparent for (use expressions (20) substituting i_2 into the cost of funds instead of 1) for:

$$\begin{cases} a\gamma < ql(1-t)\,(X-i_2) \\ B < q(1-l)t\,(X-i_2) \end{cases}. \tag{26}$$

Since $i_2 > 1$, the owner-manager will choose to be liquid and transparent only for lower costs of hedging $a\gamma$ and B compared to those is (20). This represents a narrower range of parameter values, and a larger scope for distortions from first best risk management, compared to the case when initial funding benefitted from not priced deposit insurance.

Similarly, if creditors expect the bank to be only liquid (or only transparent), the interest rate will be:

$$i_1 = \frac{1}{1-(s+q)+ql} \quad \left(\text{and } = \frac{1}{1-(s+q)+qt}, \text{ since we assumed } l=t\right). \tag{27}$$

The bank will choose to be at least liquid (use expressions (17) and (18) substituting i_1 into the cost of funds instead of 1) for:

$$a\gamma < ql\,(X-i_1)\,, \tag{28}$$

and at least transparent for:

$$B < qt\,(X-i_1)\,. \tag{29}$$

Again, since $i_1 > 1$, there is a larger distortion from the first best compared to the base model with not priced deposit insurance. Therefore, abandoning a simplifying assumption of not priced deposit insurance strengthens the result of Proposition 2 that bank choices of liquidity buffers and transparency may be suboptimal.

The bank will choose to be transparent, while it is socially optimal that it is both liquid and transparent, *and* liquidity requirements will make the bank abandon transparency for (use (12), (19), (24) substituting i_1 into the cost of funds instead of 1, and (26)):

$$\begin{cases} ql(1-t)(X-i_2) < a\gamma < q(1-t)lX \\ q(1-l)t(X-i_1) < B < a\gamma \end{cases}. \tag{30}$$

This confirms that the result of Proposition 3 that liquidity requirements may compromise bank transparency choices is robust to introducing into the model risk-sensitive debt.

B A Quantitative Example

The model is stylized, and showcases the existence of results. It is not well suited for a calibration exercise. Yet, it is instructive to demonstrate that there exist plausible parameter values, such that the key results of the model – a divergence of private and socially optimal choices, and the fact that liquidity requirements may compromise bank transparency choices – hold.

An example of such parameter values is offered below. These can be thought of as describing bank returns and risk over a 10-year period.

- $X = 1.35$, corresponding to a 3.5% per annum return on bank assets;
- $s = 0.08$ and $q = 0.02$, corresponding to a 1% a year risk of bank failure;
- $w_L = 0.09$, giving $a = 0.1$, corresponding to a liquidity buffer of 10% of bank assets;
- $l = t = 0.9$, so that most shocks are small and transparency is most often effective.

The above parameter values satisfy (1) for $\gamma < 0.215$, and it is easy to verify that they satisfy (2). Substituting the parameter values into (22) and applying the additional restriction on γ obtains that the bank is only transparent while it is optimal that a bank is both liquid and transparent for:

$$\begin{cases} 0.063 < \gamma < 0.215 \\ B < \gamma/10 \end{cases}, \tag{31}$$

and, using (20), the bank will abandon transparency in response to liquidity requirements for $B > 0.0063$.

To close the example, consider $\gamma = 0.15$ (corresponding to the administrative costs of 1.5% per year), making $B < 0.015$. For $0.0063 < B < 0.015$ the bank will abandon transparency in response to liquidity requirements. For $B \leq 0.0063$, the bank will maintain transparency even under liquidity requirements. Interestingly, in this example, the range of values of B for which liquidity requirements compromise bank transparency choices is wider than the range of values of B for which they don't. This suggests that the effects described in the model are plausible and reasonably likely to appear in practice.

