Imperfect Competition in the Interbank Market for Liquidity as a Rationale for Central Banking

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First draft: May 2007

This draft: November 4, 2010

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We study the interbank lending and asset sales markets in which banks with surplus liquidity have market power, frictions arise in lending due to moral hazard, and assets are bank-specific. Illiquid banks have weak outside options that allow surplus banks to ration lending, resulting in inefficient asset sales. A central bank can ameliorate this inefficiency by standing ready to fund illiquid banks, provided it is better informed than outside markets, or prepared to extend loss-making loans. This rationale for central banking finds support in episodes that precede the modern central-banking era and informs debates on the supervisory and lender-of-last-resort roles of central banks.

JEL: G21, G28, G38, E58, D62.

Keywords: Competition, Interbank lending, Market power, Asset specificity, Central bank, Lender of last resort.

The liquidity squeeze during the ongoing financial crisis has been likened by some, including the International Monetary Fund (IMF), to the turmoil of the Depression era. During the early part of the crisis, central banks faced difficulties in channelling liquidity to the neediest parts of the financial system via open-market operations, the discount window, or securities lending. Some lending facilities, such as the discount window, were not availed by players, and others resulted in liquidity hoarding by banks and other institutions.[1] In response, central banks around the world, most notably the Federal Reserve (Fed), undertook significant changes to their lender-of-last-resort (LOLR) facilities, in particular, by extending maturities of discount window and open-market operations, extending eligible collateral to include investment-grade debt securities, and making such adjustments for lending to primary dealers.

We propose that, during crises, efficient liquidity transfers may not occur between banks with liquidity surplus (surplus banks) and those that are liquidity-stricken (needy banks). We analyze one source of inefficiency that arises when surplus banks use their market power in the interbank lending to purchase assets from illiquid banks at fire sale prices, thus gaining market share at the needy banks' expense. We determine conditions under which a central bank can mitigate this inefficiency by standing ready to lend to needy banks. We report historical episodes in support of this role and discuss the implications of recent debates on the central banks' supervisory and LOLR functions.

We consider liquidity transfers between a surplus bank and a needy bank through two markets: the interbank lending market and the asset sales market. Our model has three main ingredients. First, we assume that some assets are bank-specific, i.e. they are worth more under current than alternative ownership. For instance, alternative owners may lack the current owner's expertise in running these assets. For this reason, asset sales are less efficient than borrowing. Second, we assume frictions in the interbank lending market, which we model as arising from a moral hazard problem. Specifically, we assume that banks can engage in the costly monitoring of their assets to improve their performance. A bank borrowing in the interbank market must retain a large enough claim on its own assets to have incentives to monitor them. This friction limits banks' borrowing capacity. Third, we

[1] Acharya and Merrouche (2009) report that the liquidity buffers of U.K. banks experienced an almost permanent 30% rise in August 2007 (relative to their pre-August levels), resulting in higher borrowing costs between banks and an almost complete drying up of liquidity in interbank markets beyond the very short maturities. See also "Hoarding by banks stokes fears over crisis: Borrowing costs rise between institutions; (Central Bank) Efforts on lending fail to bear fruit," *Financial Times*, March 26, 2008.

assume that during crises, liquidity is concentrated within a few banks, giving them market power. The latter assumption, and its interaction with the other two, drive the core of our analysis.

We show that the surplus banks' market power can lead to more asset sales, and importantly, more *inefficient* asset sales by the needy bank. The intuition is that the surplus bank can exploit its market power to capture a larger part of the surplus created by a liquidity transfer. To do so, the surplus bank first increases the cost of borrowing it charges the needy bank. Eventually, however, that cost is so high that it discourages the borrowing bank from monitoring its assets. At that point, asset sales become more attractive. The higher the surplus bank's market power, the greater the inefficiency due to excessive asset sales.

The surplus bank's ability to exploit its market power is limited by the needy bank's outside option e.g. raising liquidity from outside (non-bank) markets through commercial paper or public debt. Therefore, the problem of inefficient asset sales is more acute when the outside market is weaker, a scenario that would arise, for instance, in the liquidation of opaque or information-sensitive assets and bank-specific loans made to small borrowers.

Overall, due to market power, even states without an aggregate shortage of liquidity can exhibit effective liquidity shortage. For several reasons, this effect and the implied inefficiency are likely to be more severe during financial crises. For instance, if aggregate liquidity shortages are more likely ex ante, banks may not be able to pre-arrange sufficient insurance through lines of credit as each seeks to preserve liquidity for its own purpose. Ex post, this would make market-power-related effects stronger even if an aggregate liquidity shortage does not materialize. In addition, the inability of needy banks to borrow can cause them to fail if their funding conditions are weaker in general (e.g. due to outside markets experiencing liquidity shocks), and this may even lead to contagion to other banks if they are also liquidity stricken or are perceived to be similar to needy banks.

We argue that this market-power-related inefficiency in interbank markets provides a rationale for the lender-of-last-resort role of a central bank. A central bank that is credible in providing liquidity to needy banks curbs the market power of surplus banks in the interbank lending market and thus improves the efficiency of liquidity transfers. In particular, the central bank can play a "virtual and virtuous" role: In our model, it never actually lends to needy banks in equilibrium, but it does improve their bargaining position vis-à-vis surplus banks. We show, however, that such an improvement requires the central bank to either be better than outside markets at extending loans to needy banks or be ready to incur losses. The former situation is more likely if the central bank also has a supervisory role, allowing it to improve its ability to monitor its lending to illiquid banks. In particular, in our theory, ex-ante investments in supervision do not reduce the incidence of the central bank making loans ex post, but make such intervention credible, thereby improving the private allocation of liquidity among banks.

In Section 4, we present historical and current evidence supporting the notion of market power of cash-rich banks during crises. In particular, we review episodes of (i) failure of private coinsurance arrangements, such as the Clearinghouse System established by the New York City banks in 1853; (ii) liquid players exploiting their market power over illiquid ones during crises, such as J.P. Morgan and National City Bank in the 1907 crisis; (iii) the emergence of modern central banks as public institutions concerned with financial stability rather than as business rivals to other banks as was the case previously; (iv) the establishment of the Federal Reserve as a lender of last resort preventing surplus banks from exerting market power; and (v) market power between banks and non-bank financial institutions (without access to central bank lending) during the crisis of 2007-10 and the previous decade.

To summarize, our model illustrates that the public provision of liquidity, in fact, its mere credibility, can improve the private provision of liquidity, even in times of aggregate liquidity surplus when strategic issues can result in a market failure in the private provision of liquidity. This rationale for the central bank's role as a lender of last resort complements the traditional one, which is to deal with aggregate liquidity shortages and contagious failures (Allen and Gale (1998), Holmström and Tirole (1998), Diamond and Rajan (2005), Gorton and Huang (2006)). In the traditional rationale, central banks generate information about banks through supervision or other interactions e.g. open market operations, emergency lending facilities, resolution authority where it is combined with the central bank, etc. Our analysis suggests that central banks should assume the roles of both supervisor and lender of last resort from the standpoint of mitigating market-power-induced inefficiencies in interbank lending. Of course, there may be other reasons for central banks to assume those roles, in which case our model helps highlight an additional benefit of combining them. Nevertheless, historical evidence suggests that market power issues were an important factor in the creation of the Federal Reserve System and, more broadly, of modern central banking.

Our paper is related to the literature on the failure of interbank markets that justifies the

LOLR role of central banks.[2] Goodfriend and King (1988) argue that with efficient interbank markets, central banks should not lend to individual banks, but instead provide liquidity via open market operations, which the interbank market would then allocate among banks. Others, however, argue that interbank markets may fail to allocate liquidity efficiently due to frictions such as asymmetric information about banks' assets (Flannery (1996), Freixas and Jorge (2007)), banks' free-riding on each other's liquidity (Bhattacharya and Gale (1987)), or on the central bank's liquidity (Repullo (2005)). Instead, our paper focuses on the (additional) frictions brought about by market power.[3]

Donaldson (1992) is, to our knowledge, the only paper with a similar focus. It shows that even if aggregate liquidity is in surplus, if some surplus banks have a significant proportion of the excess cash such that other cash-rich banks cannot satisfy the total liquidity demand, the surplus banks can charge higher-than-competitive rates.

While some papers study the allocation of funds (Holmström and Tirole (1998)) and others that of assets (Shleifer and Vishny (1992), Gorton and Huang (2002)), our paper studies both and illustrates the trade-offs involved. We believe the banks' dual role as each other's financiers and business rivals to be an important and specific aspect of their relationships. For instance, the sale of Bear Stearns to JPMorgan Chase (JPMC), in March 2008 illustrates well the confluence of the roles of lender and asset purchaser (by JPMC). During the liquidity crisis at Bear Stearns and its subsequent resolution, JPMC explicitly stated its interest in Bear Stearns' prime brokerage business. While there were systemic-risk concerns about Bear Stearns' possible collapse, JPMC seems to have made the acquisition at a fire-sale price: In early March 2008, Bear Stearns started experiencing a run on overnight repurchase agreements against mortgage-backed securities; on March 13, Bear Stearns' stock price was \$57; JPMC agreed to acquire Bear Stearns on March 17 at \$6 a share with a guarantee of \$30 billion from the Fed to fund Bear Stearns' less liquid assets such as mortgage-backed securities; JPMC's stock increased 10% on March 17, whereas most other financial

[2] Indirectly, therefore, it is also related to the literature justifying the existence of interbank markets in the first place, specifically their role in allowing banks to insure each other against liquidity shocks through borrowing and lending facilities (e.g. Rochet and Tirole (1996), Allen and Gale (2000)).

[3] Under asymmetric information, a central bank unwilling to extend loss-making loans can help ex post only if it is a better monitor of needy banks relative to surplus banks. Instead, in our model instead, the central bank can help even if it is worse than surplus banks in monitoring needy banks as long as it is better than outsiders. Further, with asymmetric information, the central bank will in equilibrium lend to needy banks to improve ex-post outcomes, unless it can credibly convey its information to surplus banks. In our model, the central bank need not lend in equilibrium; its mere credibility as a lender of last resort curbs surplus banks' bargaining power.

stocks lost value; finally, JPMC agreed to raise the purchase price to \$10 a share and to bear the first \$1 billion of loss that may arise from the loan provided by the Fed.

Our paper is also related to studies of predation i.e. rivals taking actions to impede a firm's access to funds (Bolton and Scharfstein (1990), Cestone (2000)). Here, however, the dual relationship between banks means that the predator is also the prey's financier.

The paper proceeds as follows: Section 1 presents the model, Section 2 its analysis, and Section 3 the rationale for central banking. Section 4 provides empirical support for assumptions and results. Section 5 presents policy implications. Section 6 concludes. Proofs are in the Appendix. An online Appendix addresses ex-ante liquidity insurance.

1 The model

Consider a model with three dates $t = 0, 1, 2$; two banks, Bank A and Bank B; universal risk neutrality; and no discounting.[4] The timeline is illustrated in Figure 1.

At $t = 0$, Bank A has a continuum of measure 1 of risky assets, e.g. corporate loans. At $t = 2$, the portfolio of risky assets yields a random return $\widetilde{R} \in \{0, R\}$.

At $t = 1$, Bank A needs some refinancing of ρ units of cash per unit of asset, e.g. rolling over of an existing mortgage or corporate loan, or a drawdown on a line of credit.[5] If assets are not refinanced, $\widetilde{R} = 0$. If they are refinanced, the return is $\widetilde{R} = R$ with probability p and $\widetilde{R} = 0$ otherwise. Bank A can affect the probability p by monitoring its assets at $t = 1$: $p = p_H$ if it monitors, and $p = p_L = p_H - \Delta p$ otherwise, with $\Delta p > 0$. Monitoring is non-verifiable and if it does not monitor, the bank enjoys a private benefit b per unit of asset. If the assets are not refinanced, the bank does not derive a private benefit either. We assume that it is efficient to refinance assets only if they are monitored, i.e.

$$p_H R > \rho > p_L R + b. \qquad (1)$$

We assume that Bank B has enough excess liquidity to fund Bank A's assets.[6] Liquidity can be transferred in two ways: Bank A can borrow from Bank B or sell Bank B some of its assets.

[4] The model builds on Holmström and Tirole (1998).

[5] Alternatively, in a model with liability structure of banks, the liquidity need could stem from depositor withdrawals or the bank's inability to roll over unsecured funding such as short-term commercial paper.

[6] This assumes implicitly that banks that form interbank lending relationships have imperfectly correlated liquidity shocks. Cocco et al. (2009) provide supporting evidence that (Portuguese) banks with more volatile shocks rely more on lending relationships and borrow from banks with less volatile and less correlated shocks.

