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

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Abstract

We study liquidity transfers between banks through the interbank borrowing and asset sale markets when (i) surplus banks providing liquidity have market power, (ii) there are frictions in the lending market due to moral hazard, and (iii) assets are bank-specific. We show that when the outside options of needy banks are weak, surplus banks may strategically under-provide lending, thereby inducing inefficient sales of bank-specific assets. A central bank can ameliorate this inefficiency by standing ready to lend to needy banks, provided it has greater information about banks (e.g., through supervision) compared to outside markets, or is prepared to extend loss-making loans. The public provision of liquidity to banks, in fact its mere credibility, can thus improve the private allocation of liquidity among banks. This rationale for central banking finds support in historical episodes preceding the modern era of central banking and has implications for recent debates on the supervisory and lender-of-last-resort roles of central banks.

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Abstract

We study liquidity transfers between banks through the interbank borrowing and asset sale markets when (i) surplus banks providing liquidity have market power, (ii) there are frictions in the lending market due to moral hazard, and (iii) assets are bank-specific. We show that when the outside options of needy banks are weak, surplus banks may strategically under-provide lending, thereby inducing inefficient sales of bank-specific assets. A central bank can ameliorate this inefficiency by standing ready to lend to needy banks, provided it has greater information about banks (e.g., through supervision) compared to outside markets, or is prepared to extend loss-making loans. The public provision of liquidity to banks, in fact its mere credibility, can thus improve the private allocation of liquidity among banks. This rationale for central banking finds support in historical episodes preceding the modern era of central banking and has implications for recent debates on the supervisory and lender-of-last-resort roles of central banks.

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1 Introduction

The liquidity squeeze during the ongoing sub-prime crisis of 2007-08 has been likened by some observers, including the IMF, to the financial sector turmoil of the Depression era. A nagging problem faced by central banks during the early part of this crisis was the difficulty in getting open-market operations, discount window and securities lending to channel liquidity to the most needy parts of the financial system. Some of the lending facilities such as the discount window were not availed by players, and others when availed merely resulted in hoarding of liquidity by banks and other institutions. In the UK, for example, banks' liquidity buffers have experienced an almost permanent upward shift of 30% in August 2007 (relative to their pre-August levels) and the result has been a rise in borrowing costs between banks and an almost complete drying up of liquidity exchange in money markets beyond the very short maturities.[1] In response, central banks around the world, most notably the US Fed, have undertaken significant changes to their lender-of-last-resort 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 as well.

The episode begs several important questions: Why have the interbank markets, which in normal times act as lubricant to financial flows amongst banks, dried up so suddenly? Why have the traditional forms of central bank's lender-of-last-resort facilities failed to allocate liquidity to places needing it most? Indeed, going forward, how should central banks provide these facilities for them to be effective during crises? Do limits to the precision of supervisory information about banks compromise central banks' effectiveness in overcoming the failure of money markets? Our paper attempts to answer some of these questions based on a specific market failure stemming from the exercise of market power in liquidity transfers between banks.

We propose that during crises, efficient liquidity transfers may not occur between surplus and needy banks. We attribute this inefficiency to the market power of surplus banks in the market for interbank liquidity transfers and the strategic gains they derive from buying asset from needy banks as fire sale prices and more generally gaining market share at their 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 rationale for central banking and discuss implications for recent debates on the supervisory and lender-of-last-resort functions.

We consider liquidity transfers 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 under alternative ownership. For instance, alternative owners may lack the current owner's expertise. For this reason, asset sales may be 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 monitor their assets to improve their performance, and that monitoring is costly. A

[1] Source: "Hoarding by banks stokes fears over crisis: Borrowing costs rise between institutions; (Central Bank) Efforts on lending fail to bear fruit," *Financial Times*, 3/26/2008.

bank borrowing on 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, leading to inefficient asset sales. Third, we assume that during crises, liquidity is concentrated with a few banks, giving them market power.

In this context, we show that the market power of surplus banks can lead to more asset sales, and importantly, more *inefficient* asset sales by banks in need of liquidity. The intuition is as follows. Banks with market power in the interbank lending market will charge higher interest rates to banks seeking liquidity. As a result, the latter will retain smaller claims on their assets, which diminishes their incentives to monitor them. If monitoring is low enough, it becomes preferable to sell some assets to a liquid bank. These asset sales also generate liquidity that can provide relief for the selling bank's other assets. The higher the liquid banks' market power, the higher the interest rate and the greater the illiquid banks' incentives to sell assets.

Surplus banks' ability to exploit market power is limited by the outside option provided by the market for liquidity outside the banking sector. Therefore, the problem and the implied inefficiencies are more acute the weaker is the outside market, a scenario that would arise, for instance, in liquidation of information-sensitive and bank-specific loans made to small borrowers.

Our analysis also implies a rationale for the existence 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, but merely improves their outside options when bargaining for liquidity with surplus banks. We show however that for such an improvement requires the central bank to be ready to extend loss-making loans and/or be better than outside markets at extending loans to needy banks. The latter situation is more likely if the central bank has also a supervisory role, allowing it to improve its ability to monitor its loans to needy banks.

We also study the possibility for banks to insure against liquidity shocks. This possibility reduces the inefficiency in interbank liquidity transfers. However, as long as banks can only get partial liquidity insurance, surplus banks' ex post market power still increases or creates inefficiencies in the allocation of liquidity. Indeed, if banks that are likely to have excess liquidity and market power ex post are also the best liquidity insurers ex ante, their market power ex post will reduce the scope for liquidity insurance ex ante. Other reasons for liquidity insurance to be only partial include the impossibility to enter binding long-term contracts, the fragility of implicit contracts in crises situations,[2] or the possibility of aggregate liquidity shortage combined with liquid banks' cost of capital being non-verifiable.

To summarize, our model illustrates that the public provision of liquidity (in fact, its mere credibility) can improve its private provision even in times of aggregate liquidity surplus. This

[2] Banks could enter implicit contracts for liquidity provision, sustained through reputation and repeated interactions. This may however 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. Crises, in our opinion, represent exactly such situations.

lender-of-last-resort rationale for the existence of a central bank complements the traditional one pertaining to times of aggregate liquidity shortages and contagious failures (e.g., Holmström and Tirole (1998), Diamond and Rajan (2005), Gorton and Huang (2006)). Our analysis also clarifies why central banks should assume both roles of supervisor and lender-of-last-resort.

Our paper is related to the literature on the failure of interbank markets that justifies the lender-of-last-resort role of central banks.[3] Goodfriend and King (1988) argue that with efficient interbank markets, central banks should not lend to individual banks but instead provide sufficient liquidity via open market operations, which the interbank market would then allocate efficiently 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.[4,5]

Donaldson (1992) is, to our knowledge, the only paper with a similar focus. Using Dunn and Spatt (1984)'s strategic pricing model, it shows that even if aggregate liquidity is in surplus, if some banks have a significant proportion of the excess cash so that the other cash rich banks' resources are not enough to satisfy the total liquidity demand, banks can exploit this captive demand and charge higher than competitive rates.[6,7]

While some theory papers study the reallocation of funds (e.g. Holmström and Tirole (1998))

[3] Indirectly, therefore, our model 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)).

[4] In Bhattacharya and Gale (1987), for example, banks coinsure against liquidity shocks through an interbank lending market, but each bank has private information about the fraction of its portfolio composed of liquid assets and about the size of its liquidity shock. Since liquid assets yield lower returns, banks under-invest in liquid assets and free-ride on the common liquidity pool. Hence, even in the presence of an interbank market, there can be aggregate liquidity shortages, a problem a central bank can alleviate by monitoring banks' asset choices. In our paper, the interbank market's failure stems from the strategic benefit accruing to potential lenders once liquidity shocks have affected some banks. This failure arises due to market power and is above and beyond the limits to liquidity transfer between borrowing and lending banks given the moral hazard problem. As in Bhattacharya and Gale (1987), a central bank that can monitor banks' asset choices may alleviate the inefficiency. Also, in both setups, pumping liquidity into the banking sector at large does not guarantee it will end up at needy banks; however, there is potentially an important difference. In models of asymmetric information, this is efficiently so at the level of individual banks given the information they have; in our model, surplus banks will have incentives to acquire additional liquidity in open-market operations and hoard liquidity to inefficient levels or ration needy banks by extending liquidity to them only at non-competitive rates.

[5] Section 2 reports historical evidence of such cash hoarding. Casual empiricism suggests that such cases are not uncommon in recent times either. Our private communications with bankers suggest that one of the perceived reasons for interbank lending markets drying up during the recent sub-prime crisis of 2007-08 was the hoarding of liquidity by banks for acquisitions of troubled institutions at fire-sale prices, the other two reasons being a precautionary motive from the risk of being distressed and asymmetric information about borrowing institutions.

[6] Dunn and Spatt (1984)'s model can be understood with the following example: Consider banks A, B and C. Bank A and Bank B each has a surplus of x units of cash, whereas Bank C needs y units of cash where $y < 2x$ so that there is enough liquidity in the system. For $x \geq y$, each surplus bank is able to supply the y units of cash needed by Bank C. In that case, none of the surplus banks is essential and Bertrand competition among surplus banks led to competitive rates. However, when $x < y$, neither surplus bank can supply y. In that case, each of them is pivotal and has a captive demand for $(y - x)$ units of cash, and can therefore charge a higher than competitive rate on the *first* $(y - x)$ units it supplies.

[7] Donaldson (1992) also conducts an empirical analysis, which we summarize in Section 2.

and others that of assets (e.g. Shleifer and Vishny (1992), Gorton and Huang (2002)), ours studies both and illustrates the trade-offs involved. We believe banks' dual role as each other's financiers and business competitors to be an important and specific aspect of their relationships.[8]

Our paper is also related to the literature on predation, i.e., when rivals take actions that weakens a firm's access to finance (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 2 reports historical evidence. Section 3 presents the model and Section 4 its analysis. Section 5 discusses the banks' outside option. Section 6 presents the rationale for central banking. Section 7 liquidity insurance and its limits. Section 8 discusses broader policy implications and failures in liquidity transfers among non-bank financial institutions. Section 9 concludes. Proofs are in the Appendix.

2 Historical evidence

This section discusses some of the private arrangements amongst banks to manage liquidity shocks before the modern central banking era, as well as the role of strategic behavior in their failure, as witnessed during significant historical episodes (see Freixas et al. (1999) for a survey).