Figure 1. The Timeline

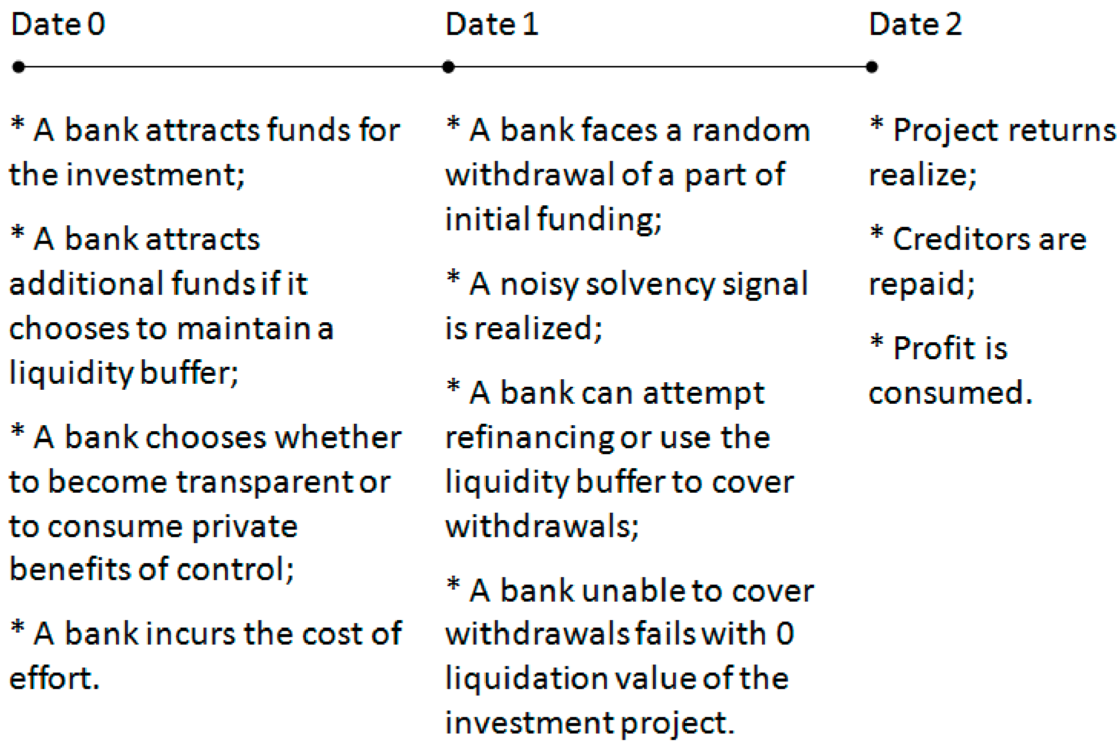