Borrowing: Due to limited liability, moral hazard in monitoring limits Bank A's borrowing capacity. Indeed, an interbank loan is a transfer L from Bank B to Bank A against a repayment r if $\widetilde{R} = R$ and 0 if $\widetilde{R} = 0$.[7] Bank A chooses to monitor its assets only if

$$\Delta p \left(R - r \right) \geq b. \tag{2}$$

This incentive compatibility constraint requires the repayment r to be small enough, i.e.

$$r \leq R - R_b \text{ with } R_b \equiv b/\Delta p. \tag{3}$$

Bank A's borrowing capacity conditional on monitoring, i.e. the maximum funding it can raise against each unit of asset while retaining monitoring incentives is therefore

$$p_H \left(R - R_b \right). \tag{4}$$

Asset sales: Each unit of asset can be sold to Bank B for P. Yet Bank A is the most efficient user of its assets, i.e. they are Bank A-specific. This may stem from expertise or learning-by-doing in making and administering loans or from customer relationships, expertise relevant for renewal, renegotiation, or termination decisions.[8] Moreover, Bank A's advantage over Bank B may vary across assets. For instance, small loans or loans relying on Bank A's relationship with the borrower may be difficult for Bank B to take over. The relevant characteristic is captured by a variable θ distributed over $[0, 1]$ according to the cumulative distribution function (cdf) F. Assets with smaller values of θ are less redeployable to Bank B. Nevertheless, we assume that it is efficient to refinance assets even if they are owned by Bank B. If Bank B owns an asset with characteristic θ, then $p = p_B(\theta)$ with

$$p_H > p_B(\theta) > \rho/R \quad \text{and} \quad \frac{dp_B(\theta)}{d\theta} > 0. \tag{5}$$

With bank-specific assets, asset sales are less efficient than borrowing (conditional on monitoring).[9] However, more funds can be raised from asset sales than from borrowing. In particular, we assume that moral hazard in monitoring is severe (i.e. b large) enough so that Bank A can raise more funds by selling an asset than by pledging some of its return.[10]

[7] Note that with two cash flows, one being zero, the distinction between debt and equity is immaterial.

[8] This assumption is natural if banks forming interbank lending relationships are in different businesses or have relationship-specific, information-sensitive loans. For instance, a commercial bank focused primarily on prime mortgage lending may not be able to take efficient renegotiation decisions if it were to acquire a portfolio of sub-prime mortgages.

[9] Implicitly, we are assuming that acquiring a bank affects its operations, i.e. ownership has real effects. For brevity, we use this reduced form rather than providing a foundation for the effect of ownership.

[10] Our results would be largely unchanged if the conditions $p_B(\theta) R > \rho$ and $p_B(\theta) R > p_H (R - R_b)$ both held only for some loans.

Assumption 1 *For all* $\theta \in [0,1]$, $p_B(\theta)R > p_H(R - R_b)$.

We model the banks' interaction in the interbank lending and asset markets as a two-stage bargaining game of alternating offers with a risk of breakdown (Figure 2). First, Bank B makes Bank A an offer with three components: A subset of measure α of Bank A's assets to be acquired by Bank B, a repayment $r \leq (1-\alpha)R$ from Bank A to Bank B per unit of asset when $\widetilde{R} = R$, and a transfer T from Bank B to Bank A. This transfer corresponds to a price P per unit of asset sold and a loan L per unit of asset retained, i.e. $T = \alpha P + (1-\alpha)L$. Note that the split between P and L is generally indeterminate: A transfer T corresponds to various combinations of asset-sale price and amount lent.

If Bank A accepts the offer, it is implemented and bargaining is over. If Bank A rejects the offer, then, with probability β, bargaining breaks down and each bank receives its outside option: $X_i \geq 0$, for $i = A, B$ (Section 2.4 discusses possible determinants of these). With probability $(1-\beta)$, however, bargaining continues and Bank A gets to make Bank B an offer. If Bank B accepts the offer, it is implemented. Otherwise, bargaining breaks down and each bank receives its outside option.

Some observations are in order. First, the model nests the case of perfect competition, i.e. $\beta = 0$. Second, considering $\beta < 1$ allows us to study the effect of Bank B's outside option. Third, the bargaining surplus is affected by how it is shared due to specificity of Bank A's assets and moral hazard in monitoring.

Finally, we assume that X_A and X_B are small enough, i.e. there are always gains from trade between the banks. Since Bank B's ability to make transfers to Bank A is limited, we assume that trade is beneficial even if Bank A has to sell all its assets to Bank B, i.e.

$$\int_0^1 p_B(\theta) R dF(\theta) > X_A + X_B + \rho. \tag{6}$$

2 The interbank market for liquidity

We begin with the case $\beta = 0$ where Bank A can always make the final offer. In this case, Bank A can pin down Bank B to its outside option. This corresponds to the case of perfect competition in the supply of liquidity in the interbank market in the sense that Bank B makes zero profit. Then, we turn to the case in which Bank B has market power ($\beta > 0$).

2.1 Perfect competition

Bank A's optimal offer maximizes its payoff subject to Bank B's payoff meeting its outside option. It is easily seen that the optimal offer will satisfy three further properties. First, it must satisfy the incentive compatibility constraint (3), $r \leq (R - R_b)$. Otherwise Bank A would not monitor its remaining assets so that selling them to Bank B would be more efficient. Second, Bank B's transfer to Bank A must be sufficient to refinance Bank A's remaining assets. Otherwise, these assets would be worthless and selling them to Bank B would again be more efficient. Last, Bank A will sell its most redeployable assets (if any), i.e. all loans with θ above a threshold $\hat{\theta}$. Hence, Bank A's problem is:

$$
\begin{array}{ll}
\max\limits_{\hat{\theta},r,T} & \int_0^{\hat{\theta}} \left[p_H (R - r) - \rho\right] dF(\theta) + T \\
s.t. & r \leq (R - R_b) \\
 & T \geq F(\hat{\theta})\rho \\
 & \int_0^{\hat{\theta}} p_H r dF(\theta) + \int_{\hat{\theta}}^1 \left[p_B(\theta)R - \rho\right] dF(\theta) - T \geq X_B.
\end{array}
\tag{7}
$$

Under the optimal offer $(\theta_A^*, r_A^*, T_A^*)$, Bank A sells a fraction $\alpha_A^* = 1 - F(\theta_A^*)$ of its assets.

Proposition 1 *Under perfect competition ($\beta = 0$), the outcome is as follows.*

• *If $p_H(R - R_b) - \rho \geq X_B$, the outcome is efficient: Bank A funds all its assets by borrowing from Bank B and sells no assets ($\alpha_A^* = 0$). Its payoff is*

$$
\pi_A = p_H R - (X_B + \rho) . \tag{8}
$$

• *Otherwise, the outcome is inefficient: Bank A sells a fraction $\alpha_A^* = 1 - F(\theta_A^*)$ of its assets to Bank B with θ_A^* defined by*

$$
\int_{\theta_A^*}^1 \left[p_B(\theta)R - p_H(R - R_b)\right] dF(\theta) = (X_B + \rho) - p_H(R - R_b), \tag{9}
$$

and funds its other assets with the sale's proceeds and a loan from Bank B. Its payoff is

$$
\pi_A = p_H R - (X_B + \rho) - \int_{\theta_A^*}^1 \left[p_H - p_B(\theta)\right] R dF(\theta). \tag{10}
$$

In equilibrium, Bank B must contribute ρ to fund all of Bank A's assets and enjoy an expected payoff X_B. Hence, Bank A must pledge $(X_B + \rho)$ to Bank B, which it can do by borrowing from Bank B or selling it assets. Since the assets are Bank A-specific, borrowing is Bank A's preferred source of funds. Hence, if Bank A's pledgeable income $p_H(R - R_b)$ exceeds $(X_B + \rho)$, Bank A will meet its entire funding needs by borrowing. In that case, it captures the full value of its assets, net of Bank B's outside option (expression (8)). Otherwise, it must sell some assets to Bank B to fund the shortfall, i.e. the right hand side of (9). Indeed, owning an asset is more valuable to Bank B than holding a debt claim against it (Assumption 1). Asset sales being inefficient, Bank A will sell as few assets as needed for the shortfall to be covered by the increased funding capacity these sales allow, i.e. the left hand side of (9). In that case, Bank A's payoff is curtailed by the inefficiency associated with asset sales, i.e. the last term of (10). The larger the shortfall, the more assets that must be sold and the more inefficient is the outcome.

2.2 Imperfect competition

Now consider now imperfect competition in the supply of liquidity ($\beta > 0$). In that case, Bank B's market power allows it to extract a payoff exceeding its outside option, i.e. the zero profit condition no longer holds. We solve the model by backward induction. If Bank A gets to make the final offer, the outcome is as in Proposition 1. In the previous stage, Bank B makes the first offer. When deciding whether to accept it, Bank A must consider the possibility that bargaining will break down, which happens with probability β. Hence Bank A will accept an offer only if its expected payoff is at least

$$E(\pi_A) = \beta X_A + (1 - \beta)\pi_A. \tag{11}$$

As before, the optimal offer satisfies three further properties: Bank A will sell its most redeployable assets, i.e. with θ above some threshold $\hat{\theta}$, and set $r \leq (R - R_b)$ and $T \geq F(\hat{\theta})\rho$. Hence, Bank B's problem is

$$\begin{array}{ll} \max\limits_{\hat{\theta},r,T} & \int\limits_0^{\hat{\theta}} p_H r dF(\theta) + \int\limits_{\hat{\theta}}^1 [p_B(\theta)R - \rho]\, dF(\theta) - T \\ s.t. & r \leq (R - R_b) \\ & T \geq F(\hat{\theta})\rho \\ & \int\limits_0^{\hat{\theta}} [p_H(R - r) - \rho]\, dF(\theta) + T \geq E(\pi_A) \end{array} \tag{12}$$

Under the optimal offer (θ^*, r^*, T^*), Bank A sells a fraction $\alpha^* = 1 - F(\theta^*)$ of its assets.

Proposition 2 *The negotiation's outcome is as follows.*

- *If* $E(\pi_A) \geq p_H R_b$, *the outcome is efficient: Bank A funds all its assets by borrowing from Bank B and sells no assets* ($\alpha^* = 0$).
- *Otherwise, the outcome is inefficient: Bank A sells a fraction* $\alpha^* = (1 - E(\pi_A)/p_H R_b)$ *of its assets to Bank B (all loans with* $\theta > \theta^* = F^{-1}(E(\pi_A)/p_H R_b)$*) and funds its other assets with the sale's proceeds and a loan from Bank B.*

Bank B aims to acquire as many of Bank A's assets as possible, subject to Bank A getting its reservation payoff. Indeed, under Assumption 1, a sale is the most effective way to transfer value from Bank A to Bank B. For instance, for $E(\pi_A) = 0$, Bank B acquires all of Bank A's assets for free, i.e. sets $\alpha^* = \theta^* = 1$ and $T^* = 0$. As $E(\pi_A)$ increases, Bank B must ensure that Bank A accepts its offer. The most efficient way to increase Bank A's payoff is for Bank B to leave it some assets and fund them, i.e. $T = F(\hat{\theta})\rho$. Since the assets are Bank A-specific, this is preferred to Bank B making a cash transfer to Bank A above its funding needs. In that case, Bank A should obviously keep its least redeployable assets. For the same reason, maximizing r is always weakly optimal, i.e. $r^* = (R - R_b)$. Indeed, leaving Bank A with a stake exceeding R_b on an asset is akin to a cash transfer. In turn, α^* is determined by Bank A's participation constraint. When $E(\pi_A) = 0$, Bank B acquires all of Bank A's assets ($\alpha^* = 1$). As $E(\pi_A)$ increases, Bank B must leave Bank A some assets financed with borrowing with $r = R - R_b$. Hence, for each asset, Bank A's expected payoff is $p_H R_b$. Hence α^* is determined by $(1 - \alpha^*) p_H R_b = E(\pi_A)$.

2.3 Properties

Bank A selling all assets with $\theta > \theta^*$ involves a deadweight loss

$$K^* \equiv \int_{\theta^*}^{1} (p_H - p_B(\theta)) R dF(\theta).$$

We begin with the effect of Bank B's market power on the equilibrium liquidity transfer.

Corollary 1 *Efficiency (weakly) decreases with Bank B's market power. More precisely,*

- *A threshold* $\beta^* \in [0,1]$ *exists such that the outcome is efficient if and only if* $\beta < \beta^*$.
- *For* $\beta > \beta^*$, *asset sales and the associated inefficiency increase strictly with* β.
- *In some cases, the outcome is efficient only if competition is intense enough:* $\beta^* \in (0,1)$.

The intuition for the existence of a threshold β^* is as follows. Bank B does not acquire assets when $E(\pi_A) \geq p_H R_b$. Since $E(\pi_A)$ decreases with β, a threshold β^* exists such that asset sales occur only if $\beta > \beta^*$. If $p_H R_b > X_A$, there will be asset sales if Bank B is certain to make an offer ($\beta = 1$) and hence $\beta^* < 1$. If $p_H(R - R_b) - \rho > X_B$, no assets are sold if Bank A always has the option to make an offer ($\beta = 0$) and hence $\beta^* > 0$.

The intuition for the fraction of Bank A's assets sold increasing with β (for $\beta > \beta^*$) is as follows. When β increases, Banks A's reservation payoff $E(\pi_A)$ decreases. Therefore, Bank B must transfer less value to Bank A. Once Bank A has exhausted its borrowing capacity, it must start selling assets to Bank B even though doing so is inefficient, as this is the most effective means of transferring value to Bank B (Assumption 1).

