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Money market derivatives and the allocation of liquidity risk in the banking sector

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Abstract:

Money markets have two functions, the allocation of liquidity and the processing of information. We develop a model that allows us to evaluate the efficiency of different money market derivatives regarding these two objectives. We assume that due to its size, a large bank receives a more precise signal about the overall liquidity development in the banking sector. In an upcoming liquidity shortage this large bank can exploit its informational advantage in the spot money market by rationing liquidity. Using *forward contracts*, the large bank can credibly commit not to squeeze small banks in the event of a liquidity shortage. But forward contracts do not provide incentives for the large bank to pass on its information to other banks. In contrast, *lines of credit* between the large and the small banks ensure that the large bank provides its information to other banks.

Keywords: Liquidity, money market derivatives, lines of credit, forward contracts, options.

JEL Classification: G21, G33, D82.

Non technical summary

Financial innovations have gained substantially in importance in the recent decade. The development of stock options as well as the emergence of credit market derivatives has attracted considerable research attention. At the same time interest rate derivatives– probably the most important financial derivatives–were more or less neglected by theoretical research. However, interest rate derivatives are an important means for the reallocation of liquidity risks in a financial system, particularly within the banking sector. Thus understanding the implications of the different interest rate derivatives for the allocation of liquidity risks is an important issue particularly given that few large banks seem to play a central role in these market.

The present paper develops a novel argument for why smaller banks hold interest rate derivatives with large banks in order to hedge liquidity risks. Since large banks are typically involved in many lines of business and have more depositors than small banks they can better extract information about upcoming aggregate liquidity shortages. This enables large banks to adapt their liquidity holdings to an upcoming liquidity shortage. In addition they can use this informational advantage to corner the money market in a liquidity crisis at the cost of small banks. Forward contracts written well in advance, i. e. before large banks receive any signal about the upcoming aggregate development, can prevent this. However, forward contracts do not implement an efficient mechanism to force large banks to disseminate their information about the aggregate development to small banks. But such a dissemination of information could be welfare improving. It would enable also small banks to adjust their liquidity holdings to an upcoming liquidity shortage.

In contrast to forward contracts, lines of credit or interest rate options provided by large banks to small banks ensure that the dissemination of information about upcoming liquidity shortages.[1] Lines of credit provide an option to small banks to receive liquidity at a pre-specified price from the large banks. Thus if small banks have not been informed about an upcoming liquidity shortage, they execute this option. Given a sufficient option volume and a sufficiently low strike price this will cause losses to large banks that overcompensate any additional profit that large banks could make from not disseminating their information. Thus interest rate options serve as an ex-ante commitment device for large banks to transmit any signal they receive to the rest of the banking sector.

Whether the dissemination of information about upcoming liquidity shortages is ac-

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[1] Lines of credit at a pre-specified price and interest rate options are synonyms in this context. For small banks, the credit line is a long position of a call option on an interbank loan at a certain short-term interest rate; the large bank takes the respective short position.

tually beneficial from a social perspective and whether interest rate options are efficiency enhancing depends on the likelihood of aggregate liquidity shocks. If these shocks are frequent events, then interest rate options increase efficiency; but for rare liquidity shortages, the introduction of interest rate options is detrimental to welfare. However, for certain modifications and extensions of the model interest rate options are also efficiency enhancing given rare aggregate liquidity shocks.

Nicht technische Zusammenfassung

Finanzinnovationen haben in den letzten Jahren enorm an Bedeutung gewonnen. Die besondere Aufmerksamkeit der Forschung richtete sich dabei im Wesentlichen auf Aktienoptionen und Kreditderivate. Zinsderivate, die bedeutendsten Finanzderivate, wurden dagegen von der theoretischen Forschung weitgehend vernachlässigt. Zinsderivate sind aber eines der wichtigsten Instrumente zur Reallokation von Liquiditätsrisiken im Finanzsystem, insbesondere innerhalb des Bankensektors. Ein genaues Verständnis der Implikationen verschiedener Zinsderivate für die Allokation von Liquiditätsrisiken ist daher von großer Bedeutung – nicht zuletzt auch vor dem Hintergrund der zentralen Rolle einiger weniger Banken in diesen Märkten.

Das vorliegende Papier entwickelt eine neue Begründung dafür, warum kleinere Banken Zinsderivate von großen Banken nutzen, um ihre Liquiditätsrisiken zu hedgen. Da große Banken in zahlreichen Geschäftsfeldern tätig sind und über eine weit größere Masse von Einlegern verfügen, können sie besser Informationen über bevorstehende aggregierte Liquiditätsengpässe extrahieren. Dies erlaubt es größeren Banken, ihre Liquiditätshaltung an bevorstehende Liquiditätsengpässe anzupassen. Darüber hinaus können große Banken diesen Informationsvorsprung nutzen, um am Geldmarkt auf Kosten kleiner Banken eine beherrschende Stellung zu erlangen. Im Vorhinein (d.h. bevor große Banken ein Signal über die zukünftige Liquiditätsentwicklung erhalten können) geschlossene Forward Kontrakte können dies verhindern. Forward Kontrakte können aber nicht sicherstellen, dass große Banken Informationen bezüglich aggregierter Liquiditätsentwicklungen weitergeben. Eine Weitergabe dieser Informationen könnte aber wünschenswert sein, da sie auch kleineren Banken ermöglicht, aggregierte Liquiditätsengpässe zu antizipieren.

Im Gegensatz zu Forward Kontrakten können Kreditlinien oder Zinsoptionen von großen Banken an kleine Banken die Weitergabe dieser Information sicherstellen.[2] Kreditlinien stellen eine Option für kleine Banken dar, zu einem bestimmten Preis Liquidität von großen Banken zu erhalten. Sind kleine Banken nicht informiert und werden von einem Liquiditätsengpass überrascht, können sie die Optionen ausüben. Für hinreichend umfangreiche Optionen zu einem hinreichend niedrigen Ausübungspreis bringt dies ex-post einen Verlust für die großen Banken mit sich, der etwaige Vorteile aus der Ausnutzung des Informationsvorsprungs kompensiert. Zinsoptionen stellen somit ex-ante einen Selbstbindungsmechanismus dar, um glaubwürdig die Weitergabe von Informationen über drohende Liquiditätsengpässe zu versprechen.

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[2] Kreditlinien zu einem vorher bestimmten Zinssatz und Zinsoptionen sind in diesem Modellkontext Synonyme. Für kleine Banken stellt eine Kreditlinie eine Kaufoption eines Interbankenkredites zu einem bestimmten Kurzfristzins dar.

Ob aus gesamtwirtschaftlicher Perspektive eine Weitergabe von Informationen über bevorstehende Liquiditätsengpässe wünschenswert ist und damit die Einführung von Zinsoptionen wohlfahrtssteigernd wirkt, hängt von der Häufigkeit aggregierter Liquiditätsschocks ab. Treten solche Schocks häufig auf, sind Optionen effizienzsteigernd; sind Liquiditätsengpässe dagegen selten, so führen Zinsoptionen zu einer Wohlfahrtsreduktion. Bei bestimmten Modifikationen und Erweiterungen des Modellrahmens erweisen sich aber auch bei seltenen Liquiditätsschocks Zinsoptionen als wohlfahrtssteigernd.

Contents

Money Market Derivatives and the Allocation of Liquidity Risk in the Banking Sector[‡]

1 Introduction

In the recent decade, financial innovations have increased the scope for the reallocation of risks in the financial system. The costs and benefits of credit risk reallocation through credit market derivatives have attracted considerable attention in the literature (see for instance Allen and Carletti, 2006, or Wagner, 2006). The importance of interest rate derivatives as a measure to reallocate liquidity risks in the financial sector has been largely neglected, even though interest rate derivatives have gained substantially in importance.

Traditionally the spot money market was and still is the major instrument to deal with idiosyncratic liquidity risks in the banking sector. In the euro area, financial integration has lead to a significant increase in the transaction volume in this market. According to the European Central Bank's money market survey, average daily turnover particularly in secured money lending grew over the last five years at a remarkable average annual rate of more than 21%, while the unsecured money market lending increased only by an average annual rate of 4%. However, as indicated by figure 1, the transaction volume of euro denominated interest rate derivatives between banks experienced at the same time an even more dynamic development. Following the Bank for International Settlement's OTC derivatives statistics, notional amounts outstanding of interest rate options between financial institutions rose by an average annual rate of 30%. Euro denominated forward rate agreements that only reached around a forth of the transaction volume of interest rate options grew on average at an annual rate of 15%.

As the European Central Bank points out in its money market study 2005, the trading activity in money market derivatives is fairly concentrated on few banks, even though more than 50% of the banks reporting to the money market survey participate in this market (see ECB, 2005, pp. 27-30). This suggests that the large banks dominating this market