2.1 The failure of private coinsurance arrangements

Orchestrated liquidity support operations occurred often in the past. In the US, the Clearinghouse System assumed a crisis prevention and management role before the establishment of the Federal Reserve System in December 1913 (e.g. Gorton (1985), Gorton and Mullineaux (1987), Calomiris and Kahn (1996), Gorton and Huang (2002, 2006)). The first clearinghouse, established by the New York City banks in 1853, created an organized market for exchange between banks. During normal times, clearinghouses performed their service of clearing payments, whereas during crisis periods, they evolved into an organization that managed the crisis by helping member banks sustain their solvency and liquidity positions. During such periods, clearinghouses used several methods such as suspension of payments, equalization of reserves and issuance of clearinghouse loan certificates to ease the suffering of the member banks in distress. The equalization of reserves, essentially the pooling of all legal reserves of clearinghouse member banks in an emergency and granting member banks equal access to that pool, eased the liquidity

[8] While Bear Stearns is formally not a bank, its sale to J.P.Morgan Chase, in the aftermath of the sub-prime crisis of 2007-08, illustrates well the confluence of (J.P.Morgan Chase's) roles as lender and asset purchaser. During the liquidity crisis at Bear Stearns and its subsequent resolution, J.P.Morgan Chase explicitly stated its strong interest in Bear Stearns' prime brokerage business. While there were systemic-risk concerns about Bear Stearns' possible collapse, which are outside the scope of current paper, it is interesting to note that J.P.Morgan Chase does seem to have made the acquisition at a fire-sale price: On 3/13/2008, Bear Stearns' stock price was \$57, J.P.Morgan Chase agreed to acquire Bear Stearns on 3/17/2008 at \$2 a share with a guarantee of \$30 billion from the Fed to fund Bear's less liquid assets such as mortgage-backs; J.P.Morgan Chase's stock went up 10% on 3/17/2008, whereas most other financial stocks lost value; finally, the deal was revised and J.P.Morgan Chase agreed to increase 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.

constraint on banks experiencing runs. Also, clearinghouses issued loan certificates that were acquired by banks by depositing qualifying assets with the Clearing House Association to be used in interbank settlements. These loan certificates prevented costly asset liquidations and improved affected banks' liquidity position. Since they were provided only when the Clearing House Association decided that the bank had enough assets to back them up, loan certificates also served the purpose of certifying that the bank was healthy (Park (1991)).

Such private arrangements and voluntary participation into efforts to help distressed banks worked well at times. However, their effectiveness was hampered by competitive pressures in the banking industry. In particular, voluntary participation was often difficult to elicit due to the short-term competitive advantage healthy banks could enjoy during crises. The Clearinghouse System was eventually brought down early in the 20th century by the sharp increase in banking competition in New York.

2.2 1907 panic in the US

We now discuss the 1907 panic in the US, a salient example in which the private rescue of distressed banks was hampered by competitive behavior among banks.

The role of J.P.Morgan: Sprague (1910)'s discussion of the 1907 panic in New York suggests that the banks' initial reluctance to organize a private rescue of distressed trust companies might have lain in the fact that other banks were not adversely affected by trust companies' difficulties or even benefited by attracting their depositors.

The immediate cause of the panic was the collapse of copper stocks. On October 17, depositors started running on the Mercantile National Bank. The bank's 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, suspicious about their involvement in speculation, started running on the Knickerbocker Trust Company on October 21 and on the Trust Company of America on October 23. The New York Clearing House, an organization of banks, did not extend assistance to the trust companies. The Knickerbocker was forced to suspend on October 22, and the Trust Company of America, a solvent institution, had to suffer runs for two weeks. Eventually, US Secretary of the Treasury George B. 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, redirected money between banks, secured further international lines of credit, and bought plummeting stocks of healthy corporations.[9] In particular, they raised a \$25 million fund for distressed trust

[9] 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.

companies and required the Trust Company of America to deposit its shares and assets with a committee of trust company presidents. Runs on the Trust Company of America and other small institutions subsided after the resolution.

While J.P.Morgan is credited as having played the role of coordinator and rescuer of this financial crisis, several aspects of his involvement suggest strategic behavior and market power.

First, in 1906 Heinze had acquired Knickerbocker Trust and Morse gained control of the Bank of North America. Even prior to the 1907 crisis, banking industry leaders, one being J.P.Morgan, staged a financial attack on Heinze's Knickerbocker Trust. 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, pages 262-265), 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 leading assistance to the trust companies is thus often perceived to be strategic on part of the clearinghouse banks.

Third, and most important, Chernow (1990) discusses how J.P. Morgan benefited from trust companies' difficulties during the 1907 crisis (see pages 126-128). On November 2, Morgan (finally) organized a rescue package for the distressed Trust Company of America, Lincoln Trust, and Moore and Schley. Moore and Schley, a speculative brokerage house that was \$25 million in debt, held a big majority stake in the Tennessee Coal and Iron Company as collateral against loans. If Moore and Schley had to liquidate that stake, it might collapse the stock market, and Moore and Schley's collapse might 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 where US Steel, his favorite creation that could profit from Tennessee Coal's huge iron ore and coal holdings in Tennessee, Alabama and Georgia, would buy Tennessee Coal stock from Moore and Schley if trust company presidents assembled a \$25 million pool to protect weaker trusts. While the takeover would normally have been impossible for antitrust reasons, US Steel managed to secure President Roosevelt's approval and the Sherman Antitrust Act was not be used against it. Senator La Follette said bankers had rigged up the panic for their own profit. Financial analyst John Moody said that the Tennessee Coal and Iron's property had a potential value of about \$1 billion, which confirmed the \$45 million distressed price being a steal. Later on, Grant B. Schley, head of Moore and Schley, admitted that his firm could have been rescued by an outright cash infusion rather than 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)).[10] The Fed was a natural response to the

[10] Strouse (1999) details how during the crisis, panicked crowds on the streets of Manhattan would stop to cheer as J.P.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 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

realization that control and leadership of the US financial system had effectively been outsourced to one private businessman.

Cash hoarding by Citibank: Cleveland and Huertas (1985) discuss the 1893 and 1907 crises and specifically the strategy of the National City Bank (which was to become Citibank) to anticipate crises and to build up liquidity and capital beforehand to benefit from the difficulties of its competitors. About the 1907 crisis, they 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."[11]

2.3 Evidence from other countries

Other historical episodes seem to confirm a tension exists between the viability of private arrangements and competition. An important example is the 1893 financial crisis in Australia. The Australian banking system, which was relatively unregulated during the second half of the 19th century with no central bank and no government-provided deposit insurance, entered a crisis in 1893, when eleven commercial banks failed and the rest experienced severe 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 the occasion arose, they would provide financial assistance to each other (*The Economist*, 3/25/1893, 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 from other banks' failures through increased market shares.

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.

[11] Competitive gains to banks from failures of peers are evident in modern times as well: see Saunders (1987) on the 1984 failure of Continental Illinois, Saunders and Wilson (1996) on flight to quality of depositors during the Depression era, Slovin, Sushka and Polonchek (1999) on many bank regulatory actions over 1975-92, Schumacher (2000) also on depositors' flight to quality during the 1994-95 Argentinian crisis, among others. Several of these papers also find evidence of contagion (Lang and Stulz (1992)).

2.4 Emergence of modern central banking

It is important to distinguish two possible reasons for the failure of private coinsurance arrangements: lack of coordination among clearinghouse members (e.g., due to free-riding)[12] and strategic behavior. It appears that the coordination aspect was factored into the organization of clearinghouses and that it was really market power that led to their failure.

Timberlake (1984) argues that in US clearinghouses one bank usually assumed the central administration role for clearing the other member banks' accounts. However, the fact that the central commercial banks were also competitors had a significant effect on the failure of these private arrangements. In particular, a temptation for the central commercial banks to take the opportunity of a crisis to force a rival out of business by not providing the loans/assistance that a correspondent could have expected in normal times. This concern accords well with the case of J.P.Morgan's role in 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, the key feature of a central bank 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 develop until the need for the central banks to be noncompetitive had become 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. We summarize some of these below.

Bagehot wrote his famous *Lombard Street* in 1873 in the aftermath of the Overend Gurney crash of 1866 when there was suspicion that the unwillingness of the Bank of England, then a private commercial bank, to support that House was due to commercial rivalry. Discussing this episode, Bagehot points out that while it was accepted that the central bank should only assist banks which could expect to be solvent or to regain solvency under normal conditions, a central bank 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 response to heightened competition in the financial sector (Capie et al. (1994)) are prominent examples of the Bank performing its role in a non-competitive fashion.

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.

These episodes suggest that while competition issues were not central banks' sole *raison*

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

d'être, their modern form – non-competitive, non-profit maximizing institutions – does find its roots in these issues.

2.5 Interest-rate behavior during crises in pre- and post-Federal Reserve era

Using US data over 1873-1933, Donaldson (1992) shows that interest rates increased and stock prices plunged during banking panics. He shows that during panics interest rates were substantially larger than before crisis (by as much as 500% at times!) and extremely volatile, which he interprets as evidence of the market power by surplus banks. He shows that in contrast to the pre-Fed episode, interest rates during crises after the establishment of the Federal Reserve System were not significantly different from the rates before the crises.

Donaldson also tests whether there was a structural change in the pricing of cash between panic and non-panic periods. This would be consistent with the thesis that surplus banks may have used their market power to exploit the difficulties of needy banks during crises. He divides the sample into the pre-Fed (1867-1913) and post-Fed (1914-33) periods, and confirms that cash was indeed priced during panics at higher than non-panic rates in the pre-Fed period whereas this was not so in the post-Fed period (Donaldson (1992), Table 2).[13] He concludes that the establishment of the Fed to act as a lender-of-last-resort during panic periods prevented surplus banks from exerting market power and exploiting needy banks.

3 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 (Figure 1).[14]

At $t = 0$, Bank A has a continuum of measure 1 of risky assets, e.g., loans to the corporate sector. At $t = 2$, each loan yields a random return $\widetilde{R} \in \{0, R\}$ which depends on whether the loan was monitored and on an unobservable state of nature ω uniformly distributed over $[0, 1]$.

At $t = 1$, each loan needs some refinancing of ρ units of cash. If a loan is not refinanced, $\widetilde{R} = 0$. If it is refinanced, $\widetilde{R} = R$ if $\omega \in [0, p]$ and $\widetilde{R} = 0$ otherwise. The bank can affect the probability p by monitoring its loans 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 the bank enjoys a private benefit b per loan it does not monitor. If the loan is not refinanced, the bank derives no private benefit

[13] The 1914 panic took place in August. The Federal Reserve System was created via the Federal Act of 23/12/1913 and the Reserve Banks opened for business on 16/11/1914. These dates imply that the 1914 panic took place before the Fed was open. Donaldson (1992), Table 1, covers the behavior of 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.