Intuitively, the incentive problem can require that Bank A sell some assets. However, with perfect competition in liquidity supply, asset sales would be at the constrained efficient level. It is imperfect competition among surplus banks that leads to constrained inefficiency by inducing more asset sales than necessary, given the incentive problem.[11]

Confirming this intuition, Corollary 1 shows that the market power of liquid banks can lead to an inefficient allocation of liquidity, even in situations where the allocation would be efficient if those same banks were perfectly competitive. This scenario corresponds to $\beta > \beta^* > 0$. There are also situations in which frictions in the interbank market (here, moral hazard in monitoring) would lead to an inefficient allocation of liquidity even if liquid banks were perfectly competitive. This corresponds to $\beta^* = 0$. In those situations, liquid banks' market power increases the inefficiency of the allocation of aggregate liquidity. It must be stressed that market power alone would not lead to an inefficient outcome. Indeed, absent moral hazard in monitoring, Bank B would be able to increase its interest rate without affecting the value of Bank A's asset. It would find it optimal to do so since Bank A's assets are bank-specific. The reason why Bank B's market power would not lead to an inefficient allocation is that we allow its offer to Bank A to specify *both* price and quantity.

Corollary 2 *Efficiency (weakly) decreases with the liquidity need ρ and with Bank B's outside option X_B, and increases with Bank A's outside option X_A. Formally, an increase in ρ, an increase in X_B, and a decrease in X_A all have the following effect:*

- *β^* decreases weakly for $\beta^* = 1$ and strictly for $\beta^* \in (0, 1)$.*

[11] This could also lead to other costs such as spillover to other needy banks, for example through fire-sale externalities (Cifuentes et al. (2005)).

- *For $\beta > \beta^*$, asset sales and the associated inefficiency increase.*

By reducing Bank A's reservation payoff $E(\pi_A)$, an increase in X_B or a decrease in X_A tilts the bargaining outcome toward Bank B's interest, which is to acquire more of Bank A's assets. If $\beta > \beta^*$, Bank A has exhausted its borrowing capacity and an increase in ρ forces it to sell more assets to Bank B. The properties of α^* imply those of β^*.

2.4 Asset characteristics

We now focus on how the specificity of Bank A's assets affects the outcome. We model explicitly the fact that Bank A has access to competitive outside markets for borrowing and asset sales. We assume that Bank B has an advantage over outsiders both for using Bank A's assets and for lending against them, which we model as follows.

Asset sales: If an outsider owns an asset of Bank A with characteristic θ, then $p = p_o(\theta)$. We assume that Bank B has an advantage over outsiders for managing Bank A's assets. That is, banks are special relative to outsiders, i.e. they are better monitors of small, relationship-specific loans. Moreover, we assume that those assets for which Bank A's advantage over Bank B is the greatest are also those for which Bank B's advantage over outsiders is the greatest, i.e. assets' Bank A-specificity and their bank-specificity relative to outsiders are correlated:

$$p_o(\theta) < p_B(\theta) \quad \text{and} \quad \frac{dp_o(\theta)}{d\theta} > \frac{dp_B(\theta)}{d\theta}. \tag{13}$$

Nevertheless, we assume that it is efficient to fund Bank A's assets even if they are owned by an outsider:

$$p_o(\theta) > \rho/R. \tag{14}$$

Borrowing: We assume that Bank B is more effective than outsiders at lending to Bank A.[12] This advantage may be due to a past lending relationship or expertise in assessing Bank A's business. Specifically, we assume that when borrowing from outsiders, Bank A's benefit from not monitoring is $b_o \geq b$, so that it must retain a larger exposure to its assets to have an incentive to monitor, i.e. $R_b^o \equiv b_o/\Delta p \geq R_b$.

To simplify, we assume again that Bank A can raise more funds by selling outsiders an asset than by pledging some of its return to them, i.e.

$$\forall \theta \in [0,1]\,,\; p_o(\theta)R > p_H(R - R_b^o). \tag{15}$$

[12] Section 4 discusses the role of peer monitoring in interbank markets.

The outcome is obtained from Proposition 1 by replacing Bank B's characteristics with those of outsiders, i.e. by setting $X_B = 0$, $b = b_o$, and $p_B = p_o$. The intuition is similar. If Bank A's borrowing capacity $p_H (R - R_b^o)$ exceeds its funding need ρ, Bank A should only borrow from outsiders as this is more efficient. Otherwise, it must sell them some assets.

Lemma 1 *If bargaining between Bank A and Bank B breaks down, the outcome is as follows.*

- *If $p_H(R - R_b^o) - \rho \geq 0$, the outcome is efficient: Bank A funds all its assets by borrowing from outsiders and sells no assets ($\alpha_o^* = 0$). Its payoff is*

$$X_A = p_H R - \rho. \tag{16}$$

- *Otherwise, the outcome is inefficient: Bank A sells a fraction $\alpha_o^* = 1 - F(\theta_o^*)$ of its assets to outsiders with θ_o^* defined by*

$$\int_{\theta_o^*}^{1} [p_o(\theta)R - p_H(R - R_b^o)]\, dF(\theta) = \rho - p_H(R - R_b^o), \tag{17}$$

and funds its other assets with the sale's proceeds and loans from outsiders. Its payoff is

$$X_A = p_H R - \rho - \int_{\theta_o^*}^{1} [p_H - p_o(\theta)]\, R dF(\theta). \tag{18}$$

We can now analyze bargaining between Bank A and Bank B. For now, we assume that Bank B's outside option X_B is independent of Bank A's distribution of loan characteristics F. Recall that Bank A sells all its loans with θ above θ^*. This threshold does depend on the distribution of loan characteristics. Hence the fraction α^* of its assets Bank A sells to Bank B depends on F directly but also through its effect on θ^*.

Proposition 3 *Efficiency increases with the outsiders' ability to monitor loans to Bank A, with their ability to operate assets, and with the redeployability of Bank A's assets. Formally, for $\beta > \beta^*$, a decrease in b_o, an increase in the function $p_o(\cdot)$, or a shift of the distribution F towards higher values in the sense of FOSD results in fewer asset sales α^* and a lower inefficiency K^*.*

The effect of a decrease in b_o or an increase in $p_o(\cdot)$ is simple. Indeed, such changes increase X_A but keep all other variables constant. Therefore, this result is a simple implication of

Corollary 2. The effect of a shift in F is more complex as it affects not only Bank A's outside option in its bargaining with Bank B, but also other variables relevant to that bargaining.

Our analysis implies that the market failure in the transfer of liquidity is more severe when banks needing liquidity have more small, relationship-specific loans, as this decreases their outside option and gives surplus banks a better opportunity to exert market power.

3 Central bank as lender of last resort

We have shown how the market power of surplus banks can worsen or even create inefficiencies in the interbank market for liquidity. An important implication is that an aggregate liquidity surplus is no guarantee that liquidity will find its way to banks needing it most. In this context, we study how a central bank acting as a lender of last resort can mitigate inefficiencies by curbing surplus banks' ability to exploit their market power. We also determine the conditions under which such an improvement can occur.

Note that our analysis sidesteps the issue of the central bank's optimal policy. First, we focus only on the ex-post effects of central bank intervention. However, central bank actions can affect bank behavior ex ante, e.g. lead to moral hazard and mismanagement of liquidity and credit risk (Repullo (2005) and Acharya, Shin and Yorulmazer (2007)). Also, we do not analyze the optimality of the intervention. Indeed, our model as it stands is ill-suited for such an analysis as it does not specify explicitly the limits to central bank intervention. Hence, taking the model literally, the central bank could "force" the efficient allocation of liquidity by directly setting transfers between banks. For instance, it could set caps on interest rates and floors on asset prices. In practice, several problems might make such direct intervention less effective, and a meaningful analysis of optimal regulation should account for these.

We introduce a central bank. Say bargaining between banks A and B breaks down. Bank A can seek liquidity first from a central bank and then from competitive outside markets. For brevity, we assume the central bank to have full bargaining power vis-à-vis Bank A.

To simplify, the central bank cannot buy Bank A's assets, only lend to it. In that case, Bank A's benefit from not monitoring its assets is b_C, and we define $R_b^C \equiv b_C/\Delta p$. Importantly, the central bank is worse than Bank B at making loans to Bank A, i.e. $b_C \geq b$. Else, it would be the efficient lender to Bank A even under perfect interbank competition.[13]

[13]Central banks have other features which we do not model e.g. a longer horizon than private banks, especially in a crisis, or a lower cost of providing funds with immediacy given its flexibility in creating reserves. These would only strengthen central banks' LOLR role.

The incentive problem created by private benefits limits the income Bank A can pledge to its lender. The larger the private benefit, the greater the imperfection in the lending relationship between Bank A and its lender. For instance, a smaller private benefit can reflect the lender's greater ability to monitor Bank A.

We model the central bank's objectives and constraints as follows. Ex post (i.e. after banks A and B bargain), the central bank seeks to minimize the inefficiency in the allocation of Bank A's assets subject to its own expected losses not exceeding some level $\Lambda \in [0, \bar{\Lambda}]$ chosen ex ante (i.e., before banks A and B bargain).[14] The upper limit $\bar{\Lambda}$ captures that losses may have to be met through government funds, adding to government debt and fiscal costs that need to be financed through distortionary taxes, and that the central bank itself might loathe to rely on government support to protect its independence. The ex ante choice of $\Lambda \in [0, \bar{\Lambda}]$ captures the central bank's ability to commit to limited intervention. (We discuss briefly the no commitment case in Section 6).

Finally, denote β_o^* the value of β^* absent any intervention by the central bank. If $\beta < \beta_o^*$, the efficient outcome is reached, i.e. Bank A does not sell any of its loans and refinances them all. In that case, there is no role for the central bank. Instead, we now assume that $\beta > \beta_o^*$ and study the effect of central bank acting as a LOLR.

3.1 Central bank ex post intervention

We discuss the form of the central bank's ex post optimal intervention. Since it is, up to a limit, willing to extend some potentially loss-making loans, it would be willing to make a transfer to Bank A of up to Λ, or a larger transfer against some claim on Bank A's assets. To clarify, we denote L_C the part of the transfer that corresponds to a fairly priced (i.e. zero profit) loan from the central bank to Bank A, and T_C the part of the transfer above that loan. The latter part of the transfer corresponds to a pure transfer, a subsidy from the central bank to Bank A. We discuss the possible forms in can take below.

Proposition 4 *The central bank's optimal intervention is as follows.*

- *If the central bank is not better than outsiders at making loans to Bank A ($b_C \geq b_o$), its optimal intervention amounts to a pure transfer to Bank A*

$$T_C = \min\left\{\Lambda, \rho - p_H\left(R - R_b^o\right)\right\}. \tag{19}$$

[14]We also assume that all else equal, the central bank minimizes its expected losses.

Bank A should borrow $p_H(R - R_b^o)$ from outsiders and sell them the remaining assets, if any.

• *Otherwise ($b_C < b_o$), its optimal intervention amounts to lending to Bank A and possibly making it a pure transfer*

$$(20) \qquad L_C = p_H(R - R_b^C) \qquad \textit{and} \qquad T_C = \max\left\{\min\left\{\Lambda, \rho - p_H\left(R - R_b^C\right)\right\}, 0\right\}.$$

Bank A should not borrow from outsiders and should only sell them the remaining assets, if any.

• *In both cases, as the central bank's maximum expected loss Λ increases, asset sales decrease (until they reach zero).*

Consider first the case of a central bank that is not better than outsiders at monitoring loans to Bank A. In that case, loans should be made only by outsiders, i.e. the central bank should not use Bank A's limited borrowing capacity. Moreover, being competitive, the outsiders make zero profits; thus, there is no action by the central bank that can induce them to extend more loans. Hence the central bank's actions do not affect Bank A's borrowing capacity. The only action the central bank can take is to make (what amounts to) a pure transfer to Bank A. Such a transfer can be implemented in different ways: a pure transfer, or possibly a guarantee of Bank A's debt towards outsiders. Importantly, however, the central bank should not receive claims on Bank A's cash flows because outsiders value these more.

Consider now the case of a central bank that is better than outsiders at monitoring loans to Bank A. This advantage may, for instance, stem from the central bank's supervisory role.[15] In that case, it should substitute itself to outsiders, i.e. the outsiders should not use Bank A's limited borrowing capacity. The central bank increases Bank A's borrowing capacity, which eventually reduces the need for inefficient asset sales.[16]

There is no room for collateral or secured lending as such in our model. However, the central bank's liquidity transfer can be interpreted as a lowering of the quality of collateral against which the central bank extends liquidity support, e.g. by lending to needy

[15] Using U.S. data, Berger et al. (2000) show that shortly after supervisors have inspected a bank, supervisory assessment of the bank is more accurate than the market's. However, the reverse holds for periods where the supervisory information is stale. Hirtle and Lopez (1999) show that supervisory information gathered during examinations ceases to provide a useful picture of a bank's condition after six to twelve quarters. The decay rate is faster when the banking industry experiences financial difficulties, and for troubled banks.

[16] Note, however, that in our model, outsiders have incentives to supervise banks since they would gain from the improved ability to lend to needy banks. One reason they may not do so is that banks may be more forthcoming in disclosing information to a not-for-profit regulator than to outsiders who may be (or become) players in similar markets, and might be tempted to exploit such information for their own benefit.

banks against mortgages at a lower rate than the market does if these loans are likely to be terminated in the absence of liquidity support.

3.2 Impact on interbank market outcomes

We now study how the possibility of central bank intervention ex post affects the bargaining between banks A and B ex ante. As a benchmark, consider a central bank that is neither better than outsiders at monitoring Bank A nor willing to accept losses.

Proposition 5 *A central bank that is not better than outsiders at monitoring Bank A ($b_C \geq b_o$) and is not ready to accept losses ($\bar{\Lambda} = 0$) cannot ameliorate the inefficiency arising from Bank B's market power.*

The intuition is simple. Indeed, if the central bank is willing and able to take a given action, so are any of the outsiders. In effect, the central bank is like an outsider, possibly one that is less effective at extending loans. Hence, Bank A's outside option is the same as it is absent the central bank, and the outcome of its negotiation with Bank B is unchanged.