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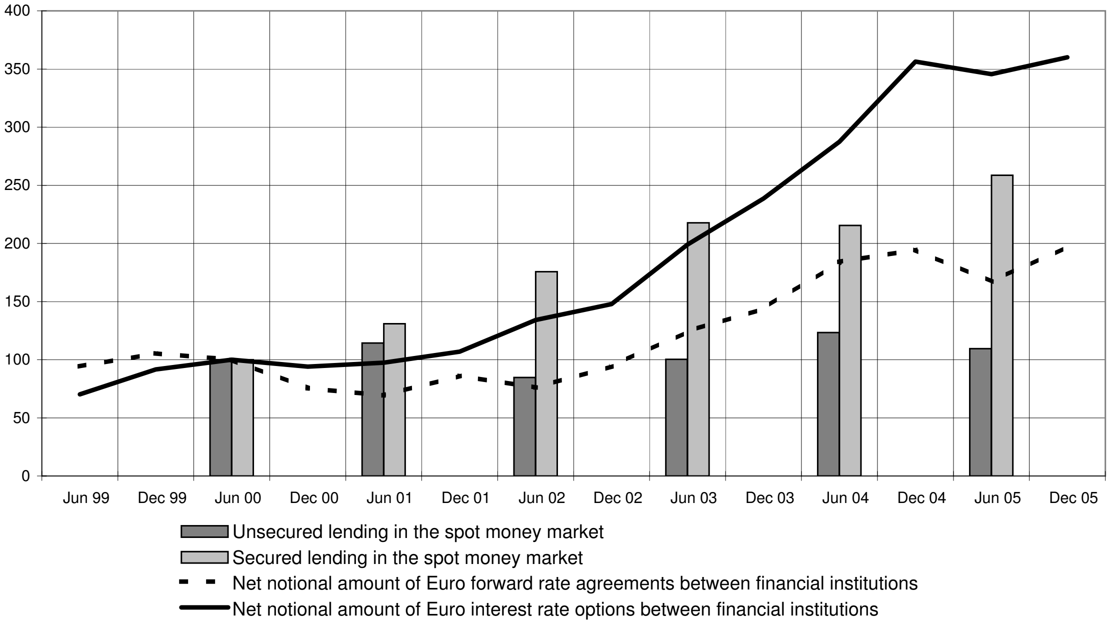
[‡] We thank Christina Bannier, John Boyd, Nuno Cassola, Phil Dybvig, Martin Hellwig, Roman Inderst, Thilo Pausch, Isabel Schnabel, and participants of the CFSresearch conference "Risk Transfer between (Re-)Insurers, Banks, and Markets" in Frankfurt, the ESSFM in Gerzensee, the MFA in Chicago, the EFA in Zürich, and the conference on "Microstructure of Financial and Money Markets" in Paris for comments and discussion. The views expressed here are those of the authors and not necessarily those of the Deutsche Bundesbank.

Figure 1:
Development of the turnover in the spot money market relative to transaction volume in money market derivatives[1]



Sources: ECB Money Market Survey 2005 and BIS OTC derivatives market statistics

are typically at least on one side of the derivatives contracts.

Our Paper In this paper we develop a novel argument for why banks, in addition to trading in the interbank spot market for liquidity, also use hedging contracts in the interbank business. Large banks are typically involved in many lines of business and have more depositors than small banks. Therefore, they can better extract information about upcoming aggregate liquidity shortages. They learn earlier, for instance, about a flight to cash. This enables large banks to prepare in advance for these upcoming liquidity shortages and buffer their impact. However, they will tend to corner the money market in a liquidity crisis – at the cost of small banks. Forward contracts written well in advance, i. e. before large banks receive any signal about the upcoming aggregate development, can prevent this. Yet, forward contracts do not implement an efficient mechanism to force large banks to disseminate their information about the aggregate development to small banks. But such a dissemination of information could be welfare improving. It would enable also small banks to prepare for an upcoming liquidity shortage well in advance.

We show in our approach that lines of credit provided by large banks to small banks can solve this problem. Unlike forward contracts, they not only prevent large banks from

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[1] Reported numbers are indices with 2000 being the base year.

exploiting their informational advantage. They also urge large banks to provide their information to the whole banking sector. The reason is straightforward. In contrast to forward contracts, lines of credit provide an *option* to small banks to receive liquidity at a pre-specified price from the large banks.[2] If small banks have not been informed about an upcoming liquidity shortage, they will draw on these credit lines. If the volumes of the lines of credit are sufficiently high, and the interest rate is sufficiently low, this will cause losses to the large bank that overcompensate any additional profit that the large bank could make from not disseminating its information. Thus offering such lines of credit against an ex-ante fee is a commitment device for large banks to transmit any signal it receives to the rest of the banking sector. This allows small banks to adjust their liquidity holdings, while still enabling large banks to collect a rent for their information dissemination.

However, as we point out in our model lines of credit do not necessarily improve welfare. If a systemic liquidity shock is a *frequent* event then small banks expecting to be squeezed in the interbank market will hold sufficient liquidity to buffer this shock. But these liquidity buffers are associated with some cost, because each unit of liquidity reduces banks' investment in more profitable assets. Using lines of credit, banks can reduce their liquidity holding and invest more in the asset: welfare is enhanced. However, if a systemic shock is a *rare* event, lines of credit reduce welfare. In this case, banks do not hold buffer liquidity against systemic shocks. Thus in an aggregate liquidity shortage, some banks must sell off assets to get liquidity. The interest rate in the money market shoots up. However, the only impact of this price effect is that assets and liquidity are reallocated, but no assets are liquidated. Now if banks are informed about the systemic shock in advance, they have an individual incentive to liquidate some of their assets in order not to be forced to sell off. This liquidation is welfare-decreasing. Hence the paper contains a normative message: Lines of credit and the interest rate smoothing that they allow are only efficient if systemic shocks occur frequently. With rare aggregate liquidity shortages lines of credit or interest rate options are welfare reducing. However, extending the model by assuming, for instance, costly asset transfers, interest rate options can turn out to be welfare enhancing even for rare liquidity shocks.

Related Literature Our paper is related to the literature that models the interbank market in a Diamond and Dybvig (1983)-style setting, like Bhattacharya and Gale (1987), Bhattacharya and Fulghieri (1994) and Allen and Gale (2004). This literature offers a

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[2] For small banks, the credit line is a long position of a non-fungible put option on the short-term interest rate; the large bank takes the respective short position.

reasoning why the interbank spot money market is unable to provide an efficient liquidity insurance to individual banks. The reason put forward in these papers is that banks are hit by idiosyncratic liquidity shocks that are not publicly observable. Given this informational asymmetry, the interbank spot market is not an incentive-compatible mechanism that can implement the optimal risk-sharing among banks. In contrast, as Allen and Gale (2000) and Freixas, Parigi, and Rochet (2000) show, interbank lines of credit or interbank deposit contracts can implement an efficient risk sharing among banks in such a setting. These interbank contracts provide a self-revealing mechanism that implements the optimal insurance against idiosyncratic liquidity shocks. Thus this literature also shows that interbank credit lines or interbank deposits improve the liquidity allocation in the banking system as compared to the interbank spot market. However, the reason is complementary to our line of argument. While in this strand of the literature, interbank credit lines offer an incentive compatible mechanism to reveal private information about individual liquidity shocks, our argument shows that credit lines offer a commitment device to refrain from exploiting informational advantages on systemic liquidity shocks and credibly commit to disseminate this information to other banks. Thus our paper develops an argument explaining why banks, in addition to trading in the interbank spot market, use money market derivatives.

Cocco, Gomes, and Martins (2003) find empirical evidence of relationship lending in the Portuguese interbank market suggesting that at least implicit lines of credit between banks play indeed an important role in the money market.

There is a vast literature dealing with the emergence of financial innovations, especially options. Following Allen and Gale (1994, p. 37, AG94 in the following), various explanations point to the following different motives for financial innovations: (i) to increase risk-sharing opportunities, (ii) to avoid regulation or taxation, (iii) to reduce transaction costs and increase liquidity, (iv) to reduce agency costs, (v) to capture temporary profits, and (vi) to change prices. In a more recent overview, Tufano (2005) offers very similar reasons for financial innovations. Our paper is related to the *first*, *third* and *fourth* arguments. However, the mechanisms described by AG94 differ significantly from those of our model. Concerning the *first* argument, AG94 refer to van Horne (1985) who shows that risk can be allocated better if a market is more complete. In our paper, the spot markets for liquidity are complete at each point in time. However, markets are dynamically incomplete. Risk allocation is improved when agents can commit in advance (before a crisis occurs) to provide liquidity. Concerning the *third* argument, AG94 cite Merton (1989) and refer to real transaction costs, rather than transaction costs induced by information asymmetries. In our model, the initial inability of agents to allocate liquidity risk efficiently is due to the different access to information. In our model financial innovations reduce the impact of these informational asymmetries and improve the credible transmission of information. The *fourth* argument in AG94 focuses on agency costs in connection with corporate control problems within a firm. Principals can use financial innovations to bring the agent's incentives in line with their own. In our model small banks might use financial innovations to align the incentives of the large bank when using its informational advantage. Summing up, our paper has a lot in common with the benefits of financial innovations put forwards in AG94, but the rationale differs substantially. Furthermore, we show that if shocks are rare, it is individually rational to use financial innovations. However, aggregate welfare is reduced if banks use lines of credit in this case. In this sense, our model also shows that financial innovation can actually lead to an inferior allocation of liquidity risk.

Apparently, our paper also has a lot in common with the literature that analyzes the contractual arrangements limiting the informational asymmetries in principal-agent relations. The problem in our model is to find an incentive compatible mechanism that commits an agent who can provide information relevant for risk management (the large banks) to other agents (the small banks) to actually communicate this information. This is particularly related to Laux (2003), Hakenes (2004), Laux and Walz (2004) and Gromb and Martimort (2004). In these models, the information must be produced at a cost, and the producer can save these costs by shirking. The information has no intrinsic value for the producer. In our paper, the large bank gets the information for free. The large bank is reluctant to communicate the information because of its strategic value. However, all papers (including ours) propose similar solution mechanisms. The bearer of the information must participate in the losses of the buyers of the information, thus generating incentive compatibility.

The remainder of the paper is organized as follows. In section 2, we introduce a formal model. In section 3, we discuss the subgame perfect equilibrium on the money market in the absence of derivatives, first without a large bank that receives information (section 3.1), then with a large bank (section 3.2). Section 4 discusses how money market derivatives can be used to facilitate the dissemination of the information on systemic shocks, differentiating between forward contracts (section 4.1) and credit lines (section 4.2). Section 5 analyzes the different welfare implications of the introduction of forward contracts and credit lines given frequent and rare aggregate liquidity shocks. Section 6 discusses assumptions and provides some extensions of the model. Section 7 concludes.