[14] The model has some features similar to Holmström and Tirole (1998) including the assumptions of exogenous liquidity shocks and moral hazard-induced limited financing capacity. Note also that with two possible cash flows, one being zero, the distinction between debt and equity is immaterial.

either. We assume it is efficient to refinance a loan only if it monitored, i.e.,

$$p_H > \rho/R > p_L \qquad \text{and} \qquad \Delta p R > b. \tag{1}$$

Bank B is assumed to have enough excess liquidity to refinance Bank A's loans. The liquidity transfer can occur in two ways: Bank A can borrow from Bank B or sell it some of its loans.

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 $\widetilde{R} = 0$. Bank A chooses to monitor its loans if the following incentive compatibility constraint holds:

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

Therefore, for the constraint to hold, the repayment r must be sufficiently small, i.e.,

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

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

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

Asset sales: Each loan can be sold to Bank B at a price P. We assume Bank A to be the most efficient user of its assets, i.e., they are Bank A-specific. This may stem from expertise or learning-by-doing effects for making and administering loans or from customer relationships. Moreover, Bank A's advantage over Bank B may vary across loans. For instance, smaller loans, or loans relying more on Bank A's relationship with the borrower may be more difficult for Bank B to take over. The relevant loan characteristic is captured by a variable θ distributed over $[0, 1]$ according to the cumulative distribution function (c.d.f.) F. Loans with smaller values of θ are less redeployable to Bank B. Nevertheless, we assume it is efficient to refinance loans even if run by Bank B. If Bank B operates a loan of Bank A with characteristic θ, then $p = p_B(\theta)$ with

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

With bank-specific assets, asset sales are less efficient than borrowing, conditional on monitoring.[15] However, we assume that moral hazard in monitoring is severe (i.e., b large) enough so that Bank A can raise more funds by selling a loan than by pledging some of its return.[16]

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

[15] Implicitly, we are assuming that acquiring the ownership of the bank but leaving its operations unchanged is impossible, i.e., the change in ownership has real implications. For brevity, we use this reduced form rather than providing a foundation for the effect of ownership.

[16] Our analysis would be qualitatively unchanged if each of the assumption that a loan's value to Bank B, $p_B\,(\theta)\,R$, exceeds Bank A's valuation of the loan if unmonitored, $p_L R$, and its borrowing capacity against the loan if monitored, $p_H\,(R - R_b)$, held for some but not necessarily all loans.

We model the two banks' interaction in the interbank lending and the asset markets as a two-stage bargaining game of alternating offers with risk of breakdown (Figure 2).[17] First, Bank A makes Bank B 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 an average 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 for a given T, the split between P and L is generally indeterminate: A transfer T can be obtained through a variety of combinations of asset-sale price and amount lent as Bank B can earn rents, if any, either by acquiring assets at fire-sale prices or charging a hair-cut while lending against Bank A's assets.

If Bank B accepts the offer, it is implemented and bargaining is over. If Bank B rejects the offer then, with probability $(1-\beta)$, bargaining breaks down and each bank receives its outside option: X_i, for $i = A, B$.[18] With probability β, however, bargaining continues and Bank B gets to make Bank A an offer. If Bank A accepts the offer, it is implemented. Otherwise, bargaining breaks down and each bank receives its outside option.[19] We assume that X_A and X_B are small enough, i.e., there will always be gains from trade between the banks. Since Bank A's ability to make transfers to Bank B is limited, we assume that trade will be beneficial even if Bank A had to sell all of its assets to Bank B, i.e.,

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

We also assume Bank B's opportunity cost of capital uses at $t = 1$ is μ. Hence X_B is the sum of the opportunity cost of using the necessary liquidity μT, and the other costs, $Y_B \geq 0$, arising from keeping Bank A in business (e.g., not being able to steal some of Bank A's business). Hence, we can write $X_B = \mu T + Y_B$.[20,21]

4 The interbank market for liquidity

We solve the model by backward induction. Suppose Bank B gets to make an offer. Bank B's offer maximizes its payoff subject to Bank A's payoff exceeding its outside option. It is

[17] More generally, some players in the interbank markets may be big and pivotal even in normal times. The nature of competition in interbank markets has not been studied fully yet, but the evidence in Cocco et al. (2005) suggests some banks are more important lenders than others. Even if there is no market power in normal times, liquidity crises are often times when the distribution of liquidity is asymmetric and our model is perhaps a best caricature of such extreme events.

[18] Section 5 discusses factors that might affect these outside options.

[19] The model nests the case of perfect competition in the interbank markets for liquidity, which corresponds to $\beta = 0$. Also, considering $\beta < 1$ allows us to study how the outcome is affected by Bank B's outside options in addition to Bank A's outside options and financing constraints.

[20] We assume that Bank B cannot re-sell its claim on Bank A's assets to third parties or use them as collateral to borrow from third parties. Indeed, this would amount to Bank A being able to borrow from third parties. Similarly, Bank B cannot re-sell or borrow against the assets it buys from Bank A. What is needed is that when Bank B uses liquidity, at least part of its investment capacity is destroyed.

[21] Note that unlike the typical alternating-offers bargaining game of Rubinstein (1982), the total surplus to be shared is affected by how it is shared because of Bank A's moral hazard in monitoring.

easily seen that the optimal offer will satisfy three further properties. First, it must satisfy the incentive compatibility constraint (3), i.e., $r \leq (R - R_b)$. Indeed, otherwise Bank A would not monitor its remaining loans and it is more efficient to sell them to Bank B. Second, Bank B's transfer to Bank A must be sufficient to refinance Bank A's remaining loans. Indeed, these assets would otherwise be worthless and it would again be more efficient to sell them to Bank B. Last, Bank B's optimal offer will be for Bank A to sell its most redeployable assets, i.e., all loans with θ above a threshold θ_B. Given these remarks, Bank B's problem can be written as:

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

Lemma 1 *If Bank B gets to make an offer, it will acquire all loans with $\theta > \hat{\theta}_B$, representing a fraction $\hat{\alpha}_B$ of Bank A's assets, and a debt claim $\hat{r}_B$ against a total transfer $\hat{T}_B$.*

- *If $X_A \geq p_H R_b$, no loan is sold (i.e. $\hat{\alpha}_B = 0$ and $\hat{\theta}_B = 1$). Instead, Bank B gets a debt claim $\hat{r}_B = (R - X_A/p_H)$ against a transfer $\hat{T}_B = \rho$, and its expected payoff is*

$$\pi_B = p_H R - \rho - X_A. \tag{8}$$

- *Otherwise, Bank B acquires a fraction $\hat{\alpha}_B = (1 - X_A/p_H R_b)$ of Bank A's loans (i.e. all loans with $\theta > \hat{\theta}_B = F^{-1}(X_A/p_H R_b)$) and a debt claim $\hat{r}_B = (R - R_b)$ against a transfer $\hat{T}_B = \rho X_A/p_H R_b$, and its expected payoff is*

$$\pi_B = \int_0^1 [p_B(\theta)R - \rho]\, dF(\theta) - X_A + \int_0^{\hat{\theta}_B} [p_H - p_B(\theta)]\, R dF(\theta). \tag{9}$$

The intuition for the form of the offer is as follows. Bank B prefers to acquire as much of Bank A's assets as possible subject to Bank A getting its reservation payoff. This is because, under Assumption 1, a sale is the most efficient means of transferring value from Bank A to Bank B. For instance, for $X_A = 0$, Bank B acquires all of Bank A's assets for free, i.e., sets $\theta_B = 1$ and $T = 0$. As X_A increases, Bank B must ensure that Bank A accepts its offer. The most efficient way of increasing Bank A's payoff is for Bank B to leave it with some assets and refinance them, i.e., $T = F(\theta_B)\rho$. Because Bank A is best at managing its assets, this is preferred to Bank B making a cash transfer to Bank A in excess of the funding needs. For the same reason, it is always weakly optimal to maximize r, i.e., set $r = (R - R_b)$.

The intuition for Bank B's expected payoff is as follows. The first term is the payoff Bank B if it acquires all of Bank A's assets at price $T = 0$, i.e., if $X_A = 0$. When $X_A > 0$, Bank B must "transfer back" X_A to Bank A. This is the second term. This transfer is efficient since Bank A is the assets' best user. Therefore, leaving value X_A to Bank A costs less than X_A to Bank B as reflected in the third term.

Now consider the previous stage, when Bank A makes the first offer. Bank B will accept an offer only if its expected payoff is at least equal to

$$E(\pi_B) = \beta\pi_B + (1-\beta)X_B. \tag{10}$$

As before, the optimal offer satisfies three further properties: Bank A will sell its most redeployable loans, i.e., with θ above some threshold θ_A, and set $r \leq (R - R_b)$ and $T \geq F(\theta_A)\rho$. Hence, Bank A's problem can be stated as:

$$\begin{array}{ll} \max\limits_{\theta_A, r, T} & \int\limits_0^{\theta_A} \left[p_H(R-r) - \rho\right] dF(\theta) + T \\ s.t. & r \leq (R - R_b) \\ & T \geq F(\theta_A)\rho \\ & \int\limits_0^{\theta_A} p_H r dF(\theta) + \int\limits_{\theta_A}^1 \left[p_B(\theta)R - \rho\right] dF(\theta) - T \geq E(\pi_B). \end{array} \tag{11}$$

Proposition 1 *In equilibrium, Bank B acquires all loans with $\theta > \theta^*$, representing a fraction α^* of Bank A's assets, and a debt claim r^* against a total transfer T^*.*

- *If $p_H(R - R_b) - \rho \geq E(\pi_B)$, no loan is sold (i.e. $\alpha^* = 0$ and $\theta^* = 1$). Instead, Bank B gets a debt claim $r^* = (E(\pi_B) + \rho)/p_H$ against a transfer $T^* = \rho$. Bank A's expected payoff is*

$$\pi_A = p_H R - (E(\pi_B) + \rho). \tag{12}$$

- *Otherwise, Bank B acquires a fraction $\alpha^* = 1 - F(\theta^*)$ of Bank A's loans and a debt claim $r^* = (R - R_b)$ against a transfer $T^* = F(\theta^*)\rho$, where θ^* is defined by*

$$\int\limits_{\theta^*}^1 \left[p_B(\theta)R - p_H(R - R_b)\right] dF(\theta) = E(\pi_B) + \rho - p_H(R - R_b). \tag{13}$$

In that case, Bank A's payoff is $\pi_A = p_H R_b F(\theta^*)$.

The expression for θ^* is intuitive. In equilibrium, Bank B must contribute ρ to refinance all of Bank A's loans, and enjoy an expected payoff $E(\pi_B)$. Part of $[E(\pi_B) + \rho]$ is funded with claims of Bank B in Bank A. Due to moral hazard, the maximum value of the claims Bank B can hold in Bank A is $p_H(R - R_b)$. Therefore the RHS is simply the shortfall that Bank A can cover only by selling assets. Indeed owning one loan is more valuable to Bank B than the maximum claim it can hold against that loan (Assumption 1). If the shortfall is positive, Bank A will indeed need to sell assets. If the shortfall is negative, there is no need for such asset sales.