Turning the result on its head, we can characterize situations in which central bank intervention can have a positive impact.

Proposition 6 *The central bank can improve outcomes if it is better than outsiders at monitoring Bank A ($b_C < b_o$) or ready to accept losses ($\bar{\Lambda} > 0$). Moreover, asset sales and the associated inefficiency decrease with the central bank's willingness to make losses and with its ability to monitor Bank A (if $b_C < b_o$), i.e. for $\alpha^* > 0$,*

$$\frac{\partial \alpha^*}{\partial \Lambda} < 0 \qquad \textit{and} \qquad b_C < b_o \Rightarrow \frac{\partial \alpha^*}{\partial b_C} > 0.$$

The central bank can improve outcomes without actually extending loans in equilibrium, i.e. it can play a "virtual and virtuous" role: It is sufficient that the central bank provides potential competition to Bank B. By acting as a LOLR, the central bank can improve Bank A's outside option in its negotiation with Bank B, provided that the central bank is either better than outsiders at monitoring Bank A or willing to extend loss-making loans. Of course, the central bank's impact would be greater if it were better than Bank B at monitoring Bank A, a case we assume away. Importantly, our analysis shows that this arguably unrealistic condition is not necessary for the central bank to be effective.

We find that the central bank's willingness to incur losses can be effective at curbing Bank B's market power. Such willingness may however be limited and costly. The central bank's effectiveness at making loans to Bank A is can reduce the losses it ought to be ready to incur. For a given b_C, define $\Lambda^* (K, b_C)$ as the expected loss Λ the central bank must be ready to incur ex post so that bargaining between banks A and B results in an efficiency loss no greater than K.

Corollary 3 *If the central bank is better than outsiders at monitoring Bank A ($b_C < b_o$), the expected loss it must incur to ensure a given level of efficiency decreases with its ability to monitor Bank A, i.e.*

$$\frac{\partial \Lambda^* (K, b_C)}{\partial b_C} > 0. \tag{21}$$

The intuition is simply that as b_C decreases, Bank A can pledge a larger fraction of its return to the central bank so that loss-making loans are less costly to the central bank. Hence if the central bank stands as a LOLR, it will have incentives to improve its ability to make loans, e.g. to assess and monitor borrowing banks. From a policy standpoint, it may also be optimal to assign other tasks (such as supervision) to the central bank if they increase its expertise in monitoring loans to banks.[17] In other words, through its supervisory role, the central bank can limit its commitment to losses. Note that this argument differs from the one that states that since the central bank is a LOLR, it ought to supervise banks to avoid being in a position to need the LOLR.

3.3 Liquidity insurance

So far, we have considered liquidity transfers after a liquidity shock, ignoring the possibility for banks to insure against such shocks (Bhattacharya and Gale (1987), Allen and Gale (2000), and Leitner (2005)). In an online appendix, we study this possibility, which reduces

[17] The Bank of England recently getting some of its supervisory role back from the Financial Services Authority constitutes one such example. During the Northern Rock episode, the division of responsibilities between the U.K. Treasury, the Bank of England, and the FSA had been subject to criticism. In a Treasury Committee hearing, William Buiter argued that: "The notion that the institution that has the knowledge of the individual banks that may or may not be in trouble would be a different institution from the one that has the money, the resources, to act upon the observation that a particular bank needs lender of last resort support is risky. It is possible, if you are lucky, to manage it, but it is an invitation to disaster, to delay, and to wrong decisions." (Source: The Run on the Rock, report for the House of Commons Treasury Committee, page 105).

the inefficiency in interbank liquidity transfers. However, as long as banks can only get partial liquidity insurance, surplus banks' ex-post market power increases (or creates) inefficiency in the allocation of liquidity. This yields further results. First, if banks likely to have excess liquidity and market power ex post are also the best liquidity insurers ex ante, their market power reduces the scope for liquidity insurance. Put simply, committing to provide liquidity conflicts with incentives to retain market power. Second, committing to provide liquidity is costly for banks that may need liquidity in the future too. Thus, if states of aggregate shortage of liquidity are more likely (as in a financial crisis), liquidity insurance is more costly, resulting in less insurance. This, in turn, increases the ex-post market power of cash-rich banks even in states of aggregate liquidity surplus.

Other reasons that liquidity insurance is only partial include the impossibility to enter binding long-term contracts, the fragility of implicit contracts during crises, or the possibility of aggregate liquidity shortage combined with liquid banks' cost of capital being non-verifiable. For instance, banks could enter implicit contracts for liquidity provision, sustained through repeated interactions. This may, however, also be less relevant during crises. Indeed, Carlin, Lobo and Viswanathan (2007) show that such contracts break down when the "prey" is large or close to default since the continuation of a relationship is less valuable. Again, crises may represent such situations.

This discussion and our results in the online appendix imply that ex-ante liquidity insurance is likely to be incomplete, as observed in practice, and market power considerations arise when liquidity distribution across banks is highly skewed. An implication is that as long as only partial liquidity insurance occurs in equilibrium, the central bank can improve efficiency by committing to act as a lender of last resort.

4 Empirical evidence and robustness

We provide evidence supporting our main assumptions, discuss historical and current episodes suggesting market power of liquid banks during crises, and examine robustness issues.

4.1 Support for assumptions

Asset specificity: We have assumed that some assets are bank-specific. That is, banks are special relative to outsiders, e.g. better monitors of small, relationship-specific loans (Fama (1985), James (1987), James and Houston (1996)). This notion was first introduced in Corporate Finance by Williamson (1988) and Shleifer and Vishny (1992): Firms whose assets cannot be readily redeployed by other firms are likely to experience lower liquidation values ("fire-sale" discounts), especially when industry peers simultaneously get into financial or economic distress.[18] For U.S. data for 1985-1988, James (1991) reports that significant going-concern value is preserved if a failed bank is sold to another bank, but lost if it is liquidated by the Federal Deposit Insurance Corporation. Furthermore, Dell'Arricia et al. (2008) and Krozner et al. (2007) report that financially dependent sectors perform relatively worse during banking crises, which is consistent with the importance of bank relationships and information-sensitive loans.

Moral hazard and inside ownership in banking: Our model relies on the feature that moral hazard is addressed by greater ownership of the bank by insiders. This assumption finds considerable empirical support in cross-country data on bank ownership. Caprio, Laeven, and Levine (2007) study the ownership patterns of 244 banks across 44 countries, collecting data on the 10 largest publicly listed banks in those countries. They document that banks in general are not widely held (where a widely held bank is one in which no legal entity owns 10% or more of the voting rights), a finding that is similar to that of La Porta, Lopez de Silanes, and Shleifer (1999) for corporations in general. In particular, Caprio, Laeven, and Levine (2007) document that inside ownership of banks (especially by families that are found to have controlling stakes more than half the time in the average country) and ownership by the state are more commonly observed than a dispersed ownership of banks, which is found in less than 25% of the banks. This observation is stronger in those countries that have weaker shareholder protection laws.[19] Importantly, they also find that greater inside ownership of banks enhances bank valuation, especially in those countries where the shareholder protection laws are weaker.

Overall, these findings are consistent with the moral hazard aspects of our model since weaker shareholder protection laws should imply a greater risk of cash-flow appropriation by insiders, and, in turn, lead to greater inside ownership of banks in equilibrium. At the same

[18] Also, see Allen and Gale (1994, 1998) for theoretical models of cash-in-the-market pricing. There is strong empirical support for this idea. See, e.g. Pulvino (1998), Acharya et al. (2007), Berger et al. (1996), and Stromberg (2000).

[19] For example, more than 90% of the banks in Canada, Ireland, and the U.S. are widely held, but not more than 50% in Italy, Spain, and Venezuela are widely held. A significant proportion of the remaining ones are controlled by families, whereas 21 out of 44 countries (e.g., Argentina, Brazil, Chile, Israel, Mexico, and Thailand) do not have a single widely held bank among their largest banks.

time, however, this evidence makes it clear that our model may not be literally applicable to countries with strong shareholder protection since their banks are indeed widely held. In such countries, the relevant moral hazard is likely to be at the level of bank managers. There is evidence that such managerial moral hazard is an important determinant of bank performance and failures. The Office of the Comptroller of the Currency in the United States in 1988 completed a study based on 171 banks that failed, became distressed and recovered, or remained healthy during the 1979–1987 period, and identified characteristics and conditions present when the health of the banks deteriorated. The study found that "Management-driven weaknesses played a significant role in the decline of 90 percent of the failed and problem banks the OCC evaluated." The study also concluded that principal-agent problems within banks are a key reason for bank failures, in addition to the deteriorating quality of assets during business downturns. Our model does not explicitly consider incentive contracts for managers of widely held banks, but the moral-hazard problem we study can be considered as a metaphor for a general class of principal-agent problems affecting banks.

Concentration and market power: Our simplified model of interbank markets aims at capturing market-power issues. These issues can arise from "tiering", whereby some banks ("tier-1" banks) access central bank liquidity and act as clearing banks for other banks ("tier-2" banks). Even in large interbank markets, such tiering exists, and therefore issues of market power and concentration remain important. For example, in the U.S. Fed Funds market, JPMC and Bank of America are much bigger borrowers than others, and State Street and JPMC are much bigger lenders. Furthermore, many banks are connected with only one or two banks, the average number of connections being between three and four (Bech and Atalay (2008)). The U.K. also has a tiered system, and the volatility induced in interbank lending rates due to the cornering of collateral and liquidity by some of the large settlement banks during 2001-2005 was one of the primary rationales for the Sterling Money Market Reform in 2006. Post-reform, the Bank of England increased the number of banks allowed to participate in open market operations from 10 to over 35 (Bank of England (2005) and Tucker (2004)).

Another important feature is that large and unsecured interbank loans make peer monitoring among banks important (see Rochet and Tirole (1996) and Freixas and Holthausen (2005) for theory). Such monitoring confers information monopolies to larger players in interbank markets. Cocco et al. (2009) report evidence of strong relationships in the Portuguese interbank market, suggesting that some banks are more important lenders and pivotal, even in normal times. Furfine (2001) and Cocco et al. (2009) document that large banks, in terms of size and participation in interbank lending, enjoy market power: they borrow and lend at more favorable terms. Often small banks, with limited access to foreign interbank markets, concentrate all their borrowing in the domestic interbank markets and with a few large banks. Cocco et al. also highlight the essentially bilateral nature of interbank lending: most of the lending volume is accounted for by "direct" loans in which loan amount and interest rate are agreed to on a one-to-one basis between borrower and lender, other banks do not necessarily have access to the same terms and may not even observe the transaction, posted quotes are merely indicative, and the identity of lending banks affects the interest rate.

4.2 Historical evidence

Our analysis clarifies that to empirically identify market-power effects in interbank markets, it is important to focus on the pre-central banking era or on institutions without access to central-bank lending. Hence, we provide historical evidence (see Freixas et al. (1999) for a survey) and then present some recent evidence.

I) The failure of private coinsurance arrangements

Liquidity support operations occurred often in the past. In the United States, the Clearinghouse System assumed a crisis prevention and management role before the Federal Reserve System was established in December 1913 (Gorton (1985), Gorton and Mullineaux (1987), Calomiris and Kahn (1996), Gorton and Huang (2002, 2006)). The first clearinghouse, set up by the New York City banks in 1853, created an organized interbank market. In normal times, clearinghouses performed their service of clearing payments; whereas during crises, they helped member banks sustain their solvency and liquidity positions. At such times, clearinghouses suspended payments of the distressed member banks. They equalized reserves, pooling all legal reserves of member banks and granting them equal access to that pool. In addition, clearinghouses issued loan certificates that banks acquired by depositing qualifying assets with the Clearing House Association to be used in interbank settlements. These certificates prevented costly asset liquidations. Since they were provided only when the Clearing House Association judged that the bank had enough assets to back them up, certificates also certified the bank as healthy (Park (1991)).

These measures, aimed at easing liquidity constraints on banks experiencing runs, worked well at times. However, their effectiveness was hampered by competitive pressures in the banking industry. In particular, voluntary participation by healthy banks was difficult to elicit due to the short-term competitive advantage they enjoyed during crises. The Clearinghouse System was eventually brought down early in the 20th century by the sharp increase in banking competition in New York.[20]

II) 1907 panic in the United States

i) The role of J. P. Morgan: Discussing the 1907 panic in New York, Sprague (1910) suggests that the banks were initially reluctant to rescue distressed trust companies[21] since they were not adversely affected by the distressed companies' problems and even benefited by attracting their depositors.

The immediate cause of the panic was the collapse of copper stocks. On October 17, depositors started a run on the Mercantile National Bank, whose president Heinze had tried to corner the stock of United Cooper. Runs spread to banks controlled by Morse and Thomas, two speculators financially affiliated with Heinze. The New York Clearing House Association granted assistance to those banks after examining their solvency and forcing Heinze, Morse, and Thomas to resign. This action subdued severe runs on banks.