2 The model

Consider an economy with four periods, $t = 0, 1, 2$ and 3. Two investment alternatives are available in this economy: a liquid storage technology and an illiquid investment technology. The storage technology allows the transfer of funds from one period to the next, without earning any interest. Let l_t be the volume invested in the storage technology at the end of date t, called *liquidity*. The investment technology (called the *asset*) produces R in $t = 3$ for each unit invested in $t = 0$, if it is not liquidated. Let k_t be the amount of assets (not their value) at the end of date t. In $t = 1$ the premature physical liquidation of assets is possible. To get an amount of Δl of liquidity, a bank must liquidate $\Delta k = g(\Delta l)$ of its assets.[3] Thus the amount of assets of a bank at the end of $t = 1$ equals the amount at $t = 0$ less the liquidated assets, $k_1 = k_0 - \Delta k = k_0 - g(\Delta l)$. Analogously, the amount of liquidity at the end of $t = 1$ is the amount at $t = 0$ plus liquidity obtained from liquidation, $l_1 = l_0 + \Delta l = l_0 + g^{-1}(\Delta k)$. We assume that $g(0) = 0$ and $g'(\Delta l) \geq 0$; the more assets liquidated, the more liquidity generated. Furthermore, $g'(0) = 1$, the liquidation of few assets does not cause losses. Let $g''(\Delta l) > 0$, the costs of liquidation increase with the volume of liquidated assets. This captures the idea that the liquidation costs of assets vary and that those assets with the lowest costs are liquidated first. In $t = 2$ physical liquidation is no longer possible. By that time the only way to liquidate assets is over the money market which is open in $t = 2$ and allows agents to trade liquidity against assets.

This specific time structure of asset liquidation reflects in a simplified manner the idea that after investing funds in assets the real liquidation becomes more and more costly because the invested resources get more and more adapted to the respective production process. At some point real liquidation is prohibitively costly and only liquidation over the money market is reasonable.

Table 1: Investment Possibilities

t	0	1	2	3
Storage (liquidity)	–1	1	0	0
	0	–1	1	0
	0	0	–1	1
Production (asset)	–1	$g^{-1}(\Delta k)$	0	$(1 - \Delta k)\, R$

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[3] One can interpret this physical liquidation option as, for example, the direct consumption of goods that were originally intended for production (computers, stationary, tools, digging planted potatoes from the ground and eating them immediately, ...). Alternatively, and more appropriately for a bank, one may think of the cancellation or the non-rollover of a loan.

There are two kinds of agents, a continuum of small banks and one large bank. For simplicity, we assume that the large bank is just as large as the continuum of small banks in aggregate, both have measure 1. Each bank is endowed with 1 unit of money. We assume that small banks operate on regionally bounded deposit markets. It is not possible for a bank to invest its funds in another bank.

Banks are assumed to have the following objective (or profit) function:

$$\pi(l_2,\, k_2) = \begin{cases} l_2 & : \quad l_2 < \underline{l} \\ l_2 + R\, k_2 & : \quad l_2 \geq \underline{l} \end{cases} , \tag{1}$$

with $R > 1$. A bank is called insolvent if it ends up in the upper part of the objective function. In this case, its liquidity holdings at the end of $t = 2$ do not suffice to meet the exogenous liquidity needs $\underline{l}$. The bank is forced into liquidation. Because a physical liquidation is not available, its assets are worthless if the bank is unable to sell the asset against liquidity in the interbank market. In the lower case, the bank is solvent and can enjoy the returns from its capital investments.

Apparently, this objective function captures the most important aspect of banks' liquidity management put forward in Diamond and Dybvig-style models: Banks that provide liquidity insurance run the risk of becoming illiquid if they do not hold sufficient liquidity to meet short-run withdrawals. In such an event, banks are forced to liquidate assets at any cost (i. e., even if the short-run liquidation return is close to zero. Since this does not leave enough funds to honor the remaining deposits in the long-run, all depositors have an incentive to immediately withdraw forcing the bank to liquidate actually all of its assets. Thus in the event of a liquidity crisis the bank cannot enjoy the higher yield on long-term investments–it cannot use the returns on assets to refinance repayments on deposits. Only the liquidity holdings can be distributed to depositors. Given that competition for deposits forces banks to maximize depositors' utility, banks will manage their liquidity holdings to prevent these inefficient liquidity crisis. Thus our objective function can be seen as a short-cut for this rational of banks' liquidity management.

The liquidity management of small banks is complicated by two different types of liquidity shocks that both occur in $t = 2$.[4] Firstly, small banks are hit by a systemic liquidity shock $\tilde{\lambda} \in \{0;\ \bar{\lambda}\}$. With probability q, a systemic shock occurs, and $\bar{\lambda}$ is deducted from small banks' liquidity; with probability $1-q$, the systemic shock is zero; $\Pr\{\tilde{\lambda} = \bar{\lambda}\} = q$ and $\Pr\{\tilde{\lambda} = 0\} = 1 - q$. Secondly, small banks are hit by idiosyncratic liquidity shocks $\tilde{\nu} \in \{-\bar{\nu}, \bar{\nu}\}$. With equal probability, $\bar{\nu} > \bar{\lambda}$ is added or subtracted from small banks'

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[4] Note that we only assume for simplicity that liquidity shocks only affect small banks. As will become apparent below, assuming that also the large bank is hit by liquidity shocks would qualitatively not affect our results, it would only complicate the analytical exposition.

liquidity reserves; $\Pr\{\tilde{\nu} = -\bar{\nu}\} = \Pr\{\tilde{\nu} = +\bar{\nu}\} = 1/2$.[5] Assume that the systemic shock and all idiosyncratic shocks are pairwise independent. If a small bank has l_1 amounts of liquidity in $t = 1$, the shocks reduce it to $l_1 - \tilde{\lambda} + \tilde{\nu}$ in $t = 2$.[6]

Immediately after the shock, banks can trade liquidity against assets on a *spot money market*. The market only allows a mere reallocation of assets and liquidity, as opposed to the physical liquidation. After having sold some assets (and after the shocks), a bank's liquidity holding by the end of $t = 2$ is $l_2 = l_1 - \tilde{\lambda} + \tilde{\nu} +$ *bought liquidity*; assets are $k_2 = k_1 -$ *sold assets*.

The idiosyncratic liquidity shocks are assumed to be private information. Thus banks cannot write contingent contracts on the realization of individual liquidity shocks. However, apart from that there is no asymmetric information in the spot money market. When the market is active in $t = 2$, all banks observe whether a systemic liquidity shock has occurred or not.

However, we assume that the large bank has an informational advantage because it learns about a systemic liquidity shock in advance. The *large* bank receives already in $t = 1$, a perfect signal about an upcoming systemic liquidity shock. Small banks do not receive this signal.[7] Thus the large banks has an informational advantage because it can prepare for a shock already in $t = 1$.

To sum up, the overall time structure of the our model is given by figure 2.

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[5] Apparently, that the large bank is not hit by idiosyncratic liquidity shocks can also be seen as reflecting the (assumed) law of large numbers: If each small bank is hit by an idiosyncratic shock with zero mean, and if these shocks are stochastically independent, and if the large bank is interpreted as a merger of a continuum of small banks, then the shocks are diversified away at the large bank.

[6] For convenience we have assumed that shocks are simply subtracted from banks' liquidity buffers. Equivalently, one could have assumed that $\underline{l}$ is stochastic, for example, because the fraction of early consumers in a setting à la Diamond and Dybvig varies. Alternatively, one could imagine that the projects of banks need some stochastic liquidity injection at $t = 2$, as in Holmström and Tirole (1998).

[7] Note that this assumption can be seen as a natural outflow of the larger (non-vanishing) size of this bank. To see this assume that the business in each region contains a noisy signal about the upcoming aggregate liquidity shock. However, the signal to noise ratio in a single region does not allow to extract information about the actual extent of the imminent aggregate liquidity shock. Thus small bank operating in only one region cannot anticipate a systemic liquidity shock, whereas the large bank operating in many (a continuum of) regions can extract precise information about the future aggregate liquidity shock. An alternative justification would be the assumption that there is an information technology that warns against liquidity shocks, but that bears some small but positive fixed cost. Then for the large bank, investing in this technology is relatively cheap, whereas for small banks, it is prohibitively expensive.

Figure 2: Time Structure

$t = 0$	Banks write financial contracts and invest into assets and liquidity.
$t = 1$	The large bank receives a signal about the future systemic liquidity shock. Banks can readjust their portfolio choices by physically liquidating parts of their assets.
$t = 2$	Systemic and idiosyncratic shocks occur. The spot market for liquidity opens: Banks can trade assets against liquidity. Banks with insufficient liquidity lose their assets.
$t = 3$	Assets yield a return of R.

3 The spot money market

This section examines the influence of the large bank on the liquidity allocation and the management of liquidity risk in the banking sector if no money market derivatives are available. Within this section, we show that the large bank has no incentive to hand on the information it receives in $t = 1$. Therefore, small banks cannot adjust their portfolio choice in $t = 1$, hence their capital holding stays constant, $k_1 = k_0 =: k$.

3.1 Small banks only

It is important to note first that because of the no-arbitrage condition the expected equilibrium price of liquidity in the secondary market must be $E(P) = 1$, measured in assets.[8] Small banks must be indifferent between initial investment in liquidity or raising liquidity in the spot money market. However, to obtain an equilibrium in the interbank market there have to be some banks demanding liquidity if some offer liquidity. Small banks' initial liquidity holding must not be sufficient to fully meet either negative or positive idiosyncratic liquidity shocks: $\bar{l} - \bar{\nu} < l_0 < \bar{l} + \bar{\nu}$. Consequently, if a small bank is hit by an idiosyncratic shock $(-\bar{\nu})$, it demands liquidity on the spot market; if it is hit by a positive shock $(+\bar{\nu})$, it supplies liquidity.[9]

We start by analyzing the small banks' demand for liquidity. There are three cases, depending on the price P for liquidity. P is measured in [liquidity per asset], hence to buy one unit of liquidity on the market, a bank must pay P units of assets. *First*, if P is extremely high, then banks that suffer a negative idiosyncratic shock cannot buy enough

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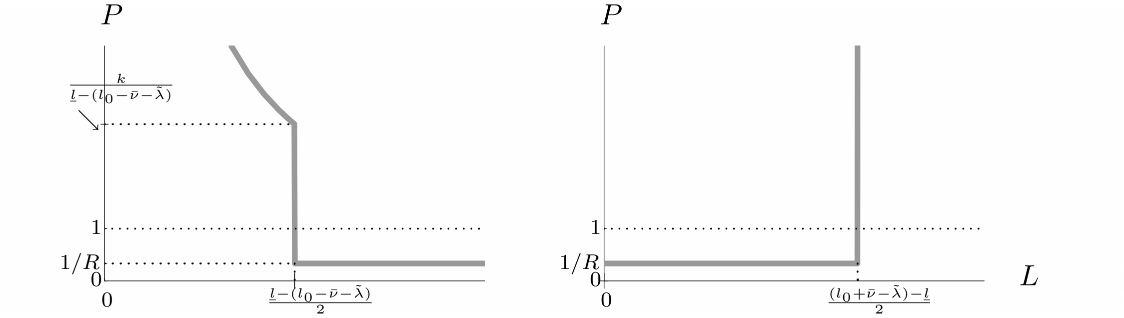
[8] Note that with only small banks in the economy there is no new information available in $t = 2$. Thus banks there is no reason why banks would use the less efficient liquidation technology.