We now highlight some properties of the negotiation's outcome. Note that in equilibrium, Bank A sells a fraction α^* of its assets which involves a deadweight loss K^* where

$$\alpha^* \equiv (1 - F(\theta^*)) \qquad \text{and} \qquad K^* \equiv \int\limits_{\theta^*}^1 \left[(p_H - p_B(\theta))R\right] dF(\theta).$$

We begin with the effect of Bank B's market power on the equilibrium liquidity transfer. Importantly, the (positive or negative) shortfall increases with Bank B's power β. As a result, market power can increase and even create inefficiencies relative to perfect competition.

Corollary 1 *A threshold $\beta^* \in [0,1]$ for Bank B's market power β exists such that:*

- *If $\beta < \beta^*$, the efficient outcome is reached, i.e., Bank A refinances all its assets without selling any to Bank B.*

- *If $\beta > \beta^*$, the fraction α^* of Bank A's assets sold to Bank B and the associated inefficiency K^* increase strictly with β.*

Moreover, if $p_H R_b > X_A$ and $p_H(R - R_b) - \rho > X_B$ then $\beta^* \in (0,1)$, i.e., the efficient outcome is reached only if Bank B is sufficiently competitive.

The intuition for the existence of a threshold β^* is as follows. Bank A does not need to sell assets when the maximum payoff it can offer Bank B solely from borrowing, $p_H(R - R_b) - \rho$, exceeds Bank B's reservation payoff, $E(\pi_B)$. Since $E(\pi_B)$ increases with β, a threshold β^* exists such that asset sales occur only if $\beta > \beta^*$. If $p_H R_b > X_A$ then $\hat{\theta}_B < 1$, i.e., assets will be sold if Bank B is certain to make an offer ($\beta = 1$) and therefore $\beta^* < 1$. If $p_H(R - R_b) - \rho > X_B$, no assets are sold if Bank B cannot make an offer ($\beta = 0$) and therefore $\beta^* > 0$.

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

Our analysis (Corollary 1) shows that the market power of liquid banks can lead to an inefficient allocation of aggregate liquidity even in situations where the allocation would be efficient if those same banks were behaving in a perfectly competitive fashion. This scenario corresponds to the configuration $\beta > \beta^* > 0$. There are also situations in which frictions in the interbank market (here, moral hazard in monitoring) would lead to an inefficient allocation of aggregate liquidity even if liquid banks were perfectly competitive. This corresponds to the case $\beta^* = 0$. In those situations, the market power of liquid banks increases the inefficiency of the allocation of aggregate liquidity.[22]

Corollary 2 *An increase in the liquidity need ρ, an increase in Bank B's outside option X_B, and a decrease in Bank A's outside option X_A all have the following effects:*

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

[22] Note 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.

• *For $\beta > \beta^*$, the fraction α^* of Bank A's assets sold to Bank B and the associated inefficiency K^* increase.*

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

5 Loan portfolio characteristics

We discuss how the specificity of Bank A's assets affects the negotiation's 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 operates a loan of Bank A with characteristic θ, then

$$p_o(1) > \rho/R > p_o(0), \quad \text{and} \quad \left(\frac{dp_o(\theta)}{d\theta}\right) > 0. \tag{14}$$

Define $\bar{\theta}_o$ by $p_o(\bar{\theta}_o) = \rho/R$. Loans with $\theta < \bar{\theta}_o$ are more valuable terminated than run by an outsider. Note that this is in contrast with our assumption that loans are always more valuable run by Bank B than terminated (expressions (5)). More generally, we assume that Bank B has an advantage over outsiders for managing Bank A's assets. This assumes that banks are special relative to outsiders, e.g., better monitors of small, relationship-specific loans (e.g., Fama (1985), James (1987), James and Houston (1996)). Moreover, we assume that those projects 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., loans' Bank A-specificity and bank-specificity (relative to outsiders) are correlated:

$$p_o(\theta) < p_B(\theta) \qquad \text{and} \qquad \frac{dp_o(\theta)}{d\theta} > \frac{dp_B(\theta)}{d\theta}. \tag{15}$$

Borrowing: We assume that Bank B is possibly more effective than outsiders at making loans to Bank A.[23] Specifically, we assume that when borrowing from outsiders, Bank A's

[23] Several papers focus on peer monitoring in interbank markets (see Rochet and Tirole (1996), and Freixas and Holthausen (2005) for models based on this assumption, and Furfine (2001) and Cocco et al. (2005) for supportive evidence). Peer monitoring among banks is considered important because interbank loans are the large and unsecured. Also, interbank lending relationships are seen to mitigate agency problems. Both Furfine (2001) and Cocco et al. (2005) suggest that large banks, in terms of size as well as participation in interbank lending, have some market power in lending: they borrow and lend at more favorable terms, and often small banks, who have limited access to foreign interbank markets, concentrate all their borrowing in the domestic interbank markets relying on a few lending relationships with 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 where loan amount and interest rate are agreed 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, and posted quotes are merely indicative. The bilateral nature of the market is also evidenced in that the identity of lending banks affects the interest rate. Cocco et al. document that banks with higher return on assets lend at higher interest rates, more profitable banks lend less.

benefit from not monitoring is $b_o \geq b$, so that it must retain a larger exposure to its loans to have an incentive to monitor, i.e., $R_b^o \equiv b_o/\Delta p \geq R_b$.

Lemma 2 *If bargaining between banks A and B breaks down, outsiders acquire all loans with $\theta > \hat{\theta}_o$ (i.e. a fraction $\hat{\alpha}_o = 1 - F(\hat{\theta}_o)$ of Bank A's assets), and a debt claim $\hat{r}_o$ on each of those Bank A retains against a total transfer $\hat{T}_o$. A fraction $\hat{\lambda}_o$ of Bank A's loans are terminated.*

- *If $p_H(R - R_b^o) \geq \rho$, no loan is sold ($\hat{\alpha}_o = 0$) or terminated ($\hat{\lambda}_o = 0$). Instead, outsiders get a debt claim $\hat{r}_o = \rho/p_H$ against a transfer $\hat{T}_o = \rho$. Bank A's expected payoff is*

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

- *If $\int_{\bar{\theta}_o}^{1} p_o(\theta) R dF(\theta) + p_H(R - R_b^o) F\left(\bar{\theta}_o\right) \geq \rho \geq p_H(R - R_b^o)$, no loan is terminated ($\hat{\lambda}_o = 0$), outsiders acquire some of Bank A's loans ($\hat{\alpha}_o > 1$) and a debt claim $\hat{r}_o = (R - R_b^o)$ against a transfer $\hat{T}_o = F(\hat{\theta}_o)\rho$, where $\hat{\theta}_o$ is defined as the largest solution to*

$$\int_{\hat{\theta}_o}^{1} p_o(\theta) R dF(\theta) + p_H(R - R_b^o) F(\hat{\theta}_o) - \rho = 0. \tag{17}$$

Bank A's payoff is $\pi_A = p_H R_b^o F(\hat{\theta}_o)$.

- *Otherwise, Bank A terminates some loans ($\hat{\lambda}_o > 0$), retains some (a fraction $(F\left(\bar{\theta}_o\right) - \hat{\lambda}_o)$), and sells the rest ($\hat{\alpha}_o = 1 - F\left(\bar{\theta}_o\right)$) to outsiders who also get a debt claim $\hat{r}_o = (R - R_b^o)$ against a transfer $\hat{T}_o = (F\left(\bar{\theta}_o\right) - \hat{\lambda}_o)\rho$, with $\hat{\lambda}_o$ defined by*

$$\int_{\bar{\theta}_o}^{1} p_o(\theta) R dF(\theta) + p_H(R - R_b^o)(F\left(\bar{\theta}_o\right) - \hat{\lambda}_o) - (1 - \hat{\lambda}_o)\rho = 0. \tag{18}$$

Bank A's payoff is $\pi_A = p_H R_b^o (F\left(\bar{\theta}_o\right) - \hat{\lambda}_o)$.

The first two points are obtained from Proposition 1 by replacing Bank B's characteristics with the outsiders', i.e., by setting $\beta = 0$, $X_B = 0$, $b = b_o$ and $p_B = p_o$. The intuition is therefore similar. If Bank A's borrowing capacity $p_H\left(R - R_b^o\right)$ exceeds its funding need ρ, Bank A should only borrow from outsiders as this is more efficient. In the opposite case, some loans will have to be sold or terminated. Bank A's funding capacity from outsiders is $\int_{\bar{\theta}_o}^{1} p_o(\theta) R dF(\theta) + p_H(R - R_b^o) F\left(\bar{\theta}_o\right)$. If this exceeds the funding need ρ, Bank A should only borrow from outsiders and sell them some loans. Otherwise, it has to terminate some loans until the funding capacity meets the funding needs. The latter possibility arises from the assumption that some loans are better terminated than managed by an outsider.

We can now analyze bargaining between banks A and 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 assets Bank A sells to Bank B depends on F directly but also through its effect on θ^*.

Corollary 3 *An improvement of the outsiders' ability to monitor loans to Bank A (i.e., a decrease in b_o) and a shift of the distribution F of loan characteristics towards higher values in the sense of FOSD have the following effects:*

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

- *For $\beta > \beta^*$, the fraction α^* of Bank A's assets sold to Bank B and the associated inefficiency K^* decrease.*

The effect of a decrease in b_o is simple. Indeed, such a change increases X_A but keeps all other variables constant. Therefore, this result is a simple implication of Corollary 2. The effect of a shift of 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 that need liquidity have a large share of their portfolio in small, relationship-specific loans, as this decreases the outside option of needy banks, giving surplus banks a better opportunity to exert market power and exploit needy banks' difficulties.

6 Central bank as lender-of-last-resort

We have shown how surplus banks' market power can worsen or even create inefficiencies in the interbank market. 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 (LOLR) can provide an outside option to needy banks, thereby curbing surplus banks' ability to exploit their market power. We find that 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 it provides potential competition to Bank B.

We also determine the circumstances under which a central bank can improve market outcomes. We find that unless the central bank is a more effective lender than outsiders, these loans would have to be loss-making. This in turn raises several issues: (i) 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; and (ii) it may be optimal to assign other tasks (e.g., supervision) to the central bank if they increase its expertise in monitoring loans.[24]

[24] Note that this argument is different from that saying that since the central bank is a LOLR, it ought to supervise/monitor banks to avoid that they be in a position to need the LOLR.