Trust companies, however, were also experiencing difficulties. Depositors, fearing their involvement in speculation, started a run on the Knickerbocker Trust Company on October 21 and on the Trust Company of America on October 23.[22] The New York Clearing House, an organization of banks, did not assist these trusts. Knickerbocker had to suspend on

[20] Other historical episodes confirm the tension between the viability of private arrangements and competition. An example is the 1893 financial crisis in Australia. The Australian banking system was relatively unregulated during the second half of the 19th century with no central bank and no government-provided deposit insurance. In 1893, eleven commercial banks failed, and the rest experienced severe bank runs. At the time, the Associated Banks of Victoria was a coalition of private banks, just like the Clearing House Association in New York, and had been initially set up to coordinate and divide the finances of the colonial governments. Before the crisis, the Associated Banks announced that, if and when needed, they would provide financial assistance to each other (*The Economist*, March 25, 1893, page 364). However, during the crisis, this arrangement proved ineffective when Federal Bank was allowed to fail without any assistance in January 1893. Pope (1989) suggests that competitive pressures played a major role in the failure of private arrangements as banks stood to gain market share from failed banks.

[21] These companies are effectively commercial banks, organized to perform the fiduciary role of trusts and agencies.

[22] Goodhart (1969) documents that on October 21, 1907, the National Bank of Commerce refused to act as clearing house for Knickerbocker, which had not yet experienced any significant problems, precipitating a run on Knickerbocker. He suggests that this move was part of severe competition – "internecine rivalry" – and a fight for market share between national banks and trust companies in New York, with the National Bank of Commerce taking the opportunity to eliminate a rival, indeed a set of rivals, since the Knickerbocker run spilled over to all other trust companies.

October 22, and the Trust Company of America, a solvent institution, suffered runs for two weeks. Eventually, Treasury Secretary Cortelyou earmarked $35 million of federal money to quell the storm. On November 6, New York trust companies, urged by J. P. Morgan, organized a team of bank and trust executives, raised a $25 million fund for distressed trust companies, redirected money between banks, secured further international lines of credit, and bought the plummeting stocks of healthy corporations.[23] Runs on the Trust Company of America and other small institutions subsided after the resolution.

While J. P. Morgan is credited as the coordinator and rescuer in this financial crisis, several aspects of his involvement suggest strategic behavior and market power. First, in 1906, Heinze had acquired Knickerbocker, and Morse gained control of the Bank of North America. Even prior to the 1907 crisis, banking industry leaders, including Morgan, staged a financial attack on Knickerbocker. They felt threatened by the developing trusts and wished to sway public and congressional opinion against them.

Second, the banks controlled by Morgan and his associates experienced only minor difficulties in 1907, thanks to their reputation for soundness. According to Sprague (1910), while five banks controlled by Heinze and Morse suffered severe deposit withdrawals, the six strongest clearinghouse banks showed slight gains in deposits. The delay in assisting the trust companies is thus often perceived as a strategic move on the part of the clearinghouse banks.

Third, and most important, Chernow (1990) discusses how J. P. Morgan gained from the trust companies' problems in the 1907 crisis. On November 2, Morgan finally organized a rescue package for the distressed Trust Company of America, and Lincoln Trust, as well as Moore and Schley, a speculative brokerage house $25 million in debt. Moore and Schley held a majority stake in the Tennessee Coal and Iron Company as collateral against loans. If they had to liquidate that stake, they might collapse and, in turn, pull down other institutions. To save Moore and Schley, Morgan wanted some benefit for himself and told friends he had done enough and wanted some *quid pro quo*. He arranged a deal in which U.S. Steel, his favorite creation that could profit from Tennessee Coal's huge iron ore and coal holdings, would buy Tennessee Coal stock from Moore and Schley if the trust company presidents assembled a $25 million pool to protect weaker trusts. While the takeover would normally

[23] Moen and Tallman (2006) confirm that the large New York banks acted as *private* liquidity providers using New York Clearing House loan certificates, and that this led to difficulties in the distribution of liquidity.

have been barred on antitrust grounds, U.S. Steel secured President Roosevelt's approval, and the Sherman Antitrust Act was not used. Senator La Follette said bankers had rigged up the panic for their own profit. Financial analyst John Moody said the Tennessee Coal and Iron's property had a potential value of about $1 billion, confirming the $45 million distressed price as a steal. Later on, Grant B. Schley, head of Moore and Schley, admitted that his firm could have been rescued by a cash infusion rather than by the sale of the Tennessee Coal stock.

The 1907 crisis paved the way for the establishment of the Federal Reserve System as Senator Aldrich declared: "Something has got to be done. We may not always have Pierpont Morgan with us to meet a banking crisis" (Sinclair (1981)).[24] The Federal Reserve System was a natural response to the realization that control and leadership of the U.S. financial system had effectively been outsourced to one private businessman.

III) Emergence of modern central banks

One should distinguish two possible reasons for the failure of private coinsurance arrangements: lack of coordination among clearinghouse members (e.g. due to free-riding)[25] and strategic behavior. It appears that coordination was factored into the organization of clearinghouses, and that it was really market power that led to their failure.

Timberlake (1984) argues that in U.S. clearinghouses, one bank usually assumed the central administration role for the clearing member banks' accounts. However, a temptation existed for the central commercial banks to exploit a crisis to force a rival out of business by not providing them with the assistance they could have expected in normal times. This concern accords well with J. P. Morgan's role in the 1907 crisis. Hence, such conflicts of interest create a natural need for a non-competitive, non-profit maximizing central bank.

Interestingly, early central banks did not take this non-competitive form. In the first half of the 19th century, a central bank's key feature resided in its relationship with the government and its privileged role as a (monopolistic) note issuer. Importantly, a central bank was considered to be one of the competitive banks. True central banking did not

[24]Strouse (1999) details how, during the crisis, panicked crowds on the streets of Manhattan would stop to cheer as Morgan walked past, puffing at a cigar. So powerful was the House of Morgan - more powerful in the financial world than the government - that nobody dared to say no to him. The 1907 crisis was played out in his library amid his collection of books and art. Dozens of financiers would be in the room as Morgan told them they had to work collectively. At one point he locked the doors, refusing to let anyone leave until he had the answer he wanted - at 4am.

[25]Kindleberger (1978), Corrigan (1990), and Goodhart and Schoenmaker (1995) allude to such a possibility.

develop until the need for central banks to be non-competitive was realized and established. Bagehot (1873, chapter 7), Goodhart (1985) and Goodhart and Schoenmaker (1995) report episodes of commercial rivalry between central banks and needy (regular) banks.

Bagehot wrote his famous *Lombard Street* in 1873 in the aftermath of the Overend, Gurney & Company crash of 1866 when there was suspicion that the Bank of England, then a private commercial bank, was reluctant to support Overend Gurney due to commercial rivalry. Bagehot points out that while it was accepted that the central bank should only assist banks expected to be solvent or to regain solvency under normal conditions, it should seek to act for the public good, and not simply as a business competitor. In contrast, the Bank of England's coordination of the rescue of Baring Brothers in 1890, its organization of a "life-boat" during the secondary banking crisis in the early 1970s, and its rescue of Johnson Matthey Bankers Ltd. in 1984 in response to heightened competition in the financial sector (Capie et al. (1994)), are prominent examples of the Bank of England performing its role in a non-competitive fashion.[26]

These episodes suggest that even if it is not their sole *raison d'être*, at least central banks' modern form as non-competitive, non-profit maximizing entities does find its roots in competition issues.

IV) Interest-rate behavior during crises in the pre- and post-Federal Reserve era

Using U.S. data from 1873-1933, Donaldson (1992) shows that during banking panics interest rates were substantially higher than they were pre-crisis (by as much as 500% at times) and extremely volatile, which he interprets as evidence of market power by surplus banks. He shows that in contrast to the pre-Fed era, interest rates during crises after the establishment of the Federal Reserve System were not significantly different from pre-crisis rates. He also documents a structural change in the pricing of cash between panic and non-panic periods, consistent with surplus banks using their market power to exploit needy banks during crises. Cash was indeed priced higher during panics than they were during non-panic times in the pre-Fed period, but not so in the post-Fed period.[27] He concludes that the

[26] The relation between Banque de France and potential competitors in the mid-19th century is another good example. In particular, Banque de France used its influence to restrict competition from chartered banks. Because of such strong influence, the Conseil d'Etat was reluctant to grant charters to banks. And in 1867, after being involved in unsuccessful real estate speculation, Credit Mobilier experienced difficulties, and its enemies at Banque de France took advantage of the situation and forced it into liquidation.

[27] The 1914 panic took place in August. The Federal Reserve System was created via the Federal Act of December 23, 1913 and the Reserve Banks opened for business on November 16, 1914. These dates imply that the 1914 panic took place before the Fed was open. Donaldson (1992), Table 1, covers the behavior of

Fed's establishment as a lender-of-last-resort during panics prevented surplus banks from exploiting needy banks. The fact that banks hoarded liquidity for such strategic purposes – which would contribute to liquidity shortages and rises in interbank rates – is confirmed in Cleveland and Huertas (1985)'s accounts of the 1893 and 1907 crises. They describe the strategy of the National City Bank (which was to become Citibank) to anticipate crises and to build up liquidity and capital beforehand to attract dealers away from its troubled rivals.[28]

4.3 Recent evidence

We provide evidence of market power of banks vis-à-vis hedge funds (which did not have access to central bank lending) during the crisis of 2007-10 and in the preceding decade.

I) Hedge fund failures in the crisis of 2007-10

The allegations below are gathered from press reports and concern some hedge funds in the context of the role played by the counterparties – in all cases, banks – in their failures.[29] In particular, a number of large hedge funds that failed in the crisis of 2007-10 have claimed they were at the mercy of banks who could force them into liquidation at will. While lenders may force liquidations, even absent market power, the specific discussions and examples below suggest that market power played a role, especially due to the specificity – and illiquidity – of the asset-backed securities in hedge fund portfolios.

Tequesta Capital Advisors: This hedge fund was asked by its banks to put up more money or risk losing its loans. It was unable to meet the margin call as the market for mortgage-backed debt seized up, which prevented it from selling securities to raise the cash, and ultimately led to the liquidation of the $150 million fund. The fund's founder Ivan Ross claimed: "Because it's impossible in this environment to move among dealers, you're at the

interest rates between weeks 31-49 of 1914. A careful examination reveals that the interest rates for 1914 are (slightly) higher than the rates in 1933, which is still consistent with Donaldson's overall argument.

[28] Regarding the 1907 crisis, Cleveland and Huertas (1985) write (page 52): National City Bank again emerged from the panic a larger and stronger institution. At the start, National City had higher reserve and capital ratios than its competitors, and during the panic it gained in deposits and loans relative to its competitors. Stillman (President) had anticipated and planned for this result. In response to Vanderlip's (Vice President) complaint in early 1907 that National City's low leverage and high reserve ratio was depressing profitability, Stillman replied: "I have felt for sometime that the next panic and low interest rates following would straighten out good many things that have of late years crept into banking. What impresses me as most important is to go into next Autumn (usually a time of financial stringency) ridiculously strong and liquid, and now is the time to begin and shape for it. If by able and judicious management we have money to help our dealers when trust companies have suspended, we will have all the business we want for many years."

[29] This discussion is based on various Bloomberg articles.

mercy of counterparties. To the extent they want to shut you down, they can."

Peloton Partners: On February 24, 2008, this London-based hedge fund gave up efforts to stave off demands from banks, including UBS and Goldman Sachs for 25% collateral for securities that once required 10%. Peloton, run by former Goldman partners Ron Beller and Geoff Grant, liquidated the $1.8 billion ABS Fund, its largest. In a letter to clients, Beller and Grant said "Credit providers have been severely tightening terms without regard to the creditworthiness or track record of individual firms, which has compounded our difficulties and made it impossible to meet margin calls."

Thornburg Mortgage: This home lender had lost 93% of its market value and was near collapse on March 7, 2008, after it failed to meet $610 million of margin calls. CEO Larry Goldstone said the company fell victim to a "panic that has gripped the mortgage financing industry." Goldman Sachs was one of the 22 financial companies that had lent money to Thornburg; it was using about $200 million of a Goldman credit line backed by mortgage loans. In August 2007, Goldman was the first firm to begin aggressively marking down the assets that Thornburg had used as collateral for the loan, arguing they were not valuable enough to repay the loan if Thornburg defaulted. Goldman demanded more cash to shore up the account, arguing that the value of similar mortgages traded by other parties had been priced at lower levels. "When we tried to negotiate price, they argued that they were aware of transactions that were not broadly known on the Street," said a former Thornburg employee who was briefed on the talks with Goldman: "That was their justification for why they were marking us down as aggressively as they were - that they were aware of things that others were not." But Goldman, according to two people with knowledge of the situation, had not actually seen such trades. However, soon after Goldman demanded more funds from Thornburg, analysts began downgrading its shares on news of the collateral calls. Beaten down by the broader mortgage collapse, Thornburg filed for bankruptcy on May 1, 2009.

While these allegations of market power are still being evaluated, the fact that they have been raised suggest that market power issues are important in the midst of a financial crisis.

II) Hedge-fund failures prior to the crisis

In the decade preceding the crisis of 2007-10, two major hedge funds had collapsed: Long Term Capital Management (LTCM) in 1998 and Amaranth Advisors LLC in 2006. In both cases, other players seem to have tried to exploit their difficulties.