[9] Remember that $\bar{\nu} > \bar{\lambda}$. Thus a bank with a positive idiosyncratic liquidity shock has excess liquidity even in an aggregate liquidity shortage.

Figure 3: Liquidity demand (left) and supply (right)



liquidity with their assets to remain solvent. In this case, they pay for any amount of liquidity with all the assets they own. Consequently, if $\underline{l}-(l_0-\bar{\nu}-\tilde{\lambda}) \geq k/P$, then the liquidity demand of a single small bank is k/P. Because only every other small bank has a liquidity need, aggregate demand is $L_D = k/P\,/2$. *Second*, if P is in a middle range, then the banks that have suffered a negative idiosyncratic shock demand just enough liquidity to remain solvent. They have liquidity reserves of $l_0-\tilde{\lambda}-\bar{\nu}$ and need $\underline{l}$, hence they demand the difference of $\underline{l}-(l_0-\bar{\nu}-\tilde{\lambda})$. *Third*, if the price is below $P = 1/R$, then selling assets yields a return of more than R. Hence all banks (even those who have no liquidity problem) sell all their assets. Summing up, the demand for liquidity is given by

$$2\,L_D = \begin{cases} \frac{k}{P} & : \; P \geq \frac{k}{\underline{l}-(l_0-\bar{\nu}-\tilde{\lambda})} \\ \underline{l}-(l_0-\bar{\nu}-\tilde{\lambda}) & : \; \frac{k}{\underline{l}-(l_0-\bar{\nu}-\tilde{\lambda})} > P > \frac{1}{R} \\ \left[\frac{k}{P};\ \infty\right] & : \; P = \frac{1}{R} \end{cases} .$$

This function is plotted in the left panel of figure 3. Now consider the liquidity supply. Banks that are hit by a positive idiosyncratic shock hold liquidity $l_0+\bar{\nu}-\tilde{\lambda}$, hence excess liquidity of $(l_0+\bar{\nu}-\tilde{\lambda})-\underline{l}$. If the price for liquidity is above $1/R$, banks will sell all excess liquidity and buy assets instead. If the price is below $1/R$, no bank will sell any liquidity. Hence the aggregate supply function (plotted in the right panel of figure 3) is

$$2\,L_S = \begin{cases} \left[0;\ (l_0+\bar{\nu}-\tilde{\lambda})-\underline{l}\right] & : \; P = \frac{1}{R} \\ (l_0+\bar{\nu}-\tilde{\lambda})-\underline{l} & : \; P > \frac{1}{R} \end{cases} .$$

Now the market equilibrium is given by the intersection of demand and supply function, $L_D = L_S$. The equilibrium correspondence is then

$$P = \begin{cases} \frac{k}{(l_0+\bar{\nu}-\tilde{\lambda})-\underline{l}} & : \; l_0 < \underline{l}+\tilde{\lambda} \\ \left[\frac{k}{(l_0+\bar{\nu}-\tilde{\lambda})-\underline{l}};\ \frac{1}{R}\right] & : \; l_0 = \underline{l}+\tilde{\lambda} \\ \frac{1}{R} & : \; l_0 > \underline{l}+\tilde{\lambda} \end{cases} . \qquad (2)$$

Now that we have calculated market equilibrium prices for exogenous liquidity reserves l_0 we complete the equilibrium analysis by determining the optimal l_0. There are two prominent choices of l_0. First, small banks could choose l_0 so high that, on average, they hold sufficient reserves against a systemic shock, $l_0 = \underline{l} + \bar{\lambda}$. This will typically be the equilibrium behavior if the shock probability q is large. Second, small banks could choose l_0 so low that, on average, they suffice only as a buffer against idiosyncratic, but not against systemic shocks, $l_0 = \underline{l}$. This may be optimal if systemic shocks are unlikely, for sufficiently small q. Start with analyzing the first case.

Define $P_{\tilde{\lambda}}$ the price of liquidity given that a systemic shock of size $\tilde{\lambda}$ occurs. Hence P_0 is the price in the absence of a shock, $P_{\bar{\lambda}}$ is the price under a shock. For $l_0 = \underline{l} + \bar{\lambda}$, according to (2), the price under a systemic shock will be $P_{\bar{\lambda}} \in [\frac{k}{\bar{\nu}};\ \frac{1}{R}]$. If no shock occurs, there is abundant liquidity, the price is $P_0 = 1/R$. Hence the expected objective function of small banks is

$$\pi = (1-q)\left[R\,k + l_0\right] + q\left[\underline{l} + R\,k - R\,P_{\bar{\lambda}}\,(\underline{l} - l_0 + \bar{\lambda})\right].$$

The first order condition implies

$$(1-q) + q\,R\,P_{\bar{\lambda}} = R.$$

Thus given that $P_0 = 1/R$, small banks are indifferent between holding liquidity and assets only if the price for liquidity in a crisis is

$$P_{\bar{\lambda}} = \frac{R - (1-q)}{q\,R}. \tag{3}$$

Summing up, we have a subgame perfect equilibrium that is described by $l_0 = \underline{l} + \bar{\lambda}$, $P_0 = 1/R$ and $P_{\bar{\lambda}}$, as in (3). However, banks will hold sufficient reserves only if systemic shocks are high-frequency events. A minimum shock probability $\underline{q}$ is established in the appendix. We call a crisis *frequent* if its probability is larger than $\underline{q}$. In the remainder of this section, we will show that under rare crises, an equilibrium with $l_0 = \underline{l}$ exists, and we will examine its properties.

Thus, consider the case $l_0 = \underline{l}$. Banks do not hold sufficient liquidity to avoid their bankruptcy if they are hit by both systemic and idiosyncratic shock. Consequently, the price in a crisis jumps to

$$P_{\bar{\lambda}} = \frac{1 - \underline{l}}{\bar{\nu} - \bar{\lambda}}. \tag{4}$$

The price is determined by the fact that small banks with an idiosyncratic shock offer all the assets they own, $(1 - \underline{l})/2$, against all the excess liquidity from the banks that do not suffer an idiosyncratic shock, $(\bar{\nu} - \bar{\lambda})/2$. The objective function of small banks is

$$\begin{aligned} \pi = {} & (1-q)\left[\underline{l} + R\,k - R\,P_0\,(\underline{l} - l_0)\right] \\ & + q\left[\frac{l_0 - \bar{\nu} - \bar{\lambda} + k/P_{\bar{\lambda}}}{2} + \frac{\underline{l} + R\,k + R\,P_{\bar{\lambda}}\,(l_0 + \bar{\nu} - \bar{\lambda} - \underline{l})}{2}\right]. \end{aligned} \tag{5}$$

Considering that $k = 1 - l_0$, the derivative with regard to l_0 is

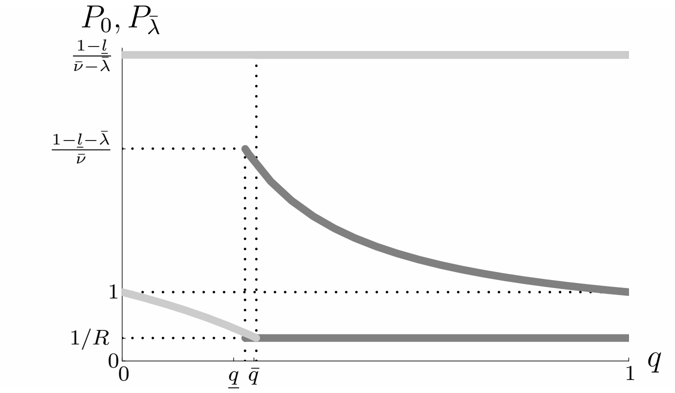
$$\frac{\partial \pi}{\partial l_0} = (1-q)\,(-R + R\,P_0) + q\left[\frac{1 - 1/P_{\bar{\lambda}}}{2} + \frac{-R + R\,P_{\bar{\lambda}}}{2}\right] = 0,$$

$$P_0 = 1 - \frac{q}{1-q}\,\frac{P_{\bar{\lambda}} - 1}{2}\left(\frac{1}{R\,P_{\bar{\lambda}}} + 1\right). \tag{6}$$

The first fraction in the square brackets describes the marginal costs and benefits of holding liquidity for a bank in the case of both a systemic and an idiosyncratic negative liquidity shock. In this case, the bank becomes insolvent, therefore it must sell its assets immediately. It cannot wait until maturity to collect the interest R. Accordingly, the rate of exchange between assets and liquidity is the same as without the idiosyncratic shock, $P_{\bar{\lambda}}$, but because of the illiquidity of the bank (and the consequential need to consume early), both assets and liquidity are worth less on the margin. This has the same effect as if the bank believed that under the idiosyncratic shock, payments were the same as without this shock, but the situation did not occur with probability $q/2$, but only with $p/(2\,R\,P_{\bar{\lambda}})$. Note that $\partial P_0/\partial P_{\bar{\lambda}} < 0$. The higher the price in a crisis, the lower it needs to be in a non-crisis to keep banks indifferent about holding liquidity. Summing up, for sufficiently small q, we have found an equilibrium determined by $l_0 = \underline{l}$, with prices given by (4) and (6). We call a crisis *rare* in this case. A sufficient condition $q \leq \bar{q}$ is established in the appendix.