We modify the model as follows. If bargaining with Bank B breaks down, Bank A can first seek liquidity from from a central bank and then from competitive outside markets.[25] When borrowing from the central bank, Bank A's benefit from not monitoring is b_C, and we define $R_b^C \equiv b_C/\Delta p$. We assume that Bank B is better than the central bank at making loans to Bank A, i.e., $b_C \geq b$. To simplify, assume that the central bank has full bargaining power in its bargaining with Bank A. We assume that ex post, the central bank maximizes social surplus subject to its expected losses not exceeding some level $\Lambda \geq 0$.

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.

6.1 LOLR with no supervision

Suppose the central bank is no better than outsiders at monitoring Bank A's assets, i.e., $b_C \geq b_o$.

As a benchmark, assume further that it is not willing to accept any expected losses from the loans it makes to Bank A, i.e., $\Lambda = 0$. In that case, if the central bank is able and willing to take a given action, so is 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 absent the central bank and the outcome of its negotiation with Bank B is unchanged.

Proposition 2 *A central bank that is no better than outsiders at monitoring Bank A (i.e., $b_C \geq b_o$) and does not extend any loss-making loans (i.e., $\Lambda = 0$) cannot ameliorate the inefficiency arising from Bank B's market power.*

Now assume that the central bank is, up to a limit, willing to extend some loss-making loans. For instance, it is 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. In the case at hand, central bank's optimal policy is a pure transfer to Bank A. Indeed, the central bank being no better than outsiders at monitoring loans to Bank A, loans should be monitored by outsiders, i.e., the central bank should not use Bank A's limited borrowing capacity. Moreover, outsiders being competitive, they make zero profits and so no action by the central bank will induce them to extend more loans. Hence the central bank's actions do not affect Bank A's borrowing capacity.

Proposition 3 *If the central bank is no better than outsiders at monitoring Bank A (i.e., $b_C \geq b_o$), its optimal intervention amounts to a pure transfer to Bank A, i.e.,*

$$\hat{T}_C = \min\left\{\Lambda, \max\left\{\rho - p_H\left(R - R_b^o\right), 0\right\}\right\}. \tag{19}$$

[25] For simplicity, we assume that the central bank cannot buy Bank A's assets. The central bank owning assets could correspond to nationalization of some or all of Bank A's assets.

As the central bank's maximum expected loss Λ increases, the central bank's transfer is first used to finance those loans that would otherwise be terminated, i.e., $\hat{\lambda}_C$ decreases from $\hat{\lambda}_o$ to 0, then to allow Bank A not to sell its loans to outsiders, i.e., once $\hat{\lambda}_C = 0$, $\hat{\alpha}_C$ decreases from $\hat{\alpha}_o$ to 0.

Intuitively, the central bank's transfer should be used in priority to solve the greatest inefficiencies, i.e., the termination of some loans, which generates a surplus $(p_H R - \rho)$ per loan. Only once this inefficiency resolved ($\hat{\lambda}_C = 0$) should the transfer be used to avoid the sale of Bank A's loans to outsider, which generates a surplus $(p_H R - p_o(\theta))$ per loan of characteristic θ.[26]

6.2 LOLR with supervision

Suppose now that the central bank can monitor banks better than outsiders, i.e., $b \leq b_C \leq b_o$, and is willing to extend some loss-making loans.[27,28]

Proposition 4 *If the central bank is better than outsiders at monitoring Bank A (i.e., $b_C < b_o$), its optimal intervention is to extend loans to Bank A, i.e.,*

$$\hat{T}_C = \frac{\min\left\{\rho - p_H(R - R_b^C), \Lambda\right\}}{\rho - p_H(R - R_b^C)}\rho. \tag{20}$$

Bank A should not borrow from outsiders. As the central bank's maximum expected loss Λ increases, the central bank's transfer is first used to finance those loans that would otherwise be terminated, i.e., $\hat{\lambda}_C$ decreases from $\hat{\lambda}_o$ to 0, then to allow Bank A not to sell its loans to outsiders, i.e., once $\hat{\lambda}_C = 0$, $\hat{\alpha}_C$ decreases from $\hat{\alpha}_o$ to 0.

The intuition for the central bank's optimal policy is that since it is better than outsiders at monitoring loans to Bank A, 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.

For a given b_C, define $\Lambda^*(K, b_C)$ as the level of expected losses the central bank must incur to achieve efficiency loss no greater than K.

Corollary 4 *If the central bank is better than outsiders at monitoring Bank A (i.e., $b_C < b_o$), the expected loss it must incur to achieve a given level of efficiency decreases with its ability to*

[26] There is no room for collateral or secured lending as such in our model. However, the central bank's loss maps effectively into a liquidity transfer, which in turn can be interpreted as lowering the quality of collateral against which the central bank extends liquidity support, e.g., by lending to needy banks against mortgages at the same rate as treasury collateral if these loans are likely to be terminated in absence of liquidity support.

[27] Our results would be stronger if we allowed the central bank to be more efficient than other banks in monitoring. However, what we derive is a stronger result as we show that even a central bank that is not necessarily as efficient as other banks in monitoring can decrease the inefficiency in liquidation.

[28] Berger et al. (2000) test the hypothesis that supervisors have more accurate information than the market on the soundness of financial institutions using data from the US. They show that shortly after supervisors have inspected a bank, supervisory assesment of the bank is more accurate than the market. However, for periods where the supervisory information is not up-to-date, market has more accurate information than supervisors.

monitor loans, i.e.,

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

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, by through its supervisory role, the central bank can limit its losses.

6.3 Impact on equilibrium outcomes

We can now draw implications for the bargaining between banks A and 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.

Corollary 5 *The fraction of loans α^* sold to Bank B and the deadweight loss K^* decrease with the central bank's ability to monitor loans to Bank A (if it exceeds that of outsiders) and with its willingness to extend loss-making loans to Bank A, i.e.,*

$$\left(\frac{\partial \alpha^*}{\partial b_C}\right) > 0 \quad \textit{and} \quad \left(\frac{\partial \alpha^*}{\partial \Lambda}\right) < 0. \tag{22}$$

6.4 Comments

6.4.1 Outsiders as monitors?

The analysis begs the natural question of why outsiders do not supervise banks and assume some of the roles of the regulator. One potential reason for this is that banks may be more forthcoming to disclose information to the regulator, knowing that such information may not be used against them competitively, whereas outsiders, who may be participants of similar markets as banks, may not be credible in not using such information for their own advantage. The historical evidence in Section 2 of the competitive behavior of commercial central banks during crises reinforces this point. The monitor or the supervisor must be a non-competitive, non-profit maximizing institution such as the central bank.

6.4.2 Alternative policies and limitations

Our analysis has side-stepped the issue of the central bank's optimal policy, be it intervention ex post or regulation ex ante. The reason is that our model (so far) is ill-suited for such an analysis. Indeed, it does not specify explicitly the limits to central bank intervention. In the model as it stands, the central bank could "force" the efficient allocation of liquidity by setting directly the liquidity 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.

Among others, one might assume that the cost of capital of liquid banks (parameter μ in the model) is only partially observed by the central bank. Another consideration is that the central bank may have limited powers to coerce liquid banks into supplying liquidity. It would thus have to bargain with these banks, possibly leaving them with rents.[29] In fact, these two limitations to the central bank's ability to force directly the efficient outcome may be related to each other. Indeed, the central bank may be reluctant to force liquid banks to supply liquidity to needy banks precisely because it is imperfectly informed about the liquid banks' cost of capital and therefore about the efficient level of liquidity transfer. We leave these issues aside for now.

7 Ex-ante liquidity insurance

So far, we have considered liquidity transfers once a liquidity shock has occurred, ignoring the possibility for banks to insure against such shocks.[30] We now consider the possibility for Bank A to insure, completely or partially, against liquidity shocks. We modify the model as follows.

At $t = 0$, Bank A can approach Bank B to organize liquidity insurance.[31] For simplicity, we also assume that Bank A makes Bank B a take-it-or-leave it offer at $t = 0$.

At $t = 1$, Bank A's loans need refinancing of ρ units of cash with probability x. Otherwise Bank A's loans do not need any refinancing. Whether Bank A incurs a liquidity shock or not is verifiable. If Bank A incurs a liquidity shock, Bank B's opportunity cost of capital is $\mu > 1$ with probability y and 1 otherwise. We assume that $p_H R - \mu\rho < 0$, i.e., if Bank $B's$ opportunity cost is high, efficiency requires that Bank B does not transfer funds to Bank A. We assume that Bank B's opportunity cost of capital is not verifiable. At that point, banks A and B can renegotiate their contract.

Finally, we make simplifying assumptions. First, we assume that all of Bank A's loans have the same characteristics θ.[32] Second, we assume that Bank B cannot pledge any of its assets

[29] The financial turmoil in the UK and the bailout and subsequent nationalization of Northern Rock in 2007 has shown recently that surplus banks can exert power not only on needy banks but also on authorities (Source: "The Bank loses a game of chicken," *Financial Times*, 9/20/2007; "Lessons of the fall," *The Economist*, 10/8/2007): On 8/13/2007, Northern Rock approached regulatory authorities in the UK (the Bank of England, the HM Treasury and the Financial Services Authority) and informed them 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 lender of last resort had been discussed among the authorities, the option of selling Northern Rock to another bank had been tried first. While 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 by the tripartite authorities 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 footnote 8 for details).

[30] See the large literature on liquidity insurance among banks (e.g., Bhattacharya and Gale (1987), Allen and Gale (2000), Leitner (2005)).

[31] For now, we do not consider the possibility for Bank A to get liquidity insurance from outsiders.

[32] With heterogeneous values of θ, the optimal contract would generally involve some asset sale to Bank B even when Bank A does not incur a liquidity shock. Indeed, the sale of more liquid loans absent a shock could avoid

to Bank A. This ensures that if Bank A makes a transfer to Bank A but turns out to have a high cost of capital, Bank A will not transfer back the appropriate amount of liquidity to Bank B. Third, we assume that Bank B has full bargaining power at the contract renegotiation stage (i.e., $\beta = 1$). Fourth, we assume that outside markets are so weak that only Bank B can refinance Bank A's loans, i.e., any loan not refinanced by Bank B must be terminated.

There are three states of the world. In principle, Bank A's offer specifies for each state of the world three components per state of the world $\omega \in \{(\rho, 1), (\rho, \mu), (0, 1)\}$ a transfer $T(\omega)$ from Bank B to Bank A, a set of loans of measure $\alpha(\omega)$ transferred to Bank B, and a claim $r(\omega)$ by Bank B on Bank A's remaining assets. However, the fact that Bank B's cost of capital is not observable constraints the set of feasible contracts at $t = 0$. In can be shown that the contract's terms cannot differ across states $(\rho, 1)$ and (ρ, μ).