After its remarkable success from 1994-97, LTCM began to experience difficulties during the financial turmoil triggered by the Russian default in August 1998. LTCM had to buy large amounts of Treasury bond futures to unwind its short position. Anticipating the direction of LTCM's trades and with the advantage of observing customer order flow, market makers had incentives to engage in front running, i.e. trading in the same direction knowing that the order will be coming and unwinding the position afterwards to profit from the order's price impact.[30] For example, *BusinessWeek* wrote: "...if lenders know that a hedge fund needs to sell something quickly, they will sell the same asset, driving the price down even faster. Goldman Sachs & Co. and other counterparties to LTCM did exactly that in 1998."[31] Cai (2003) examines the trading behavior of market makers in the Treasury bond futures market when LTCM faced binding margin constraints in 1998 and finds that during the crisis market makers in the aggregate engaged in front running against customer orders from a particular clearing firm (coded PI7) that closely match features of LTCM's trades through Bear Stearns. Furthermore, many market makers made abnormal profits on most trading days during the crisis. Eventually, fearing that LTCM's fall might disrupt financial markets, the New York Fed hosted a meeting of fourteen financial institutions that led to a private-sector recapitalization of LTCM, which helped avoid fire sales. This, in turn, reversed the profitability of speculative trading against LTCM.

Similarly, the *Wall Street Journal* reported Amaranth Advisors LLC's failure and the efforts of other energy market players to exploit its difficulties.[32] When Amaranth's bets in the energy market turned out to be unfavorable, it started to lose value and by the end of Friday, September 15, 2006, was down more than $2 billion from its August value. The losses prompted J.P. Morgan, Amaranth's natural-gas clearing broker, to raise margin calls to be paid by Monday, September 18. In the past, Amaranth had met such demands by selling non-energy investments, but thinking that some of these could not be liquidated quickly, Amaranth started negotiations with Wall Street banks to raise cash, eventually securing a deal with Goldman Sachs. However, J.P. Morgan refused to release Amaranth's cash collateral claiming that the deal did not free it from the risk that Amaranth's trades

[30] Some recent papers model such strategic behavior. In Brunnermeier and Pedersen (2005), traders exploit the difficulties of other traders facing forced liquidations. If a distressed large investor must unwind her position, other traders initially trade in the same direction, and, to benefit from the price impact, buy back the same asset. Hence, as in our model, market participants withdraw liquidity, instead of providing it when liquidity is most needed. See also Carlin et al. (2007).

[31] *BusinessWeek*, February 26, 2001, "The Wrong Way to Regulate Hedge Funds."

[32] *Wall Street Journal*, January 30, 2007, "Amid Amaranth's Crisis, Other Players Profited."

may not get paid. This killed the deal. Later on, J.P. Morgan itself got into the game and agreed to jointly assume most of Amaranth's energy positions with a partner, Citadel Investment Group.[33] In a speech in November 2006, Jamie Dimon, J.P. Morgan's CEO, said the Amaranth deal produced a "very nice increment to fixed-income trading" and in January 2007, *RISK* magazine named J.P. Morgan "Energy Derivatives House of the Year."

These episodes illustrate that liquidity markets can be ridden by strategic behavior by counterparties and lenders, especially when they stand to gain from failure of needy firms.

5 Policy implications

5.1 The discount window

The result that central banks change needy banks' outside option, forcing surplus banks to adjust their liquidity supply, has implications for central banks' LOLR facilities.

For example, the Federal Reserve's discount window offers banks a lending facility at a premium to the federal funds rate, i.e. the rate at which banks (depository institutions) lend their balances at the Fed to other banks, usually overnight. However, this discount window is however seldom used. Some have argued that the stigma of being seen as having funding problems explains banks' reluctance to use it. Our analysis implies that this need not necessarily mean that the discount window is useless. The federal funds rate plus the premium sets an upper bound on the cost of borrowing when aggregate liquidity is in surplus. In particular, this limits the surplus banks can squeeze out of needy banks.

A second implication concerns the discount window premium. How high should the premium be? Could it be so high that it has little effect on borrowing outcomes?[34] Lack of borrowing at the discount window should not cause as much alarm as the lack of any effect

[33] The deal with Goldman Sachs would require Amaranth to pay nearly $1.85 billion to take toxic trades off its hands. Amaranth intended to use the $1 billion to $2 billion in cash J.P. Morgan held in a margin account, to pay Goldman Sachs for the deal. In the final deal, Amaranth's total payments to Merrill Lynch, J.P. Morgan, and Citadel, plus the last few days' market losses, came to about $3.2 billion. While Amaranth suffered huge losses during the process, J.P. Morgan earned an estimated $725 million from the deal.

[34] For example, in August 2007, the Fed cut the discount rate to just a half percentage point above the federal funds rate, from the usual spread of a full point, hoping to encourage banks to seek funds from the window to help customers finance holdings of illiquid securities. Fed officials told banks at the time that any such borrowing would be seen as a sign of strength, not weakness. "This change did not lead to a big increase in borrowing . . . (because) even at a (half point) spread, the (discount) rate was higher than the rate on alternative sources of funds for most depository institutions," William Dudley (Executive Vice President), who managed open market operations at the New York Fed at that time, told an audience at the Philadelphia Fed in October 2007.

of a change in the premium at the discount window on interbank borrowing rates – an issue that has not received much attention. Within our model, the discount window has no effect on borrowing outcomes if the lending rate at the window is not below that at which outside (non-bank) markets would lend against the same assets. Indeed, the central bank may find it desirable to commit to bearing some potential losses in which case the effective lending rate at the window should be below the outside market rate. Historically, there has been some evidence of such use of the discount window at a discount to the federal funds rate (rather than at premium) having been effective during the 1970 Penn Central commercial paper crisis.[35]

An important question is whether central banks need to lend to individual institutions directly, or whether they should rely on open market operations (OMO) (Goodfriend and King, 1988). Our model implies that when there are market power issues, OMOs may not succeed unless the central bank pumps enough liquidity to break the market power of some banks. Consistent with this view, Governor of Bank of England Mervyn King and the Chancellor of the Exchequer Alistair Darling, during the hearings about the Northern Rock episode in Fall of 2007, pointed out the difficulties with OMOs in channeling liquidity to needy banks as the primary reason for lending directly to individual institutions. In particular, they pointed out that to channel the £14 billion that Northern Rock borrowed from the Bank of England to that institution would have required many more billions of pounds to be injected through the OMOs.

5.2 New forms of central bank funding

Our analysis also implies that unless outside markets are themselves strapped of liquidity, needy banks should have no trouble raising liquidity against collateral that requires little monitoring skills or expertise. Illiquidity issues arise for those loans over which other banks have an advantage in terms of monitoring and usage, conferring upon them market power. Indeed, collateral that is highly bank-specific may be inefficiently liquidated. Hence, a discount window or other LOLR facility that lends *only* against high-quality collateral may not

[35] Calomiris (1994) describes the crisis, and the Fed's use of the discount window to combat it. The Fed lent to member banks through the discount window for purposes of making loans to commercial paper issuers. Importantly, funds were lent at a discount to the federal funds rate, rather than the normal premium, which succeeded in channeling liquidity to needy institutions reliant on commercial paper market during normal times. Firms likely to have had outstanding debt in the form of commercial paper suffered larger negative abnormal returns during the onset of the crisis, and larger positive ones after the Fed intervened to lower the cost of commercial paper rollover.

improve much the allocation of liquidity.

This perspective is useful for understanding the new facilities set up by the Fed in 2007-09 aimed at channeling liquidity to the neediest corners of the financial system. These new facilities have extended maturities to include up to 90-day loans, maturities at which money markets have dried up in the aftermath of sub-prime losses; extended eligible collateral to include investment-grade debt securities (including high-rated but illiquid mortgage-backed securities); and extended these privileges not only to banks but also to securities dealers since they are also affected by funding problems caused by the drying up of liquidity extension from banks.[36] These changes are more likely to be effective than are traditional facilities in restoring liquidity in the interbank markets, even if they are not directly tapped into, since they have created a direct option for raising funding against assets rendered illiquid.[37]

Early in the crisis of 2007-09, the Federal Reserve used OMOs to ease the strain in money markets. While OMOs had some success in stabilizing the overnight rate, the rates on term loans continued to rise. On December 12, 2007, the Fed introduced the Term Auction Facility (TAF), which provides term funding to eligible depository institutions through auctions. McAndrews et al. (2008) study whether TAF succeeded in easing the strain in money markets, measured as downward shifts in LIBOR. They show that TAF was successful, where a cumulative reduction of 50 basis points in the LIBOR-OIS spread can be associated with the TAF announcements and its operations (see also Wu (2008)).

[36] In particular, in addition to the traditional tools the Fed uses to implement monetary policy (e.g., Open Market Operations, Discount Window, and Securities Lending program), new programs have been implemented since August 2007: 1) Term Discount Window Program (announced August 17, 2007) - extended the length of discount window loans available to institutions eligible for primary credit from overnight to a maximum of 90 days; 2) Term Auction Facility (TAF) (announced December 12, 2007) - provides funds to primary credit eligible institutions through an auction for a term of 28 days; 3) Single-Tranche OMO (Open Market Operations) Program (announced March 7, 2008) - allows primary dealers to secure funds for a term of 28 days. These operations are intended to augment the single day repurchase agreements (repos) that are typically conducted; 4) Term Securities Lending Facility (TSLF) (announced March 11, 2008) - allows primary dealers to pledge a broader range of collateral than is accepted with the Securities Lending program, and also to borrow for a longer term — 28 days versus overnight; and, 5) Primary Dealer Credit Facility (PDCF) (announced March 16, 2008) - is an overnight loan facility that provides funds directly to primary dealers in exchange for a range of eligible collateral; 6) Commercial Paper Funding Facility (CPFF) (announced November 7, 2008) - is designed to provide a liquidity backstop to U.S. issuers of commercial paper; 7) Money Market Investor Funding Facility (MMIFF) (announced November 21, 2008) - is aimed to support a private-sector initiative designed to provide liquidity to U.S. money market investors; 8) Term Asset-Backed Securities Loan Facility (TALF) (announced November 25, 2008) - is designed to help market participants meet the credit needs of households and small businesses by supporting the issuance of asset-backed securities (ABS) collateralized by auto loans, student loans, credit card loans etc.

[37] Acharya and Backus (2009) point out, however, that given potential solvency concerns about borrowing banks, such LOLR might need to be combined with solvency-linked covenants, as in the private lines of credit that banks write for their borrowers.

Furthermore, during the crisis, many central banks extended maturities and accepted a broader range of collateral. William Buiter provides a rationale for this by criticizing the Bank of England's strict collateral requirements early in the crisis: "Basically, they would discount only stuff that is already liquid: U.K. government securities; European Economic Area government securities; a few international organizations' debt like the World Bank; and then under special circumstances, U.S. Treasury bonds. All that stuff is liquid already."

5.3 Coordination role of central banks

Outside the scope of our model, but relevant to its conclusions, is the role of central banks beyond that of LOLR. Much like the constraints of the IMF in dealing with the 1980s' LDC debt crisis, in most serious financial crises, central banks have too little resources to deal with the crisis out of their own funds or expertise to nationalize a large part of the financial sector. Hence, central-bank funding in rescue packages is often tied with private sector funding and ownership of rescued institutions either by a single private player or a consortium. Such quasi-regulatory support operations are likely to be effective only if done under the leadership of a central bank that must impress upon profit-maximizing players the need to coordinate an outcome that balances their profit objectives with broader welfare concerns. To be able to carry out this function, a central bank should be above the competitive battle, a non-competitive, non-profit-maximizing body. The success of the LTCM rescue in 1998 with a consortium of bankers, and the expedient resolution of Bear Stearns' distress through a sale to JPMC in March 2008 both at the initiative of the Fed, point to the importance of this coordination role of central banks.

6 Conclusion

We propose that when the distribution of liquidity among banks is highly skewed, in particular during crises, surplus banks may strategically ration their liquidity provision to needy banks to gain from the needy banks' closure or from the liquidation of their assets. This problem is more acute the weaker the market for assets outside of the banking sector, a scenario that would arise, for instance, in the liquidation of opaque and information-sensitive assets and relationship-specific loans made to small borrowers.

Such strategic behavior illustrates crises in the pre-Fed era and provides a rationale for the LOLR role of central banks. A central bank that is credible in providing liquidity to banks in need at competitive rates, can curb the market power of surplus banks in the interbank market and improve the efficiency of liquidity transfers and asset sales. This LOLR rationale for the existence of a central bank complements the traditional one observed in times of aggregate liquidity shortages and contagious failures. Our model illustrates that the public provision of liquidity can improve its private provision even when aggregate liquidity is in surplus. More broadly, it also provides a rationale for central banks to play the role of coordinating liquidity injection to needy institutions.