Prices for both types of equilibria are plotted in figure 4. Let us discuss the figure, starting with a large q (frequent systemic shocks, dark gray curves). For $q = 1$, the systemic shock occurs with certainty. As a consequence, $P_{\bar{\lambda}} = 1$. If this were not the case, e. g. if $P_{\bar{\lambda}} > 1$, there would be an arbitrage possibility: small banks would have an incentive to hold only liquidity, $l_0 = 1$, and then sell on the spot market. Now if q goes down, $P_{\bar{\lambda}}$ must go up. Because the probability that the price drops to $P_0 = 1/R$ increases, banks must be compensated for holding liquidity at all – by an increase in $P_{\bar{\lambda}}$. If q decreases further, $P_{\bar{\lambda}}$ rises more. When q reaches $\underline{q}$, $P_{\bar{\lambda}}$ is so high that small banks become insolvent if they are hit by an idiosyncratic shock. This changes their objective function to (5). For even smaller q (rare shocks, light gray curves), prices are determined by (4) and (6). Now $P_{\bar{\lambda}}$ is fixed, thus if q decreases, now P_0 must rise to compensate small banks for holding liquidity. In a middle region, there are multiple equilibria.

Figure 4: Spot rates in subgame perfect equilibrium



Dark gray curves denotes prices with and without crisis in the frequent shock regimes, light gray curves stand for rare shock equilibria. In some intermediate range, there may be multiple equilibria. In the extreme cases $q = 0$ and $q = 1$, the size of the liquidity shock is known almost surely, hence the price is $P = 1$ almost surely.

3.2 The large bank on the spot market

Up to now, we have looked at the equilibrium on the spot money market in the absence of a large bank, i. e. in the absence of a player that has an information advantage. Again, we differentiate between frequent and rare shocks, starting with *frequent* ones.

The large bank anticipates that the price of liquidity will go up to $P_{\bar{\lambda}} = (R-1+q)/(R\,q)$ in a crisis. Because it scents the crisis in advance, it is able to adopt the strategy to produce liquidity and sell at a high price if the crisis is imminent, otherwise remain inactive. For a given price $P_{\bar{\lambda}}$, if it would sell Δl on the market, it would earn $P_{\bar{\lambda}}\,\Delta l$ assets. However, it would have to liquidate $g(\Delta l)$ assets first. The optimal supply would be determined by the first order condition, $P_{\bar{\lambda}} = g'(\Delta l)$. Define Δl^* implicitly by $P_{\bar{\lambda}} = g'(\Delta l^*)$. Yet the large bank must bear in mind that, as soon as it enters the market, it spoils prices due to its non-negligible size. There would be an oversupply of liquidity, the price would drop from $P_{\bar{\lambda}}$ to $P_0 = 1/R$. As an apparent solution to this problem, small banks could anticipate that the large bank will offer liquidity Δl^* under a crisis. As a best response, small banks could reduce their liquidity reserve from $\underline{l}+\bar{\lambda}$ to $\underline{l}+\bar{\lambda}-\Delta l^*$. As a consequence, the aggregate supply of liquidity in a crisis would remain unchanged, the price in a crisis would again be the original $P_{\bar{\lambda}}$. Small banks would be indifferent between a situation in which a large bank is on the spot market and one in which it is not; the large bank would make an additional profit of $\pi^{\text{large}} = q\,R\,\big(P_{\bar{\lambda}}\,\Delta l^* - g(\Delta l^*)\big)$.

Yet this apparent solution is not time consistent. In the case of a crisis, when the large bank decides upon liquidation in $t = 1$, it prefers to produce slightly less liquidity, $\Delta l^* - \epsilon$. That way, liquidity is undersupplied to the market, and the price jumps up to

$(1-\underline{l}-\bar{\lambda})/\bar{\nu}$. The profit of the large bank goes up, because the price jumps up discretely, but trading volume drops only marginally. Now there is insufficient liquidity to save all banks from insolvency, hence those banks that run into insolvency determine the price of liquidity. The large bank, in order to make the price rise, deliberately risks the insolvency of small banks. Yet small banks anticipate the behavior of the large bank, and the soaring price of liquidity. In response, they increase their reserves by ϵ. This argument shows that, in equilibrium, the small banks will not reduce their liquidity holdings below $\underline{l}+\bar{\lambda}$. Consequently, if shocks occur frequently, the only equilibrium with the large bank is identical with the equilibrium that emerges *without* the large bank. There is no incentive for the large bank to provide additional liquidity in the event of a liquidity crisis, and the timely information about aggregate liquidity shortages remains unused.

Now turn to the discussion of *rare* shocks. In the absence of a large bank, the price jumps to $P_{\bar{\lambda}} = (1-\underline{l})/(\bar{\nu}-\bar{\lambda})$ in a crisis. Small banks that are not hit by a negative idiosyncratic shock offer excess liquidity of $(\bar{\nu}-\bar{\lambda})/2$. If the large bank offers an additional Δl, the price drops to $P_{\bar{\lambda}} = P_{\bar{\lambda}}(\Delta l) = (1-\underline{l})/(\bar{\nu}-\bar{\lambda}+2\,\Delta l)$. Now the large bank must take into account that, by offering liquidity in a crisis, it spoils the price for liquidity. The additional profit of the large bank is $\pi^{\text{large}} = q\,R\left(P_{\bar{\lambda}}(\Delta l)\,\Delta l - g(\Delta l)\right)$, hence the first order condition becomes

$$P_{\bar{\lambda}}(\Delta l^*) + \Delta l^*\,P_{\bar{\lambda}}'(\Delta l^*) - g'(\Delta l^*) = 0. \tag{7}$$

As a consequence, the amount of liquidity that the large bank inserts in the spot market Δl^* is smaller than what it would be if the bank acted under perfect competition (and did not take into account the consequences of its decisions on prices). As a result of the activity of the large bank, the price for liquidity in a crisis goes down. Yet small banks do not respond to this price decline by holding less liquidity. If they reduced l_0 below $\underline{l}$, they would end up in a liquidity crisis even if there was no systemic shock. However, to keep small banks indifferent about holding liquidity, the price in the non-crisis situation P_0 must increase: The large bank offers additional Δl^*, the small banks do not reduce their liquidity, hence $P_{\bar{\lambda}}$ goes down. Because (6) is an equilibrium condition, P_0 must go up.

Proposition 1 (Spot money market) *If shocks are* frequent *events, the large bank supplies no liquidity, $\Delta l = 0$. Under a* rare *shock, it supplies Δl^* as determined by (7).*

4 Money market derivatives

4.1 Forward contracts

In the above section, we have shown that, due to a time inconsistency problem, the large bank cannot efficiently use its information to supply liquidity. Small banks anticipate that the large bank will corner the money market in a liquidity crisis, and hence will hold excessive liquidity buffers themselves. In this section, we point out how forward contracts can be used to solve this problem. We have already shown that the large bank would like to commit to produce Δl^* units of liquidity in a crisis, implicitly determined by $g'(\Delta l^*) = P_{\bar{\lambda}}$. If the solution to this equation exists, it is unique because $g'(\Delta l)$ rises monotonously. Given that the small banks must continue to be indifferent between the alternatives of holding liquidity or investing in capital in $t = 0$, the equilibrium price in crisis situations must still be $P_{\bar{\lambda}} = (R - 1 + q)/(q\,R)$ in a *frequent* crisis. Thus, in equilibrium, small banks must adjust their ex-ante liquidity holding such that in a crisis, the aggregate liquidity reserves and the additionally supplied liquidity of the large bank will be just enough to prevent illiquidity of small banks, $l_0^* = \underline{l} + \bar{\lambda} - \Delta l^*$. Now envisage that the large bank offers forward contracts to the small banks promising a liquidity supply of Δl^* at a strike price of $P_{\bar{\lambda}}$. This ensures that the large bank will indeed supply the promised amount of liquidity to small banks in a crisis. The profit that the large bank expects in a crisis is

$$\pi_{\bar{\lambda}}^{\text{large}} = q\,R\,\big(P_{\bar{\lambda}}\,\Delta l^* - g(\Delta l^*)\big). \tag{8}$$

This profit results from the informational advantage of the large bank; it reflects the efficiency gains that can be realized because excess liquidity holdings can be reduced due to the ability of the large bank to adjust liquidity holdings to upcoming systemic liquidity shocks. In non-crisis situations, though, the large bank makes some additional profits because it can buy the liquidity it has to provide at a price $P_0 = 1/R$ on the spot market and sell it to the small banks at $P_{\bar{\lambda}}$. Doing so ensures that no long-term investment projects are liquidated by the large bank. This would be inefficient in a non-crisis situation.[10] The expected profit that the large bank achieves in non-crisis situations is

$$\pi_0^{\text{large}} = (1 - q)\,R\,(P_{\bar{\lambda}} - P_0)\,\Delta l^*.$$

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[10] Remarkably, a (linear) forward contract leads to an *option* to produce liquidity for the large bank: it produces if the market price is high; it evens up (squares) its forward contracts if the market price is low (or it buys the liquidity on the market).

However, the large bank has to compensate the small banks for these profits, because otherwise it would be preferable for small banks to invest in liquidity rather than in forward contracts to insure against systemic liquidity shocks. Thus the large bank pays π_0^{large} for each forward contract with a small bank that allows the large bank to sell Δl^* at a fixed price $P_{\bar{\lambda}}$ in $t = 2$. As a result, the aggregate profit of the large bank is $\pi_{\bar{\lambda}}^{\text{large}}$. In other words, the large bank earns money only in a crisis, when it makes use of its liquidation technology. For the profits in a non-crisis (which reduces the profits of small banks), small banks are remunerated. However, the small banks' benefits from the large bank's activity are completely skimmed by using forward contracts.