Proposition 5 *An optimal contract at $t = 0$ is as follows.*[33] *Define*

$$T^* \equiv \frac{(1-x)\, p_H\, (R - R_b)\, \rho}{x\left[(1-y)\,(p_B R - p_H\,(R - R_b)) + y\frac{R_b}{R}\mu\rho\right]}. \tag{23}$$

- *If $T^* \geq \rho$, Bank A gets full liquidity insurance from Bank B so that no loans is sold to Bank B in the event of a liquidity shock, i.e., $T(\rho) = \rho$.*
- *If $T^* < \rho$, Bank A gets only partial liquidity insurance from Bank B, i.e.,*

$$T(\rho) = T^*. \tag{24}$$

If Bank A incurs a liquidity shock, Bank B acquires a fraction α^* of Bank A's loans defined as

$$\alpha^* = 1 - \frac{T^*}{\rho}. \tag{25}$$

Corollary 6 *The fraction of loans Bank A sells following a liquidity shock, and the associated inefficiency increase with the probability x of a liquidity shock for Bank A, the probability y that Bank B's cost of capital is high, and with the value of Bank B's high cost of capital μ.*

The intuition is simple. As a shock becomes more likely, there is less scope for liquidity insurance. As y and/or μ increase, Bank B is less keen to commit to a transfer to Bank A.

As long as only partial liquidity insurance is obtained in equilibrium, the central bank can improve efficiency by acting as a lender-of-last-resort.

the sale of less liquid loans in the event of a shock.

[33] This contract is not uniquely optimal. Indeed, a contract with some asset sales when there is no shock and less sales when there is a shock can also be optimal.

8 Implications for policy and broader financial markets

8.1 The discount window

In our model, central banks do not lend in equilibrium but merely change needy banks' outside option, forcing surplus banks to adjust their liquidity supply. In essence, central banks play a virtual and virtuous role. This observation has implications for the purpose of discount windows in central banks' lender-of-last-resort facilities and its usage by banks.

Usually, the discount window (e.g. the US Fed's) offers a lending facility to banks 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. It has been a puzzle to many as to the purpose of the discount window given it is seldom used. Some have argued that a bank borrowing from the discount window would be seen as having funding problems in interbank and other markets, and that this stigma explains banks' reluctance to use the discount window. Our analysis, however, implies that this reluctance need not mean that the discount window serves no purpose. The federal funds rate plus the premium sets an upper bound on the cost of borrowing when aggregate liquidity is in surplus. In particular, it may limit the rents 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 by itself should not cause as much alarm as lack of any effect of changing the premium at the discount window on interbank borrowing rates, an issue that has not received significant attention. In the context of our model, the discount window would have 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 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 discount window at discount to federal funds rate (rather than at premium) having been effective during the 1970 Penn Central commercial paper crisis.[35]

[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 Vise President), who manages open market operations at the New York Fed, told an audience at the Philadelphia Fed in October 2007.

[35] Calomiris (1994) provides an account of 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 seemed to eliminate any stigma issues and actually 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.

8.2 New forms of central bank funding

Another implication of our analysis is that unless outside markets are themselves strapped of liquidity, needy banks should have no trouble raising liquidity against collateral requiring little monitoring skills or expertise. The issue of illiquidity arises for those loans over which other banks have an advantage in terms of monitoring and usage, conferring upon them market power during crises. Indeed, collateral that is highly bank-specific may be inefficiently liquidated due to inefficiently low transfer of liquidity. Hence, a discount window or other lender-of-last-resort facility that lends *only* against high-quality collateral may fail to have much of an effect on improving private allocation of liquidity.

This perspective is useful for understanding the new facilities set up by the Fed in 2007-08 aimed at channeling liquidity to the most needy 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 to not just banks but also to primary dealers since these are also affected by funding problems due to drying up of liquidity extension from banks.[36] These changes are more likely to be effective than traditional facilities in restoring liquidity of interbank markets, even if they are not directly tapped into, since they have created a direct option for raising funding against assets rendered illiquid.

8.3 The moral suasion and leadership role of central banks

Outside of the scope of our model, but of relevance to its conclusions, is the role of central banks beyond that of LOLR. Much like the constraints of the IMF in dealing with the 80s' LDC debt crisis, in most serious cases of financial crises, central banks do not have sufficient resources to be able 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 as well as 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 with leadership, guidance and moral suasion of a central bank that must impress upon profit-maximizing private players the need to coordinate an outcome that balances their profit

[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), five new programs have been implemented during August 2007 to March 2008: 1) Term Discount Window Program (announced 8/17/2007) - 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 12/12/2007) - 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 3/7/2008) - 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 3/11/2008) - 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 3/16/2008) - is an overnight loan facility that provides funds directly to primary dealers in exchange for a range of eligible collateral.

objectives with broader welfare concerns. The crucial feature necessary to allow a central bank to carry out this function is that it should be above the competitive battle, a noncompetitive, non-profit-maximizing body. The success of the Long Term Capital Management (LTCM) rescue in 1998 with a consortium of bankers, and the expedient resolution of Bear Stearns' distress through a sale to J.P.Morgan Chase in March 2008, both at initiatives of the Fed, point to the importance of this coordination role of central banks.

8.4 Market power around hedge-fund failures

The last ten years have witnessed the collapse of two major hedge funds, LTCM in 1998 and Amaranth in 2006. In both cases, other players in markets seem to have tried to exploit the funds' difficulties. We discuss both episodes together with some recent studies of such strategic behavior.

After its remarkable success over 1994-97, LTCM began to experience difficulties during the financial turmoil triggered by the Russian default in August 1998. During the crisis, 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 being able to observe customer order flow, market makers had incentives to engage in front running, i.e., trading in the same direction as LTCM knowing that the order will be coming and unwinding the position afterwards to profit from the price impact of the expected order.

For example, *Business Week* 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."[37] 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, a significant percentage of market makers made abnormal profits on most trading days during the crisis.

Eventually, fearing that LTCM's fall might lead to costly disruptions in the financial markets, the New York Fed hosted a meeting of fourteen financial institutions that led to a private sector recapitalization of LTCM. The recapitalization relaxed LTCM's constraints and helped avoid fire sales. This, in turn, reversed the profitability of speculative trading against LTCM.

Similarly, the *Wall Street Journal* reported Amaranth LLC's failure and the efforts of other energy market players to benefit from its difficulties.[38] When the risky bets Amaranth had taken 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

[37] *Business Week*, 2/26/2001, "The Wrong Way to Regulate Hedge Funds."
[38] *Wall Street Journal*, 1/30/2007, "Amid Amaranth's Crisis, Other Players Profited."

investments but thinking that some of these could not be liquidated quickly, Amaranth started negotiations with Wall Street banks to raise cash. After lengthy negotiations, Amaranth secured a deal with Goldman Sachs that would require it 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. However, J.P. Morgan refused to release Amaranth's cash collateral claiming the deal did not free it from the risk that Amaranth's trades may not get paid. This killed the deal.

Later on, J.P. Morgan got into the game and agreed to jointly assume most of Amaranth's energy positions with a partner, Citadel Investment Group. 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. In a speech in November 2006, Mr. 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 two episodes illustrate that market for liquidity transfers are often ridden by strategic behavior by counterparties and lenders, even in the broader landscape of financial institutions (not just banks), especially when the stakes are high.

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. Similarly, Carlin, Lobo and Viswanathan (2007) analyze the breakdown in cooperation between traders, which manifests itself in predatory trading leading to a liquidity crunch in the market. In their model, traders cooperate most of the time due to their repeated interaction and provide liquidity to each other. However, cooperation can break down, especially when the stakes are high, which leads to predatory trading. While our paper has similarities with these studies, our model is not exclusively about predatory trading or the break-down of implicit contracts. It is instead about the ability to exploit market power in one market (interbank lending market) to benefit in another market (market for asset sales).

9 Conclusion

We propose that during crises, surplus banks may not lend efficiently to needy banks due to the strategic gains to be made upon the closure of troubled banks or more generally, upon the liquidation of their assets. This problem was shown to be more acute the weaker the market for assets outside of the banking sector, a scenario that would arise, for instance, in liquidation of information-sensitive and specific loans made to small borrowers.

Such strategic behavior describes well crises in the pre-Fed era and provides a rationale for the existence of the central bank. A central bank that is credible in providing liquidity to banks in need at competitive rates, can eliminate the bargaining power of surplus banks in the interbank market and thereby restore the efficiency of liquidity transfers and asset sales. This lender-of-last-resort rationale for the existence of a central bank complements the traditional one pertaining to 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, our model also provides a rationale for central banks to play the role of coordinating liquidity injection to needy institutions, if required, through moral suasion.

Our analysis can be extended in several directions. On the modeling front, perhaps one limitation of our approach is that the structure of liquidity shocks is exogenous. It would be useful and interesting to endogenize this based on optimal liability structure of banks (Diamond and Rajan (2001), Acharya and Viswanathan (2007)). In particular, how do issues of market power and resulting under-provision of liquidity insurance affect the optimal asset-liability match and liquidity management by banks?

On the policy front, our modeling of central banks was along the lines of exploring two specific instruments (supervision and making liquidity transfers to needy institutions). It would be fruitful to start the analysis from primitives by fixing the central bank's information set, allowing it a general set of instruments, and examining which perform the best. For example, how should liquidity be transferred, if at all? Should it be transferred to needy bank directly, to outside markets, or to surplus banks unconditionally or through an open-market operation or as a part of an arrangement for them to acquire needy institutions (as witnessed recently in the case of Fed-assisted purchase of Bear Stearns by J.P.Morgan)?

Answering such policy-relevant questions would require us to first generalize the current setup from two to n banks so that issues of market power can be examined as a function of the organization structure of banking industry and interbank markets. Perhaps this calls for integrating the antitrust regulation literature with the banking (regulation) literature on insurance provision and liquidity crises.

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Appendix

Proof of Lemma 1: It is easily seen that we can assume $\hat{r}_B = R - R_b$ so that the problem is:

$$\begin{array}{ll} \max\limits_{\theta_B \in [0,1]} & \int_0^{\theta_B} p_H(R - R_b)dF(\theta) + \int_{\theta_B}^1 [p_B(\theta)R - \rho]\, dF(\theta) - T \\ s.t. & T = F(\theta_B)\rho + \max\{X_A - F(\theta_B)\, p_H R_b; 0\}\,. \end{array} \tag{26}$$

If $X_A > F(\theta_B)\, p_H R_b$, the objective becomes:

$$\int_0^{\theta_B} p_H R dF(\theta) + \int_{\theta_B}^1 p_B(\theta) R dF(\theta) - \rho - X_A \tag{27}$$

which increases with θ_B, i.e., $F'(\theta_B)\,(p_H R - p_B(\theta_B)R) > 0$.