Our analysis can be extended in several directions. It would be useful to endogenize the structure of liquidity shocks based on the optimal liability structure of banks (Diamond and Rajan (2001), Acharya and Viswanathan (2009)). In particular, one might ask how issues of market power and the resulting under-provision of liquidity insurance affect the optimal asset-liability (mis)match and liquidity management by banks. Our model also takes the structure of interbank relationships and market power as given. Does market power arise from interbank relationships that are efficient from an ex-ante perspective? What is the ex-ante optimal industrial organization of interbank markets? In particular, does it feature "tiering" in which some large banks hoard reserves and acquire rents during crises, and others remain smaller, less liquid players, borrowing from large banks, but get squeezed during crises? Similarly, the nature of the game between the surplus bank and the central bank raises important questions. We showed that the effectiveness of the central bank in curbing the market power of the surplus bank increases with the quality of its supervision. We have, however, ruled out direct bargaining between the surplus bank and the central bank. The former could try to extract concessions from the latter to rescue needy banks.[38] Finally, we have assumed that the central bank can commit to limited intervention. Absent this, Bank A could sometimes be tempted to exploit the central bank's soft budget constraint. This well-known moral hazard problem, which our analysis leaves aside, ought to be balanced

[38] The financial crisis in the U.K. and the bailout and subsequent nationalization of Northern Rock in 2007 showed that surplus banks can exert power not only on needy banks but also on authorities (see "The Bank loses a game of chicken," *Financial Times*, September 20, 2007; "Lessons of the fall," *The Economist*, November 8, 2007). On August 13, 2007, Northern Rock informed regulatory authorities about its liquidity problems. By mid-September, the longer-term funding markets were closed for Northern Rock. While the possibility of Bank of England acting as a LOLR had been discussed among the authorities, the option of selling Northern Rock to another bank had been tried first. Even though Lloyds TSB emerged as a serious contender, the deal did not go through since Lloyds' demand for a loan of up to £30 billion from the Bank of England had been rejected on the grounds that it would not be appropriate to help finance a bid by one bank for another. The case of Bear Stearns' acquisition by J.P.Morgan Chase in March 2008 has been much the same, except that the Fed provided a loan of up to \$30 billion for the acquisition (see the discussion in Introduction for details).

against the benefits of curbing liquid banks' market power. We leave these questions for future research.

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Appendix

Proof of Proposition 1: Setting $r = R - R_b$ is weakly optimal because Bank A can always compensate an increase in r with an offsetting increase in T. Bank B's participation constraint is binding since, otherwise, Bank A can always increase T. Hence, we have

$$T = p_H(R - R_b)F(\hat{\theta}) + \int_{\hat{\theta}}^{1} [p_B(\theta)R - \rho]\, dF(\theta) - X_B. \tag{22}$$

Substituting, we can write Bank A's problem as:

$$\text{(23)}\qquad \begin{array}{ll} \max\limits_{\hat{\theta}} & \int_0^{\hat{\theta}} p_H R dF(\theta) + \int_{\hat{\theta}}^1 p_B(\theta) R dF(\theta) - \rho - X_B \\ s.t. & F(\hat{\theta}) p_H (R - R_b) + \int_{\hat{\theta}}^1 \left[p_B(\theta) R - \rho\right] dF(\theta) - X_B - F(\hat{\theta})\rho \geq 0 \end{array}$$

As $p_H > p_B(\theta)$, the objective increases in $\hat{\theta}$. By condition (6), the constraint holds for $\hat{\theta} = 0$. Moreover, its LHS decreases with $\hat{\theta}$ (Assumption 1). If the constraint holds for $\hat{\theta} = 1$, i.e. if $p_H(R - R_b) - \rho \geq X_B$, then $\theta_A^* = 1$. If so, Bank A borrows more than needed to fund all its assets, i.e. $T_A^* > \rho$. This is equivalent to borrowing $T_A^* = \rho$ against a claim $r_A^* = (X_B + \rho)/p_H$. Otherwise, it is optimal to set θ_A^* so that it binds, i.e. $T_A^* = F(\theta_A^*)\rho$ and θ_A^* is as in (9). ■

Proof of Proposition 2: As before setting $r = R - R_b$ is weakly optimal. Since Bank A can always increase T, one of the other two constraints must bind. Hence Bank B's problem is

$$\text{(24)}\qquad \begin{array}{ll} \max\limits_{\hat{\theta}, T} & \int_0^{\hat{\theta}} p_H (R - R_b) dF(\theta) + \int_{\hat{\theta}}^1 \left[p_B(\theta) R - \rho\right] dF(\theta) - T \\ s.t. & T = F(\hat{\theta})\rho + \max\left\{E(\pi_A) - F(\hat{\theta}) p_H R_b; 0\right\}. \end{array}$$

If $E(\pi_A) > F(\hat{\theta}) p_H R_b$, the objective becomes

$$\text{(25)}\qquad \int_0^{\hat{\theta}} p_H R dF(\theta) + \int_{\hat{\theta}}^1 p_B(\theta) R dF(\theta) - \rho - E(\pi_A),$$

which increases with $\hat{\theta}$, i.e. $F'(\hat{\theta})(p_H R - p_B(\hat{\theta}) R) > 0$.

If $E(\pi_A) \geq p_H R_b F(\hat{\theta})$ for $\hat{\theta} = 1$, i.e. if $E(\pi_A) \geq p_H R_b$, then $\theta^* = 1$. This implies $T^* = \rho + E(\pi_A) - p_H R_b$. Bank A borrows more than needed to fund all its assets, i.e. $T^* > \rho$. This is equivalent to borrowing $T^* = \rho$ against a claim $r^* = R - E(\pi_A)/p_H$.

If $E(\pi_A) < p_H R_b$, it may be that $E(\pi_A) < p_H R_b F(\hat{\theta})$, in which case the objective is:

$$\text{(26)}\qquad \int_0^{\hat{\theta}} p_H (R - R_b) dF(\theta) + \int_{\hat{\theta}}^1 p_B(\theta) R dF(\theta) - \rho.$$

From Assumption 1, this objective decreases with $\hat{\theta}$, i.e. $(p_H(R - R_b) - p_B(\hat{\theta})R)F'(\hat{\theta}) < 0$. In that case, θ^* such that $E(\pi_A) = p_H R_b F(\theta^*)$ is optimal. ■

Proof of Corollary 1: $\alpha^* = 0$ if and only if $E(\pi_A) \geq p_H R_b$. (6) and (9) imply $\pi_A > X_A$. Hence, $\partial E(\pi_A)/\partial\beta < 0$. The condition holds for $\beta = 0$ if

$$p_H(R - R_b) - \rho \geq X_B \tag{27}$$

and is violated for $\beta = 1$ if $\theta^* < 1$, i.e. if

$$p_H R_b > X_A. \tag{28}$$

Note that under (6), (27) and/or (28) must hold. When both hold, $\beta^* \in (0,1)$. When only (27) holds, $\beta^* = 1$. When only (28) holds, $\beta^* = 0$. For $\beta > \beta^*$, $\theta^* = F^{-1}(E(\pi_A)/p_H R_b)$, which is strictly decreasing with $E(\pi_A)$, which is itself strictly decreasing with β. ■

Proof of Corollary 2: For $\beta^* \in (0,1)$, β^* is given by $E(\pi_A) = p_H R_b$, with $\pi_A = p_H R_b F(\theta_A^*)$. Hence

$$\beta^* = \min\left\{1; \max\left\{0; 1 - \frac{p_H R_b - X_A}{p_H R_b F(\theta_A^*) - X_A}\right\}\right\}. \tag{29}$$

By inspection, $\partial\beta^*/\partial X_A < 0$. For $\beta^* \in (0,1)$, the denominator D's derivative with respect to X_B is

$$\frac{\partial D}{\partial X_B} = \left(\frac{\partial\theta_A^*}{\partial X_B}\right)\left(\frac{\partial D}{\partial\theta_A^*}\right) = -\left(\frac{\partial\theta_A^*}{\partial X_B}\right) p_H R_b F'(\theta_A^*) > 0. \tag{30}$$

Similarly, if $\beta > \beta^*$, we have $E(\pi_A) = p_H R_b F(\theta^*)$, which can be rewritten as

$$p_H R_b F(\theta^*) = \beta X_A + (1-\beta) p_H R_b F(\theta_A^*).$$

The LHS increases with θ^* while we have

$$\begin{aligned}
\frac{\partial RHS}{\partial X_A} &= \beta > 0 \qquad \frac{\partial RHS}{\partial\theta_A^*} = (1-\beta) p_H R_b F'(\theta_A^*) > 0, \\
\frac{\partial RHS}{\partial\rho} &= \left(\frac{\partial RHS}{\partial\theta_A^*}\right)\left(\frac{\partial\theta_A^*}{\partial\rho}\right) < 0, \quad \text{and} \quad \frac{\partial RHS}{\partial X_B} = \left(\frac{\partial RHS}{\partial\theta_A^*}\right)\left(\frac{\partial\theta_A^*}{\partial X_B}\right) < 0.
\end{aligned}$$

These, together with $\frac{\partial\alpha^*}{\partial\theta^*} < 0$ and $\frac{\partial K^*}{\partial\theta^*} < 0$, complete the proof. ■

Proof of Proposition 3: $\beta > \beta^*$ requires $p_H(R - R_b^o) < \rho$. Using (17), we have

$$\frac{\partial\theta_o^*}{\partial R_b^o} = \frac{p_H F(\theta_o^*)}{-\left(p_o(\theta_o^*)R - p_H(R - R_b^o)\right) F'(\theta_o^*)}, \tag{31}$$

which is negative because θ_o^* is the largest solution to (17). Moreover,

$$\frac{\partial X_A}{\partial\theta_o^*} = (p_H - p_o(\theta_o^*))RF'(\theta_o^*) > 0. \tag{32}$$

Hence, $\frac{\partial X_A}{\partial R_b^o} < 0$, implying that $\frac{\partial X_A}{\partial b_o} < 0$. The implications for α^* and K^* stem from Corollary 2.

Consider now two distributions F_1 and F_2 with $F_1 < F_2$ over $(0,1)$ such that $F = xF_1 + (1-x)F_2$ with $x \in [0,1)$. A shift of F towards higher values in the sense of FOSD corresponds to an increase in x. Bank A's outside option is $X_A = p_H R_b^o F(\theta_o^*)$ with θ_o^* given by (17). Integrating by parts, (17) becomes

(33)

$$p_o(1)R - p_H(R - R_b^o) - [p_o(\theta_o^*)R - p_H(R - R_b^o)]\, F(\theta_o^*) - \int_{\theta_o^*}^{1} \frac{\partial p_o}{\partial \theta}(\theta) R F(\theta) d\theta = \rho - p_H(R - R_b^o)$$

Taking the first derivative with respect to x yields

$$-\frac{\partial \theta_o^*}{\partial x}\frac{\partial p_o}{\partial \theta}(\theta_o^*) R F(\theta_o^*) - [p_o(\theta_o^*)R - p_H(R - R_b^o)]\,\frac{\partial}{\partial x}F(\theta_o^*)$$
$$- \int_{\theta_o^*}^{1} \frac{\partial p_o}{\partial \theta}(\theta) R [F_1(\theta) - F_2(\theta)] d\theta + \frac{\partial \theta_o^*}{\partial x}\frac{\partial p_o}{\partial \theta}(\theta_o^*) R F(\theta_o^*) = 0,$$

which given $\partial p_o / \partial \theta > 0$ and $F_1 < F_2$, implies

$$\frac{\partial}{\partial x} F(\theta_o^*) = \frac{\int_{\theta_o^*}^{1} \frac{\partial p_o}{\partial \theta}(\theta) R [F_2(\theta) - F_1(\theta)] d\theta}{p_o(\theta_o^*)R - p_H(R - R_b^o)} > 0. \tag{34}$$

Hence $\partial X_A / \partial x > 0$. Now turn to bargaining between banks A and B. If $\pi_A = p_H R - \rho - X_B$, $\partial \pi_A / \partial x = 0$. Otherwise, $\pi_A = p_H R_b F(\theta_A^*)$ with θ_A^* given by (9). Similar steps yield

$$\frac{\partial}{\partial x} F(\theta_A^*) = \frac{\int_{\theta_A^*}^{1} \frac{\partial p_B}{\partial \theta}(\theta) R [F_2(\theta) - F_1(\theta)] d\theta}{p_B(\theta_A^*)R - p_H(R - R_b)} > 0. \tag{35}$$

Hence $\partial \pi_A / \partial x > 0$, which together with $\partial X_A / \partial x > 0$ implies $\partial E(\pi_A) / \partial x > 0$. The fraction of assets sold, $\alpha^* = (1 - E(\pi_A) / p_H R_b)$, decreases with x as does the threshold $\theta^* = F^{-1}(E(\pi_A) / p_H R_b)$. Integrating by parts, the resulting inefficiency can be written as

$$K^* = (p_H - p_B(1))\, R - (p_H - p_B(\theta^*))\, R F(\theta^*) + \int_{\theta^*}^{1} \frac{\partial p_B}{\partial \theta}(\theta) R F(\theta) d\theta.$$

Noting that $p_H > p_B(\theta^*)$, $\frac{\partial}{\partial x}\left(E\left(\pi_A\right)/p_H R_b\right) > 0$, $\frac{\partial p_B}{\partial \theta} > 0$ and $F_2 > F_1$ implies

$$\begin{aligned}\frac{\partial K^*}{\partial x} &= \frac{\partial \theta^*}{\partial x}\frac{\partial p_B}{\partial \theta}(\theta^*)RF(\theta^*) - \left(p_H - p_B(\theta^*)\right) R\frac{\partial}{\partial x}\left(E\left(\pi_A\right)/p_H R_b\right) \\ &\quad + \int_{\theta^*}^{1} \frac{\partial p_B}{\partial \theta}(\theta)R(F_1(\theta) - F_2(\theta))d\theta - \frac{\partial \theta^*}{\partial x}\frac{\partial p_B}{\partial \theta}(\theta^*)RF(\theta^*) \\ &= -\left(p_H - p_B(\theta^*)\right) R\frac{\partial}{\partial x}\left(E\left(\pi_A\right)/p_H R_b\right) - \int_{\theta^*}^{1} \frac{\partial p_B}{\partial \theta}(\theta)R(F_2(\theta) - F_1(\theta))d\theta < 0.\end{aligned}$$

■

Proof of Proposition 4: Say the central bank lends $L_C = p_H(R - R_b^C)F(\theta_C)$ against assets with $\theta \in [0, \theta_C]$, and makes a transfer T_C. Then, if needed, Bank A borrow from outsiders and sell them assets with $\theta \in [\theta_o^*, 1]$. We can apply Lemma 1, replacing ρ with $(\rho - T_C - L_C)$ and assuming the measure of asset is $(1 - F(\theta_C))$, not 1. Hence $\theta_o^* = 1$ if

(36) $$L_C + (1 - F(\theta_C))p_H(R - R_b^o) \geq \rho - T_C.$$

Otherwise, θ_o^* is the largest solution to

(37) $$L_C + [F(\theta_o^*) - F(\theta_C)]p_H(R - R_b^o) + \int_{\theta_o^*}^{1} p_o(\theta)RdF(\theta) = \rho - T_C.$$

The central bank maximizes θ_o^* subject to $T_C \in [0, \Lambda]$.