The introduction of forward contracts improves the efficiency in the money market because it provides a way for the large bank to credibly commit to deliver Δl^* to small banks. It thereby reduces the inefficient ex-ante holdings of liquidity buffers in the economy. However, it does not remove all inefficiencies. Using forward contracts, only the large bank reacts to the signal it receives about future systemic liquidity shocks. Since the signal is not transmitted to the small banks, they cannot apply the liquidation technology to adjust their liquidity holdings to an upcoming liquidity crisis. However, efficiency would be enhanced if small banks also used the liquidation technology because of the increasing marginal liquidation cost at each bank. Under the use of forward contracts, the signal cannot be credibly transmitted from the large bank to the small banks, again because of a time inconsistency problem. If the small banks expected the large bank to transmit the correct signal, they would hold less liquidity buffers than $l_0^* = \underline{l} + \bar{\lambda} - \Delta l^*$, planning to raise the required additional liquidity to sustain the shock by applying the liquidation technology after receiving a signal about an upcoming crisis. However, if small banks hold less than l_0^*, the large bank has an incentive not to signal an upcoming crisis to the small banks, because if the small banks do not learn about the upcoming crisis they will not generate sufficient liquidity. Thus prices in the spot money market will shoot up allowing the large bank to extract a rent.

Now come back to the case of *rare* liquidity shocks. We have seen that the large bank can supply some liquidity to the spot market even without using forward contracts. With the same argument as above, the large bank's aggregate profit when using forward contracts is $\pi_{\bar{\lambda}}^{\text{large}} = q\, R\, \big(P_{\bar{\lambda}}\, \Delta l - g(\Delta l)\big)$; small banks are willing to pay at most the price they would have to pay on the spot market, $P_{\bar{\lambda}}$. Now taking the derivative of this profit with regard to Δl leads to the first-order condition (7). As a consequence, the volume of traded contracts is identical with that without forward contracts; forward contracts do not lead to a further expansion of volume. Also in the case of rare shocks, the large bank cannot credibly warn against upcoming crises, for the following reason. The price of liquidity falls if liquidity is oversupplied. Because the large bank, having sold forward contracts, must also deliver liquidity in the non-crisis, it wants to buy it on the spot market as cheap as possible. If it reports a crisis even if there is none, small banks produce some liquidity, making the price on the spot market drop to $1/R$. Summing up, it is beneficial for the large bank to report a crisis in all cases – the report loses its credibility.

Proposition 2 (Forward contracts) *If shocks are* frequent *events, the large bank can sell forward contracts to commit to supplying Δl^* units of liquidity. Under a* rare *shock, forward contracts lead to no expansion of trading volume. In both cases, the large bank cannot credibly transmit information about upcoming shocks.*

4.2 Interbank credit lines

In this section, we will show that using interbank lines of credit, banks can implement a cost-efficient solution, incorporating an incentive for the large bank to truthfully signal its information about upcoming shocks. This way, both large and small banks can get prepared for the systemic shock. We use the following procedure: we assume that information is passed on, derive optimal liquidity reserves for that case, and then show that the contracts in question are incentive compatible.

Again, we start by discussing *frequent* shocks. Remember that each bank has access to the physical liquidation technology, to receive Δl units of liquidity for liquidating $g(\Delta l)$ units of assets. If it buys Δl units of liquidity on the money market, it must pay $P_{\bar{\lambda}}\,\Delta l$ units of assets. Hence the first order condition for each bank is $g'(\Delta l^*) = P_{\bar{\lambda}}$. As a consequence, each bank provides Δl^*, the aggregate amount of assets liquidated before a systemic crisis is $2\,g(\Delta l^*)$. Small banks anticipate that they will get some liquidity from the large bank. By liquidating assets, they can generate some liquidity cheaply themselves in the case of a crisis. Thus the amount of liquidity reserves in $t = 0$ reduces to

$$l_0^* = \underline{l} + \bar{\lambda} - 2\,\Delta l^*.$$

Now let us discuss how this solution can be implemented. Consider a credit line in which the small bank gets the option to buy liquidity of a volume up to ΔL (with $\Delta L > \Delta l^*$) from the large bank at a price $P_{\bar{\lambda}}$ in $t = 2$. Then if the large bank receives information about a systemic shock, it will disseminate this information to all banks that hold a credit line. If it *does* pass on the information, small banks liquidate assets until the marginal costs of liquidation equal those of using the credit line, $g'(\Delta l) = P_{\bar{\lambda}}$. Thus they produce Δl^* units of liquidity themselves. However, there is still a gap of $\underline{l} + \bar{\lambda} - l_0^* - \Delta l^* = \Delta l^*$. Hence small banks draw another Δl^* from their credit line. This is exactly the amount that the large bank can generate with marginal costs not above the agreed price $P_{\bar{\lambda}}$ in the option contract. If the large bank *did not* pass on the information, then small banks would not generate liquidity themselves and would need to draw $2\,\Delta l^*$ from the credit line. The large bank cannot buy this liquidity on the money market, because as soon as it extracts liquidity from the market, the price jumps up. It cannot produce the liquidity at a profit, because for $\Delta l > \Delta l^*$ marginal costs of physical liquidation are above the price. Thus holding back information about future shocks is unprofitable; on the contrary, it is beneficial to pass it on to the holders of credit lines.

The important difference between a line of credit and a forward contract is that it gives the large bank incentives to communicate its information early. This way, small banks can reduce their liquidity holdings in $t = 0$ and make greater use of the more productive investment. This increases expected profits of small banks. However, because only the large bank initially receives the relevant information, it can reap all rents from this information, e. g. by charging a fee for the line of credit. The maximal fee it can demand is $2\,\pi_{\bar{\lambda}}^{\text{large}}$, as defined by (8). With this maximum fee, the large bank extracts all efficiency gains that small banks can achieve from the credit line.

Interestingly, the spot money market is still active, independent of the systemic liquidity shock. Small banks that get the positive liquidity shock in $t = 2$ have $\bar{\nu}$ units of liquidity to sell; small banks that suffer a negative liquidity shock want to buy liquidity. There is a market equilibrium in which small liquid banks sell liquidity to small illiquid banks, and only after this trade, lines of credit are used. Roughly speaking, the spot money market is used to redistribute idiosyncratic risk, whereas money market derivatives (forward contracts and credit lines) are used to reallocate systemic risk efficiently. Even in the presence of money market derivatives, the spot money market remains active. In addition to this equilibrium with only credit lines and an active spot market, there are further equilibria in which the large bank sells both forward contracts and credit lines, while the spot market stays active. The function of credit lines is only to generate incentive compatibility with regard to communication. The liquidity provision of the large bank can be provided by forward contracts as well as by credit lines. For example, there is an equilibrium with forward contracts of volume Δl^* and credit lines of positive volume. Expected profits and cash flows are identical to those in the equilibrium with credit lines only.

The line of credit is used to facilitate communication between large and small banks. For this purpose, the line must be larger than the one actually used under a systemic crisis. If its volume were only Δl^*, then the large bank would not communicate its information, produce more than Δl^* and sell its excess liquidity expensively on the money market. A volume of $2\,\Delta l^*$ is more than sufficient.

Since incentive compatibility requires that in equilibrium $\Delta L > \Delta l^*$, one might think that a small bank may resell part of this line of credit to another small bank, together with the promise to pass on the communication. However, it is important to note that this arrangement is not incentive compatible. When the small bank gets the information, it prefers not to communicate it and instead benefit from the higher crisis price that occurs if some small banks cannot prepare for a the upcoming liquidity shortage. In that case, it can use parts of the liquidity that it can raise from the credit line with the large bank and sell it at a margin to other small banks.

Up to here, the discussion has focussed on frequent shocks; let us now come back to *rare* shocks. Here, the large bank needs to take into account the consequences of its actions on market prices, and, as a result, on the small banks' willingness to pay. Assume that in equilibrium, the large bank credibly communicates upcoming shocks, and that it produces Δl^{large}, whereas small banks produce Δl^{small}. This implies that the price in a crisis goes down to $P_{\bar\lambda} = (1-\underline{l})/(\bar\nu - \bar\lambda + \Delta l^{\text{large}} + 2\,\Delta l^{\text{small}})$. A single small bank's activities are negligible for market prices, hence in a crisis, small banks produce liquidity until the price equals marginal costs, $P_{\bar\lambda} = g'(\Delta l^{\text{small}})$, where Δl^{small} depends on $P_{\bar\lambda}$, which in turn depends on Δl^{small} and Δl^{large}. If the large bank reveals the information in equilibrium, it must anticipate that small banks use this information to produce liquidity, which in turn influences prices, which again influences the small banks' willingness to pay for liquidity (because liquidity may now be abundant). Summing up, the above equation implicitly defines $P_{\bar\lambda}$ as a function of Δl^{large}, taking into account the reaction of small banks. The large bank produces liquidity to maximize its objective function, $\pi^{\text{large}}_{\bar\lambda}$ as defined by (8). In equilibrium, it will produce less liquidity than the small banks ($\Delta l^{\text{large}*} < \Delta l^{\text{small}*}$) because it takes into account the consequences of its production decision on prices. In addition to the revenues from producing liquidity in a crisis, the large bank benefits from selling the credit lines; its aggregate profits are

$$\pi^{\text{large}} = \pi^{\text{large}}_{\bar\lambda} = q\,R\left(P_{\bar\lambda}\cdot(\Delta l^{\text{large}} + \Delta l^{\text{small}}) - g(\Delta l^{\text{large}}) - g(\Delta l^{\text{small}})\right).$$

Yet the large bank does not necessarily profit from selling credit lines (and the implicit commitment to communicate). Among other parameters, its decision will depend on the form of the cost function $g(\cdot)$. If small banks, once they are given the information about the systemic shock, produce a lot of liquidity, they water down the price $P_{\bar\lambda}$. This dilutes the willingness to pay of a single small bank: if liquidity is not very expensive in a crisis, why use a credit line to insure against the crisis, and not rather buy the liquidity on the market when needed? As a consequence, if the large bank anticipates that the small banks will flood the market with liquidity in a crisis, it will not provide the information. Hence it will not sell a credit line in the first place, but rather stick to selling forward contracts. If, though, the large bank anticipates that the small banks will produce only a little additional liquidity, it will sell credit lines and communicate its information. This way, it can earn twice, as a fee for the credit line and when selling more liquidity on the spot market.[11]

Proposition 3 (Credit Lines) *If shocks are* frequent *events, in equilibrium small banks buy credit lines from the large bank to insure against liquidity shocks and to provide the large bank with an incentive to pass on information about future systemic shocks. If shocks are* rare*, the large bank sells credit lines only if the small banks' liquidation Δl before a crisis is sufficiently low.*

5 Welfare analysis

Define welfare as the sum of banks' objective functions. If there are only small banks, these are assumed to compete in prices for depositors, so banks' profits are driven down to zero, and the banks' objective functions reflect the depositors' rents. If a large bank becomes active, one needs to augment welfare by the large bank's profits. Hence the sum of all banks' objective functions indeed reflects aggregate welfare.