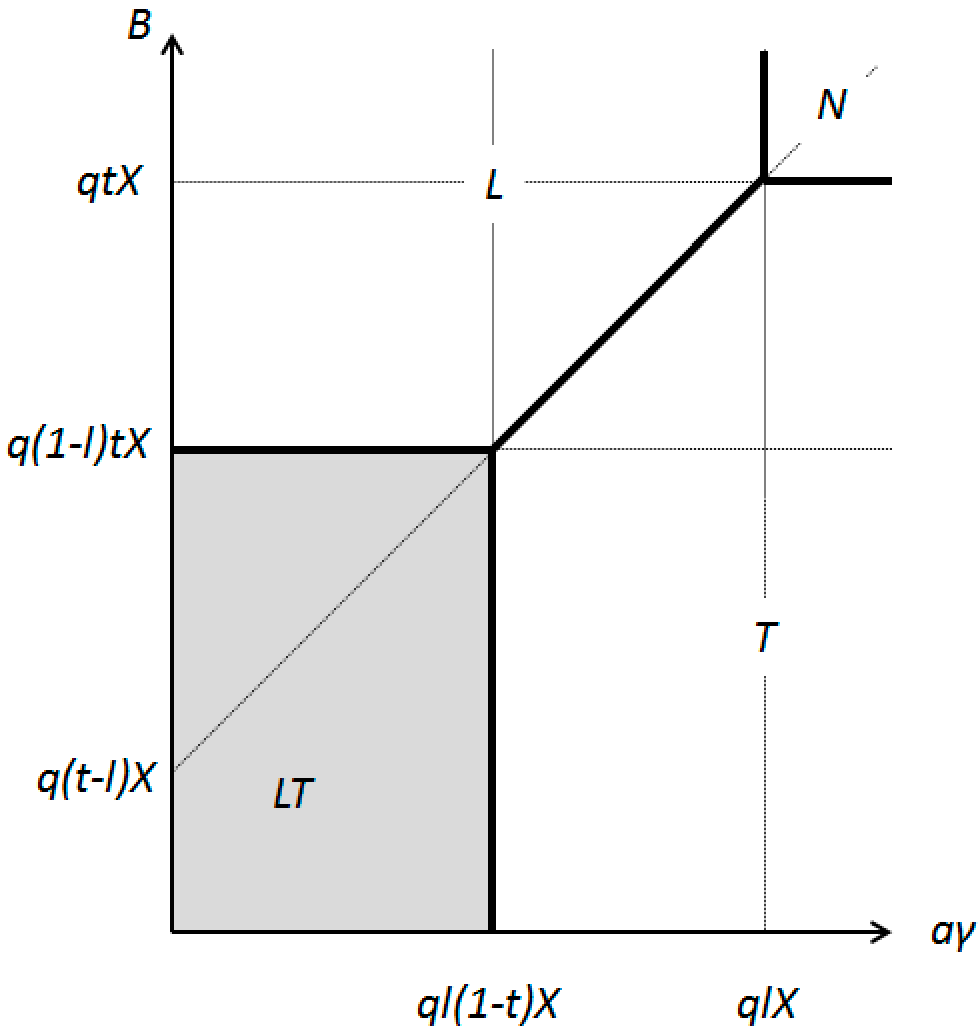