If $X_A \geq F(\theta_B)\, p_H R_b$ for $\theta_B = 1$, i.e., if $X_A \geq p_H R_b$, then $\hat{\theta}_B = 1$ is optimal. This implies $\hat{T}_B = \rho + X_A - p_H R_b$ and Bank B's expected payoff is $p_H R - \rho - X_A$. Note that in this outcome, Bank A borrows more than the funds needed to refinance all its loans, i.e., $\hat{T}_B > \rho$. This outcome is equivalent to (among others) Bank A borrowing exactly $\hat{T}_B = \rho$ against a debt claim $\hat{r}_B = R - X_A/p_H$.

If instead $X_A < p_H R_b$, we must consider the case $X_A < F(\theta_B)\, p_H R_b$, in which the objective is:

$$\int_0^{\theta_B} p_H(R - R_b)dF(\theta) + \int_{\theta_B}^1 p_B(\theta) R dF(\theta) - \rho. \tag{28}$$

From Assumption 1, this decreases with θ_B, i.e., $F'(\theta_B)\,(p_H(R - R_b) - p_B(\theta_B)R) < 0$. Therefore, in that case, it is optimal to set $\hat{\theta}_B$ such that $X_A = F(\hat{\theta}_B) p_H R_b$. This implies $\hat{T}_B = F(\hat{\theta}_B)\rho = X_A \rho / p_H R_b$ and Bank B's expected payoff is as in (9). ■

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

$$T = F(\theta^*) p_H(R - R_b) + \int_{\theta^*}^1 [p_B(\theta)R - \rho]\, dF(\theta) - E(\pi_B)\,. \tag{29}$$

In turn, we can write the maximization problem as:

$$\begin{array}{ll}\max\limits_{\theta^*} & \int\limits_0^{\theta^*} p_H R dF(\theta) + \int\limits_{\theta^*}^1 p_B(\theta) R dF(\theta) - \rho - E(\pi_B) \\ s.t. & F(\theta^*) p_H (R - R_b) + \int\limits_{\theta^*}^1 [p_B(\theta)R - \rho] \, dF(\theta) - E(\pi_B) - F(\theta^*)\rho \geq 0 \end{array} \tag{30}$$

Since $p_H > p_B(\theta)$ for all $\theta \in (0,1)$, the objective increases in θ^*. Note that the constraint is satisfied for $\theta^* = \hat{\theta}_B$. Moreover, its LHS decreases with θ^* (Assumption 1). If the constraint holds for $\theta^* = 1$, i.e., if $p_H(R - R_b) - \rho \geq E(\pi_B)$, then $\theta^* = 1$ is optimal. Note that in this outcome, Bank A borrows more than the funds needed to refinance all its loans, i.e., $T^* > \rho$. This outcome is equivalent to (among others) Bank A borrowing exactly $T^* = \rho$ against a debt claim $r^* = (E(\pi_B) + \rho)/p_H$. Otherwise, it is optimal to set θ^* at the point where it binds, i.e., $T^* = F(\theta^*)\rho$ and θ^* is as in (13). ■

Proof of Corollary 1: The efficient outcome $\alpha^* = 0$ is reached if and only if $p_H(R - R_b) - \rho \geq E(\pi_B)$. The RHS strictly increases with β. The condition holds for $\beta = 0$ if

$$p_H(R - R_b) - \rho \geq X_B, \tag{31}$$

and is violated for $\beta = 1$ if $\hat{\theta}_B < 1$, i.e., if

$$p_H R_b > X_A. \tag{32}$$

Note that under (6), (31) and/or (32) must hold. When both hold, $\beta^* \in (0,1)$. When only (31) holds, $\beta^* = 1$. When only (32) holds, $\beta^* = 0$.

For $\beta > \beta^*$, θ^* is given by (13). The LHS of (13) is strictly decreasing with θ^* and its RHS strictly increasing with $E(\pi_B)$ which is itself strictly increasing with β. Therefore, θ^* is strictly decreasing with β over that range. ■

Proof of Corollary 2: The for $\beta^* \in (0,1)$, the threshold β^* is given by $p_H(R-R_b)-\rho = E(\pi_B)$ with $E(\pi_B) = \beta\pi_B + (1-\beta)X_B$ and π_B given by (9). Therefore

$$\beta^* = \min\left\{1; \max\left\{0; \frac{p_H(R - R_b) - \rho - X_B}{\int\limits_0^1 [p_B(\theta)R - \rho] \, dF(\theta) - X_A + \int\limits_0^{\hat{\theta}_B} [p_H - p_B(\theta)] \, R dF(\theta) - X_B}\right\}\right\}, \tag{33}$$

with $X_A = p_H R_b F(\hat{\theta}_B)$. The signs $\partial\beta^*/\partial\rho$ and $\partial\beta^*/\partial X_B$ are obtained by inspection. For $\beta^* \in (0,1)$, the derivative w.r.t. X_A of the denominator D is

$$\frac{\partial D}{\partial X_A} = \left(\frac{\partial\hat{\theta}_B}{\partial X_A}\right)\left(\frac{\partial D}{\partial\hat{\theta}_B}\right) = -\left(\frac{\partial\hat{\theta}_B}{\partial X_A}\right)\left(p_B(\hat{\theta}_B)R - p_H(R - R_b)\right)F'(\hat{\theta}_B) < 0. \tag{34}$$

Similarly, if $\beta > \beta^*$, θ^* is given by (13) which can be rewritten as

$$H \equiv \int_{\theta^*}^{1} p_B(\theta) R dF(\theta) + F(\theta^*) p_H (R - R_b)$$
$$- \left[\beta \left(\int_{\hat{\theta}_B}^{1} p_B(\theta) R dF(\theta) - \rho - X_A + F(\hat{\theta}_B) p_H R \right) + (1-\beta) X_B + \rho - p_H (R - R_b) \right] = 0$$

Therefore, we have

$$\begin{aligned}
\frac{\partial H}{\partial \theta^*} &= -F'(\theta^*) \left[p_B(\theta^*) R - p_H (R - R_b) \right] < 0 \\
\frac{\partial H}{\partial \rho} &= -(1-\beta) < 0 \\
\frac{\partial H}{\partial X_B} &= -(1-\beta) < 0 \\
\frac{\partial H}{\partial X_A} &= \left(\frac{\partial H}{\partial \hat{\theta}_B} \right) \left(\frac{\partial \hat{\theta}_B}{\partial X_A} \right) = \beta F'(\hat{\theta}_B) \left[p_B(\hat{\theta}_B) R - p_H (R - R_b) \right] \frac{\partial \hat{\theta}_B}{\partial X_A} > 0
\end{aligned}$$

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

Proof of Lemma 2: The first two points are corollaries of Proposition 1 by replacing Bank B's characteristics with the outsiders', i.e., by setting $\beta = 0$, $X_B = 0$, $b = b_o$ and $p_B = p_o$. Indeed, the first inequality in condition $\int_{\bar{\theta}_o}^{1} p_o(\theta) R dF(\theta) + p_H (R - R_b^o) F\left(\bar{\theta}_o\right) \geq \rho \geq p_H (R - R_b^o)$ is the equivalent to condition (6). The LHS is the maximum funding Bank A can get from its loans, i.e., its funding capacity when $\rho \geq p_H (R - R_b^o)$. Indeed, in that case, loans with $\theta > \bar{\theta}_o$ can be sold for $p_o(\theta) R > \rho$, which therefore exceeds the amount $p_H (R - R_b^o)$ that can be borrowed against them. Therefore, when neither the condition of the first bullet point nor that of the second bullet point are satisfied, not all loans can be refinanced. Bank A should only terminate loans that cannot be managed by outsiders and as few loans as needed for the funding constraint to be satisfied. Terminating a fraction λ of loans implies a funding need $(1-\lambda)\rho$ and a funding capacity $\int_{\bar{\theta}_o}^{1} p_o(\theta) R dF(\theta) + p_H (R - R_b^o)(F\left(\bar{\theta}_o\right) - \lambda)$. Since we are in the case $\rho \geq p_H (R - R_b^o)$, as λ increases, the funding needs decreases faster than the funding capacity. Moreover, the latter goes to zero while the former goes to $\int_{\bar{\theta}_o}^{1} p_o(\theta) R dF(\theta) > 0$. Hence they cross only once, for some value $\hat{\lambda}_o$. ■

Proof of Corollary 3: For $\beta > \beta^*$, we must be in the second or third case of Lemma 2. Consider first the effect of b_o.

In the second case, $\pi_A = p_H R_b^o F(\hat{\theta}_o)$. We have

$$\frac{\partial \hat{\theta}_o}{\partial R_o^b} = \frac{p_H F(\hat{\theta}_o)}{-\left(p_o(\theta) R - p_H (R - R_b^o)\right)} \tag{35}$$

which is negative since $\hat{\theta}_o$ is the largest solution to (17). Moreover,

$$\frac{\partial \pi_A}{\partial \hat{\theta}_o} = (p_H - p_o(\hat{\theta}_o))RF'(\hat{\theta}_o) > 0. \tag{36}$$

Hence $\frac{\partial \pi_A}{\partial R_o^b} < 0$, implying $\frac{\partial \pi_A}{\partial b_o} < 0$.