There are two channels that affect welfare. First, the early liquidation of projects is always detrimental to welfare, even when a liquidity crisis is imminent. This is due to the assumption that, in a crisis, assets and liquidity are simply redistributed, thus assets never remain in the hands of insolvent banks (for whom they are relatively valueless). The redistribution itself is welfare neutral; all banks value assets similarly; the transfer of assets is costless. Second, holding liquidity is detrimental to welfare simply because assets are more profitable. This holds true, even in a crisis, for the same reasoning as above. Due to the functioning of these channels, welfare implications of forward contracts and credit lines depend on the likelihood of crises.

If shocks are *frequent* events, banks hold sufficient liquidity reserves in the absence of the large bank. If the large bank provides Δl^* units of liquidity, this reduces the small banks' liquidity reserves by just this amount. However, endowment invested in liquidity

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[11] If, instead of assuming that large bank does not suffer any shocks, we had assumed that they are also hit by systemic shocks, the result would be even more pronounced. The large bank would still sell a credit line to small banks, but this line would not be used. Nevertheless, the large bank would get a price for the line, the price for the information. Under the threat of a systemic crisis, each bank would produce liquidity for itself.

yields a social return of 1, whereas investment in the asset yields R. The liquidation technology is least favorable for the last marginal unit, with a replacement rate of $g'(\Delta l) = P_{\bar{\lambda}}$. Investment in the asset and liquidation before a crisis yields a return of $(1-q)\,R+q/P_{\bar{\lambda}}$. This is greater than one for $R > 1$ and $q < 1$. As a result, forward contracts enhance welfare, because liquidity is produced only when needed. A credit line boosts welfare even more, because the double amount of liquidity is generated at identical marginal costs. Inducing banks to reduce liquidity reserves without generating liquidity in a crisis would enhance welfare even more. If shocks are *rare*, then the provision of liquidity in a crisis does not reduce the reserves of the small banks. Therefore, the more liquidity generated in a crisis, the lower welfare. If the large bank announces a systemic shock, this causes a kind of a panic. Small bank anticipate that the price for liquidity will rise, hence they start to liquidate their assets (abort their investment projects), although it would be socially efficient to remain calm and redistribute assets when the crisis comes. The following proposition resumes this discussion.

Proposition 4 (Welfare Ordering) *Consider* frequent *systemic shocks, and start from an economy without a large bank (no information). Then the information of the large bank leaves welfare unchanged, if only a spot money market is available. Forward contracts increase welfare, and credit lines increase welfare even more,*

$$W_{\text{no information}} = W_{\text{spot market}} < W_{\text{forward contracts}} < W_{\text{credit lines}}.$$

If systemic shocks are rare*, then the activity of the large bank on the spot market decreases welfare; forward contracts have no welfare implications; and credit lines decrease welfare even more,*

$$W_{\text{no information}} > W_{\text{spot market}} = W_{\text{forward contracts}} \geq W_{\text{credit lines}}.$$

If shocks are *rare*, the actions of the large bank (the supplying of liquidity to the spot market, the selling of forward contracts, the selling of credit lines) absorb volatility: the more sophisticated the financial instrument in use, the lower the difference $P_{\bar{\lambda}} - P_0$. If shocks are frequent, volatility is not influenced by the action of the large bank. In combination with proposition 4, we can conclude that if the action of the large bank decreases the volatility of the liquidity price, this is detrimental to welfare. Compare this result to Allen and Gale (1998): in our framework, it is not always socially desirable to get prepared for a financial crisis. Furthermore, it can be optimal to leave volatility in the market, rather than to eliminate it. In a sense, financial crises should occur in equilibrium, because their prevention is costly, and the crises do not entail inherent costs. However, from the viewpoint of a single bank, the prevention is individually rational.

If some banks buy forward contracts or credit lines from the large bank, they need to buy less liquidity when there is a crisis; if shocks are *rare*, this may influence prices on the spot market. Consequently, the reserve prices of other small banks for contracts may be changed. Typically, because forward contracts and credit lines take volatility out of the market (as discussed in the above paragraph), banks will be willing to pay less for their contracts. Banks that buy contracts exert an externality on the reserve prices of other banks.

Let us not overemphasize the welfare implications – they may be sensitive to specifics of the model.[12] However, we believe that the two basic forces of the welfare analysis are quite robust: First, the dissemination of information may have a negative *ex post* effect on welfare, because banks may liquidate assets that they would otherwise have sold. Second, the anticipation of the dissemination has a positive *ex ante* effect, because banks can reduce their liquidity reserves. A high crisis probability leads to higher reserve holdings, hence there is a higher initial liquidity reserve to be reduced; consequently, the positive ex ante effect is likely to dominate.

6 Discussion and Robustness

In this section, we discuss further implications of our model, together with basic expositions of potential extensions. If not explicitly mentioned otherwise, assume that liquidity shocks are *frequent*.

The Activity of the Spot Market We have assumed that the spot market opens only in $t = 2$, after the potential shock. Why is the market closed at the other times? What would happen if we allowed for a market that trades assets against liquidity in all periods? In $t = 0$, banks have not yet taken their investment decisions, and all banks have the same investment opportunities. Consequently a market that trades liquidity against assets is irrelevant. In $t = 1$, the market is characterized by information asymmetries. The large bank already knows whether a shock will occur; small banks do not. Because of the absence of liquidity traders and because small banks are identical, a small bank that demands liquidity on the spot market can infer that its counterpart would be the large bank. If the large bank is willing to sell liquidity in $t = 1$, the only possible reason is that there will be no shock (or the price is so high that the large bank wants to sell even if there is a shock). As a consequence, the spot market is illiquid in $t = 1$. Just like the market in

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[12] Particularly, the assumption that bank assets can be transferred without any efficiency loss is crucial for the welfare implications. We discuss this issue in greater detail in the following section.

Akerlof (1970) and Rothschild and Stiglitz (1976), our $t = 1$ spot money market collapses due to the asymmetric information problem. In $t = 2$ we have already analyzed the spot market. In $t = 3$ all banks that are still solvent have sufficient liquidity. The price is $1/R$, hence trade on the spot market is again irrelevant. Our result hence contrasts with Grossman and Stiglitz (1980) who argue that market prices would reveal the superior information of the large bank. In our model, even if prices reveal the information in $t = 2$, it is too late for small banks to make use of it because the opportunity to liquidate assets has already passed. Summing up, if there were a spot market for liquidity at all times, it would be characterized by the sequence of states: irrelevance → illiquidity → activity → irrelevance.

Fungibility and Communication There is a difference between credit lines and money market options that we have not yet emphasized. Credit lines are not fungible, whereas money market options may be. From the viewpoint of our model, the non-fungibility is an important feature of credit lines. If the large bank sold fungible derivatives (and if the secondary market were liquid), it would not know who the holders of the derivative were, hence to whom it should communicate the information about a liquidity crisis. It cannot simply talk to the original buyer of the derivative; consequently, the original buyer would be able to sell the derivative at the original price and hence get the information for free. For the same reason, the large bank cannot simply make the information public; if it did, small banks would not have an incentive to buy the derivative (and implicitly pay for the information) in the first place. The only alternative is a non-fungible credit line that cannot be resold.

Note that, given that the large bank needs to *communicate* only to the owners of a credit line, it does not necessarily have to *talk* to them. A feasible (and more subtle) alternative is implicit communication via the contract's conditions. For example, imagine a credit line with a slightly variable rate between the crisis price $P_{\bar{\lambda}} = (R - 1 + q)/(q\,R)$ and a little below, $P_{\bar{\lambda}} - \epsilon$. Initially in $t = 0$, the rate is set to $P_{\bar{\lambda}} - \epsilon$, with an option for the large bank to increase it to $P_{\bar{\lambda}}$ in $t = 1$. Then the large bank has an incentive to increase the rate only if it knows that a crisis will occur – otherwise, the credit line will not be used anyway. As a result, the action of the large bank signals the relevant information to a small bank – but only if it has bought the line. From this perspective, our paper also provides an explanation for the fact that interbank business is still largely done over the counter (OTC), even though products are widely standardized.

Costs from Transferring Bank Assets In contrast to most of the banking literature, our model abstracts from any efficiency losses that may result if a bank transfers its assets to another bank. In particular we do not take into account the informational advantage that a relationship lender achieves in the lending process and that enables him to ensure higher returns from investments. Similarly to Diamond and Rajan (2001), we assume that physical liquidation is more wasteful than the sale of assets, but we take the extreme case of a completely frictionless sale. Assuming an informational advantage in our model would force banks to sell their assets at a discount. Thus the expected equilibrium price for assets would be lower, increasing the incentive for liquidity holdings (or liquidity generation by applying the premature liquidation option, respectively). But more importantly, in this case the liquidity holdings of banks are not always inefficient from a welfare perspective. If asset transfers cause efficiency losses, then higher liquidity holdings prevent that a bank has to inefficiently sell off its assets. The lower return on liquidity holdings may even be compensated by this welfare enhancing effect. Consequently, taking welfare costs of asset transfers between banks into account, the overall welfare implications of the money market arrangements may change in case of *rare* liquidity shocks. Credit lines that ensure that small banks get informed about upcoming liquidity crisis, generate additional liquidity by applying the premature liquidation, and thereby reduce the need for asset sales may in fact increase welfare also in case of rare liquidity shocks.