Figure 2. The Information Structure

<table>
<tr><td>Fundamentals</td><td colspan="2">$1-s$
Solvent</td><td>s
Insolvent</td></tr>
<tr><td>Signal</td><td>$1-s-q$
Positive</td><td colspan="2">$s+q$
Negative</td></tr>
<tr><td>Outcome</td><td>Able to refinance</td><td>q
Solvent, but unable to refinance</td><td>s
Insolvent</td></tr>
</table>

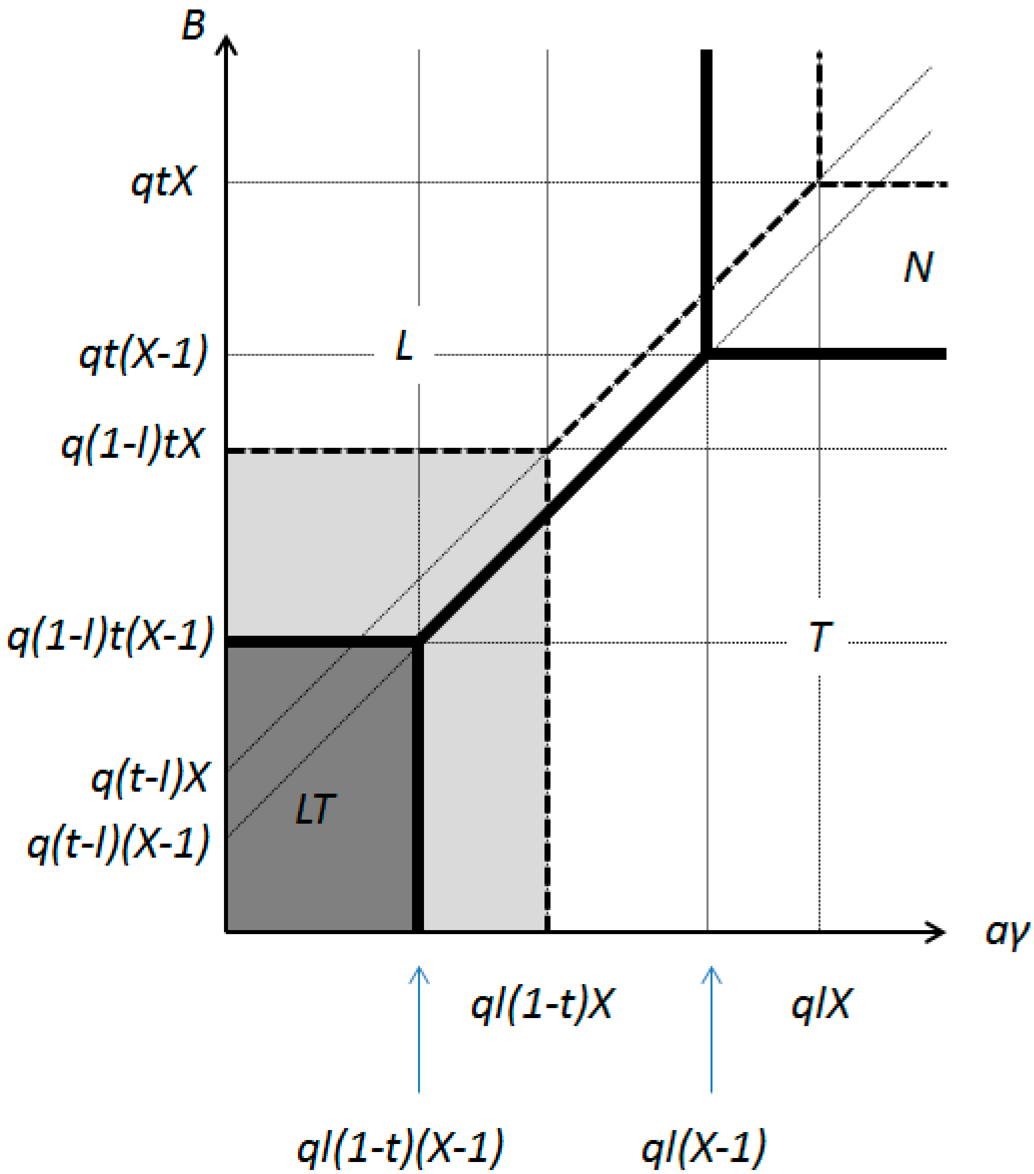
The Figure shows the probability distribution of bank fundamentals and of the intermediate signal. Although a bank is solvent with probability $1–s$, it may nevertheless receive at an intermediate date a negative signal with probability q, which makes it unable to refinance.