Case 1. $b_C \geq b_o$ ($\Leftrightarrow R_b^C \geq R_b^o$): (36)'s LHS is maximal for $\theta_C = 0$ and equals $p_H(R - R_b^o) < \rho$.

Case 1.1. $p_H(R - R_b^o) \geq \rho - \Lambda$: As the central bank can achieve $\theta_o^* = 1$, it minimizes T_C subject to $\theta_o^* = 1$, i.e. to (36) and $T_C \geq 0$. Since $p_H(R - R_b^o) < \rho$, the latter constraint is slack, i.e. $T_C > 0$. Hence the central bank makes a transfer $T_C = \rho - p_H(R - R_b^o)$ and no loan (i.e. $L_C = 0$).

Case 1.2. $p_H(R - R_b^o) < \rho - \Lambda$: As the central bank cannot achieve $\theta_o^* = 1$, it maximizes θ_o^* subject to (37), $T \in [0, \Lambda]$ and $\theta_C \in [0, 1]$. As (36)'s maximum obtains for $\theta_C = 0$ and $T_C = \Lambda$, this also maximizes θ_o^*.

Case 2. $b_C < b_o$ ($\Leftrightarrow R_b^C < R_b^o$). (36)'s LHS is maximal for $\theta_C = 1$ and equals $p_H(R - R_b^C)$.

Case 2.1. $p_H(R - R_b^C) \geq \rho - \Lambda$: As the central bank can achieve $\theta_o^* = 1$, it minimizes T_C subject to $\theta_o^* = 1$, i.e. to (36) and $T_C \geq 0$.

Case 2.1.1. $p_H(R - R_b^C) \geq \rho$: $T_C \geq 0$ binds, i.e. $T_C = 0$. Hence the central bank makes a loan $L_C \geq \rho$ but no transfer (i.e. $T_C = 0$). The largest loan, $L_C = p_H(R - R_b^C)$, is weakly optimal.

Case 2.1.2. $p_H(R - R_b^C) < \rho$: $T_C \geq 0$ is slack, i.e. $T_C > 0$. Hence the central bank maximizes L_C (i.e. $L_C = p_H(R - R_b^C)$) and makes a transfer $T_C = \rho - p_H(R - R_b^o)$.
Case 2.2. $p_H(R - R_b^C) < \rho - \Lambda$: As the central bank cannot achieve $\theta_o^* = 1$, it maximizes θ_o^* subject to (37), $T \in [0, \Lambda]$ and $\theta_C \in [0, 1]$. As (36)'s LHS is maximal for $\theta_C = \theta_o^*$ and $T_C = \Lambda$, this also maximizes θ_o^*. ■

Proof of Propositions 5 and 6: Since $\beta > \beta_o^*$, $p_H(R - R_b^o) < \rho$. Suppose $p_H\left(R - R_b^C\right) < \rho$ and denote $R_b^m \equiv \min\left\{R_b^o, R_b^C\right\}$. Say the central bank sets $\Lambda \in [0, \bar{\Lambda}]$ with $p_H(R - R_b^m) < \rho - \Lambda$. (Below we show this is weakly optimal). From Proposition 4, ex post the central bank would make a transfer $T_C = \Lambda$ and outsiders would buy loans with $\theta < \theta_C^*$ given by

(38)
$$p_H(R - R_b^m)F(\theta_C^*) + \int_{\theta_C^*}^{1} p_o(\theta)RdF(\theta) = \rho - \Lambda,$$

and Bank A's payoff would be $X_A = p_H R_b^m F(\theta_C^*)$.
Consider $b_C \geq b_o$ and $\Lambda = 0$. Since $R_b^m = R_b^o$, (38) coincides with (17). Hence Bank A's payoff, $X_A = p_H R_b^o F(\theta_o^*)$, is the same as absent the central bank. Hence the outcome of bargaining with Bank B is unchanged. This proves Proposition 5.
Consider $b_C < b_o$, $R_b^m = R_b^C$. Applying Proposition 3 replacing R_b^o with R_b^C, we get $\frac{\partial \alpha^*}{\partial b_C} > 0$ and $\frac{\partial K^*}{\partial b_C} > 0$.
Consider $\Lambda > 0$. Applying Proposition 3 replacing ρ with $\rho - \Lambda$ and R_b^o with R_b^C, we get $\frac{\partial \alpha^*}{\partial \Lambda} < 0$ and $\frac{\partial K^*}{\partial \Lambda} < 0$.
Suppose now that $p_H\left(R - R_b^C\right) \geq \rho$, which requires $b_C < b_o$. Ex post the central bank would make a loan $L_C \geq \rho$ and no transfer (Proposition 4). Hence Bank A's payoff would be $X_A = p_H R - \rho$, implying that bargaining with Bank B yields the efficient outcome $\alpha^* = 0$.■

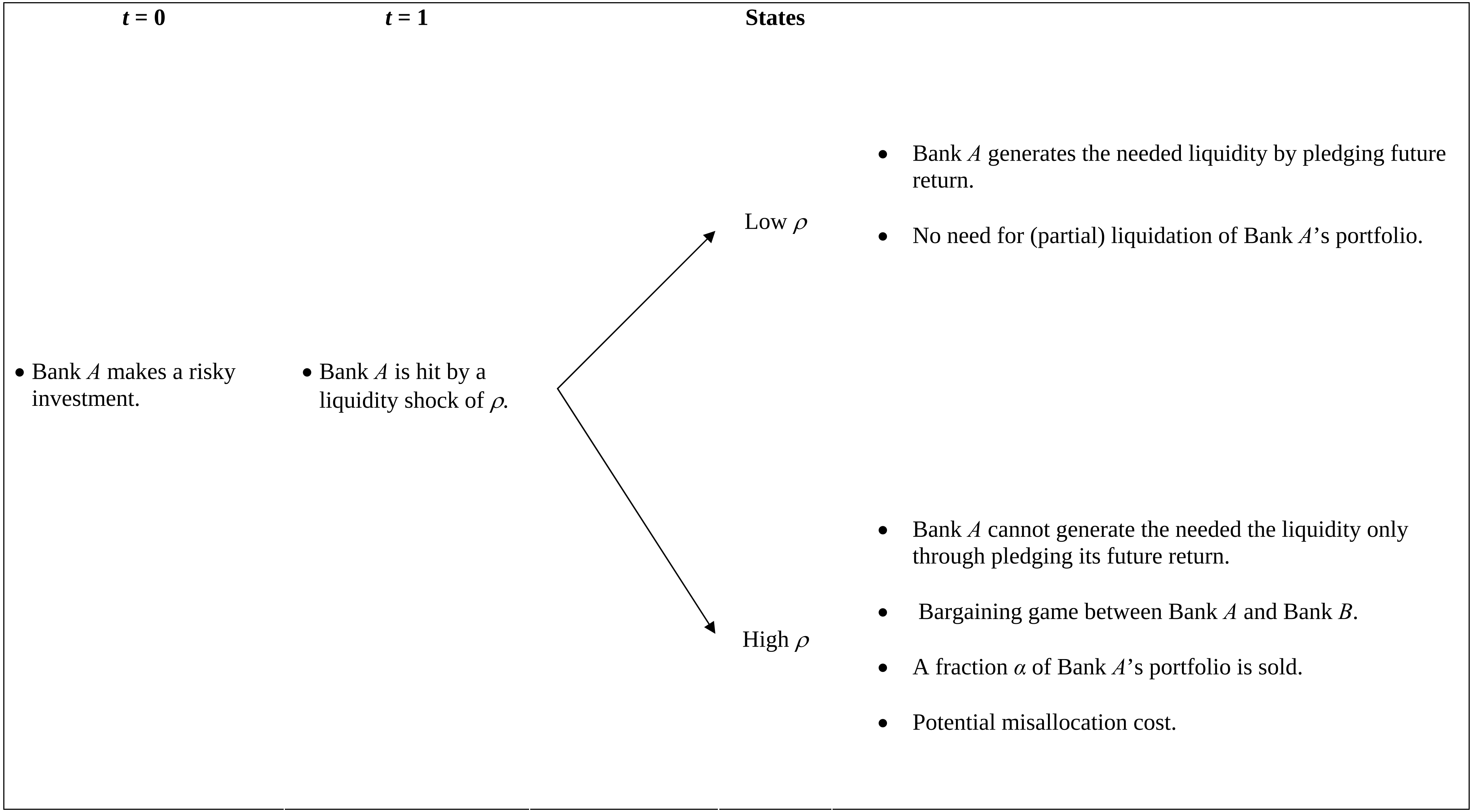

Figure 1: Timeline of the model.

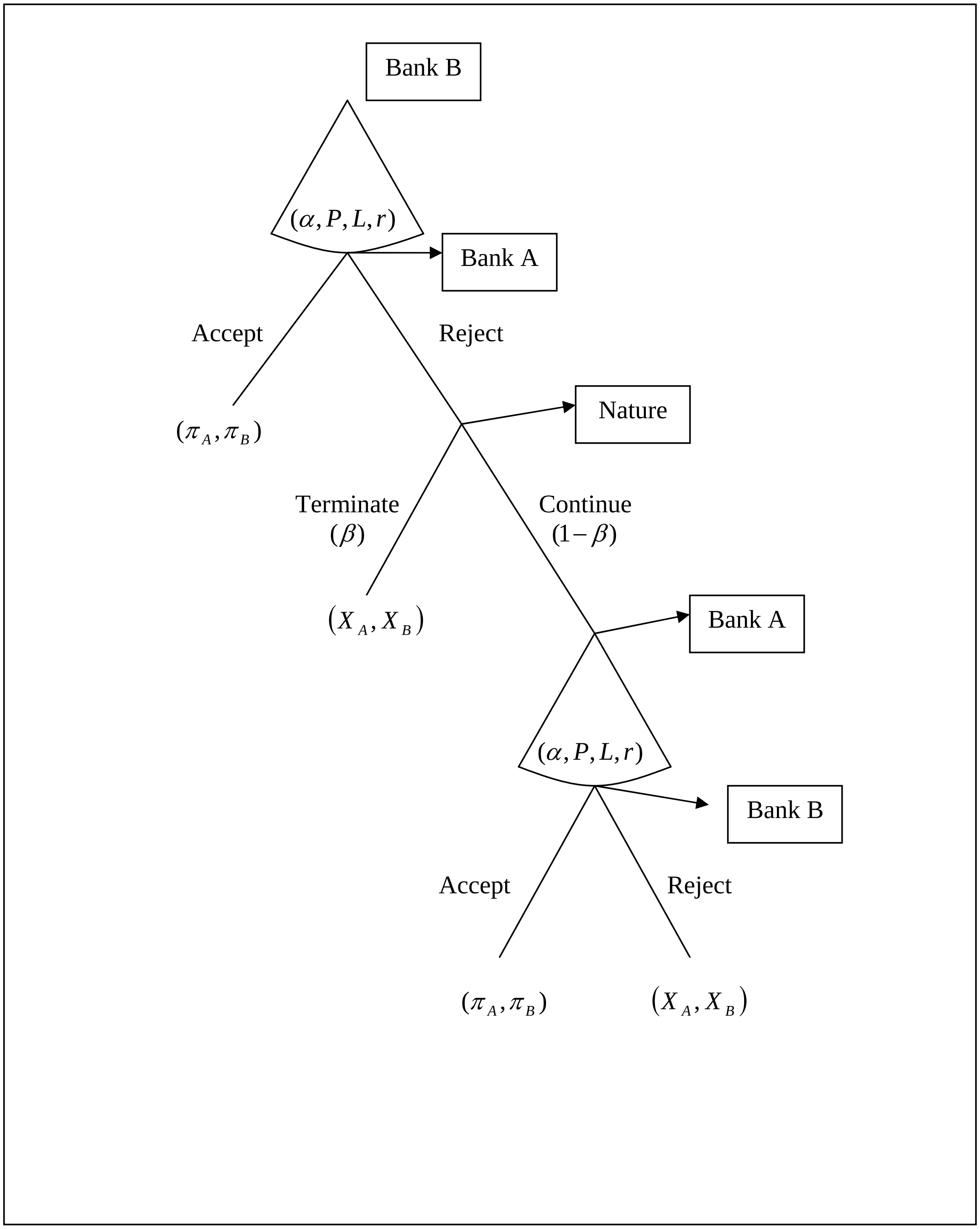

Figure 2: Game tree for the bargaining game.