For *frequent* liquidity shortages, however, the welfare implications derived in our model remain unchanged. In that case banks have incentives to hold (or generate, respectively) sufficient liquidity buffers anyway and the different money market derivatives only provide an option for a potentially more efficient liquidity provision.

Continuously Distributed Shocks We have assumed a dichotomous kind of aggregate liquidity shock; either there is a shock, or not. Our two regimes (*frequent* shocks where banks hold sufficient buffers, *rare* shocks where banks hold no buffers) are a direct result. With continuously distributed shocks $\tilde{\lambda} \in [0; \bar{\lambda}]$, banks would choose to hold sufficient buffers against small shocks, but remain insufficiently prepared for exceptionally large shocks. The exact model would become fairly complex. In our model, the large bank can only tell the truth or lie, in a model with continuous shocks, the large bank might lie "a little." However, we conjecture that some of our results would then become less pronounced. The large bank could become active on the spot market (unlike our result for frequent shocks), and could sell more liquidity using forward contracts (unlike our result for rare shocks). The welfare ordering would depend on the shape of the probability distribution of $\tilde{\lambda}$. Still, it is always beneficial for an individual small bank to get early information about upcoming shocks, so small banks would continue to buy money market derivatives from the large bank.

Oligopolistic Large Banks In our model, the fact that only the large bank gets an information gives it a monopolistic position. One may want to ask whether our results break down if more than one bank receive an early information about an upcoming shock. Clearly, if a bank has no market power, it cannot exploit and sell its information. Liquidity is sold on the (competitive) spot market. However, banks must choose how much liquidity to hold ex ante, introducing a capacity constraint. Consequently, banks in our model naturally compete in a Cournot fashion, leaving large some oligopolistic market power even if several banks get an early information. As a result, our qualitative results still hold in oligopoly.

7 Conclusion

We have derived an efficiency ranking of different money market instruments, based on two crucial assumptions: (i) that the banking sector is hit by systemic liquidity shocks that can only be anticipated by a large bank, and (ii) that all banks can make use of a costly liquidation technology if they learn of an upcoming shock in advance. Within this setting, we have shown that small banks hold liquidity buffers if shocks are sufficiently frequent and only a *spot money market* is available. The spot market does not provide an incentive for the large bank to disseminate its information about an upcoming liquidity shortage. Thus small banks cannot employ the liquidation technology to generate additional liquidity. Moreover, to reap maximum profits from its informational advantage, the large bank supplies too little liquidity to the spot market in a crisis: It has marginal costs of provision below the price. Using *forward contracts*, the large bank can commit to not exploiting the informational advantage and to providing as much liquidity as it can efficiently generate itself.

However, forward contracts do not induce the large bank to communicate its information to the small banks. Only *credit lines* (contracts with an optional structure) which promise to provide a sufficiently large amount of liquidity to the small banks at a sufficiently low rate can provide an incentive for the large bank to disseminate the information truthfully. If the small banks are not informed of an upcoming liquidity shortage, they cannot make use of the efficient liquidation option themselves, and they have to draw on the credit lines. This generates a loss to the large bank, more than compensating for any additional profit the large bank could gain from keeping its information private. Thus credit lines not only provide liquidity when it is most needed (in the crisis), they also enable small banks to efficiently liquidate assets themselves instead of holding inefficient liquidity buffers for potential liquidity shortages. In equilibrium, contractual arrangements between large and small banks and the spot money market are actively used at the same time.

However, we have also argued that the welfare implications are reversed if aggregate liquidity shortages are rare events (*rare* shocks). In that case, small banks never hold inefficient excess reserves. Thus, making use of the liquidation technology cannot reduce liquidity reserves at the small banks. On the contrary, from an aggregate perspective employing the liquidation technology in this case only means that productive assets will be destroyed. It would be preferable if assets were simply reallocated to those banks that have sufficient liquidity (which is guaranteed by the spot market). However, from the perspective of an individual bank, it is always preferable to belong to those banks that have sufficient liquidity to fully benefit from their capital holdings. Thus each individual bank has an incentive to liquidate parts of its assets when it learns about an upcoming liquidity shortage. Consequently, only credit lines, coming with an implicit promise to communicate, allow small banks to react by appropriate liquidation.

A Appendix

A Lower Bound $\underline{q}$ for Frequent Systemic Shocks A necessary condition for a price that follows (3) is $P_{\bar\lambda} \in [\frac{k}{\bar\nu};\ \frac{1}{R}]$ (see (2)). Consequently,

$$\frac{k}{\bar\nu} = \frac{1-(\underline{l}+\bar\lambda)}{\bar\nu} \ge P_{\bar\lambda} = \frac{R-(1-q)}{q\,R},$$

$$q \ge \underline{q} = \bar\nu\,\frac{R-1}{\bar\nu - R\,(1-\underline{l}-\bar\lambda)}.$$

The frequency of the shock must exceed this limit $\underline{q}$.

An Upper Bound $\bar q$ for Rare Systemic Shocks The price P_0 taken from (6) must exceed $1/R$. Solving for q, we get

$$q \le \bar q := 2\,\frac{(1-\underline{l})\,(R-1)\,(\bar\nu-\bar\lambda)}{(1-\underline{l}-\bar\lambda+\bar\nu)\,[(1-\underline{l})\,R+\bar\lambda-\bar\nu]}.$$

Note that possibly $\bar q \neq \underline{q}$. We have $\bar q > \underline{q}$ if and only if

$$R > \frac{\bar\nu-\bar\lambda}{1-\underline{l}} \cdot \frac{1-\underline{l}+\bar\lambda-\bar\nu}{1-\underline{l}-\bar\lambda-\bar\nu-2\,\bar\lambda/\bar\nu\,(1-\underline{l}-\bar\lambda)}. \tag{A1}$$

Throughout the paper, we discuss only *frequent* and *rare* systemic shocks. If $\bar q > \underline{q}$, every shock is frequent or rare (or both) in our definition. This case is pictured in figure 4; in a medium region, regimes overlap. However, if (A1) fails to hold, then there are medium shock probabilities q for which shocks are neither rare nor frequent. In this region, there is another kind of equilibrium, which we have not discussed in the paper. Small banks hold liquidity reserves that are less insufficient for a crisis, but more than sufficient otherwise, $l_0 \in (\underline{l};\ \underline{l}+\bar\lambda)$. As a consequence, prices in both situations are uniquely determined by (2). Given these prices, banks choice of l_0 must be optimal.

References

Akerlof, G. A. (1970): "Market for Lemons: Quality Uncertainty and the Market Mechanism," *Quarterly Journal of Economics*, 84(3), 488–500.

Allen, F., and E. Carletti (2006): "Credit Risk Transfer and Contagion," *Journal of Monetary Economics*, 53(1), 89–111.

Allen, F., and D. Gale (1994): *Financial Innovation and Risk Sharing.* MIT Press, Cambridge MA.

——— (1998): "Optimal Financial Crises," *Journal of Finance*, 53(4), 1245–1283.

——— (2000): "Financial Contagion," *Journal of Political Economy*, 108(1), 1–33.

——— (2004): "Financial Intermediaries and Markets," *Econometrica*, 72(4), 1023–1061.

Bhattacharya, S., and P. Fulghieri (1994): "Uncertain Liquidity and Interbank Contracting," *Economics Letters*, 44(3), 287–294.

Bhattacharya, S., and D. Gale (1987): "Preference Shocks, Liquidity, and Central Bank Policy," in *New Approaches to Monetary Economics*, ed. by W. A. B. und K. J. Singleton, pp. 69–88. Cambridge University Press, Cambridge.

Cocco, J. F., F. J. Gomes, and N. C. Martins (2003): "Lending Relationships in the Interbank Market," Mimeo.

Diamond, D., and R. Rajan (2001): "Liquidity Risk, Liquidity Creation and Financial Fragility: A Theory of Banking," *Journal of Political Economy*, 109(2), 287–327.

Diamond, D. W., and P. H. Dybvig (1983): "Bank Runs, Deposit Insurance, and Liquidity," *Journal of Political Economy*, 91(3), 401–419.

ECB (2005): *Money Market Survey.*

Freixas, X., B. Parigi, and J.-C. Rochet (2000): "Systemic Risk, Interbank Relations, and Liquidity Provision by the Central Bank," *Journal of Money, Credit, And Banking*, 32(3), 611–638.

Gromb, D., and D. Martimort (2004): "The Organization of Delegated Expertise," Discussion Paper 284, IDEI Working Paper.

Grossman, S. J., and J. E. Stiglitz (1980): "On the Impossibility of Informationally Efficient Markets," *American Economic Review*, 70(3), 393–408.

Hakenes, H. (2004): "Banks as Delegated Risk Managers," *Journal of Banking and Finance*, 28(10), 2399–2426.

Holmström, B., and J. Tirole (1998): "Private and Public Supply of Liquidity," *Journal of Political Economy*, 106(1), 1–40.

Laux, C. (2003): "Multiline Insurance and Securitization: Bundling Risks to Reduce Moral Hazard," Mimeo.

Laux, C., and U. Walz (2004): "Tying, Entry, and Competition in Investment Banking," Working Paper Series: Finance and Accounting, Goethe-University Frankfurt/M.

Merton, R. C. (1989): "On the Application of the Continuous-Time Theory of Finance to Financial Intermediation and Insurance," *Geneva Papers on Risk and Insurance*, 14, 225–261.

Rothschild, M., and J. E. Stiglitz (1976): "Equilibrium in Competitive Insurance Markets: An Essay on the Economics of Markets with Imperfect Information," *Quarterly Journal of Economics*, 90(4), 629–649.

Tufano, P. (2005): "Financial Innovations," in *The Handbook of the Economics of Finance*, ed. by George Constantinides and Milt Harris and René Stulz. North Holland, forthcoming.

van Horne, J. C. (1985): "Of Financial Innovation and Excesses," *Journal of Finance*, 40(3), 621–631.

Wagner, W. (2006): "Credit Risk Transfer and Contagion," *Journal of Banking and Finance, forthcoming.*

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