Figure 3. Socially Optimal Liquidity Risk Management



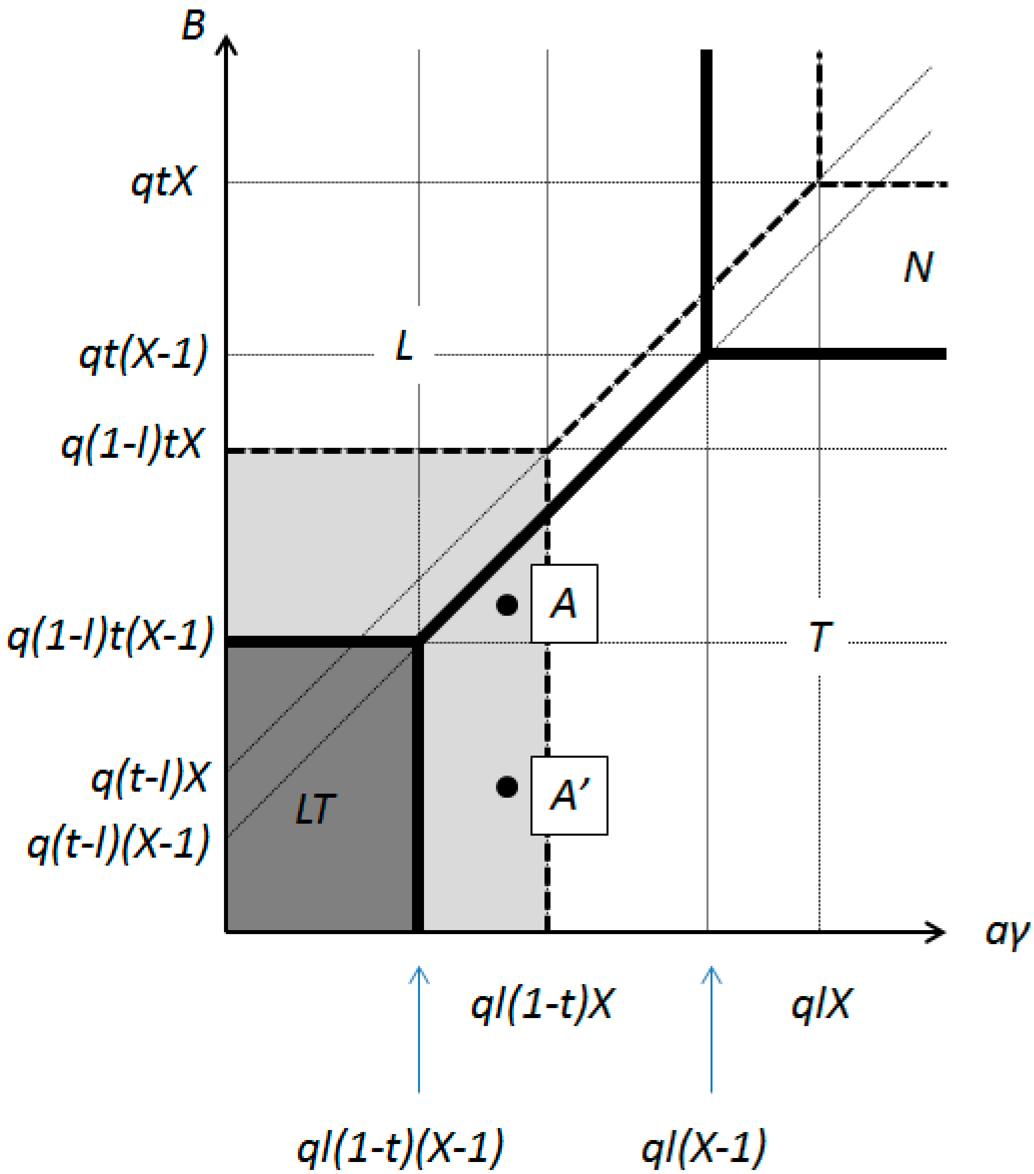
The Figure shows the bank's socially optimal liquidity risk management choices. The costs of hedging (*aγ* of holding a liquidity buffer and *B* of transparency) determine whether it is optimal that a bank has no hedges (area *N*), one hedge (areas *L* or *T*), or both hedges (area *LT*). Note: This and further figures are drawn for $t>l$.