In the third case, $\pi_A = p_H R_b^o (F(\bar{\theta}_o) - \hat{\lambda}_o)$ where $\hat{\lambda}_o$ is given by (18). The LHS decreases with R_b^o and increases with $\hat{\lambda}_o$ (its derivative w.r.t. $\hat{\lambda}_o$ is $\rho - p_H(R - R_b^o)$ which is negative in the case considered). This implies $\frac{\partial \hat{\lambda}_o}{\partial R_b^o} > 0$. Moreover

$$\frac{\partial \pi_A}{\partial \hat{\lambda}_o} = \rho - p_H R < 0. \tag{37}$$

Hence $\frac{\partial \pi_A}{\partial R_o^b} < 0$, implying $\frac{\partial \pi_A}{\partial b_o} < 0$. The implications for α^* and K^* are an application of Corollary 2. ■

Proof of Proposition 5: Consider state $\omega = (\rho, 1)$. Following the transfer $T(\omega)$, Bank A can refinance a fraction $T(\omega)/\rho$ of its loans and therefore, its expected payoff is $\pi_A(\omega) = p_H(R - r(\omega))\frac{T(\omega)}{\rho}$. Hence Bank B's best renegotiation offer ensures Bank A that same payoff, minimizing the fraction α' of loans sold to Bank B, i.e., $(1-\alpha')p_H R_b = \pi_A(\omega)$. (Note that since $r(\omega) \leq R - R_b$, we have $(1-\alpha') \geq \frac{T(\omega)}{\rho}$, i.e., Bank B does not decrease its transfer to Bank A.) Therefore, Bank B's expected payoff is

$$\begin{aligned} \pi_B(\omega) &= \alpha' p_B R + \left(1 - \alpha'\right) p_H (R - R_b) - \rho & (38) \\ &= \left(1 - \frac{(R - r(\omega))T(\omega)}{R_b \rho}\right) p_B R + \frac{(R - r(\omega))T(\omega)}{R_b \rho} p_H (R - R_b) - \rho & (39) \end{aligned}$$

Consider state $\omega = (\rho, \mu)$. As before, Bank A's expected payoff is $\pi_A(\omega) = p_H(R - r(\omega))\frac{T(\omega)}{\rho}$. Bank B's best renegotiation offer ensures Bank A that same payoff, minimizing the transfer T', which amounts to minimizing the fraction $(1-\alpha')$ of loans retained by Bank A, i.e., $(1-\alpha')p_H R = \pi_A(\omega)$. (Note that since $r(\omega) \geq 0$, we have $(1-\alpha') \leq \frac{T(\omega)}{\rho}$, i.e., Bank B does not increase its transfer to Bank A.) Therefore, Bank B's expected payoff is

$$\pi_B(\omega) = -\left(1 - \alpha'\right)\rho\mu = -\frac{(R - r(\omega))T(\omega)}{R_b}\mu.$$

Consider state $\omega = (0, 1)$. It is easily seen that the maximum expected payoff the contract can ensure in this state without asset sales is $\pi_B(\omega) = p_H(R - R_b)$.

PROOF TO BE COMPLETED.

If there is no contract at $t = 0$, Bank B's payoff is zero in all states except $\omega = (\rho, 1)$ in which it can acquire all of Bank A's assets for no transfer and refinance them, so that its expected payoff is $\pi_B = x(1-y)(p_B R - \rho)$.

The optimal contract chosen by Bank A at $t = 0$ maximizes $T(\rho)$ subject to

$$(1-x)\pi_B(0,1) + x(1-y)\pi_B(\rho,1) + xy\pi_B(\rho,\mu) \geq \pi_B.$$

This can be rewritten as

$$T\left(\rho\right)\leq\frac{\left(1-x\right)p_{H}\left(R-R_{b}\right)\rho}{x\left(R-r\left(\rho\right)\right)\left[\left(1-y\right)\frac{p_{B}R-p_{H}\left(R-R_{b}\right)}{R_{b}}+y\frac{\mu}{R}\rho\right]}.$$

The constraint is relaxed when $r\left(\rho\right)$ is maximized. Therefore it is optimal to set $r\left(\rho\right)=\left(R-R_{b}\right)$. Given this, the constraint can be rewritten as $T\left(\rho\right)\leq T^{*}$ with T^{*} as in (23). ■

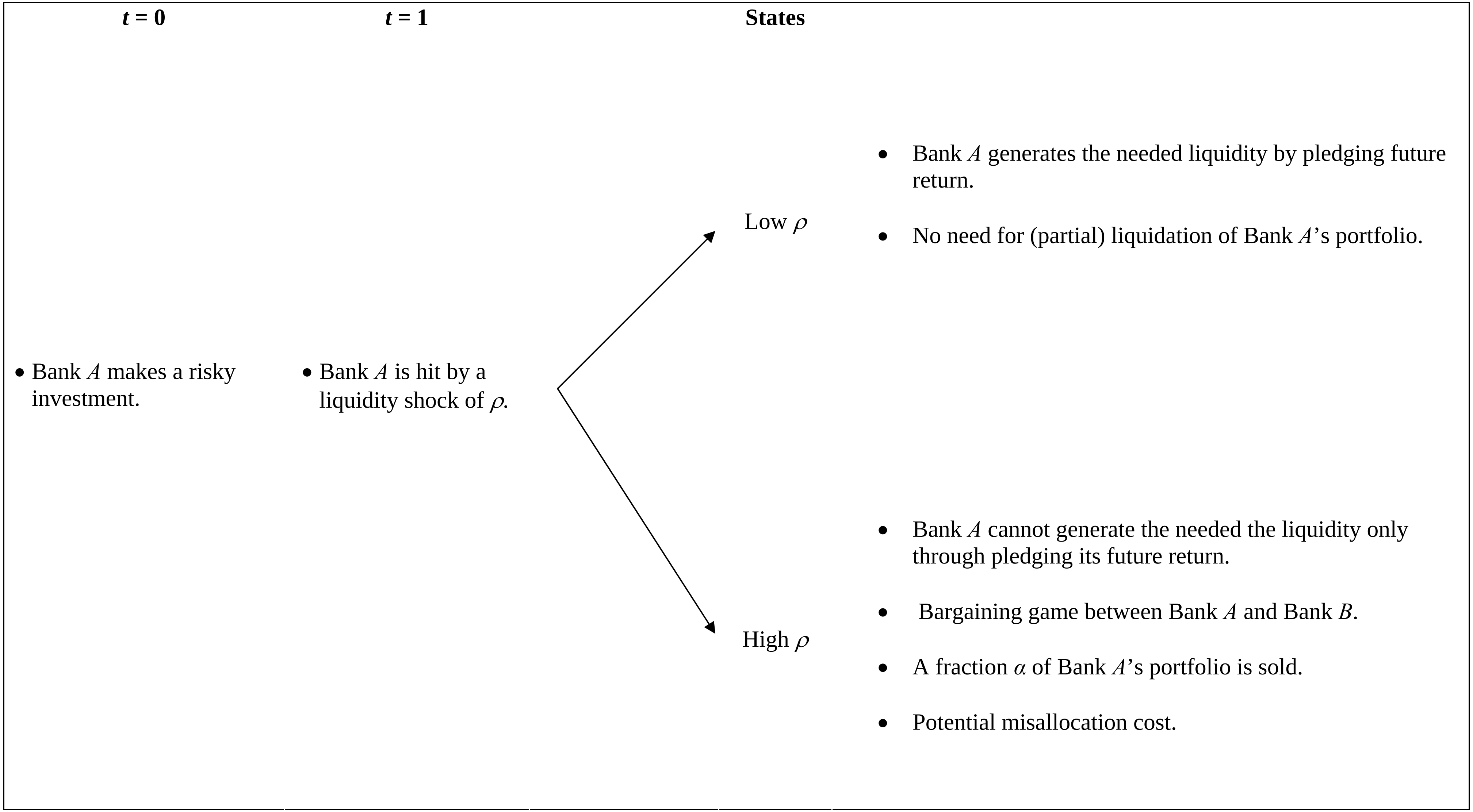

Figure 1: Timeline of the model.

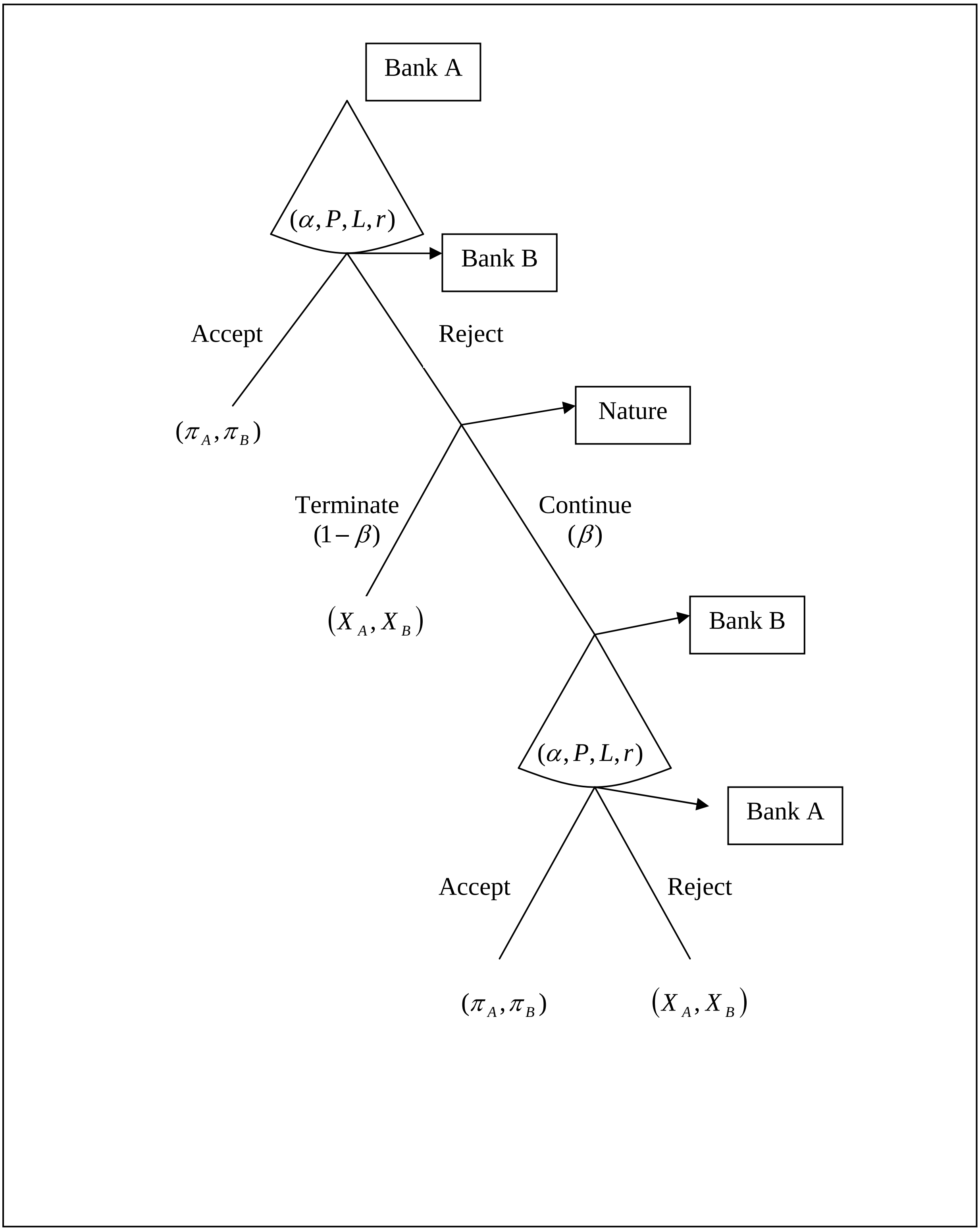

Figure 2: Game tree for the bargaining game.