Figure 4. Private Risk Management Choices



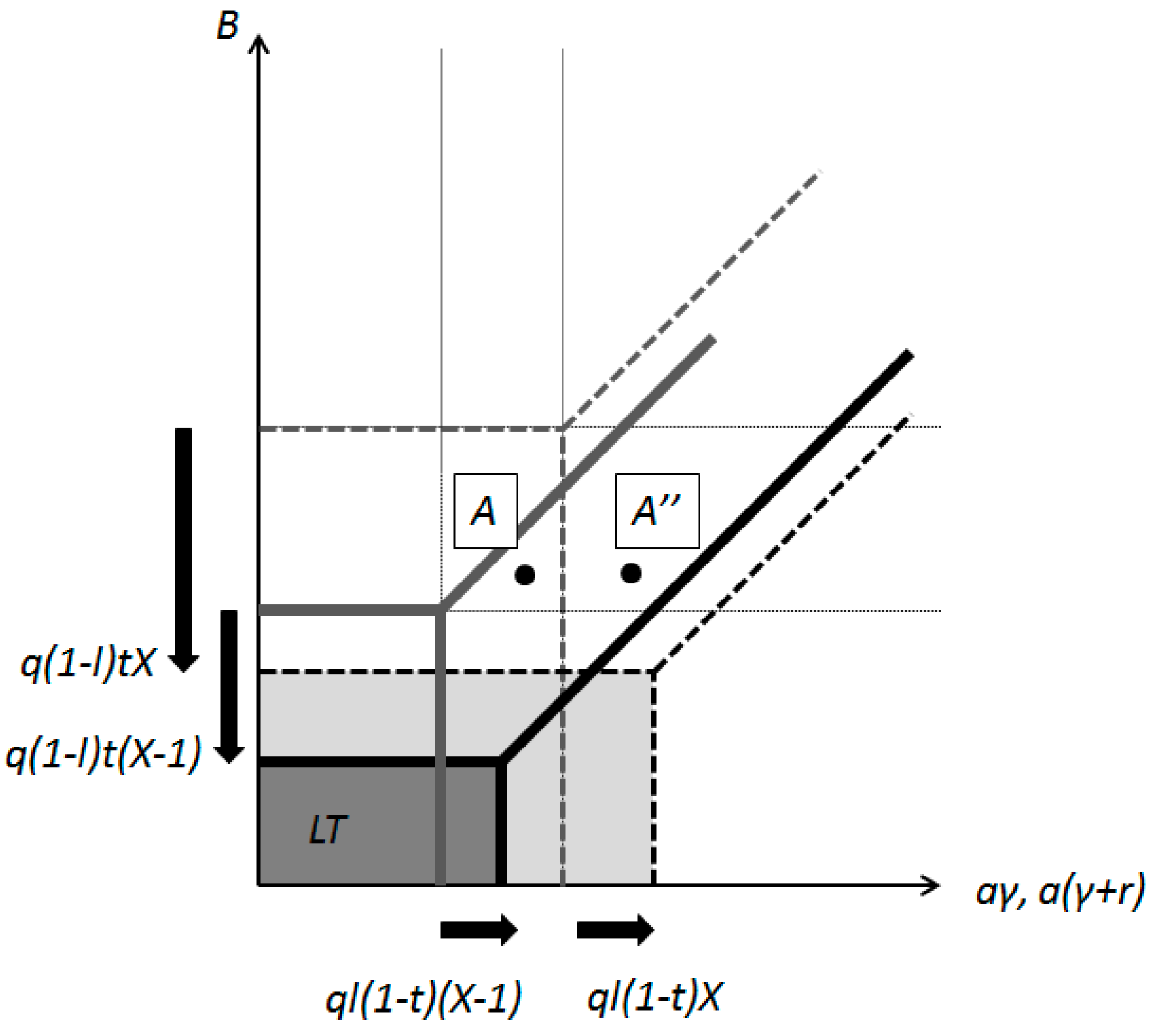
The Figure shows the bank's private risk management choices (thick solid lines) and contrasts them with the first best (dashed lines, from Figure 3). In the light gray area, the bank privately chooses to be either liquid or transparent (only one hedge), while it is socially optimal that is it both liquid and transparent (two hedges).

Figure 5. The Unintended Effects of Liquidity Requirements



The Figure shows the reaction of a bank that chooses to be only transparent, while it is socially optimal that it is both liquid and transparent, to the introduction of liquidity requirements. For a relatively high cost of transparency (point *A*), the bank abandons transparency. For a lower cost of transparency (point *A'*), the bank maintains transparency.

Figure 6. Maturity Mismatch Limits



The Figure illustrates the effects of a higher probability *l* that a refinancing need is small. Compared to Figure 5, the threshold lines for private and socially optimal choices shift down and to the right (as shown by arrows; from grey to black lines). If a larger *l* is achieved through the use of longer-term bank funding (which may be costlier, by *r*), point *A* shifts to *A''*. Either point is above the new position of the indifference line $q(1\text{-}l)tX$, implying that transparency is not anymore necessary for socially optimal liquidity risk management.